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Sedimentology and depositional environment of the Kobbe and Steinkobbe formations in the Nordkapp Basin, Sentralbanken High and the Svalis Dome, Barents Sea

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Geology
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Abstract

The Mesozoic succession in the Barents Sea was deposited in a relatively shallow epicontinental basin that gradually were infilled during the Triassic by north and north-west progradation of an extensive deltaic system mainly sourced from the Baltic Shield in the south and the Uralian Mountains and the in the east and south-east.

This study investigates the sedimentology and depositional environment of the Early to Middle Triassic Kobbe and Steinkobbe formations in the south-western Barents Sea. The material used is sediment cores from Sentralbanken High, The Nordkapp Basin and the Svalis Dome. The study aims to interpret the sedimentology of the different formations and to complement to the understanding of the temporal evolution of depositional environments in each area and the lateral distribution of facies between the three areas. This is done through a detailed facies analysis.

Thirteen facies and seven facies associations are recognized and constitutes of a wide variety of proximal to distal facies. The most proximal facies associations are found in the Kobbe Formation from the Nordkapp Basin. The results show a regressive trend where shallow marine to prodeltaic deposits gradually is shallowing up to deposits associated with a coastal plain. Cores from Sentralbanken High and the Nordkapp basin both interpreted to be deposited on a relatively deep distal shelf. The lithology of Steinkobbe Formation reveals a regressive trend dominated by pelagic deposition which gradually becomes more influenced by deposition and modification of storms and/or turbidity currents. Steinkobbe at the Svalis Dome are interpreted to have been deposited during anoxic conditions whereas slightly better ventilation or shallower depths are suggested for the formation at Sentralbanken High.

In general, there is a north to south deepening of facies which are in accordance to the theory of a sediment source located south-east of the studied areas and implies that the sediments are deposited in the early phase of the infill of the Barents Sea shelf.

Sammendrag

Den Mesozoiske lagrekka i Barentshavet ble avsatt i et relativt grunt epikontinentalt basseng som i Trias gradvis ble fylt inn av et deltasystem som bygget seg utover mot nord og nordvest. Uralfjellene i sørøst var trolig hovedkilden som matet deltaet med sediment.

Denne oppgaven undersøker sedimentologien og avsetningsmiljøet Kobbe og Steinkobbe formasjonene avsatt i Tidlig til Midtre Trias. Sedimentkjerner fra Sentralbankhøyden, Nordkappbassenget og Svalisdomen er brukt som grunnlag for oppgaven. De overordnede formålene med oppgaven er å tolke de ulike områdenes sedimentologiske karakter, å få en bedret forståelse av den tidsmessige utviklingen av avsetningsmiljøene samt å se på den laterale utviklingen av Kobbe og Steinkobbe formasjonene mellom de tre områdene. Dette er utført gjennom en omstendelig analyse av facies.

Det har blitt definert tretten facies og sju facies assosiasjoner som viser til avsetning både i proksimale og distale posisjoner i henhold kildeområdet. De mest landlige facies assosiasjonene er funnet i Kobbeformasjonen fra Nordkappbassenget. I denne kjernen er det observert en gradvis overgang mellom avsetninger som er assosiert med grunnmarine til prodeltaiske forhold til en et alluvialt miljø. Kjernene fra Sentralbankhøyden og Svalisdomen er begge tolket til å ha blitt avsatt i et relativt dypt distalt sokkelområde. Steinkobbe har en regressiv trend der et område med hovedsakelig pelagisk sedimentasjon gradvis har blitt påvirket av avsetninger fra stormer og/eller tubbidittstrømmer. Sedimentene fra Svalisdomen er tolket til å ha blitt avsatt under anoksiske forhold, mens det ved Sentralbankhøyden muligens har vært noe mindre anoksisk og et litt grunnere miljø er foreslått for formasjonen i dette området.

Generelt viser resultatene dypere vanndybder mot nord. Dette samsvarer med teorien om et kildeområde lokalisert sørøst for studieområdet og hentyder at sedimentene er avsatt i en tidlig fase da Barentshavet startet å fylles inn.

Preface

This thesis is a part of a master's degree in geology at Department of Geoscience and Petroleum at the Norwegian university of Science and Technology (NTNU). The supervisor for this thesis has been Atle Mørk, Professor II at NTNU. Most of the practical work has been done at the core storage at Dora inTrondheim in addition to four days spent at the Norwegian Petroleum Directorate in Stavanger. The core pictures from well 7534/06-U-01 are from the Norwegian Petroleum Directorate. The thesis has been written in the period from February 2018 to July 2018.

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Trondheim, 16.07.18

Ingvild Jonassen

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1. Introduction

In this study lithologies from the Early to Middle Triassic in the south western Barents Sea is investigated. Middle Triassic deposits from the Barents Sea are well known to hold both source rock and reservoir properties, and knowledge of distribution and composition of these deposits are therefore valuable information. The Spathian to Anisian Steinkobbe Formation primarily consists of black organic rich shale (Mørk and Elvebakk, 1999), and are deposited over large parts of the Barents Sea. Similar lithologies are present on Svalbard represented by Botneheia Formation, where de deposition of these organic rich shales and establishment of anoxic or periodic anoxic sea bottom conditions started later (Lundschien et al., 2014). The Anisian Kobbe Formation represents a proximal time equivalent of Steinkobbe Formation.

The purpose of the study is to investigate the sedimentology and the depositional environments from three different areas deposited during the approximately same period. This performed by a facies analysis where facies first were defined, and secondly related facies were grouped together into facies associations. In addition, XRD analysis is used to supply with additional information, but are not a central part of the study.

The objectives of the study are to **1)** describe and interpret the sedimentology of the cores, **2)** to complement the understanding of the vertical evolution of the studied formations and **3)** to evaluate the proximal-distal transition of the time equivalent formations from continental environments to a deep shelf.

1.1 Study area

Three locations in the south-western Barents Sea are the basis of this study which stretches from the Svalis Dome in south west, the Nordkapp Basin in south East and Sentralbanken High in the north west. Specific descriptions of the individual locations will be outlined in chapter 2.2.

1.2 Previous work

Investigation of the Triassic succession on the Barents Sea Shelf started in the 1970s as preparations for petroleum exploration. Prior to this, studies of the Triassic succession of Svalbard have been conducted since the late 19th century (Vigran et al, 2014), and outcrop studies of the succession have been important for the understanding of the equivalents in the

Barents Sea. The nomenclature used in this thesis follows Mørk et al (1999). The lithostratigraphy in the Barents Sea were defined by Worsley et al. (1988).

In the recent years, numerous seismic and sedimentological studies have been done to properly understand the early to mid-Triassic evolution of the Barents Sea. A recent study by Klausen et al. (2017) combined seimic data, core data and well logs to investigate clinoform development within the Kobbe formation. Triassic sequences and source areas have also been studied by Glørstad-Clark et al. (2011, 2010) and Høy and Lundschien et al. (2011). The interest in hydrocarbon potential in the western Barents Sea have resulted in numerous wells drilled by oil companies in the southern Barents Sea, contributing to the present knowledge of the Triassic succession. It has not been petroleum activity in the northern parts of the Barents Sea, but the petroleum potential has been interpreted by comparing extrapolations from the southern Barents Sea and offshore exposures on Svalbard by Lundschien et al. (2014).

2.Regional geology of the Barents Sea Shelf

The Barents Sea Shelf is an epicontinental shelf bounded in the north and west by passive continental margins (Faleide et al., 1984). Framed by Svalbard and Franz Josef land in the north, Novaya Zemlya in the east and the Norwegian coast in the south, it comprises a mosaic of local highs, platforms and basins developed through a complex history of geological and tectonic processes (Fig. 2.1) (Worsley, 2008). The shelf can be divided into two provinces separated by a monoclinal structure with the western province where the western part witnesses a more complex tectonic development compared to the eastern segment (Worsley, 2008, Smelror et al., 2009). Many regional and local events have shaped the shelf to its present-day geometries including two phases of continental collision; Formation of the Caledonian Orogeny approximately 400Ma and collision of Laurasia and Western Siberia 240Ma, creating the Uralian Mountains. Periods in between and after these mountain building events have been dominated by phases of rifting and crustal extension (Dore, 1995, Faleide et al., 1993), contributing to creation of the structural elements of the Barents Sea. Halokinesis have also played a significant role shaping the shelf and affecting the sedimentary record, especially in the southern parts of the Barents Sea (Henriksen and Vorren, 1996), where Devonian and Permian evaporites have been the main sources of salt tectonics.

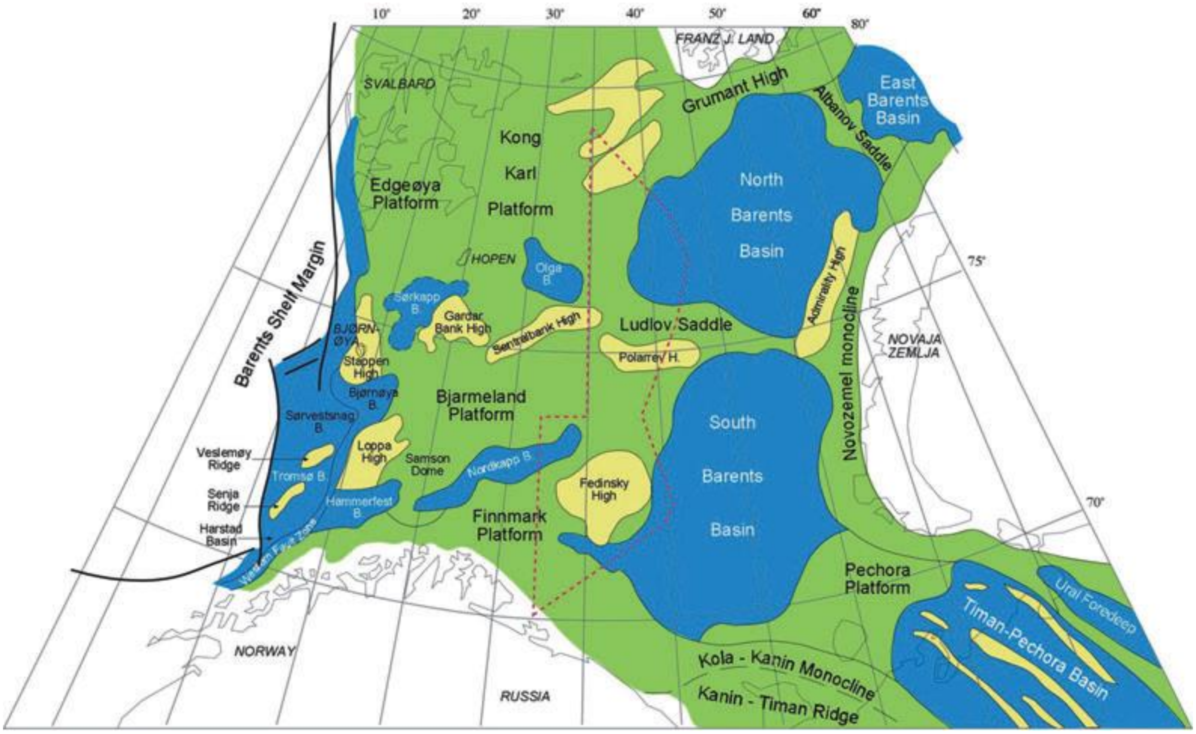


Figure 2.1: Overview map over structural elements of the Barents Sea. From Worsley, (2008).

Paleozoic

After completion of the Caledonian Mountains followed a period from Devonian to Early Carboniferous dominated by erosion of the Caledonides, resulting in accumulation of Old Red Sandstone deposits in rift basins developed along former Caledonian structural features. Early to Middle Carboniferous was in the Western Barents Sea dominated by regional extension and major rift structures is developed during this period before more stable platform conditions were established in Late Carboniferous- Early Permian (Worsley, 2008). Changed climatic conditions led to local deposition of thick evaporitic successions in the rift basins in the western parts of the Barents Sea including Tromsø Basin, Bjørnøya Basin and Nordkapp Basin (Smelror et al., 2009). Deposits from this period is affected by frequent sea-level fluctuations that are linked to periodic glaciations of the supercontinent Gondwana (Dallmann et al., 2015). Highs and platform areas were in late Permian flooded after a period of subaerial exposure contemporaneous with deepening of basin and basin margins which were sites of deposition of cold and deep-water spiculitic shales (Worsley, 2008).

Mesozoic

In the Triassic, the Barents Sea and Svalbard areas formed a big embayment located at the western corner of the supercontinent Pangea (Dallmann et al., 2015). The contact with the southern areas (Tethys Ocean and the Boreal Sea) was cut after formation of the Uralian Mountain chain in the late Paleozoic (Lundschien et al., 2014), which resulted in drastic climatic changes. Temperate climate and clastic sedimentation now replaced the subtropical conditions and carbonate deposition that had dominated in the Permian (Worsley, 2008, Dallmann et al., 2015).

Early to Middle Triassic is regarded as a period of quiescence with tectonic activity reduced to a minimum. Regionally the crust subsided in the western Barents Sea, and the sedimentation rates were high, sourced from the newly formed Uralian Mountains in the south east and Fennoscandia and the Baltic Craton in the south (Smelror et al., 2009). This is observed from seismic lines showing north-westernly to westernly prograding clinoforms (Høy and Lundschien, 2011, Glørstad-Clark et al., 2011), with the infill gradually converting the former deeper shelf to a paralic platform (Riis et al., 2008). Growth of salt diapirs led to increased accommodation space in some sub-basins, and locally development of thicker clinoforms in the Nordkapp and Tiddybanken basins (Lundschien et al., 2014). An extensive deltaic system were building out from the source area with large river systems filling the Barents Sea with sediments deposited in environments from deep basins to coastal plains (Fig. 2.2) (Lundschien et al., 2014). Progradation of the clinoform belts possibly started as early as late Permian and traversed across the Barents Sea before they reached Svalbard in late Triassic (Lundschien et al., 2014, Riis et al., 2008). The gradually infill of the embayment occurred in cycles of transgressive-regressive events (Rasmusen et al., 1992, Klausen et al., 2017), creating sequence boundaries that can be correlated through large parts of the Arctic (Mørk and Smelror, 2001). Total thickness of the Triassic succession is estimated to be 250-1200 m on Svalbard (Mørk et al., 1982) and 2000-3000 meters in the Barents Sea (Riis et al., 2008).

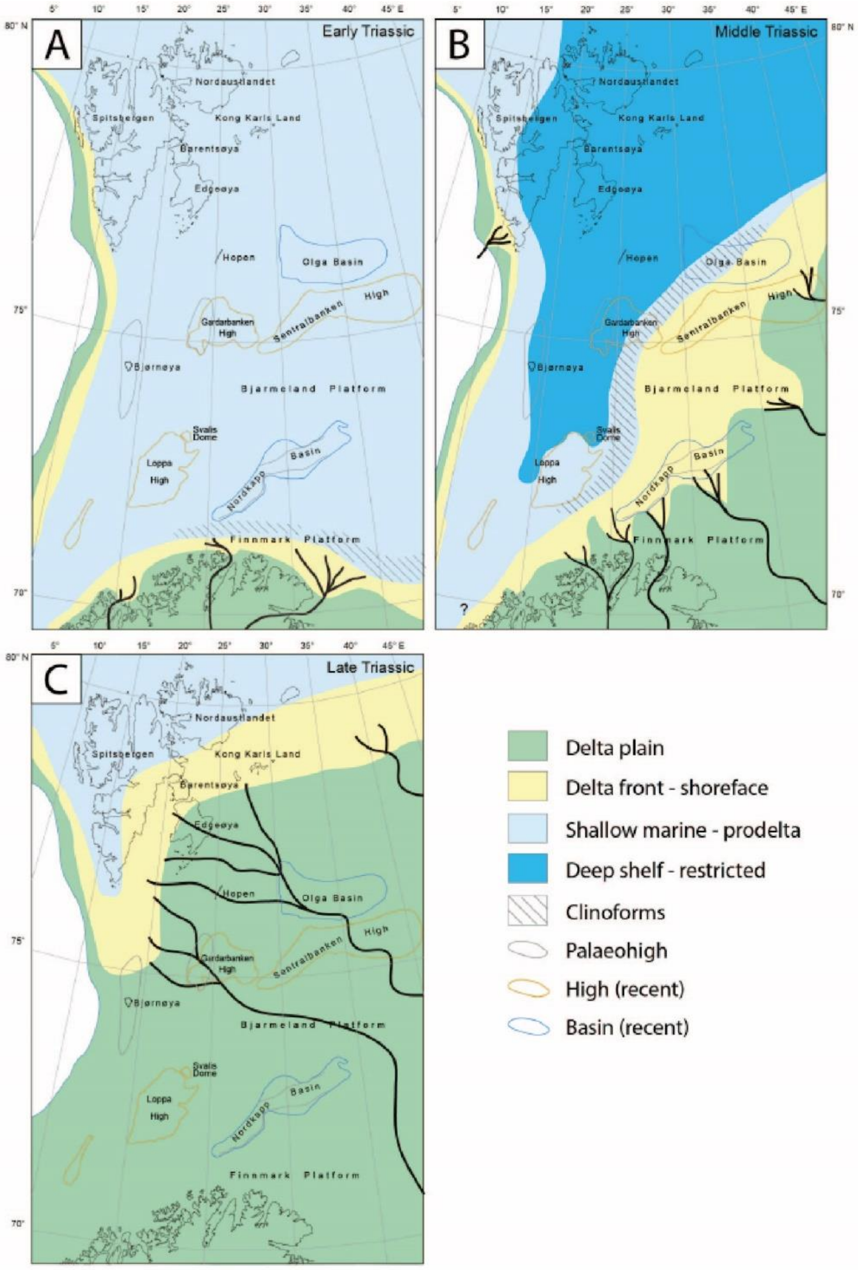


Figure 2.2: Triassic evolution of the Barents Sea shelf with the present-day location of Svalbard indicated From Lundschien et al. (2014). **A)** Early Triassic. **B)** Middle Triassic. **C)** Late Triassic.

A pronounced change of the paleogeography occurred from Middle- Late Triassic with uplift of the northern, eastern and southern Barents Sea region. This resulted in westwards thickening of the Carnian strata with sediment influx mostly from the Fennoscandian Shield. Renewed tectonic activity occurred towards the end of Triassic and continued until Early Jurassic times (Smelror et al., 2009), leading to a breakdown of the regressive/transgressive sequences that had major impact on Triassic deposition (Mørk and Smelror, 2001, Worsley, 2008). Climate was also changing during this period and shifted from arid to humid. This resulted in increased transportation of clastic sediments from the mainland into the Barents Sea (Glørstad-Clark et al., 2011).

2.1 Lithostratigraphy

A brief introduction to the stratigraphy of the Barents Sea will here be presented, emphasized on the formations that are present in the studied cores. The Triassic stratigraphy of the Barents Sea shelf is based on seismic correlations and well data from exploration wells, supplied by shallow stratigraphic cores from IKU (Continental Shelf Institute, now SINTEF Petroleum Research) and NPD (the Norwegian Petroleum Directorate) (Riis et al., 2008). The present lithostratigraphy of the Triassic stratigraphy south-west in the Barents Sea were defined by (Worsley et al., 1988) and are included in Figure 2.3 which also includes the Lithostratigraphic units of Spitsbergen.

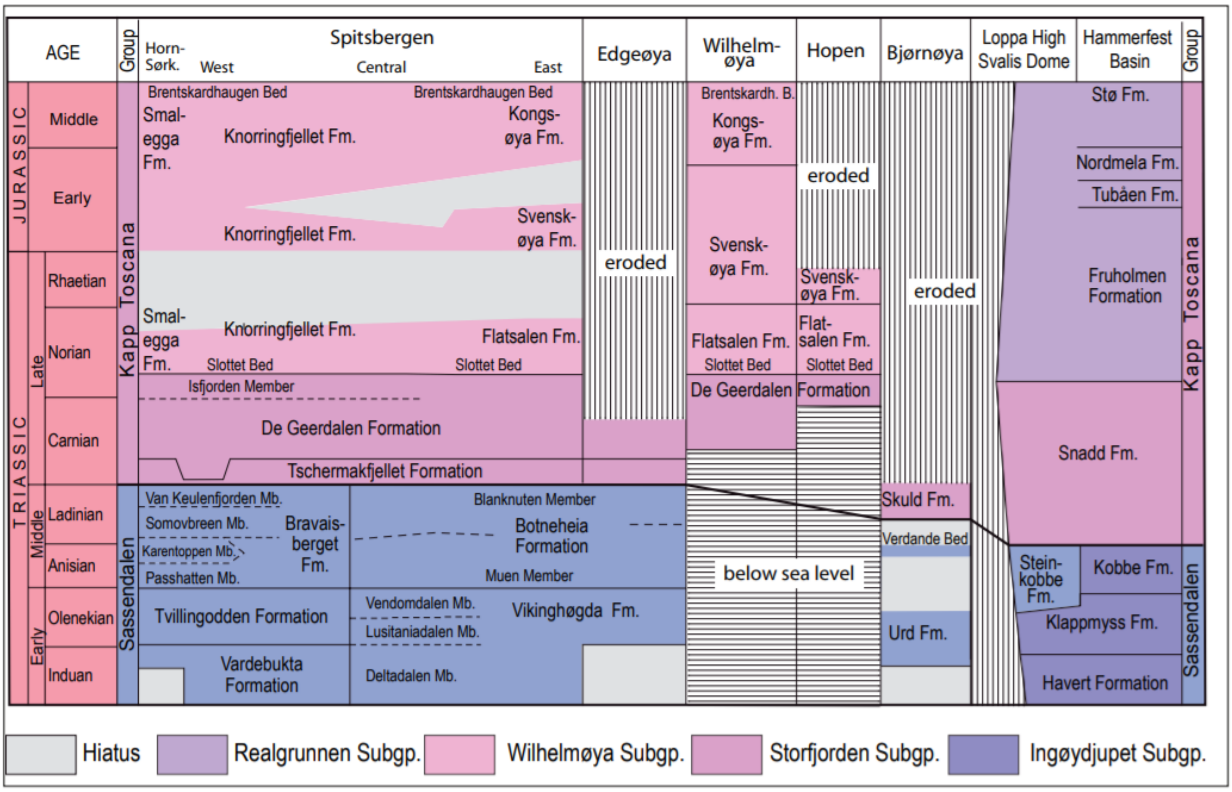


Figure 2.3: Lithostratigraphic scheme during the Triassic in Svalbard and the Barents Sea (modified from Mørk et al., 1999 in Lundschien et al., 2014).

2.1.1 Klappmyss Formation

Klappmyss Formation is in the type well in Hammerfest Basin characterized by medium to dark grey shales that passes upwards into interbedded shales siltstones and sandstones. North of the southern margins of the Hammerfest Basin the formation thickens and fines (Worsley, 1988). Wells drilled at the Sentralbanken High is dated with palynology to late Olenek and assigned to the Klappmyss Formation. The lithology in this area is composed of dark grey-green siltstones interbedded with very fine sandstones. Low diversity and assemblage of ichnofauna suggests either rapid sedimentation or reduced oxic conditions in the bottom water. The depositional environment of the formation has in this area been interpreted to represent a shallow shelf below storm wave basis (Riis et al., 2008).

2.1.2 Kobbe Formation

Kobbe Formation is Anisian to early Landinian of age and represents a proximal equivalent of Steinkobbe formation. Hosting the reservoir of the Goliat oil and gas field in close to the Troms Finmark Fault Complex, studies of the formation have been of great interest in the later years. It was deposited after a regional regression following the progradation of the Klappmyss Formation and is up to 825 m thick (Dalland et al., 1988, Glørstad-Clark et al., 2011). A wide range of depositional environments have been reposted from the formation, from offshore deltaic depositions to coastal plain/delta top deposits with a general fining upward trend (Klausen et al., 2017, Mørk and Elvebakk, 1999), including several regressive and transgressive episodes seen as variations of shallow marine – paralic depositional environments (Glørstad-Clark et al., 2011, Bugge et al., 2002). The most proximal facies are composed of coastal sandstones and found along the southern margin of the Hammerfest basin and fines basinwards where it transitions to marine shales (Worsley et al., 1988). According to Glørstad-Clark et al. (2011), the sediment sources of these deposits are most likely both the Baltic Shield and the Uralian Mountains based on interpretation of progradational seismic clinoform successions. Contribution of sediments from the Upper Paleozoic to lower Triassic basement might also be the case in western parts of the Barents basin, but there is no evidence for progradation of the system further west (Lundschien et al., 2014, Klausen et al., 2017).

2.1.3. Steinkobbe Formation

Steinkobbe Formation is the distal time equivalent of Kobbe Formation, characterized by general high content of organic carbon. The formation is defined by Mørk and Elvebakk (1999) at the Svalis Dome and spans from late Spathian to Late Anisian over an interval of 250 m in the type area. The formation primarily consists of dark, fossiliferous and phosphatic rich shales occasionally interbedded with laminated siltstones and claystones. Deposited under open shelf conditions with anoxic or periodically anoxic sea bottom conditions, it hosts good preservation potential for organic matter, and parts of the formation is considered an important source rock for hydrocarbons. The organic rich facies are found over major parts over the Barents Sea, including Svalbard, where it was established by the onset of Anisian and are assigned to the Botneheia Formation (Mørk et al., 1999, Krajewski, 2008, Vigran et al., 2014). During the same period, more oxygenized conditions developed in the southern parts of the Barents Sea with the establishment of Kobbe Formation (Lundschien et al., 2014).

2.2 Locations

2.2.1 Nordkapp Basin

Core 7230/5-U-06 was sampled from a borehole in the central/eastern segment of the Nordkapp Basin by SINTEF Petroleum Research during IKUs stratigraphic drilling project from 1982-1993, where parts of the Norwegian continental shelf were mapped (Bugge et al., 2002). The core is 71m long and drilled on the flank of a salt diapir. The deposits are Anisian of age (Vigran et al., 2014), and assigned to the Kobbe Formation, and have several similarities to Bravaisberget Formation known from western Svalbard (Krajewski et al., 2007).

The Nordkapp Basin is a 300 km long elongated basin stretching in the direction of ENE-WSW with a maximum width of 75 km characterized by several salt diapirs forming continuous salt walls (Faleide et al., 1984). The early origin of the basin is probably a result of regional crustal extension during the Late Devonian-Early Carboniferous (Bugge et al., 2002), followed by reactivation and a renewed period of regional rifting in Mid Carboniferous. Fault blocks are rotated and syn-sedimentary deposits from this period can be observed at several locations (Gudlaugsson et al., 1998), with the primary infill of the basin believed to consist of coaly alluvial siliciclastics of the Billefjorden Group (Bugge et al., 1995). A major transgression by the end of Late Carboniferous led to development of a big carbonate platform with deposition of thick evaporitic successions stretching out of the present-day basin margins. Halite rich end members are documented from the flanks and the south westernmost parts of the basin and movement of the salt have interacted with faulting while forming the basin margins (Gabrielsen et al., 1992, Koehl et al., 2018). However, according to Faleide et al. (1984), the main salt source for the diapirs are situated below the Permian evaporites, possibly deposited as early as Devonian, and the Permian evaporites are mainly responsible for smaller salt pillows.

Uplift of the Uralian mountains by the end of Permian led to a new period of clastic deposition with thick Triassic deposits in the Barents Sea, hugely influenced by the orogenic source of the Uralides (Glørstad-Clark et al., 2010, Smelror et al., 2009, Høy and Lundschien, 2011). Initial salt tectonics started in Early Middle Triassic age have affected the thickness variations of the Triassic succession in the basin greatly due to salt movement causing increased basin subsidence (Bugge et al., 2002). Several episodes of remobilization and reactivation of the salt have been postulated from Jurassic and to present day with the general assumption by most authors that density contrasts and buoyancy are the main controlling factors (Bugge et al., 2002)

The present-day basin is to large degree shaped by uplift and erosion during Tertiary. Uplift and glacial erosion in the late Pliocene/Pleistocene removed up to 1200 meters of Mesozoic and Cenozoic strata, and the residual strata is presently left tilted and truncated around the salt diapirs (Smelror et al., 2009).

2.2.2 Svalis Dome

The cores 7320/07-U-01,03 & 04 are also sampled for the IKU-Barents Sea mapping program. Cores are respectively 31.9m, 33,3m and 38.7m and assigned to Klappmyss Formation and Steinkobbe Formation. The Svalis Dome is a diapiric structure with a diameter of approximately 35km located south in the Barents Sea, west of the Nordkapp Basin (Gabrielsen et al., 1990). Numerous faults intersect the diapir giving it a triangular shape with a crest cross-cut by collapse grabens. Uplift of the height occurred already in the early Permian by vertical movements of salt deposits. During late Permian The Svalis Dome became partly subaerially exposed (Mørk and Elvebakk, 1999), which led to onlap of Lower and Middle Triassic deposits on the eastern flank mainly consisting of sediments deposited in shallow marine to deep shelf conditions (Lundschien et al., 2014). During late Middle Triassic the high subsided and was transgressed.

2.2.3. Sentralbanken High

Core 7534/06-U-01 from Sentralbanken High is 109.9 meters thick but are missing several meters at the top. Few papers describe the formation and nature of the Sentralbanken High. Geometrically it is an ENE-WSW trending elongated dome structure situated between 75°20 75°50 N and 31° and 35°E, bounded to the Olga Basin in the north and the Bjarmeland platform in the south. The Mesozoic strata at Sentralbanken High is partly deformed by a series folds and compressional faults, postdated late Cretaceous (Riis et al., 2008). The Jurassic strata have been eroded and are thus not present. The height is assumed a uplifted part of the platform area, and not a basement high as opposed to the highs in the western Barents Sea (Riis et al., 2008, Gabrielsen et al., 1990).

3.Methods

3.1 Logging procedure

The cores 7230/05-U-06, 7323/07-U-01, 7323/07-U-03, 7323/07-U-04 and 7534/06-U-01was closely examined to create a detailed sedimentological log in scale 1:20 for core 7232/07-U-01 and 7534/06-U-01 and in 1:50 for the remaining cores. According to Lundschien et al (2014), the cores comprises three formations in total: Kobbe Formation, Klappmyss Formation and Steinkobbe Formation, and formation boundaries have been adapted from there.

A graphical log with all observations was created to give a detailed visual impression of the content of the sedimentary succession. Observations included grainsize, color variations, textures, sedimentary structures, content of fossils, bioturbation, vertical variations and bedding contacts. A grainsize sheet was used to estimate grainsizes and used under the microscope together with the core to adapt the eyes to the smallest sizes. 10% HCl was applied to detect presence of carbonate. In addition, loupe and a measuring stick was used. After logging, the logs were digitalized in Adobe Illustrator and downscaled to printing format. To downscale the detail level must be reduced and only the most typical features are represented. Representation of alternations of thin beds of various lithologies and heterolithic bedding are based on the most dominant grainsize, and heterolithic bedding might thus display in various ways in the log. All data collected from the cores were systematized by facies and facies associations.

3.2 X-ray diffractometer (XRD)

Eight samples from core 7230/05-U-06 have been selected for standard bulk XRD analysis to quantify their mineral assemblage. The samples are taken from selected parts of the core where it was a visible difference in factors such as color, grainsize and mineralogy. The purpose of doing an XRD analysis was to examine variations in mineralogy within the cored part of the Kobbe Formation, to confirm or enfeeble assumptions from the core investigation, to look at differences or similarities between the different paleosols and to add information to possible depositional environments.

The analysis was performed by Laurentius Tijhuis at the mineralogical/chemical lab at the Norwegian University of Science and Technology (NTNU). The samples were crushed to powder and run in the instrument Bruker D8 Advanced. The minerals were identified in the software Diffrac.pluss.EVA whereas the software Topas which is based on the Rietveld method was used to quantify the interpreted mineral assemblage.

3.3 Challenges and sources of error

Since observations are the basis of data collection, this combined with misinterpretations and lack of observations are considered the largest sources of error. Often certain features need to be interpreted in order to be described, and misinterpretations during data collection can get further consequences for the final interpretations. Finding the balance between too much and too little interpretation is subjective and depends on the observer and the observers background.

A core can provide a great deal of details of the features described in the logging procedure but has its limitations by the lack of possibility to describe lateral variations. Due to this it can be a challenge to evaluate whether the studied object is a typical feature or something uncommon cored by coincidence. Lateral variation can be of great interest due to the possibility to observe the extent and size of the feature, which will give clues about the possible sedimentary environment. Since this not can be observed, detecting the vertical variations becomes even more important. For the XRD it is possible to do mistakes during preparation of the samples and misinterpretation of the curves might happen.

4.Results

4.1 Core descriptions

This chapter gives a detailed description of the cores from all the studied locations. Description of facies is outlined in chapter 5, whereas facies associations are found in chapter 6. The different localities are described in chapter 2 The following divisions are created to provide a detailed description of the cores by separating them it into intervals based on content, it is not necessarily based on the facies associations which will be described later.

4.1.1. Nordkapp Basin (Core 7230/05-U-06)

Interval 1 (96.2m-92m)

Moderately bioturbated heterolithic bedding with siderite bands are present at the base of the core. It is overlain by a cross-stratified unbioturbated green glauconitic rich sandstone bed which gradually is transitioning into heterolithic bedding and abruptly cut by a fossil rich siderite conglomerate. The overlying lithology is a mix of silt and claystone with alternating wavy bedding and planar parallel lamination with brown, grey and greenish colors. Occasionally thin beds of very fine sandstone are present.

Interval 2 (92m-87m)

A 2 cm thin siderite conglomerate (facies D) defines the base of the interval overlain by an 8 cm thick massive sandstone. Above this there is a sharp boundary to heterolithic bedding dominated by wavy bedding which is the component of most of the section. The section is moderately bioturbated and bioturbated sand lenses are commonly filled with clusters of small pyrite nodules. The color is less green and slightly darker compared to underlying interval.

Interval 3 (87m-81.7m)

The interval is dominated by fine cross-stratified sandstone and fines upwards with more frequent interlaminations of mud towards the top. An assemblage of rounded siderite clasts and elongated mud flakes is present in a 10 cm interval at 86.5 cm. Above this the assemblage of intraclasts disappears a couple of meters before they again appear, then mostly as slightly imbricated mud flakes. Mud laminas and thin interbeds of wavy bedding starts appearing from the upper third of the interval. These parts are sparsely to moderately bioturbated whereas the sandstone is unbioturbated.

Interval 4 (81.7m-75.3m)

A general coarsening upwards sequence starts from the base with 2 meters of dark mudstone with very thin continuous sand lenses. The mudstone has sparse bioturbation that comprise subvertical and horizontal burrows. Some of them contains pyrite nodules of up to 2 cm in diameters. Above the 2 lowermost meters the heterolithic bedding changes character gets dominated by wavy bedding before a sand-dominated part starts and ripple lamination gets prominent interbedded with thin wavy bedded parts. The two upper meters are dominated by planar parallel laminated mud and sandstones, occasionally with mud drapes. The coarsening upwards sequence terminates with a siderite conglomerate at 76.6, above which a red dark mudstone layer is present similar to what is present the base of the interval. This lithology continues throughout the interval and is frequently interbedded with thin beds of very fine sandstone.

Interval 5 (75.3m-60.1m)

The first meter is composed of interlayered mud and sand with several loading structures with load casted ripples. The mud layers are in this part structureless. Above is the only occurrence of mud flake conglomerate which is resting with an erosive boundary, sharply overlain by a new interval of interlayered mud and sandstone, but here some of the mud layers show signs of indistinct thin planar parallel lamination, and the sand fractions have more prominent ripple lamination. This is followed by graded rythmites described in facies J. The following 3 meters are dominated by alternations of heterolithic bedding (wavy), coarsely interlayered mud and sand, and ripple-laminated sandstone, before a long section dominated by ripple-laminated sandstone (occasionally also with flaser-lamination) takes over. The ripples are highlighted by coal debris, and the section is partly rich in siderite sand. Brown mudflakes occur more frequently upwards. From 63.1m and up, a few interbeds of mud is present and so is minor beds of planar parallel laminated sand with abundance of coal debris.

Interval 6 (60.1m – 52.8m)

The transition from interval 5 is gradual, with ripple laminated sandstone transitioning to heterolithic bedding with alternations of grey-brown mud and very fine sand. Facies I is predominantly composed of wavy bedding and comprises the two lower meters. Sections with intense bioturbation alternates with unbioturbated to sparsely bioturbated heterolithics.

Above this the composition changes, and facies I is replaced with an intensely bioturbated muddy sandstone with a light green shade (facies C), gradually coarsening upwards before it fines again, and eventually is replaced by an intensely bioturbated version of heterolithic bedding. The top of the interval comprises facies C.

Interval 7 (52.8m-49.8m)

Interval 7 starts with a brown muddy siltstone with calcite nodules (facies A), with a sharp inclined boundary to the underlaying light green muddy sandstone. The upper boundary is gradual and coarsening upwards to gray-green siltstone with a few roots and purple spots. The organic content increases upwards with progressively more coal debris incorporated in the silt. Eventually the siltstone transitions to coal shale overlain by a 15 cm thick coal bed. Above the coal there is 50 cm of very fine sandstone with chaotic lamination, soft sedimentary deformation and roots before a new transition to coal shale and coal. The upper 5 cm is composed of a muddy light green siltstone.

Interval 8 (49.8m-45m)

The base of interval 8 has an abrupt change from the underlying muddy siltstone to very fine grey sandstone. Mud flakes are present in the lowermost 10 cm at the base of the interval. Above this cross-stratification and ripple-lamination (facies F and facies G, respectively) alternates. Both facies contain a significant amount of coal debris along the foresets. The interval is fining upwards into a soft sedimentary deformed part of mixed very fine sandstone, silt and mudstone containing roots.

Interval 9 (45m- 39.4)

The transition to interval 9 is gradual with the appearance of a mottled siltstone (facies A). The lower part has a dominant rusty red- brown color, and contains some millimeter scaled elliptical shaped root traces. Some parts react weakly by application of hydrochloric acid. No bioturbation is present. Overlain facies A, there is a thin bed of grey mudstone, coarsening up to a siltstone, both lithologies containing roots and millimeter scaled siderite concretions and a few spots of darker clay. A new paleosol bed is present on top of this, with the same characteristics as below, but with slightly more yellow color. The paleosol is gradually changing into a light grey mudstone with mottles of dark clay. The upper meter of the section comprises an intensely bioturbated siltstone with coal fragments/ plant debris and one small root trace.

Interval 10 (39.4m – 25.2m)

Fine sandstone with ripple-lamination and lenticular bedding is present at the base of the interval. The core interval fines upwards and the sandstone is replaced with heterolithic bedding with wavy lamination alternating with very fine sand to siltstone rooted beds. At 35.5m a dark brown mudstone with abundance of coal fragments occur, coarsening upwards to intensely bioturbated heterolithic bedding of silt and clay. The heterolithic bedding gradually passes into coal shale and coal. Above the coal, very fine rippled sandstone is present, overlain by heterolithic bedding with increased degree of bioturbation upwards. In between there is a 4 cm thick bed of siderite conglomerate. The top of the core is suffering from damage after drilling and is thus not representative.

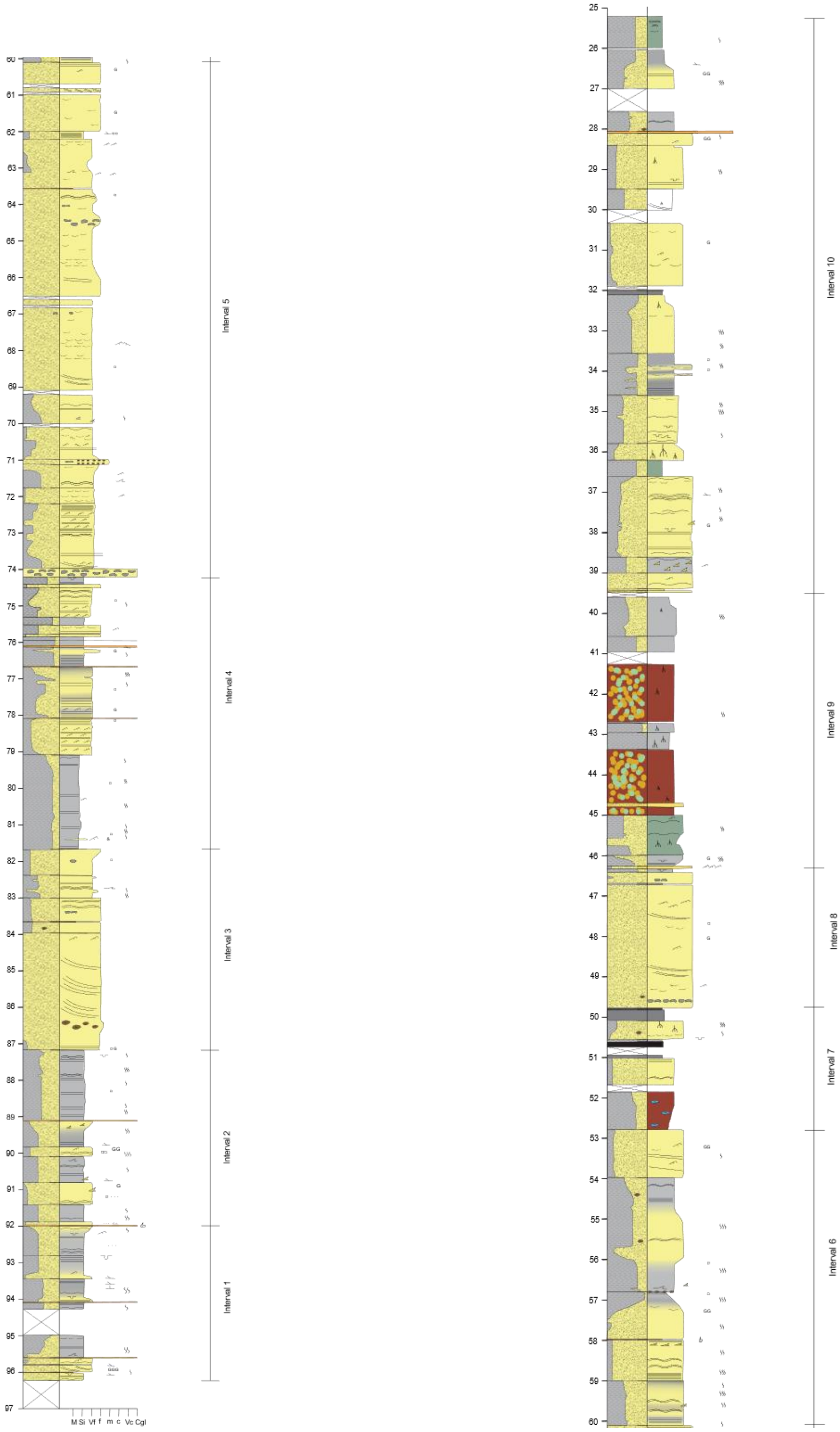


Figure 4.1: Sedimentary log of core 7230/05-U-06

4.1.2 Sentralbanken High (Core 7534/06-U-01)

The core is quite uniform both in terms of sediment type, grainsize distribution and paleontological content. Only four facies are recognized; Facies E (Siderite conglomerate), facies F (very fine to fine cross-stratified sandstone), facies K (muddy siltstone with sandstone intercalations) and facies L (dark grey mudstone). Transitions between facies K and L are almost exclusively gradual. Internal variations within these facies are also gradual, which complicates the task of making subdivisions and determine whether the lithologies are fining or coarsening upwards. However, the genuine trend of the cored interval is meter scaled coarsening upward successions composed of minor segments of mostly fining upward graded beds of up to approximately 15cm.

Interval 1 (120.1m-109m)

The interval is composed of heterolithic deposits of alternating sandstone, siltstone and mudstone. Maximum grainsize is very fine sand. The base is fining upwards from calcite cemented very fine sand to mud. Mud-silt/sandstone boundaries are usually sharp, either as horizontal, or more commonly with loading or micro-loading structures (mm loading). Transitions from silt to mud is often gradual and fining upwards, however, there might also be sharp boundaries. Thin siltstone beds and thick laminas commonly have ripple structures. The mudstones are internally structureless.

From the second half of the interval, two stacked coarsening upward units are present. They are composed of alternations of thin beds of silt, very fine sand and mud. Beds are gradational of have fining upwards lamination. At 109,1 m cone in cone structures are overlain calcite cemented very fine sand. At 113.10 m, wavy bedding with thick laminas are present above planar parallel laminated very fine sandstone. A 2 cm thick siderite conglomerate is found at 118.6 m.

The trace fossil chondrites is abundant from the base of the core and up to approximately 117 meters. Above this it is only occasionally found in more sparse clusters. The presence and diversity of trace fossils is sparse throughout the whole interval. Black small grains are interpreted to be fragments of poorly preserved *Tasmanites*. They appear commonly throughout the section, often clustered in intervals up to 2 cm and aligned with the lamination. Most often they appear within the coarser deposits but are also commonly found within the mud.

Siderite is present both as thin layers of up to 2 cm and as cement within the siltstone-mudstone alternations.

Interval 2 (108m- 100 m)

The transition from underlying interval is unknown due to core missing. The interval is dominated by mudstones coarsening up to silty mudstones or muddy siltstones. Internal structures in the mudstone is possibly parallel lamination, but mostly it appears as structureless. Siderite cementation is common roughly every 10 cm, however, it does not seem to be any system in the distribution. Bioturbation is sparse at the base of the core but increase in the upper 2 meters. The diversity is low, and usually chondrites is exclusively found alone. Siltstones seems to be massive without internal structures, possibly partly due to destruction by bioturbation. A few thin beds are gradational from silt to mud.

Interval 3 (100m- 87.5 m)

Consists alternating mudstone siltstones and is similar to interval 1. Siltstone layers are either bioturbated by chondrites and planolites, planar laminated or rippled. Thin beds are gradational and often soft sediment deformed. *Tasmanites* occur frequently.

Interval 4 (87.5 m- 79 m)

The interval fines upwards from calcite cemented very fine sandstones to light grey mudstone and silt/mud alternations. The sandstone looks planar laminated but might as well be cross stratified. It is significantly less bioturbation compared to the underlying intervals, and the lithology is more dominated by mudstones.

Interval 5 (79 m- 56 m)

The dominant lithology is medium to dark grey mudstone regularly with siderite bands or in layers with cementation. Ammonites and bivalves are present the lowermost 4 meters. Bioturbation is sparse and the only observed trace fossil is *Chondrites*. Small pyrite crystals are common, with size from 0.2-0.5 cm. Lamination is not prominent, but are visible as minor changes of color and not due to difference in grain size.

Interval 6 (56 m- 39.6 m)

The interval is composed of the dark grey silty mudstone from interval 5, but with more frequent intercalations of silt and very fine sand. Bioturbation occurs but is sparse. Of recognized trace fossils, *Teicichnus* is the most common. Calcite cement is prominent at the base of the section as well as towards the transition from mud/silt alternations to mudstone. Cone in cone structures is found at 54.4 m and 46.2m. Siderite cement and siderite bands are also common. One concretion with fibrous calcite veins and a purple core interpreted to be a septarian nodule is found at 53.2m. A 7 cm long part with soft sediment deformation is interpreted to be overturned cross bedding, which indicates that a shear stress must have been present during deformation. A moderate content of pyrite and phosphorite can be found above the transition in addition to a minor contribution of the trace fossil *Chondrites*.

Interval 7 (39.6 m- 10.63 m)

The lithology is this section is similar to what is found in interval 1. From the base of the interval and up to approximately 34 m grey mudstones are the dominating lithology, occasionally interbedded with rippled siltstones and sandstones. Above this the silt and sand content increases with more frequent alternations. *Tasmanites* is regularly observed in certain intervals. Gradational beds are typical fining upwards from very fine sandstone to silt of mudstone. Compared with interval 1 and 2 beds tends to be thinner and alternations occur more frequently. Siderite cementation is also less common in comparison. The frequency of alternations decreases above 26m but increases again at approximately 20.5m. A 10 cm thick conglomerate bed is present at 19m. The conglomerate is matrix supported with clasts of siderite and adjacent deposits. Clasts are mostly rounded, some elongated indicative of transportation. The conglomerate is poorly sorted with grain sizes ranging from very coarse sand to clasts of 1x4 cm. Several meters of core is missing towards the top of this interval.

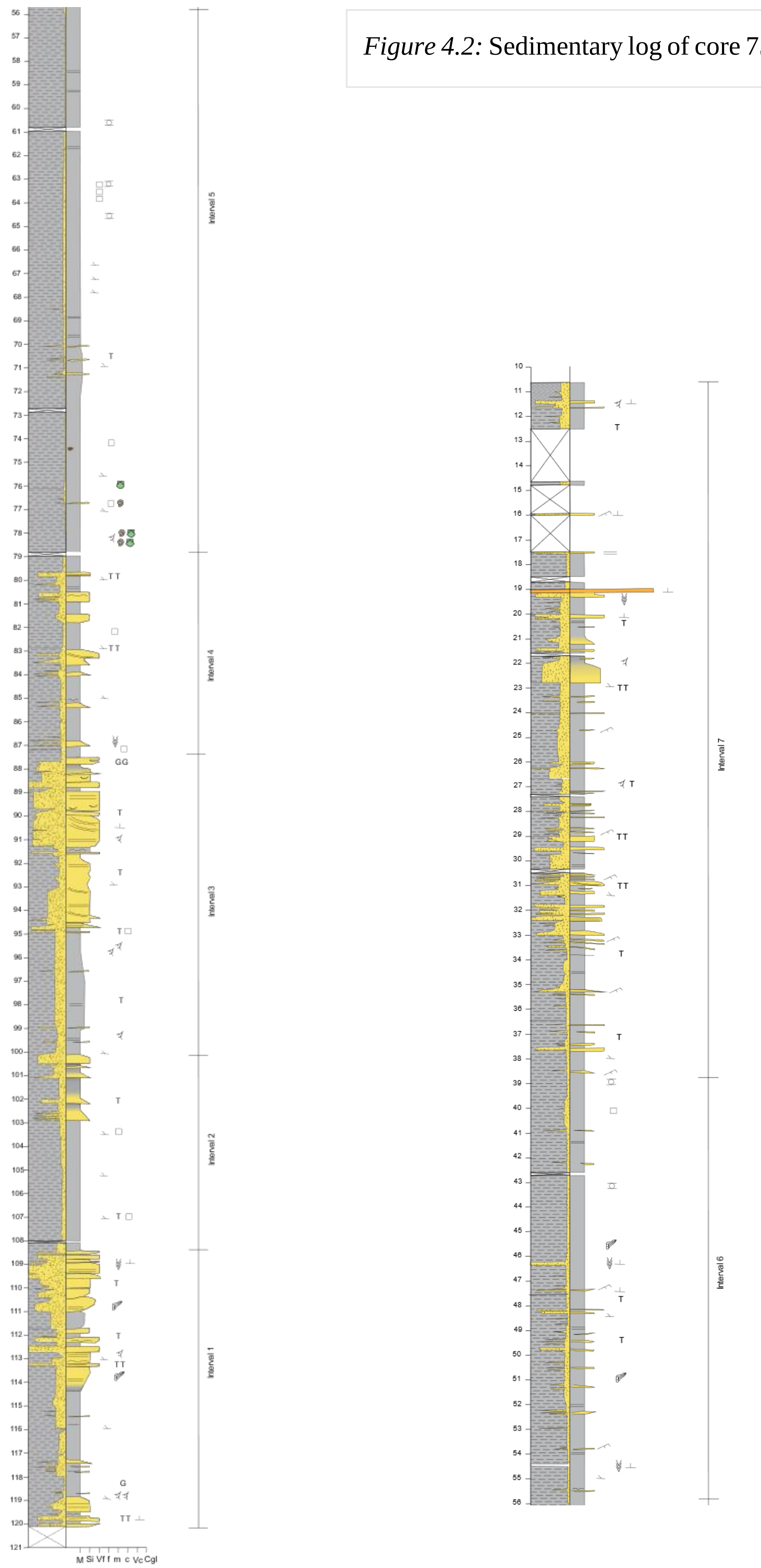


Figure 4.2: Sedimentary log of core 7534/06-U-01

4.1.3 The Svalis dome

4.1.4 Core 7323/07-U-03

Interval 1 (132m – 107.8m)

The whole interval is composed of unbioturbated laminated grey siltstone with fining upwards lamination. This is described in detail in the facies chapter.

Interval 2 (107.8m – 98.8m)

Interval 2 is separated from interval 1 with a sharp boundary where laminated dark shale abruptly replaces the long continuous interval of laminated siltstone. The shale has small millimeter scaled phosphate nodules. Two calcite cemented beds are present, one after the first meter and one at the top of the core. In addition, there is a few cm thick silt beds without any apparent structures. The sharp boundary separating the two intervals is the formation boundary between Klappmyss Formation and Steinkobbe Formation (Mørk and Elvebakk, 1999).

4.1.5 Core 7323/07-U-04

This core is regarded as one long continuous interval, following the trend of interval 2 from core 7230/07-U-03. Phosphate nodules are common throughout the interval, larger in size than observed in core 7230/07-U-03. Thin streaks of grey mud are found from 125m-115m. Calcite cemented beds occurs roughly every 10 meters and appears either as massive or with calcite filled veins. Ammonoids, bivalves and fish remains are reported from Mørk and Elvebakk (1999) and Vigran et al., (1998), and occur more frequently towards the top of the core. The core is slightly coarsening upwards from 101.5 meters with more silt incorporated within the laminated dark mudstone.

4.1.6 Core 7323/07-U-01

Interval 1 (126.9m- 106.3m)

The whole interval can be seen as a continuation of core 7230/07-U-04 with phosphatic organic rich dark shale. The interval comprises two stacked slightly coarsening upward units and one upper unit with less variation in grainsize. The two lowermost units are coarsening upwards by progressively more silt laminas and a few laminas of very fine sandstone incorporated in the shale. Most of these laminas are calcite cemented. The first interval is 5,5 meters and terminated by a thin limestone bed. Bioturbation is absent in the whole unit. Thin limestone beds are interbedded throughout the unit. Bivalves and fish remains are common throughout the unit while ammonoids are common in the lower part (Mørk and Elvebakk, 1999).

Interval 2 (106.3-95m)

The thick package of the dark laminated shale ends abruptly with the onset of interval 2 which is composed of laminated grey siltstones (facies J). The middle part of the interval contains thin siderite cemented beds. Small lenses of very fine sandstone with ripple lamination are abundant and so is graded sandstone laminae. A few black fragments, possibly *Tasmanites* occur in within the siltstone. Some of the laminae and sand lenses show minor loading structures at the base (mm scale). Bioturbation is sparse, but absent from the upper 2/3 of the interval. According to Mørk and Elvebakk (1999), fragments of bivalves and ammonoids are present, but significantly less than in the interval below.

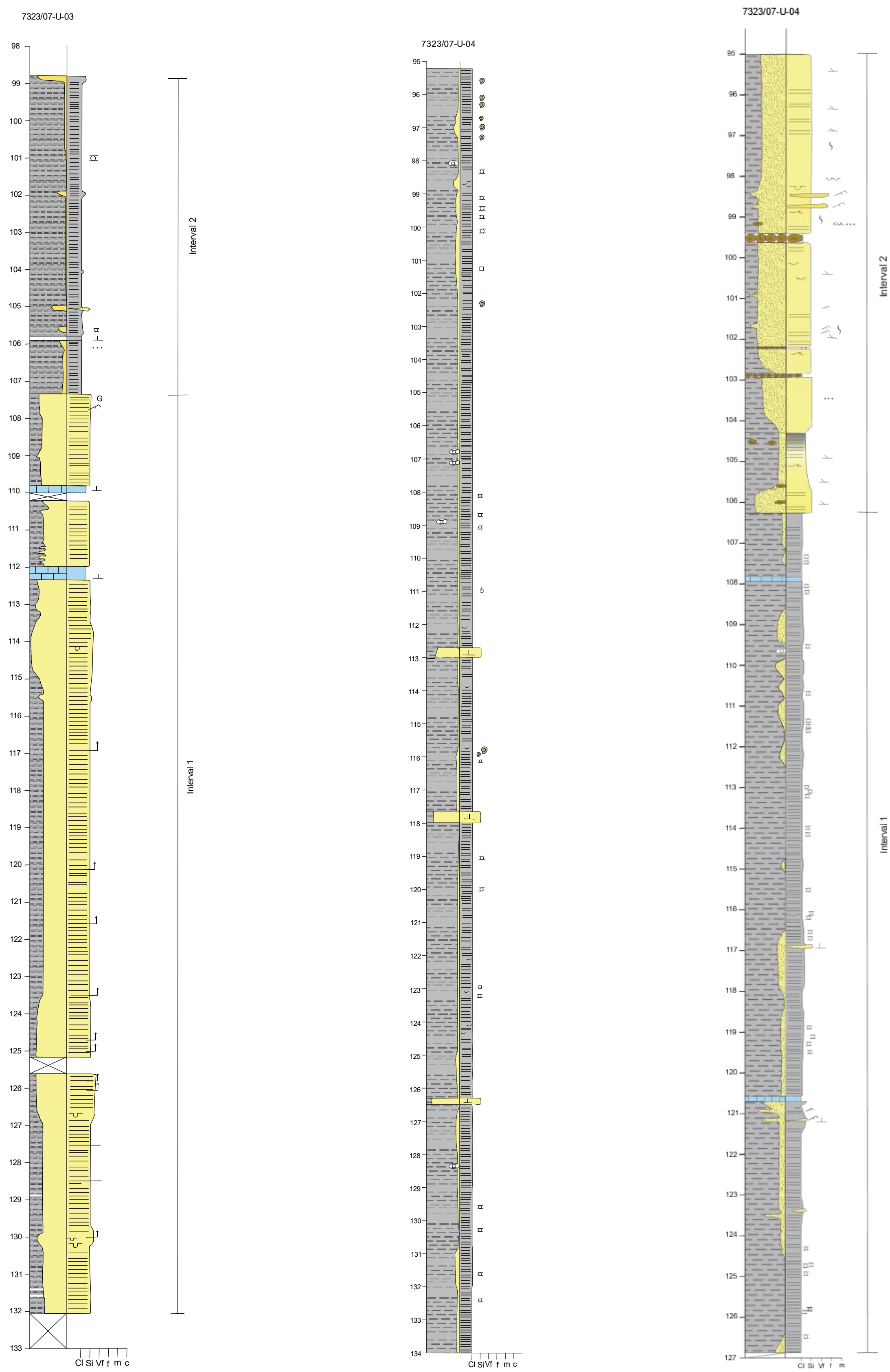


Figure 4.3: Sedimentological logs of the cores from the Svalis Dome. Note that the scales variates.

4.2 XRD analysis

Observations

Eight samples were chosen for XRD analysis (Table 4.1). The samples are taken from three different facies: Paleosol (Both the mottled variation and the red siltstone with calcite nodules), cross-bedded sandstone and light green rooted sand stone. Sample 6, 7 and 8 are sandstone samples taken on background of difference in color and apparent composition. The analysis show that they are almost identical in mineralogical composition except from sample 7 which has a minor component of siderite. The mineralogy is relatively immature with quarts as the most dominant mineral, ranging from 54-60% .

Sample 1, 3, 4 and 5 are taken from paleosols at different levels. Quartz is also here the most dominant component in all samples, ranging from 37-41%. The overall trend is a decrease in quartz from base to top in the core, although it must be considered that it is not only sampled for pure sandstones which means that this trend not is entirely representative. Kaolinite and chlorite are the most abundant clay minerals. Found only in sample 3 and 4. Paleosols from sample 1 and 4 have the same amount of quartz but differ in the composition of clay minerals. In sample 1, chlorite is the dominant fraction, and no kaolinite is present, whereas sample 4 contains only kaolinite. The mica presented in Table 4.1 predominantly consists of muscovite.

The result from the analysis provided wide curves, which is indicative of weathered rocks which complicates the interpretation. This means that these results only should be used as a coarse estimate of quantification.

Table 4.1: Mineral composition of the samples from the Nordkapp Basin based on XRD bulk analysis.

Core	7230/05-U-06	7230/05-U-06	7230/05-U-06	7230/05-U-06	7230/05-U-06	7230/05-U-06	7230/05-U-06	7230/05-U-06
Meters in core	26.25	36.05	40.66	43.90	52.48	57.24	63.83	67.08
Journal no	180333	180334	180335	180336	180337	180338	180339	180340
Sample	1	2	3	4	5	6	7	8

Mineral group	Weight %							
Quartz	37	10	41	37	47	54	59	60
Mica	21	-	40	30	27	14	9	9
Plagioclase	15	>1	10	12	13	17	12	16
Alkali-feltspar	5	-	-	3	6	5	3	5
Chlorite	18	-	-	-	6	8	9	8
Pyrite	-	5	-	-	-	>1	>1	>1
Pyroxene	3	-	-	3	-	-	2	2
Siderite	-	85	-	-	-	>1	5	-
Kaolinite	-	-	9	14	-	-	-	-
Marcasite	-	-	-	2	>1	-	-	-
Calcite	-	>1	-	-	-	-	-	-

Interpretation

The limited variation in the sandstone samples indicates approximately the same conditions for the samples. The presence of siderite in sample 7 is interpreted to represent siderite sand and not cement on background of visibility in core where small darker grains are visible within the light sand. This implies that siderite sand frequently occurs in the core and that is most likely is a product of erosion of underlying siderite rich strata. The high siderite content in sample 2 is from root-structure and are thus not regarded as an erosion product. This root-structure is found within a sandstone with drapes of green clay and indicates deposition during condition where siderite precipitation was possible. Siderite commonly forms in organic-rich brackish to meteoric pore waters depleted of SO_4^{2-} and occurs regularly in fine grained deltaic to coastal sediments (Morad, 1998). This finding is not surprising since surrounding lithologies suggests shallow marine and coastal plain environments.

Kaolinite is a clay mineral that typically develops in soils when the climate is warm and humid. The soils have often suffered from extensive leaching and the milieu is acidic. (Sheldon and Tabor, 2009, Reineck and Singh, 1980). Kaolinite is only present in two of the four paleosol samples. The other two samples lack kaolinite but contains chlorite. Abundance of chlorite is especially high in sample 1. Weathering of clay minerals are related to the climate. From hot and humid to cold and dry climate they weather in the order kaolinite→ smectite→ vermiculite→chlorite. Variation of content in the paleosols might thus reflect climatic variations of either precipitation of temperature.

Feldspar, biotite mica, and chlorite are relatively rare in paleosols because they are more susceptible to chemical weathering, and their presence is typically attributed to *i)* weak or incipient chemical weathering *ii)* diagenetic alteration (Babechuk and Kamber 2013). The high chlorite content in sample 1 might thus be related on one of these factors.

5. Facies and Facies associations
5.1 Principles and applications

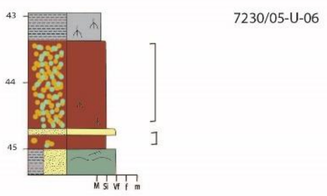
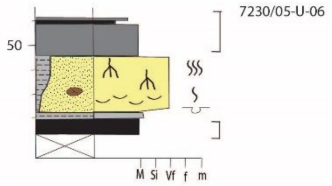
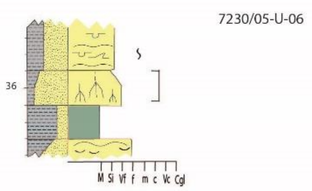
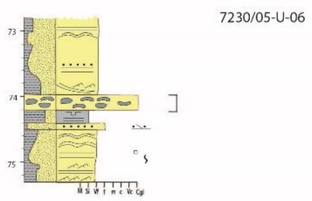
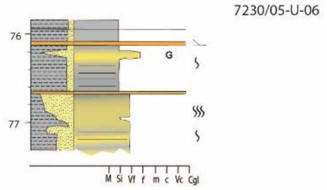
Classifying deposits as facies and grouping them to facies associations is a widely used procedure while working with a sedimentary record. The term facies have been known in geologic literature since it was introduced by Steno (1669), and since then the meaning of the word has become a topic of debate among geologists (Miall, 2016). Examples of discussions of the term and application in sedimentary rocks are well described by Reading(1996), Miall (2016) and Dalrymple (2010). Facies are categorized on background of descriptive similarities of deposits which can be related to depositional processes or environments. There are several ways to attribute facies depending on what type of observations that are of interest. Lithofacies which is the fundament of the following facies analysis is defined on the basis of distinctive lithological properties such as grainsize, structures, composition etc. (Miall, 2016), while biofacies and ichnofacies are determined on background of assemblage of fossils and trace fossils respectively. It should be noted that one individual lithofacies not necessarily is diagnostic for one specific environment only. Some facies, e.g. paleosols can be strong environmental indicators, whereas soft sediment deformed sandstone if ascribed as a facies, can be deposited in a wide range of environments and are thus not as helpful as an individual facies. Investigating the occurrence and co-occurrence with other facies is therefore necessary to group them together and put them into a broader context by relating them to facies associations, a term defined by Potter (1959) as "a collection of commonly associated sedimentary attributes" Where defining facies to large degree is dependent on observations and descriptive attributes, facies associations on the other hand are more interpretative and grouped together based several facies natural co-existence within the same depositional environment. However, it is also possible to use the term facies alone to directly relate deposits to the active depositional processes by using the description of for instance tidally influenced facies or channel conglomerate facies (Reading and Levell, 1996).

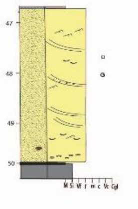
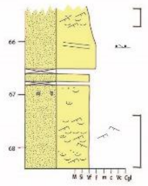
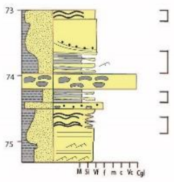
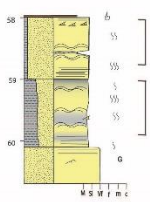
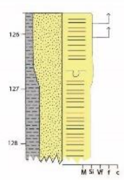
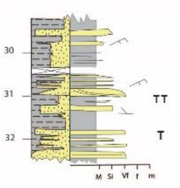
When changes in the depositional environment occur, the response is vertically stacking of more or less distinctively different facies. There is a certain predictability to these depositional changes which means that, the nature of the next facies also can be somehow predicted (Miall, 2016). Walther (1894) saw the importance of understanding the cyclicity and facies sequences and proposed that all deposits that can be found in close lateral proximity in the nature will be seen juxtaposed on each other vertically. This is an important basis for correlation of facies and depositional environment both vertically and laterally.

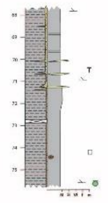
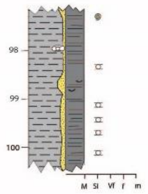
In this context, facies are attempted described and selected as objective as possible, selected more on the background of attributes linked to both physical processes than depositional environments. Facies are often intertwined and, elements that are typical for one ascribed facies often occurs within other facies. This is especially remarkable for the sandy facies, where cross bedding, ripples and interlayered bedding often occurs in a mixture where dominant singular features can be difficult to determine.

5.2 Facies

Table 5.1: Summary of facies from all studied cores.

Facies	Log example	Sedimentary structures and occurence	Interpretation
A		Paleosol Found in two varieties in the core from Nordkapp Basin. i) Unorganized mottled pattern of yellow, rusty red and light green. Contains minor intercalations of siltstone. Motteling fades gradually out where transitions can be observed. Sparse bioturbation. Minor root fragments are occationally present. ii) Brown mud-siltstone with scatterd occurence of calcite nodules. Nodules are more abundant at the top of the bed.	Paleosols form due to physical, biological and chemical modification of soil exposed at the earths surface (Kraus, 1999). Most paleosols are described from alluvial strata, but can also develop in marginal marine environments after sea level fall followed by exposure (Leander et al., 1991). Motteling are suggested related to locally changes in redox conditions possibly related to a fluctuating ground water level. Calcite rich horizons commonly form in dry environments by evaporation of CaCO3 rich water (Braithwaite, 2005). Paleosol with calcite nodules are interpreted to represent initial calcrete developement.
B		Coal and coal shale Coal appear in beds of up to 5 cm, coal shale can be up to 20 cm thick. Coal shale is usually transitioning into coal, but can also be found alone. Coal are distingluished from coal shale by darker color and more vitrineous look, assumably reflecting a higher organic content. The facies is usually found above rooted siltstones and sandstones in a fining upwards successions.	Coal forms by compaction and induration of altred plant remains (Schopf, 1956). Requirements are sufficient amount of vegetation, an elevated water table and a minimum of clastic input (Retallack, 1991). Coal and coal shale are interpreted to have originated
C		Light green silty mudstone/mudddy siltstone with roots Alternating sandstones, siltstoned and mudstones, usually with a green color from the clay. Root structures are the most prominent feature and are found in all lithologies. Usually intensely bioturbated or soft sedimentary deformed. Preserved primary structures are limited to flaser and wavy bedding. Found only in the Nordkapp basin, in proximity to coal and coal shale, paleosols and heterolithic bedding.	Variations of grainsize reflects shifting of energy in an environment with mud, sand and silt available. Roots can be indicative of subaerally exposure or shallow calm waters. The facies is interpreted to represent periodically flooding and and minor stream incursions. The green color most likely represent presence of chlorite.
D		Mud flake conglomerate Rip-up clasts of grey mud in a matrix of very fine sand. Clasts are angular but with smooth rounded outlines. Some of them may contain internal lamination. Clast size varies from 0.2-7 cm. Mud flake conglomerate is only found as one bed in core from the Nordkapp Basin.	The simple composition with mud flakes in a matrix implies that the mud flake conglomerate is an intraformational conglomerate. Mud flake conglomerate can develop in fluvial settings as a result of cut bank erosion of a muddy substrate, erosion due to increased current speed (Dalrymple and Choi 2007), or deposited due to mass transport by turbidity currents (Possamentier and Walker, 2006). Found in relation to mud drapes and heterolithic bedding it is interpreted to have been deposited in a tidally influended area, possibly from cut bank erosion.
E		Siderite conglomerate Found in thin beds, usually 2-5 cm, but can rage in thickness up to 10 cm. The conglomerate is matrix supported with a matrix composed of silt and vf sand. Clasts are subrounded, composed of mostly siderite, but mud clasts are also common. In the Nordkapp Basin siderite conglomerate is often found between heterolithic bedding. Fron Sentralbanken High it is found between interbedded mud and siltstones.	Conglomerates can form in numerous environments. In this facies conglomerate is composed of clasts from nearby facies which indicates a relatively close souce area. Thin conglomerates are commonly deposited as transgressive lags during sea level rise (Nichols, 2009), or as lag deposits at the base of fluvial channels.

F		7230/05-U-06	**Cross-stratified vf-f sandstone** Very fine to fine sandstone with unidirectional cross-stratification. Displayes both tangential and concave foresets. In the Nordkapp Basin coal debris and mud drapes are common within the foreset laminas. Rip-up clasts and siderite nodules are also frequently present. Completely lacks bioturbation. The same facies from Sentralbanken High are in comparison more homogenous and with smaller angles on the foreset laminas. Usually found alternating with ripple laminated sandstone.	Migration of dunes or ripples in an unidirectional current produces cross-stratification (Boggs, 2011). The structure can form in both marine and fluvial settings and are not indicative of a specific environment. Rip up clasts and siderite nodules found clustered together suggests a fluvial origin of the deposits from the Nordkapp basin. Cross-stratification from core material from the Svalis come contains tasmanites which implies a marine origin.
G		7230/05-U-06	**Ripple laminated sandstone** Mostly seen as unidirectional ripple lamination in very fine to fine sandstone beds. Mud drapes and coal debris is very common, highlighting ripple foresets. Bidirectional ripple lamination can occure but is more sparse. Usually found on top of or interbedded with heterolithic bedding and cross stratified sandstone. Ripple laminated intervals rage in thickness from 10 to 60 cm. Beds are usually indistinct with gradual transitions if found in priximity to cross stratified sandstone	Asymmetrical ripples are produced by unidirectional currents in the lower flow regime (Nichols, 2009). Beds with ripples in opposing directions are suggested to have a tidal imprint. So is the presence of mud drapes which forms during slack water periods. Found alternating with cross-stratified sandstone, ripple laminated sandstone beds are suggested being fluvial of origin.
H		7230/05-U-06	**Interlayered mud and sand** Alternating laminas (0.5-1 cm) and beds (1-1.3) cm of clay and very fine sandstone. Both upper and lower boundaries of the layers are sharp, and layers are slightly undulating. The sand/mud ratio is relatively equal within units. Most of the mud layers are internally structureless, but can be siderite cemented. Found in association to mudflake conglomerate, heterolithic bedding and cross stratified sandstone	Interlayered mud and sand can be produced by alternating periods of current/wave activity and periods of quiesence (Reineck and Singh, 1980), by transportation of sand into an area dominated by mud deposition or as fluid mud formed by flocculation in hte transition zone between fresh and saline waters (Ichasso et al., 2009). The structureless appearance of mud layers implies rapid deposition, which makes the facies a good candidate for fluid mud deposition. Fluid muds have been reported from tidal/fluvial channels, in tidally influenced mouth bars and delta front successions (Ichasso and Dalrymple, 2009).
I		7230/05-U-06	**Heterolithic bedding** The facies contains fractions of lenticular, wavy and flaser bedding. Lenticular bedding: Mud dominated, mostly with flat sand lenses both connected and isolated. Wavy bedding: Equal proportions of sand and mud where sand fractions commonly have ripple lamination. Flaser bedding: thin flasers of mud in troughs of ripples in very fine sandstone. The facies is sparse to completely bioturbated.	Lenticular wavy and flaser bedding gets deposited in settings with an alternating energy regime. Sand fractions are deposited in periods of current activity and mud settles from suspension in periods of quiesence (Reineck and Singh, 1980). These structures are typically seen to be tidally influenced (Davis, 2012), and are most common on intertidal and subtidal flats (Reineck and Singh, 1980).
J		7323/07-U-03	**Laminated siltstone** Caracterized by finely laminated siltstone. Laminas of very fine sandstone is present, and commonly fines upward to silt with more widely spaced laminas spaced laminas. Occationally occuring thin rippled beds. Contains a few up to 30 cm thick calcite cemented beds. Completely lacks bioturbation in Klappmyss FM and have sparse bioturbation in Steinkobbe FM. The facies is found above and below dark phosphatic rich shales in cores from the Svalis Dome.	Graded lamination or rythmites are commonly attributed to deposition from sediment clouds during the waning stages of a storm (Myrow, 1992, Reineck and Singh, 1980). Alternatively turbidity currents may be the responsible mechanism of the structures. The low content of sand suggests the facies to represent distal turbudites or tempestites deposited in a low energetic environment.
K		7534/06-U-01	**Muddy siltstone with sandstone intercalations** Appears as interbeds of very fine siltstones and mudstones. Transition from mudstones to coarser grained deposits are usually sharp. Typically sandstones and siltstones fines upwards to mudstones in alternatin beds of approximately 5 cm. Mud fractions are structureless or indistinctly planar paralell laminated. Sand and silts have planar or ripple lamination. Tasmanites are regularely found in high abundance. Bioturbation is in general sparse, but can locally be moderate to intense. Recognized trace fossils are *Chondrites*, *Teichichnus* and *Planolites*.	Graded beds and lamination are like facies J herein assigned to depositions driven by storm or turbidity currents. *Chondrites* are typically the last trace in a bioturbated section (Bromley and Ekdale, 1984) and often associated with anaerobe conditions (Bhattacharya and Banerjee, 2014). Found below dark gray mudstone the facies is suggested deposited on a muddy shelf with transportation of sand and silt by currents and storm waves.

L	 7534/06-U-01	Dark grey mudstone Medium to dark grey mudstone regularely disrupted by siderite bands and cementation. Color variation hence indistinct undulating lamination in the mudstone. Can have thin intercalations of planar paralell laminated silt. Occationally containing calcite cemented beds with cone in cone structures. bivalves and ammonoids are present in one intervall. Bioturbation is sparse and lacks in large intervalls. *Chondrites* is the only recognizable trace fossil.	Thick continuous mudstone deposits are interpreted to have originated form sites with low energetic conditions close to the storm wave- basis. This is seen by the small amount of coarser grained depositd that have reached the side of deposition. Lack of lamination can be indicative of a steady rate of deposition (Collinson et al., 2006) or fluid mud deposition by hyperpycnal flows on offshore shelfs or prodelta areas (Bhattacharya, 2006)
M	 7323/07-U-04	Dark phosphoritic rich shale Dark planar paralell laminated mudstone assumable with high organic content. High abundance of phosphorite nodules, both rounded and flattened. Contains up to 25 cm thick calcite cemented beds with slightly larger grainsize. Pelagic fossils such as bivalves, ammonides and fish remains are reported from Mørk and Elvebakk (1999). The facies is found in one long continuous intervall in the Svalis Dome.	Attributed to formation by setteling of suspended fines and organic material. Lack of bioturbation together with pelagic fossils suggests an oxidized upper water coloumn and a lower anoxic sea bottom (Mørk and Elvebakk, 1999). Phosphate nodules indicate reducing conditions. The facies is most likely deposited in a low energetic environment under anoxic conditions.

5.2.1 Facies A. Paleosols

Paleosols are found in two variations and separated on background of color variation and content of fragments (Fig. 5.1)

Variation 1: Mottled paleosols

Description

Paleosols are found in three beds in the upper part of core 7230/05-U-06. The beds have a distinct appearance with rusty red, and yellow colors in a mottled pattern of fine-grained rock. The main composition is grey-green silt, but intercalations of rusty red- yellow clay is very common. The weathering color is very dominant and often overprints the silt, giving the paleosol the characteristic red and yellow appearance.

Figure 5.1: Paleosols from well no. 7230/05-U-07 (Nordkapp Basin). A) Mottled paleosol at 44 m depth. B) Possible development of caliche at 52 m depth. White dots are calcite nodules.

The mottling pattern appears messy and unorganized with local variations in color and composition as seen in Figure 4 A. Several transitions to over and underlying beds are not observable due to core loss, but where they are displayed they tend to be gradational with slight increase or decrease of mottled material. Observable bioturbation is sparse with only a few certain evidences of vertical- sub vertical burrowing. The content of carbonaceous fragments is in general very low, but there is a sparse content of what has been interpreted as stems or small roots. They are circular and slightly elongated in shape with a hole in the middle. Paleosols are found over and underlain by fine-grained sediments in the upper part of the core from Sentralbanken.

Discussion and interpretation

Paleosols are ancient soils that have been incorporated into the geological record (Tabor and Meyers, 2015). They form due to physical, biological and chemical modification of soil exposed at the earth surface (Kraus, 1999), and are thus not actual deposits, but have developed due to modification and maturation of soils. Most paleosols are described from alluvial strata but have also been reported from marginal marine environments after a sea level fall followed by exposure (Lander et al., 1991). Presence of paleosols can provide valuable information about the drainage state of the area, and the climate, and might thus be strong indicators of the paleoclimate (Collinson, 1996).Various types of paleosols have been described and was classified by Mack et al. (1993) based on pedogenic features or formation processes. Factors as climate, topographic location, parent material and time available for formation are important for the characteristics and outcome of a paleosol, and paleosols can thus be an important tool for interpretation of paleoclimate at the time of soil formation.

Root structures is an important factor for recognition of paleosols with the best preservation potential within waterlogged soils whereas oxidized soils might not preserve organic matter as well (Retallack, 1988). Rooting depth may be related to two factors *i*) The amount of precipitation in the soil forming environment and *ii*) soil drainage characteristics. Poorly drained Paleosols usually comprise shallow rooting depth (Tabor and Meyers, 2015). Although the rooting depth not directly can be determined here, it is observed that the roots are small and thus most likely not have extended deep into the soil.

The low content of rootlets or other organic components might indicate a horizon with sparse vegetation, but more likely it or represents conditions with low preservation potential for organic matter, which can be the case if the soil is oxidized. Loss of organic matter is often a result of metabolism by bacteria, or it might be a result of deep burial and generation of oil and gas (Surdam and Crossey, 1987).

Mottling pattern and color variation is a common feature in many paleosols and a plausible explanation can be locally changes in redox conditions caused by for example a fluctuating ground water level (Retallack, 1988). The paleosols are herein thus interpreted to represent relatively well drained soils deposited in a dynamic area with changing groundwater conditions, deposited on a coastal plain.

Variation 2: Brown mud-siltstone with calcite nodules

Description

This facies variation is only found in one interval from the Nordkapp Basin (52.20-52.80m). The lower boundary is marked with a sharp contrast in color from the underlying bioturbated siltstone/mudstone, while the upper part is a gradual transition to a grey siltstone. Most of the rock is made up of a grey siltstone with spots of brown mud which gives it a browner appearance than it actually has. It is characterized by the presence of white carbonate nodules (Fig. 5.1 B). They are scattered but seems to be especially abundant at the top in the transition to siltstone. The matrix however has no calcite cementation. Bioturbation is sparse, only one long sub-vertical trace is found.

Discussion and Interpretation

Horizons rich in $CaCO_3$ are usually classified as calcrete (or caliche) (Retallack, 1988, Mack et al., 1993) and commonly form a massive layer of carbonate. Such calcite rich horizons can develop in a paleosol by both non-pedogenic processes due to evaporation of $CaCO_3$ rich waters in dry climatic conditions (Braithwaite, 2005), and pedogenic processes involving downward transport of material in a soil profile (Arakel and McConchie, 1982). Calcite cemented nodules also commonly develop around root structures on the coastal plain (Tucker, 2011), and this may possibly be the origin of the nodules within this facies.

The scattered calcite nodules are here not regarded found in high enough abundance to classify the deposits as caliche. They are the most distinctive feature, but not the main component. It may represent initial calcrete formation but has not fully developed to calcrete. Reasons for this might be change to a more humid or colder climate, limited access to a sufficient $CaCO_3$ source or abrupt burial of the soil.

5.2.2. Facies B. Coal and coal shale

Description

This facies is present only in the upper half of the core from the Nordkapp Basin as 5-20 cm thick units. Coal appears in relatively thin intervals up to 5 cm and show planar lamination. Coal and coal shale are distinguished on background of the more vitrineous appearance of coal, assumably reflecting a higher organic content. The coal shale is dark grey with a prominent component of silt. Normally the coal shale is transitioning into coal, but it is also observed alone. The coal shale also has a relatively high organic content displayed as locally occurrence of thin coal laminas and small coal fragments. Coal and coal shale are found above rooted siltstones to fine grained sandstone (facies C) in thin fining upward successions.

Discussion and interpretation

According to a definition of Schopf (1956), coal must contain more than 50 weight% and more than 70% by volume of carbonaceous material. Formation of coal takes place by compaction or induration of peat and accumulated plant material. Loss of water, nitrogen and other volatile materials then leads to an enrichment of carbon in the peat (Retallack, 1991), leaving behind coal. Development of coal require sufficient amount of vegetation or other organic material, an elevated water table to prevent extensive oxidation and a minimum of clastic input during peat accumulation (Fielding, 1987).

Environments capable of meeting the mentioned conditions can be floodplains with swamps or marshes, protected lagoons, abandoned moth bar lobes. The proximity to paleosols and rooted intervals makes it likely to believe that is has originated from a coastal plain environment where conditions with access to a water source. The fining upward trend is possibly a result of channel avulsion.

5.2.3 Facies C. Light green silty mudstone/muddy siltstone with roots

Description

The only occurrence of the facies is in the upper part of the core from the Nordkapp Basin. The facies is found in close proximity to paleosols (facies A) and coal and coal shale (facies B). Collectively this facies is composed of a great variety of grainsizes, structures and other features. The facies is often moderately rooted with roots found both in fine-grained material such as mud and siltstone and in very fine sandstones. Some of the roots are siderite cemented. Usually the deposits are intensely bioturbated or soft sedimentary deformed so primary structures are indistinguishable. Where primary structures can be seen they are limited to wavy bedding and ripple lamination, but this is rare. The degree of bioturbation varies in the rooted parts. Greenish mud with thickness between 1-5 cm is commonly interbedded with the sand.

Discussion and interpretation

Roots commonly grows when areas get subaerially exposed or in areas with shallow water and minor current activity (Bridge, 2006). Rooted deposits thus represent proximal presence to land and are very common in levee and crevasse splay deposits (Bridge, 2006), and in swamps and marshes (Bojesen-Koefoed et al., 2001). The co-occurrence of sand, silt and mud indicates a shifting energy regime with mud settling from suspension and sand transported by weak currents. Shifting mud silt and sand deposition suggests periodically flooding and minor stream incursions. Possibly also periodically tidal influence represented by wavy and flaser bedding. Siderite cementation of some of the roots suggests mixed waters or access to meteoric pore water. Green color of sediments is commonly related to presence of chlorite and illite (Reineck and Singh, 1980). The green sand is thus probably heterogenous and mixed with clay.

5.2.4. Facies D. Mud flake conglomerate

Description

Singular mud flakes or clusters of mud flakes are found within several facies such as cross-stratified sandstone (facies F) and ripple laminated sandstone (facies G). However, mud flake conglomerate is considered a facies only where abundance of clasts occur over a limited area. Mud flake conglomerate is only found at one distinct interval of 22 cm at 75. 8 m in the core from the Nordkapp Basin (Fig. 5.2). The facies is directly overlain interlayered bedding (facies H), and the transition between the two facies is sharp and marked by a load structure. The facies is recognized by the presence of immature medium grey and red-brown rip-up clasts of mud with sizes varying from 0.2 to 7 centimeters in diameters. The matrix consists of very fine to fine sand. The mud flakes have angular shapes, but the outlines are rounded. Some mud flakes tend to be slightly elongated with smooth long sides and angular short sides, others are rectangular. Very thin internal lamination occurs in some of the clasts, but the major fraction of them are structureless.

Figure 5.2: Mud flakes in a sandy matrix

Discussion and interpretation

Conglomerates can be formed in a great variety of geological settings and indicate deposition in high energetic environments such as fluvial channels, shorelines, in alluvial fans or as turbidites in subaqueous fans (Boggs, 2011). The simple composition of mud flakes in a matrix implies intraformational conglomerate as a suitable description. Intraformational conglomerate is composed of clasts of sediments which most likely have formed within a depositional basin (Boggs, 2011), and since associated facies below contain mud deposits (both stratified and non-stratified) this might be regarded as the source of the clasts.

According to Dalrymple and Choi (2007), mud clasts are common in tidally influenced channels on the delta plain or in the middle portion of estuaries. Three possible mechanisms are considered for creation of mud flake conglomerate. *i)* The clasts can have originated from dried out mud in environments as eg. flood plains or tidal flats and have been ripped up by currents such as storm waves, tidal currents or sediment-gravity flows. *ii)* A high portion of suspended material can promote deposition of relatively thick mud drapes, which in turn can be eroded by current power changes, or *iii)* Cut bank erosion of a muddy substrate (e.g. tidal flats) which usually will give rise to tabular clasts with rounded outlines, which is in accordance with the clast morphology observed in this facies.

The angular shape and the great variation in clast size is indicative of short transport and re-deposition in a proximal position to site of origin in a rapid event implied by the erosive boundary. Mud flake conglomerate is herein interpreted to be a product of cut bank erosion from the sides of a channel.

5.2.5 Facies E. Siderite conglomerate

Description

The conglomerate is mostly matrix supported with sharp upper and lower boundaries. Spherical to rounded gravel to pebble sized clasts of siderite are common and the conglomerate is unsorted with elements of both siderite and fragments of nearby facies. The matrix is usually fine-grained sand and siderite cementation is not uncommon. Especially siderite is observed in the lower conglomerate beds in core 7230/05-U-06 (Nordkapp Basin) (Fig. 5.3). Matrix in these lower conglomerates also contains a notable component of glauconite in addition to minor unspecified fossil fragments.

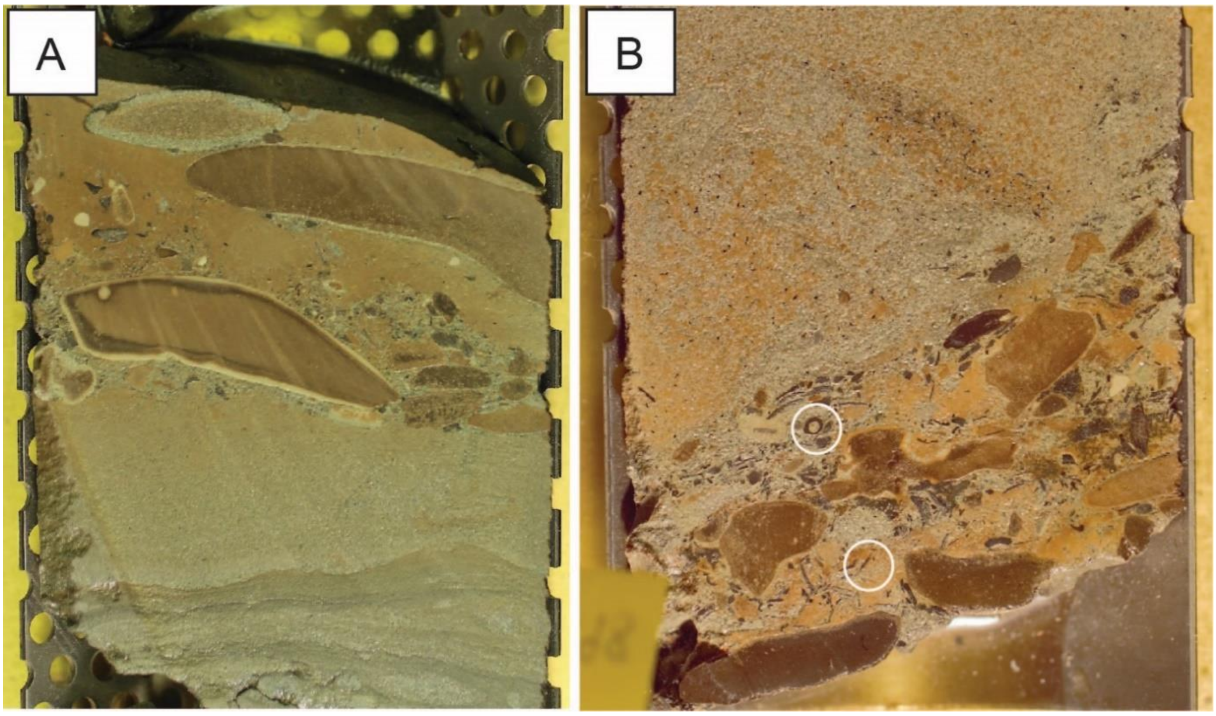


Figure 5.3: Siderite conglomerate from core 7230/05-U-06. A) Subrounded spherical clasts in a siderite cemented matrix. B) Fossil rich siderite conglomerate. Two fossil fragments are indicated with white circles. Siderite sand is present both in the matrix and the sand above.

Thickness of conglomerate beds from the Nordkapp Basin are 2-5 cm, but they can rage in size up to 10 cm at Sentralbanken High. In the core from the Nordkapp Basin they are usually found in between facies I (heterolithic bedding) with over and underlying deposits being of the same nature. Only at a few intervals siderite conglomerates separates different facies. At Sentralbanken conglomerate is found within muddy siltstone with sandstone intercalations (facies K). Fossil fragments and glauconite are not present here.

Discussion and interpretation

Conglomerates are commonly found at the base of fluvial deposits, cutting into younger deposits with an erosional boundary. When found closely spaced they could be interpreted to represent deposits from a meandering river. Another possibility for formations of thin conglomerates are deposition of transgressive lags during sea level rise (Nichols, 2009). Transgressive lags are typically followed by upwards deepening of facies (Cattaneo and Steel, 2003), but since most conglomerates are found in between the same facies, this implies that a possible transgression not have led to significant deepening and change of the depositional environment.

The commonly angular shape of the siderite leads to the assumption that a significant fraction of the nodules has been transported rather than formed autogenic by mineral precipitation. Most commonly siderite forms in organic rich brackish to meteoric pore-waters with limited Sulphur content (Morad, 1998). Since the facies often is found associated with deposits that typically form in such areas are most of the siderite conglomerate beds interpreted to be result of erosion and deposition after some sort of abrupt flooding.

Glauconite is an authigenic mineral commonly forming in shallow marine environments (Nichols, 2009). Often glauconite implies low sedimentation rates and commonly occurs in condensed sections. Found in a conglomerate the glauconite is interpreted to have been transported shoreward and redeposited.

5.2.6. Facies F. Cross-stratified sandstone

Description

The facies is characterized by the presence of very fine to fine sandstone with unidirectional cross stratification. The stratification is mostly displayed as inclined parallel lines across the core (Fig. 5.4). Tabular cross-stratification is the most common sedimentary structure both with tangential and concave foresets. Distinguishing between different types of cross-stratification and determining set thicknesses is challenging due to the limited size and different cuts of the core, and all variations of cross-stratification are thus collected under the same facies.

Bed thicknesses rage from 20 cm to 1.2 meters in core 7230/05-U-06 from the Nordkapp Basin and 7534/06-U-01 from Sentralbanken High. The characteristics of the facies from the two wells vary slightly

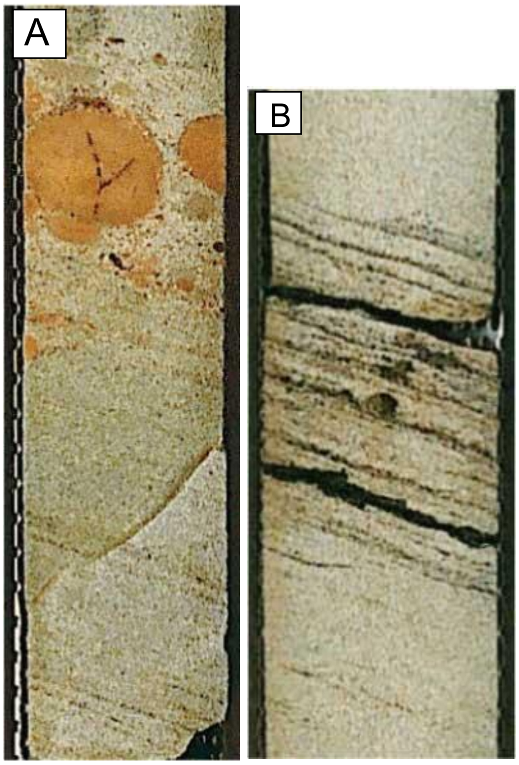


Figure 5.4: Cross-stratified sandstone from the Nordkapp Basin. Both cores are 5 cm wide. A) Cross-stratification disturbed by siderite clasts and mud flakes B) Cross-stratification with tangential foresets and coal debris within foreset laminas.

Coal debris and plant fragments are extremely common within the stratification in the core from the Nordkapp Basin. Often this is accompanied with siderite sand which is exclusively associated with coal debris. The stratification is also sometimes seen disrupted by more chaotic laminations. In addition, angular to rounded shaped siderite nodules (0.5-4 cm), and grey to red-brown mud flakes (0.2-0.7 cm) appears frequently. Usually they are found clustered and sometimes slightly imbricated over short intervals but can also be found as singular fragments. When found alone they are smaller in size compared to the areas with higher density of clasts. Glauconittic grains are also might also be present. Bioturbation is not observed within this facies. Cross stratified sandstone from the Nordkapp Basin is usually found in between heterolithic bedding (facies A) or rippled sandstone (facies E).

Cross-stratified sandstone from Sentralbanken High has a homogenous character in comparison to in the Nordkapp Basin without mud clasts and coal debris. In addition, the foresets has lower angles. Occasionally the lamination is close to horizontal. A sparse content of *Tasmanites* are present but like in Nordkapp Basin no bioturbation is observed. The sandstone is irregularly vaguely calcite cemented. At Sentralbanken cross-stratified sandstone is found interbedded with facies K.

Discussion and interpretation

Cross-stratification is not considered an environmental indicative structure and can occur in a wide range of depositional systems. The structure can develop in beach environments of both high and low energetic condition or in fluvial environments. Migration of dunes or ripples produced by unidirectional currents is often used as explanation for development of trough and tabular cross-bedding (Boggs, 2011). At shallower waters and with stronger currents dunes are thought to develop with a more complex morphology (Collinson et al., 2006, Boggs, 2011). This might explain the more unorganized style seen from the Nordkapp Basin compared to Sentralbanken High.

The foreset laminas may get different shapes depending on the factor of the hydrodynamic factors existing at the time of deposition (Reineck and Singh, 1980). In general, angular foresets are developed at low velocities by bedload movement with gravitational sliding from the top of the lee face. When current velocity increases tangential foresets develop as more sediments are taken into suspension and deposited in the form of bottomset and toeset.

The mud clasts are interpreted to be rip-up clasts of similar type as described for mudflake conglomerate. They are indicative of high energy during formation where semi-lithified mud have been ripped up during increased current activity and redeposited. A plausible explanation for the occurence of these clasts is fractions being ripped up or eroded from the sides of a channel and transported and deposited as bedload within a fluvial system. A great proportion of this facies in the Nordkapp Basin is thus interpreted to be connected to a fluvial system. Lateral migration of channels is known to produce longitudinal cross bedding as they meander (Reineck and Singh, 1980), which might be the case for these sediments. The presence of coal fragments and plant debris could be interpreted to represent proximal presence to land and indicates contact with a fluvial system.

5.2.7 Facies G. Ripple-laminated sandstone

Description

Facies G is composed of very fine to fine sand with ripple lamination. Mostly asymmetrical ripple lamination is observed (Fig. 5.5). There might also be some evidence of symmetrical ripples, but this is somehow uncertain. Intervals with rippled sandstones are often seen on top of or interbedded with intervals of heterolithic bedding (facies I), or more commonly interbedded with cross-stratified sandstone (facies F). The ripples are often highlighted with mud drapes and can in some cases easily be confused by flaser bedding from facies I. The two structures are distinguished by the more continuous foresets of the ripples ascribed to facies G.

Fig 5.5: Very fine sandstone with ripple lamination from the Nordkapp Basin.

Different cuts of the core results in an uncertainty regarding the direction of the ripples at several levels in the core. However, at certain places with longer intact core intervals, there is evidence of current ripples in opposing directions. This is especially common in the sand dominated intervals in the lower half of core 7230/05-U-06. Where mud drapes not are present, coal debris is common in the trough of the ripples sometimes accompanied with siderite sand. Very little bioturbation is found within this facies.

Discussion and interpretation

Asymmetric ripples are formed during accumulation of sediments in a unidirectional current, usually in the lower flow regime in relatively shallow waters. This creates an asymmetric shape with the highest point representing the downstream point (Collinson et al., 2006). They usually form by river or stream flow, longshore currents, backwash on beaches, longshore currents, tidal currents or deep-water bottom currents (Boggs, 2011), which means that asymmetric ripple-lamination can be formed in numerous of depositional environments.

Some of the rippled intervals seems to be deposited in opposite current directions, but since lateral view of the core is very limited they are not regarded as herringbone structures. Regardless, these intervals are interpreted to be deposited within an area with frequently shifting current directions. However, the most common trend is similarly directed current ripples representing deposition within a unidirectional current. The mud drapes that often characterize the ripple foresets are strong evidences of tidal imprint, formed during slack-water periods where mud settles from suspension.

Where the facies is found in proximity to paleosols and coal (Facies A and B) a continental fluvial environment is suggested. Sections containing bidirectional ripple lamination and are located close to heterolithic bedding (facies I) and interlayered mud and sandstones (facies H) also suggests deposition in a fluvial environment, but here with a possible tidal component.

5.2.8 Facies H. Interlayered mud and sandstone

Description

Coarsely interlayered bedding is composed of thick clay laminas (0.5-1 cm) and thin beds (1-1.3 cm) alternating with thin sandstone beds (Fig. 5.6). Both upper and lower boundaries are sharp but undulating. The amount of sand and mud is approximately equal. The structures remind of wavy bedding from facies I (heterolithic bedding) but are distinguished from it on background of the thickness of the layers. Interlayered bedding has thicker layers and more distinct separation between them. Most of the mud layers are completely structureless, but a few of them show very thin lamination. A few of the mud layers are siderite cemented. The facies is found in close proximity to mud flake conglomerate (facies D), heterolithic bedding (facies I) and cross stratified sandstone (facies F).

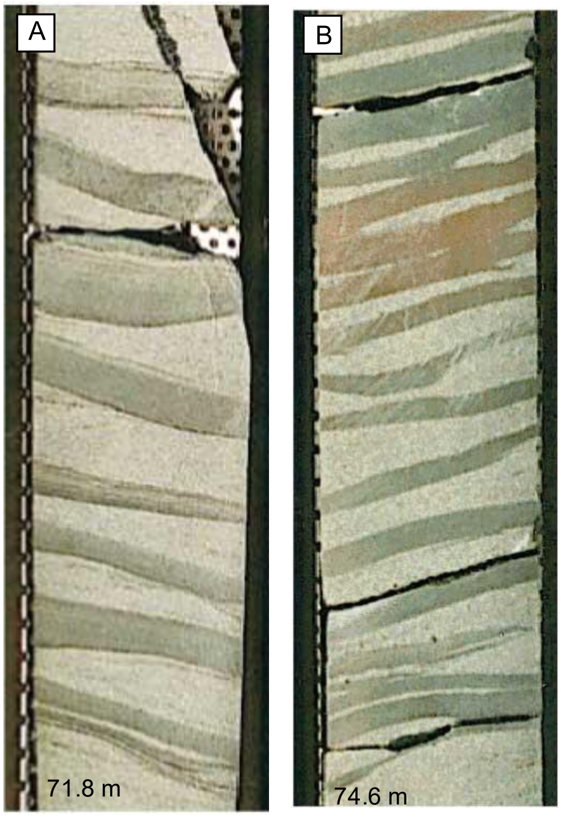


Figure 5.6: Variations of facies B from the well in the Nordkapp Basin. A) Very finely laminated mud layers. B) Structureless mud layers, some with siderite cementation.

Discussion and interpretation

The thickness of the laminas and layers are relatively uniform. Herein this is interpreted to represent more rapid depositional changes compared to the gradual transitions of facies B1. Reineck and Singh (1980) described similar type of bedding to typically occur in mixed intertidal flats for example by alternating periods current/wave domination and periods of slack water, or by transportation of sand into an area currently dominated by mud deposition.

Alternatively, the structures represent fluid mud deposition. Fluid muds are well known from modern tidal channels (McAnally et al., 2007, Kirby and Parker, 1983), but there are somehow limited descriptions from the ancient record (MacKay and Dalrymple, 2011). Fluid muds are described as bodies of fine grained sediments within a concentration of fluids (Kirby and Parker, 1983), formed where suspended sediment concentrations are created by flocculation in the mixing zone between fresh and saline water (Ichaso and Dalrymple, 2009). The process of flocculation produces deposition prone aggregates which then can be deposited during slack water periods. According to the description of Ichaso and Dalrymple (2009), a mudstone layer of minimum 5mm that lacks internal structures and syn-depositional bioturbation can be a good candidate for a fluid mud deposit. This is in good accordance with the observations from core 7230/05-U-06.

5.2.9 Facies I. Heterolithic bedding

Description

Heterolithic bedding is here defined as alternating thin beds of mudstones and very fine to fine sandstones subdivided into wavy, flaser and lenticular bedding (Fig. 5.7). The thickness of mud and sand layer rages from 1 mm to 1.5 cm. The ratio between sand and mud varies within the facies and determines the outcome of the formed structure. Lenticular bedding has the lowest sand/mud ratio and seldom show preserved sedimentary structures in the sand fractions. Wavy bedding has approximately equal proportions of very fine sand and mud. Wavy bedding is displayed as undulating alternations of sand and mud, where the sand fractions commonly contain ripple lamination. Flaser bedding have mud/ finer grained material only preserved in the troughs of the ripples.

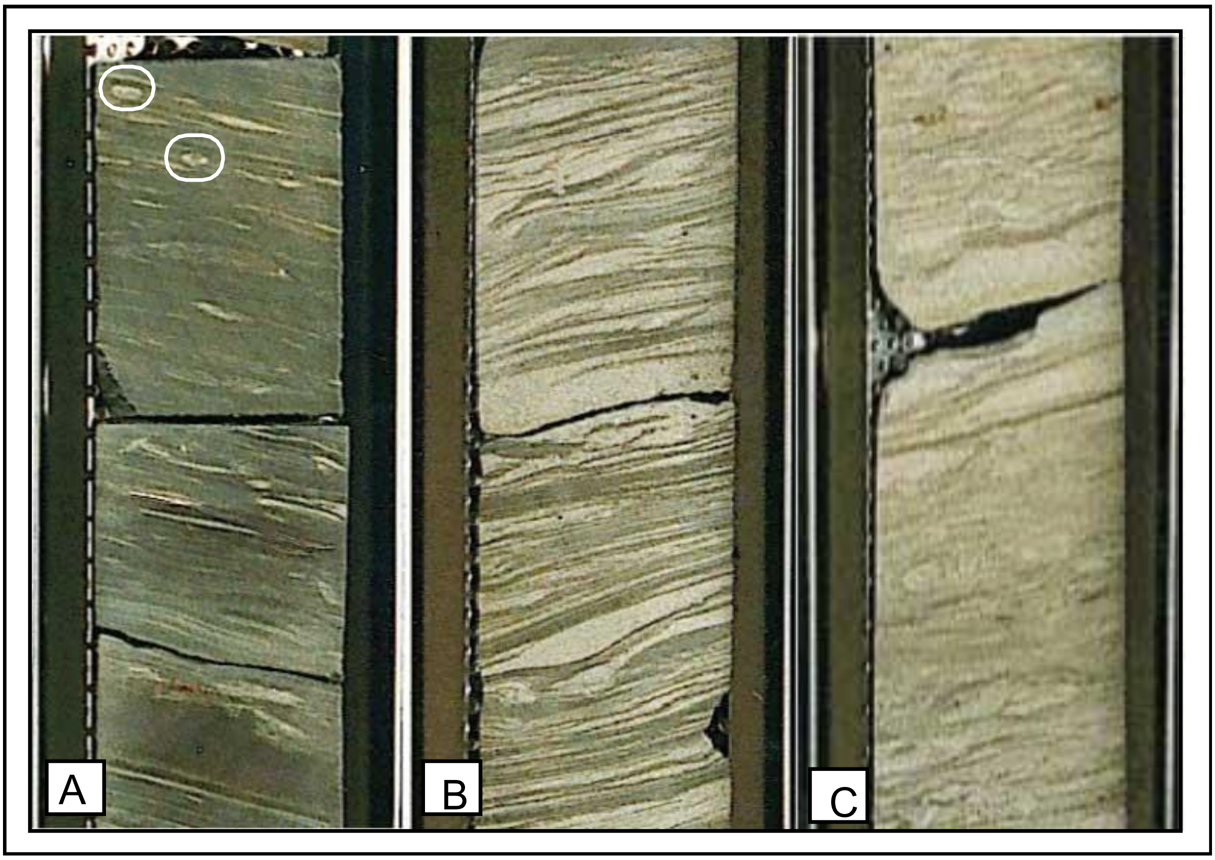


Fig 5.7: Variations of heterolithic bedding. Cores are 5 cm in diameter. A) Claystone with lenticular bedding. White circles indicate undifferentiated horizontal bioturbation. B) Wavy heterolithic bedding. C) Completely bioturbated heterolithic bedding. Original structures can not be recognized.

The degree of bioturbation is highly variable. Both horizontal and vertical burrows are common and typically occur in intercalated intervals. The burrows tend to be rather small raging in sizes from millimeters to a couple of centimeters. Load structures and overturned cross-bedding are also prominent features and vary in size from millimeters to several centimeters. The dominating color is mostly affected by the sand/silt/mud ratio and is mostly light grey-dark grey. However, minor intervals of brownish color occur where siderite cementation is present. Pyrite is found as nodules of up to a few cm.

Heterolithic bedding is one of the most frequently displayed facies in the core from Sentralbanken, and not found in the cores from other localities. It is typically found interbedded with sandstone and siltstone units of facies F and G and in association to mud flake conglomerate and interlayered mud and sandstones.

Completely bioturbated heterolithic bedding

This is a variation of heterolithic bedding that is separated on background of the extensive bioturbation. The facies variation is rare but occurs at least to places in the core. Both horizontal and vertical burrows are considered present, but to exactly determine various types of burrows is difficult since these intervals are strongly deformed. Recognition of primary structures is also challenging, which means that whether these fractions actually belong to the previously described heterolithic bedding or to another facies remains unknown. It is the co-occurrence of sand and mud that is the background for this division.

Discussion and interpretation

Deposition of mud, siltstone and sandstone require different conditions in terms of energy. Mud is often deposited from fallout from suspension during periods of calm water, whereas the ripples in the sand fraction indicates deposition during periods of current or wave activity. This implies that both sand and mud are available in the depositional system, and that periods of quiescence alternate with periods of increased current activity (Reineck and Singh, 1980). Distribution of the various types of heterolithic bedding thus depends on whether the conditions are more favorable for deposition of either sand or mud. Lenticular bedding represents slack-water periods that allows settling of mud interrupted with current activity (Boggs, 2011). This favors mud deposition. Increased current speed leads to deposition of wavy bedding and even higher increase of current speed can lead to formation of lenticular bedded mudstone. This also increases deposition and preservation of mud drapes (Collinson et al., 2006). Collectively, both wavy, flaser and lenticular bedding have originated from an environment with mixed influence of energy and are distinct indicators of tidal environments (Davis, 2012).

Sections in the core showing relatively small size and low diversity of burrows together with the regularly presence of siderite bands can indicate a certain degree of fresh water influence or brackish water which is common in the transition zone from a continental to a marine environment (MacEachern et al., 2005). Variations with intensely bioturbated deposits indicates more favorable stable conditions in comparison.

Loading structures and overturned cross-bedding both indicates deformation of primary depositional structures. Overturned cross-bedding is described as a result of soft sediment deformation with a component of shear stress acting on a liquidized cross bedded sand (Allen, 1985). In this case, cross bedding is interpreted to be overturned due to increased current activity. Loading is indicative of deposition of sand over a hydroplastic mud layer. The structure is not restricted to any specific environment but are well known to occur when ripple crests sinks down into a soft layer of mud (Reineck and Singh, 1980).

Heterolithic bedding is herein interpreted to represent depositions in tidally influenced channels or tidally influenced nearshore environments.

5.2.10. Facies J. Grey laminated muddy siltstone

Description

Facies J is characterized by finely planar parallel laminated clayey siltstone to silty sandstone with a notable component of mud within the laminas. Laminations are often gradational in minor coarsening or fining upward cycles of up to 5 cm thickness stacked on top of each other. Typically, laminas become thinner and more widely spaced when fining upwards (Fig. 5.8 A). Loading structures can be found, but this is not a typical feature, and are restricted to small sizes. Bioturbation is sparse and mostly confined to deposits at the top of Steinkobbe Formation.

The facies is found at the Svalis Dome the lower part of core 7323/07-U-03, ascribed to the Klappmyss Formation and at the top of core 7323/07-U-01, belonging to Steinkobbe Formation (formation boundaries are adapted from Mørk and Elvebakk (1999)). A 15 cm thick interval of the facies is also present in the core from the Nordkapp Basin, there with slightly larger grain-size and laminas of silt and mud. Here the silt laminas get thicker upwards and is replaced with very fine sand. In the Nordkapp Basin such graded rythmites are terminated by a sand dominated interval with asymmetrical ripples (Fig.5.8 B) and found below interlayered bedding.

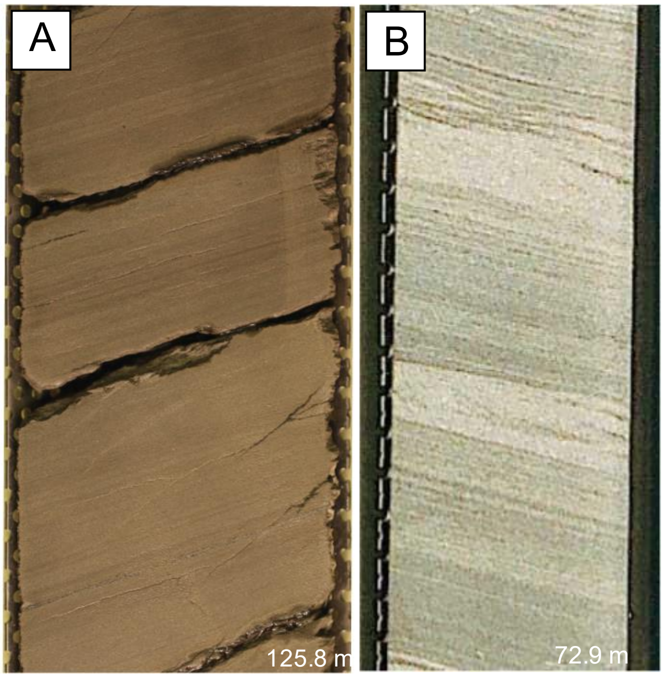


Figure 5.8: Planar parallel laminated siltstones in A) well 7323/07-U-03 in repetitive cycles. B) Well 7230/05-U-06 with thicker laminas at the top and terminated by ripples.

The facies characteristics vary slightly between the two formations from the Svalis Dome. In Klappmyss Formation calcite is the most common cement in certain beds, especially towards the top of the formation where strongly cemented structureless to slightly laminated beds are present, often containing fibrous calcite filled veins. In Steinkobbe Formation, however, siderite cemented intercalations are more common together with siderite nodules. In beds with slightly increase in grainsize ripple lamination might be present.

The facies is thick and continuous in core 7323/07-U-01, and comprises the whole cored part ascribed to Klappmyss Formation.

Discussion and interpretation

The dominance of laminas in the deposits suggests small variations in the sediment input with a steady sediment rate. Graded lamination or rhythmites are depositional features typically attributed to deposition from sediment clouds during the waning stages of a storm (Myrow, 1992, Reineck and Singh, 1980), or from turbidity currents. Turbidity currents can form lamination during primary deposition from the current (Walker, 1967). Turbidity currents are high density flows driven by the density contrast between water masses with suspended material and the surrounding water masses (Reineck and Singh, 1980). This allows transportation of coarser grained sediments to areas that are usually mud prone and dominated by paralic deposition. Bouma (1962) described idealized turbidite sequences in terms of five units which specific sedimentary structures, however, complete sequences are seldom found preserved. The graded planar laminated intervals are thus suggested to represent incomplete distal turbidite sequences or tempestites deposited in a calm relatively low energetic environment with minor supply of sand.

Sparse assemblage and diversity of trace fossils witnesses unfavorable conditions for benthic fauna and may represent reduction in oxygen supply.

5.2.11. Facies K: Muddy siltstone with sandstone intercalations

Observations

The facies is displayed as interbeds of very fine sandstone siltstone and mudstone (Fig. 12 D). Transitions from mudstone to coarser grained deposits are usually sharp, either horizontal, or more commonly introduced with mm scaled loading structures. Sandstone or silt to mud transitions are to larger degree gradual and fining upwards but may also be sharp and distinct. Mud fractions are internally structureless or with indistinct planar lamination, whereas sand and silt beds mostly are planar parallel laminated or rippled. Bands with low to moderate siderite cementation frequently intersects the core.

Small black angular, sometimes rounded grains are possibly remnants of the algae *Tasmanites* (Fig. 5.9 C and F). *Tasmanites* is very common in the deposits and are usually found in abundance over minor intervals (up to 2 cm), layered with the stratification if stratified. Usually they are found in the coarsest deposits, but also occur in clay fractions but then in lower numbers and more scattered.

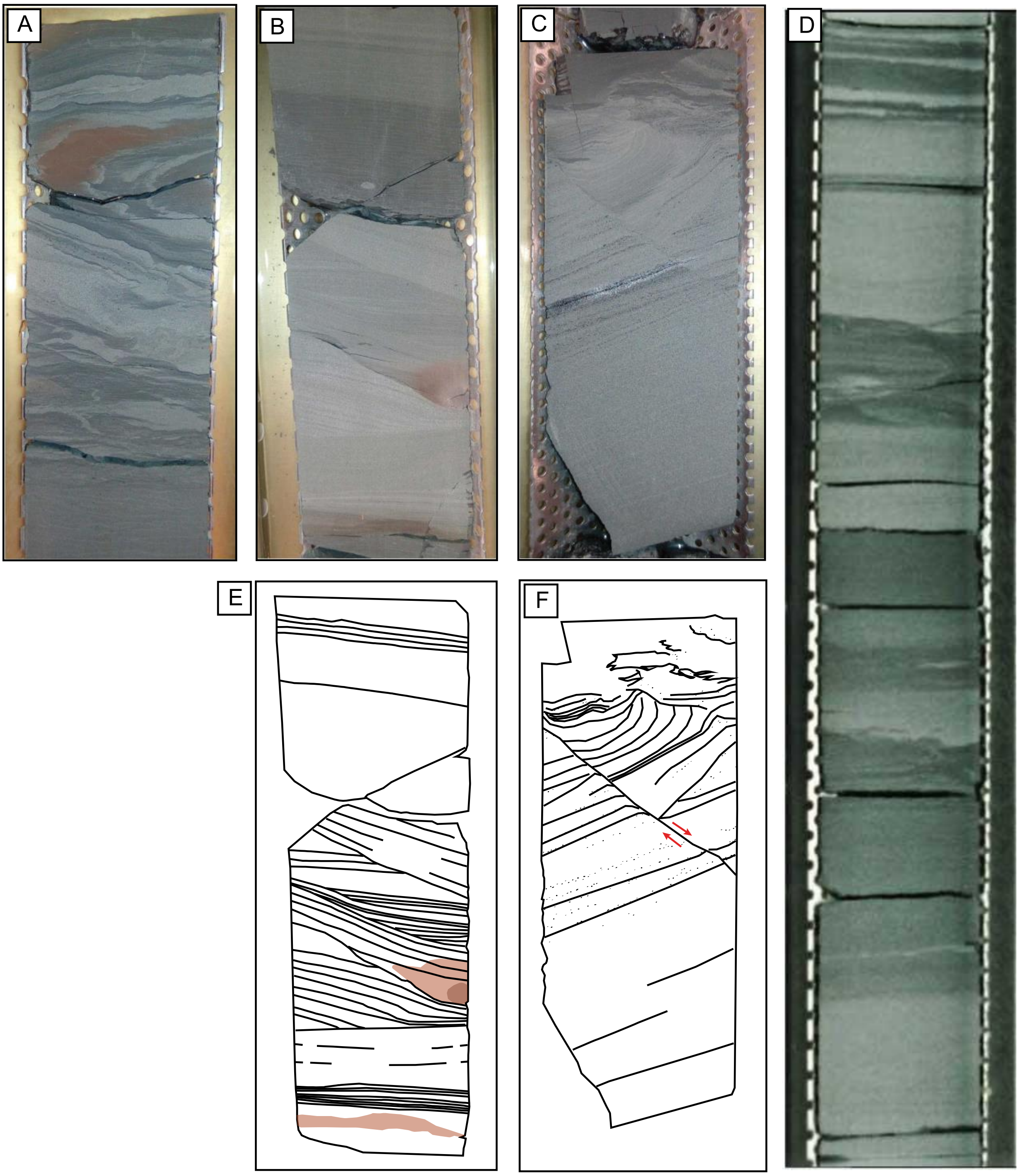

A
B
C
D
E
F

Figure 5.9: Variations of facies J from Sentralbanken High. All cores are 5 cm in diameter. A) Soft sedimentary deformed interlayered claystone and siltstone with siderite cementation. Possibly a slump structure B) Unidirectional stratification in very fine sandstone and siltstone. Grainsize varies in each set. Planar parallel lamination at the top and base. C) A slump structure gravity fault separating a soft sedimentary deformed upper part and a stratified lower part that fines upwards from vf sand to silt. Small black dots are *Tasmanites*. D) Typical section of facies J with alternations of vf sandstone, siltstone and claystone. Minor loading structures are indicated by the dashed line. Triangles indicates minor fining upward gradations. E) Sketch of B. Dashed lines are interpreted stratification. F) Sketch of C. Red arrows indicate the fault. Note that lines not indicate marker horizons. Displacement is not known.

Minor fining upward sequences appear frequently. Either as massive graded bedding from sand or silt to mud, or as fining upwards planar laminas. Individual fining upward gradations are normally between 3-8 cm thick. Often, they are stacked in series of 2-5, overlain by claystone. Individual very thin silt/sand beds or lenses are also common usually containing asymmetric ripples. In addition, a few beds with unidirectional cross-stratification (Fig. 5.9 B and E) is present, but this is relatively rare. Other less common features are minor gravity faults and slump structures (Fig. 5.9 A and C). A limited amount of thin beds has inverse gradation from clay to silt. The lithological composition is moderately variable and gradually changes between being dominated by clay, silt and sand.

Collectively the total amount of bioturbation is sparse. However, beds can locally be moderately to intensely bioturbated. Deposits that are subjected to intense bioturbation primarily consists of *Chondrites* found in large quantities clustered together in muddy deposits. *Chondrites* are found more frequently in deposits belonging to Klappmyss Formation and in significantly larger quantities compared to in Steinkobbe Formation where they are present. *Teichichnus* is the second recognizable trace fossil found, primarily as scattered singular traces.

Calcite cemented beds:

Occasionally the typical mud/silt/sand alternations are interrupted by beds of very fine calcite cemented sand or silt. Beds are from 3-40 cm thick and several of them are marked with cone in cone structures at the top. Minor intervals of calcite cementation are also found regularly, usually with a massive appearance.

Discussion and interpretation

Graded beds with fines restricted to the upper parts of the beds are most likely deposited by currents with a gradual decrease of velocity and competency (Reineck and Singh, 1980). Turbidity currents are held responsible for the origin of most graded beds in deep waters, although they might also be produced by traction currents (Reineck and Singh, 1980). Traction currents are also known to produce reverse gradation, low angled cross-stratification and current ripples (Shanmugam et al., 1993).

Assumed the background sedimentation mainly is mud and sand and silts mostly are deposited during periods with increased energy from turbidity or traction currents, the facies is interpreted to have originated in a shallow marine environment.

Chondrites are known to occur in all types of sediments, typically representing the last traces in a bioturbated sequence (Bromley and Ekdale, 1984). Found alone they are a good indicator of poorly oxygenated bottom waters, and the species are often associated with low oxygen conditions (Bhattacharya and Banerjee, 2014, Bromley and Ekdale, 1984).

Tasmanites in deposits from Paleozoic deposits from Goandwana have been interpreted to be associated with algal bloom in areas with meltwater supply (Revill et al., 1994). Occurrence of *Tasmanites* are well documented from Triassic deposits from Svalbard and the Barents Sea, where they are confirmed to be an important contributor of organic material in oil prone deposits from middle Triassic (Vigran et al., 2008). Most of the *Tasmanites* found in this core are fragmented and poorly preserved, not rounded as found at Kong Karls Land by Vigran et al (2008). They are regularly found in laminated silt and sandstones, which may imply that they have undergone reworking and redeposition during storm events or by turbidity currents.

5.2.12. Facies K: Dark grey mudstone

Observations

This facies is only found in core 7534/06-U-01 and is characterized by medium to dark grey mudstone regularly intercalated with siderite bands or shades with siderite cement (Fig. 5.10 B). Weak horizontal to gently undulating lamination is visible as color variations. Color is to large degree the apparent cause to the indistinct laminas in the mudstone, the grain size tends to be overall uniform. Large fractions seem to be structureless or without any obvious lamination. Thin intercalations of silt occasionally occur, often with planar parallel lamination and more rarely with gradations. The silt intercalations rage in thickness from 0.5-1.5 cm and are often introduced with minor loading structures. Bioturbation is present but sparse, restricted to *Chondrites*. Large sections are unbioturbated. Small pyrite crystals are very common, with size from 0.2-0.5 cm. A few yellow rounded phosphorite nodules are found, but these are not diagnostic components.

Very thin calcite cemented laminas and cone in cone structures is sporadically found where the sediments tend to be of a little coarser character (Fig. 5.10 A).

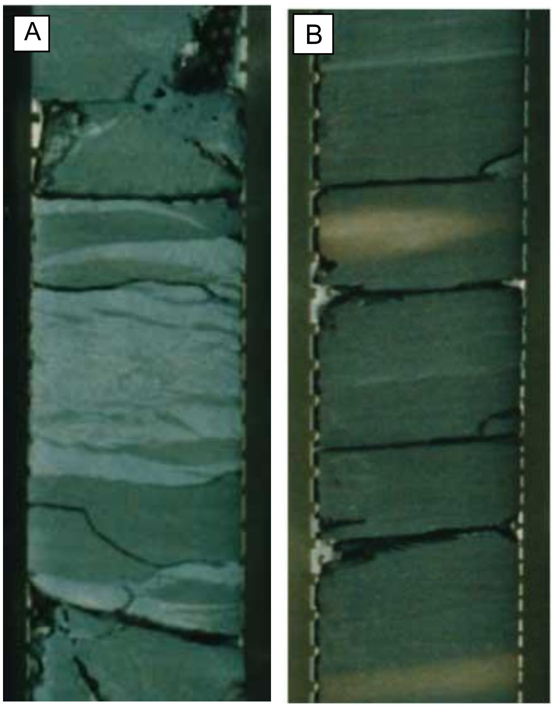


Figure 5.10: Typical elements from facies B from Sentralbanken High. **A)** Dark claystone with cone in cone structures **B)** Dark claystone with bands of siderite cementation and thin lighter silt laminas. Pictures: NPD.

The facies comprise one thick interval of approximately 26 meters which gradually transitioning into facies J, and two in two shorter sections of approximately 6 meters which also coarsens upwards into facies J. The two shorter sections are found from 108 m and 87 m ascribed to the Klappmyss Formation. The long continuous interval belongs to the Steinkobbe Formation and is present from 78.5 m. These deposits are somewhat darker in color and contains less and thinner silt laminas compared to the same facies from Klappmyss Formation.

Fossiliferous mudstone:

This variation is dominated by the abundance of pelagic ammonite and bivalve fossils. They appear in an interval from 78.6 m to 76 m. At the base, the mudstone is structureless, only occasionally interrupted by red shades of siderite cement and slightly bioturbated by *Chondrites*. Towards the top of the section bioturbation disappears and siderite cementation becomes more prominent. Millimeter sized pyrite crystals are abundant throughout.

Discussion and interpretation

Laminated mudstone is attributed to mud settling down from suspension. Lack of lamination or other structures in the mudstones can be indicative of a steady rate of deposition , represent rapidly deposited mud (Collinson et al., 2006), or fluid mud deposition by hyperpycnal flows on offshore shelfs or prodelta areas (Bhattacharya, 2006).

Siderite generally occurs in freshwater with high iron content and low Sulphur content, but can also develop in shallow marine environments (Boggs, 2011). In fully marine conditions siderite can develop only by diagenetic processes (Reineck and Singh, 1980) if the water is rich in iron and conditions are reducing (Boggs, 2011).

The low bioturbation index and assumable high organic content suggests low energy and limited oxygen supply at the sea bottom. However, the fossiliferous intervals suggest more favorable conditions for pelagic animals higher up in the water column.

5.2.13. Facies K. Dark phosphoritic shale

Description

Dark phosphoritic shale is present only in the core from the Svalis Dome. It is the most dominant facies in Steinkobbe Formation. It is unbioturbated, finely laminated and easily fractured. All the fractures make it somehow difficult to detect the lamination, and paper shale is considered a suited term to describe most of this facies. A minor contribution of silt is also present throughout the logged intervals. A few calcite cemented siltstone beds with thickness between 20-30 cm can be found, otherwise there is little variation in grainsize. Phosphatic nodules occurs in large quantities, mostly as singular nodules, but can also occur as thin beds. They are usually small and rounded with a yellowish color but can also appear as slightly elongated with a darker color. Surrounding rocks are usually draped around the rounded nodules. Pelagic fossils such as ammonites, bivalves and fish remains is reported (Mørk and Elvebakk, 1999) but are taken out of the core and no longer visible.

Discussion and interpretation

Finely planar parallel laminated mud is indicative of a calm environment with pelagic particles settling from suspension. There is notable little interruption of other lithologies except from the few calcite cemented siltstone beds which can indicate that the shelf have been little affected by storm actions and subaqueous turbidity currents. Presence of pelagic fossils found together with unbioturbated deposits can be indicative of an upper oxidized water column and a lower anoxic water column with reduced conditions (Mørk and Elvebakk, 1999). Reducing sea bottom conditions are also supported by the presence of phosphate nodules, which are likely to occur where organic rich sediments are accumulating on the sea floor under reducing conditions (Boggs, 2011). Anoxic conditions occur where limited oxygen is supplied to the water column (Demaison and Moore, 1980). Some of the causes for development such conditions may be by isolation of bottom waters, extraction of oxygen by organisms (Boesch and Rabalais, 1991) or reduced water circulation.

6. Facies associations

In total seven facies associations have been recognized and divided into three main groups where each group containing facies associations that are likely to be found within similar depositional environments (Fig. 6.1). The facies associations are identified on background of interpretation of facies, and the vertical stacking of facies. A brief overview of the different facies associations is found in Table 6.1.

Table 6.1: Summary of the identified facies associations from all localities.

Depositional environment	Facies associations	Facies included	Characteristics	Occur in core
Coastal plain	1. Floodplains and interdistributary areas	A, B, C, E, I	Alternating coals, paleosols and rooted sand and siltstones. Minor marine influence.	7230/05-U-06
	2. Fluvial channel	F, G	Alternating cross-stratified and ripple-laminated fine sandstones with intra-clasts.	7230/05-U-06
Marginal marine to shallow marine	3. Tidal flat	G, I, J	Mostly flaser bedded mudstones and wavy bedded siltstones inter-bedded with nonstratified mudstones	7230/05-U-06
	4. Tidally influenced channel	D, F, G, H, I,	Cross-stratified to rippled sandstone with intraclasts above alternating beds of heterolithic bedding and fluid mud deposits	7230/05-U-06
Offshore transition - offshore	5. Prodelta/ offshore transition	E, F, J, K	Mudstone or siltstone dominated sections with distal storm and turbudite deposits	7230/05-U-06 7230/07-U-03 7230/07-U-01 7534/06-U-01
	6. Outer shelf	K, L	Dark slightly laminated mudrocks with minor bioturbation.	7534/07-U-01
	7. Outer restricted shelf	M	Long continuous interval of dark organic rich shale rich in posphate nodules	7230/07-U-03 7230/07-U-04 7230/07-U-01

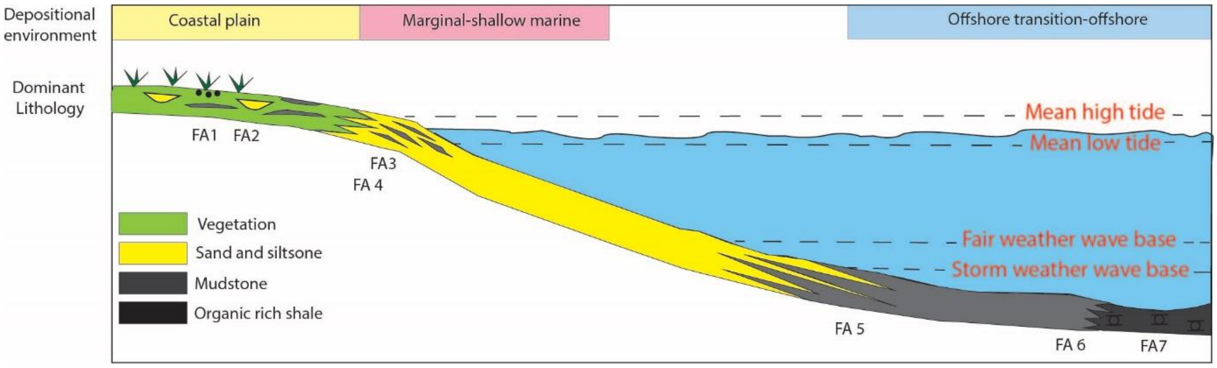


Figure 6.1: A conceptual profile shoving the different depositional environments and approximate location of the facies associations (FA) from the three cores.

6.1. Coastal plain environments

This facies association is recognizing facies representing the most proximal positions to land that are found in all the logged sections. The coastal plain depositional environment is divided into two facies associations; Floodplains and interdistributary areas (FA 1) and fluvial channel (FA 2). Marine influence is very limited, and only represented vaguely by heterolithic bedding, which possibly reflects a marine component in the system. Overall the coastal plain is herein regarded as a continental environment. Several of the facies are indicative of subaerial exposure and limited sediment input. Shift of facies can both represent varying positions to the shoreline and various degree of wetting and drying of the surface. This will be further discussed. The facies association is found directly above shallow marine to marginal marine deposits from facies association 2 in the Nordkapp Basin.

6.1.2. FA 1: Floodplains and interdistributary areas

Observations

The most characteristic and recognizable features of this facies association is the presence of paleosols (facies A), coal and coal shale (facies B). These facies clearly represent alluvial deposited strata and are very typical for floodplain areas. Paleosols and coal and coal shale are found interbedded with very fine sandstones and siltstones that are either rooted, intensely bioturbated, rippled or have wavy bedding (facies I), or above ripple laminated sandstone (facies G) (Fig. 6.2) The mud fractions in facies I typically have a green color, and thus show other characteristics compared to what is typical for heterolithic bedding. The facies association is found directly above and below fluvial channel deposits (FA 2) and above tidal flat deposits (FA 3).

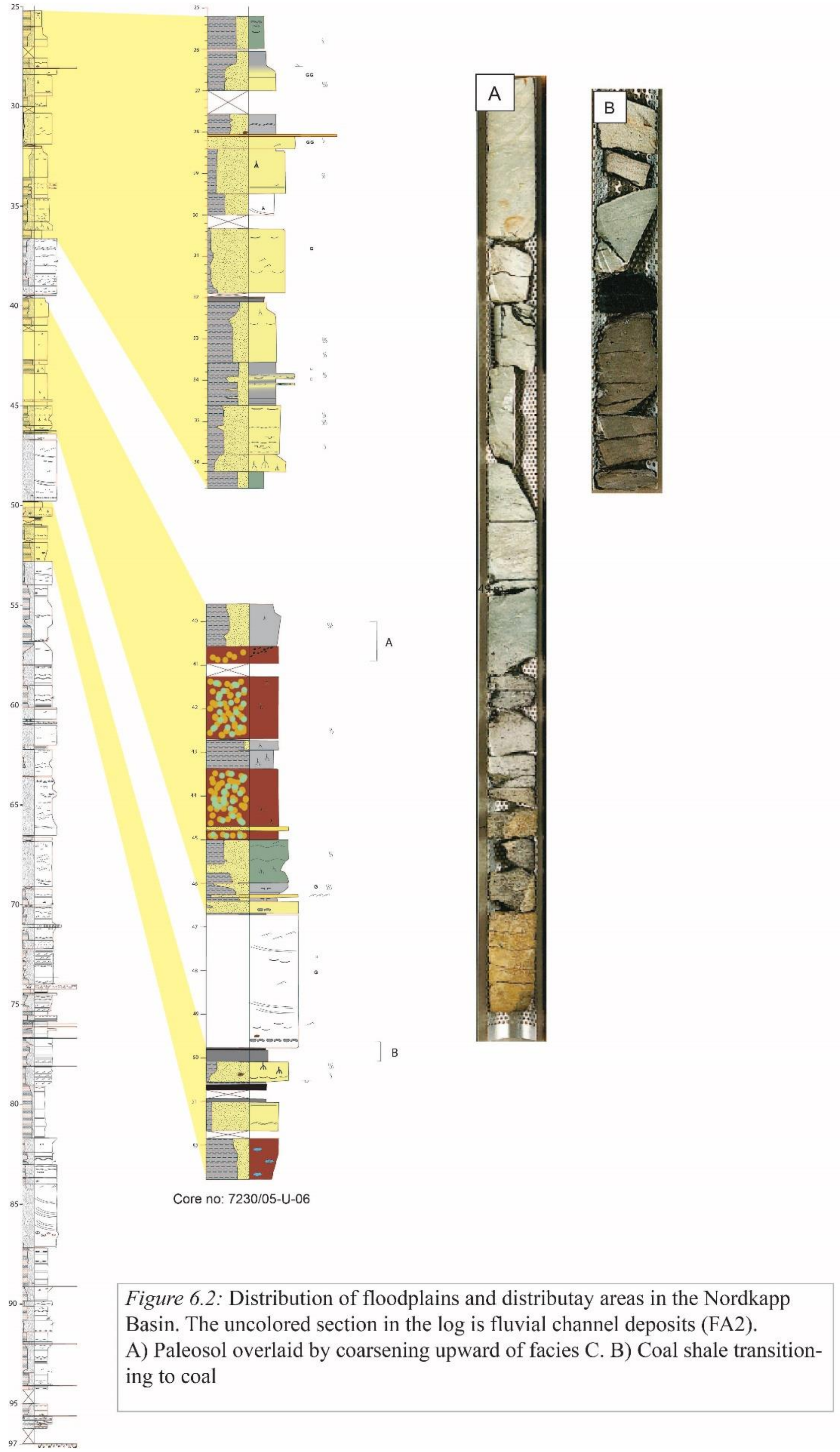


Figure 6.2: Distribution of floodplains and distributay areas in the Nordkapp Basin. The uncolored section in the log is fluvial channel deposits (FA2).
A) Paleosol overlaid by coarsening upward of facies C. B) Coal shale transitioning to coal

Discussion and interpretation

Floodplains and interdistributary areas are herein merged to one facies association due to the very similar characteristics and the challenge of distinguishing between them. Interdistributary areas are typically calm environments with standing bodies of water either open to the sea or bounded by fluvial channel (Reineck and Sings, 1980). The intervals showing signs of possible marine influence (facies C with wavy bedding) are possibly deposited in such kind of environment with a limited connection to the sea. However, most of the deposits are interpreted to origin from floodplains.

Floodplains receive sediments from distributary channels and are therefore strongly related and often found in association to channels. Deposition on floodplains are episodic and dependent on the stability of the fluvial channel, how often it will flood and how intense floods are. In between flooding events floodplains commonly dry out and become sites of subaerial exposure. Depending on the climate, water table and vegetation, pedogenic processes or coal formation might take place (Collinson, 1996). A typical cross section from a fluvial channel and to a floodplain will show the coarsest material deposited close to the channel and the fines further away. Floodplain deposits are characterized by fine grained deposits that may be interrupted by silts and sands from crevasse splays.

Coal and coal shale and paleosols can be formed under different conditions in the same depositional environment. Coal is thought to have been formed in the waterlogged parts of the coastal plain without any marine influence. Formation of coal commonly takes place where climate is humid or the water table is high (Collinson, 1996), and the coal found in this case are interpreted to have been deposited in swamps or marshes. Coal is almost exclusively overlaid coal shale, the facies is suggested to represent well vegetated areas where plant material gradually have accumulated, and sediment input have decreased. Where found directly overlain sandstone associated with fluvial deposition, the fining upwards trend possibly reflects channel avulsion. Thinner sandstone beds that commonly show root structures are interpreted to represent levees or overbank areas in a proximal position to a channel that were vegetated between floods. The small ripples that occasionally is found, most might represent stream incursion during flooding.

The mottled appearance of the paleosol is interpreted to represent periodic wetting and drying of the surface. The presence of kaolinite identified from the XRD analysis indicates a relatively warm and humid climate. According to Collinson (1996), red color indicates good drainage and an oxidizing early diagenetic regime, which also supports the theory of an in general humid and warm climate. However, the climatic conditions may have been fluctuating. The presence of the facies variation with calcite nodules might represent drier periods and indicate climatic variations with alternating periods of a humid and more arid climate. Sedimentation rates have probably been relatively low du to the frequent appearance of coal and coal shale and paleosols in the core. This may reflect low frequency or low intensity of floodings.

6.1.3. FA 2: Distributary channel

Observations

Facies association 2 is comprised of only two facies; unidirectional cross-stratified fine sandstone (facies F) and ripple-laminated fine sandstone (facies G) in an alternating pattern. Plant fragments are abundant highlighting the stratification, and an erosive lag of mud and siderite clasts is present at the base. Distributary channels are found in a 3 meter thick package in between deposits from floodplains or distributary areas in the Nordkapp Basin and assumed to be of alluvial origin. Distributary channel facies association is separated from tidally influenced channel (FA 4) due to the lack of tidal imprints in form of mud drapes, signs of opposing current directions and fluid mud deposition, and the position to other coastal plain related facies.

Discussion and interpretation

Channels are often recognized on background of typical concave upward shapes with erosional lag at the base. Cross-bedded and cross-laminated sandstones are according to Collinson (1996) the most abundant facies in fluvial channels, reflecting migration of dunes and ripples in a unidirectional flow. Both geomorphology, sediment load and fluvial discharge are important factors for the outcome of channel geometries (Bridge, 2006). However, core views are not sufficient enough to describe the nature and geometry of channels, and it is due to this not attempted to classify the type of channel system in detail.

Fluvial channels act as one of the most important sediment suppliers to the continental plain by transporting sand and gravels as bedload and mud carried in suspension (Bridge, 2006). The commonly low gradient on such plains leads to reduction in stream power and more frequent branching and smaller more temporary channels compared to areas with a higher gradient. Channel avulsion are more common during flood events on a low gradient coastal plain compared to upstream areas with higher gradient. Width to depth ratios are thus also smaller downstream due to the limited time to migrate laterally (Reading and Collinson, 1996).

The proportion interpreted to be channel sand is relatively thin, which might indicate a short-lived channel with relatively shallow depth that have eroded the underlying coastal plain. There are no signs of erosion or reactivation surfaces which suggests limited fluctuations of the water stage (Rust and Jones, 1987). However, the alternations of cross-stratified sandstone and ripple-laminated sandstones might reflect variations in the stream power within a consistent unidirectional flow with higher current speed where cross-stratification is formed and lower flow velocities where ripples were formed. The facies association is thus suggested to consist of minor fluvial channels on a relatively flat lying area.

Similar facies composition could also reflect other depositional environments than distributary channels like mouth bars, barrier bars and shoreface deposits, but these environments are disregarded due to the lack of signs of marine influence and the proximity to floodplains and distributary areas (FA 1).

6.2. Marginal marine environments

Marginal marine environments are herein defined as the transition area between continental and marine environments. Such systems are highly dynamic and are daily affected by wave motion, tidal currents and fluvial processes in addition to occasional storms. In opposite to at the coastal plain which in this study is regarded as continental, marginal marine deposits are dominated mainly by marine and fluvial processes. Sediments may have been subaerially exposed for short periods during low tides but have mostly been affected by marine and fluvial processes.

Marginal-shallow marine deposits are found above shallow marine deposits (FA 3.1), and above and below coastal plain deposits (FA 1) in the Nordkapp Basin.

6.2.1 FA 3: Tidal flat

Observations

Facies association 3 is only found from the Nordkapp Basin, where the greatest proportion is found in the lower half of core 7223/05-U-06. Associated facies are heterolithic bedding, thin rippled sandstone beds, and siderite conglomerate. Found above facies association 3.1 prodelta in the lower parts of the core interrupted by tidally influenced channel deposits (FA 4) and in between floodplain and interfluvial area deposits (FA 1) in the upper part of the core. The mud/sand ratio is highly variable, changing between mostly mud to mostly sand. Siderite conglomerates are regularly present and found in between heterolithic bedding. There is no general fining or coarsening upwards trends for this facies association. Tidal flats can host several sub-environments similar to the coastal plain deposits, especially in supra-tidal settings, but they are herein separated on background of the strong marine influence on the deposits and the lack of prominent signs of subaerial exposure.

Discussion and interpretations

The extent of tidal flats depends on the tidal range, sediment supply and the shoreline gradient, and are most extensive in macrotidal settings and along muddy low-gradient coastlines (Reading and Collinson, 1996). A lot of the sand supply in these types of settings are derived from offshore areas and transported landward by tidal currents. In the studied cores, most of the tidal deposits are dominated by mud, which possibly is supplied to the sea by neighboring rivers where large quantities of mud can be transported in suspension, and later resuspended and distributed by tidal currents (Reynaud and Dalrymple, 2012). Various types of tidal flats are described in the literature (Daidu, 2013, Reading and Collinson, 1996), based on the position of the tidal flat relative to the affection of tides, the ratio between sand and mud and whether the flat are protected from other marine processes than tides or not.

The facies included in this facies association implies that tides are the predominant mechanism of production of the sedimentary structures found within these deposits. Being located adjacent to the sea, other factors such as waves and storms are likely to interact with the tides and affect erosion and deposition of sediments. However, because no cross-stratified sandstone and thicker beds of sandstone is present, other then what is associated with channelized deposits (FA 4) or possibly mouth bars. This possibly reflects minor reworking by waves, and that tides and river processes mainly affected the sediments in the marginal marine environment at the location of well 7230/05-U-06. However, core material from one well only are not sufficient evidence for such a statement to be valid for a wider area since different processes might have been more dominant close to the well. This specific area might for instance have been more sheltered for waves by for instance having some sort of barrier.

Tidal flats are often sites of extensive vegetation, especially at supra and upper parts of intertidal flats. In such areas mangroves or saltflats commonly form depending on the climate (Daidu, 2013). The lack of evidence of vegetation and the predominant marine influence suggests that the tidal flat deposits from the lower part Nordkapp Basin were deposited in the subtidal-lower intertidal zone, whereas the upper section interpreted as tidal flats possibly are deposited in the supratidal zone based on the proximity to FA 1 (floodplains and interdistributary areas).

6.2.2. FA 4: Tidally influenced channel

Observations

Facies association 4, tidally influenced channel is composed of a great variety of facies. Cross stratified sandstone, rippled sandstone, heterolithic bedding, mud flake conglomerate and intercalated claystone and sandstone are found. Transitions between different facies are usually gradual, and facies are commonly mixed so that characteristic components from two facies are co-occurring and alternating in thin intervals. This is especially typical for rippled sandstone and cross-stratified sandstone. FA 4 is found both above and underneath shallow marine deposits, and between coastal plain deposits. Tidally influence channel facies association is introduced by heterolithic bedding overlain by intercalated claystone and sandstone which again is overlaid by mud flake conglomerate (Fig. 6.3). Above the conglomerate deposits tends to be coarser and more heterogenous in terms of grainsize with mostly deposits of fine sands. There is no overall coarsening or fining upward trends, but tidal signals seems to be stronger in the lowest proportions. Lamination is usually chaotic and is commonly interrupted by rip-up clasts of mud. The mud flakes are naturally incorporated into the sedimentary record and show no signs of erosional boundaries. Tidally influenced channel deposits are only observed in core 7230/05-U-06.

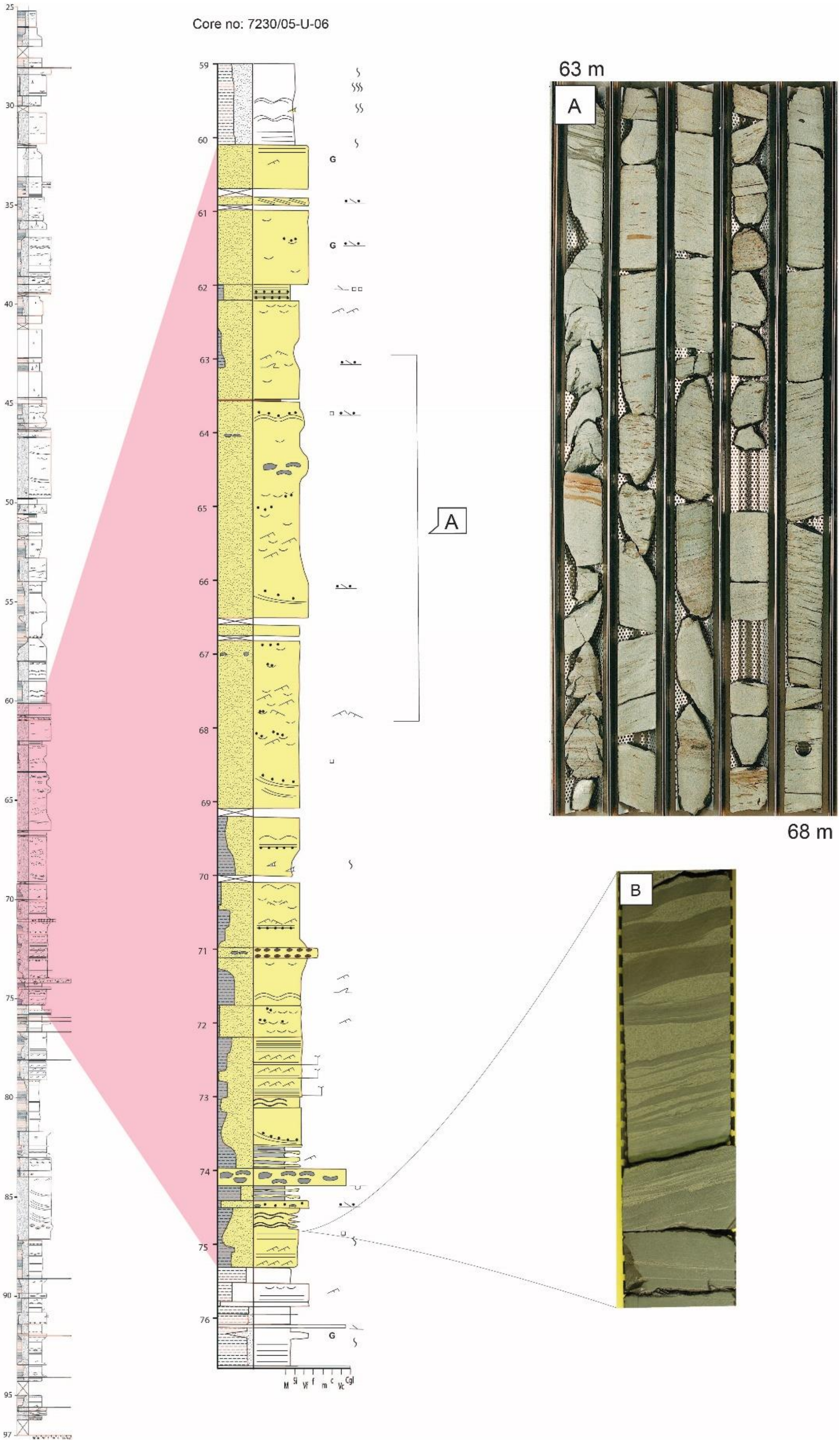

Core no: 7230/05-U-06
63 m
A
68 m
B
M Si vf f m c vc Cgl

Figure 6.3: Facies association 2.1, tidally influenced channel observed in the Nordkapp Basin. **A)** 5 meters of alternating cross-stratified and ripple-laminated very fine sandstone with intraclasts of mud. Sign of minor influence of tides only. **B)** Wavy bedded sandstone and non-stratified layers of mud imply a relatively high degree of tidal modulation.

Interpretation

Tidally influenced channels are typically relatively straight with low sinuosity and have a high depth to width ratio (Reading and Collinson, 1996). Tidal influence occurs in the lower proportions of a channel where it approaches the coast. How far up the tides can affect a channel depends on the gradient of the coastal plain and the amplitude of the tides (Reading and Collinson, 1996). One of the most prominent characteristics of a tidal channel is bidirectional flow (Hughes, 2012) formed when tides are approaching and retreating.

The sedimentary structures found in this study testify deposits with strong tidal influence. This is highlighted by the occurrence of heterolithic bedding, the frequently abundant mud drapes in the stratification, bidirectional current directions and fluid mud deposits. The lower part of the tidal channel as illustrated in Figure 6.3 seems to be more modified by tides and have had lower preservation potential for mud compared to the upper part, which are strongly affected by unidirectional currents, and seems to have slightly less fines. This might be related to two factors: *i)* seaward retreat of the shoreline, leading to a more landward position of the channel with less tidal influence and a more distal position to the sediment source, or *ii)* stronger fluvial currents, overprinting the tidal imprint.

The frequent occurrence of mud flakes and siderite clasts that was interpreted as products of cut bank erosion or rip-up clasts due to events with increased current power described under facies are possibly deposited at morphological obstacles, such as point pars or along channel bends where the stream power decreases. However, there are no erosional surfaces or other evidences for channel amalgamation, which suggests the steady development of one single channel with some signs of erosion and lateral migration seen by longitudinal cross-stratification and clusters of mud flakes.

The absence of trace fossils supports the interpretation of persistent high sedimentation rates, unfavorable for benthic colonization (MacEachern et al., 2005), in addition, tidal influence leads to mixing of saline and fresh waters, which also creates a stressed environment for organisms, which normally leads to a sparse fauna with low diversity and small size of burrows (MacEachern et al., 2005).

Finally, this leads to an interpretation of a tidally influenced channel, with upwards decrease of tidal modulation where currents partly become too strong for deposition of suspended fines. Alternatively, the lack of significant tidal signatures towards the top represents a change in the position of the channelized deposits relative to the shoreline with the upper part deposited closer to land.

6.2.3. Uncertain facies associations

A 5 meter thick sand-dominated interval is present between tidal flat deposits. The sandstone has cross-stratification with coal debris, and contains intervals dominated by siderite clasts and mud flakes. The upper level is interbedded with thin mud layers before it gradually transitions into a mudstone with flaser bedding. There are several possibilities for how this interval can have been formed, and some of the possible processes will be discussed.

Mouth bar deposits

Near the seaward limit of a distributary channel distributary mouth bars commonly form (Reineck and Singh, 1980). Mouth bar settings are sites of high sedimentation rates due to loss of current velocity and carrying capacity when the stream leaves the channel. Sand and silt is predominantly deposited, and the most common structure is trough cross-bedding (Reineck and Singh, 1980). The observed cross-stratification with coal debris directly overlaid tidal flat deposits can be an indication but not a direct evidence of mouth bar deposits. The top with heterolithic bedding may be either tidal influence or seasonal variations of the river discharge.

Channel deposits

The sand has many of the same characteristics as tidally influenced channel deposits (FA 4), but have marine facies both above and below.

Shoreface deposits

Found directly above rocks interpreted to be deposited on a shallow shelf and below tidal flat deposits a shoreface setting is possible for these sandstones. The shoreface is sites of primarily sand and silt deposition. Oscillatory and wave processes operate in the lower part of the shoreface while breaker/surf zone processes dominate the upper part of the shoreface (Reading and Collinson, 1996).

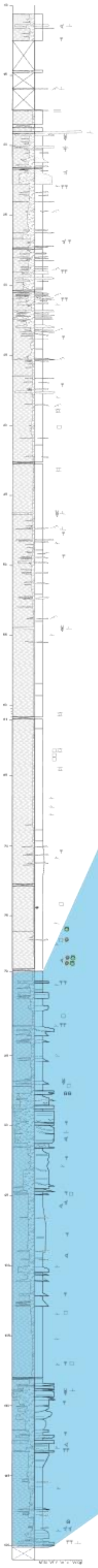
6.3. Offshore transition to offshore marine environments

The offshore transition zone is located between fairweather wave base and storm wave base and are subjected to alternating energy regimes (Reading and Collinson, 1996). The background sedimentation in these areas are primarily silt and clay settling from suspension. During storms sand might be transported out from more landward positions and deposited in the offshore transition zone by shoaling waves and storm generated currents. Hummocky cross-stratification is a common sedimentary structure in the offshore transition zone generated during storms but are not found in any of the studied cores from these environments. The offshore zone is herein defined as a low energetic environment with primarily deposition of mud located below the storm wave base. Offshore transition- offshore deposits are found in in all the studied cores.

6.3.1. FA 5: Prodelta/ Offshore transition

Observations

Facies association 5 are dominated by graded and laminated silts and mudstones with silt intercalations. In the Nordkapp Basin it is found below marginal marine- to shallow marine deposits, at the Svalis Dome and Sentralbanken High, the faces association is found both below and above outer shelf deposits (FA. 6 and 7). The characteristics, however, vary slightly between the three different areas, but common for all is that they contain very few facies, and have long intervals with subtle variations. Core 7534/06-U-01 are dominated of muddy siltstone with sandstone intercalations (facies K), typically with graded beds and rhythmic laminations and a in general sparse to moderate degree of bioturbation (Fig. 6.4). Prodeltaic deposits in this area are in general more heterolithic compared to deposits from the Svalis Dome with a wider range of sedimentary structures and thicker interbeds of clay sand and silt. At the Svalis Dome the laminated siltstone (facies J) is the only observed facies. Here the only occurrence of very fine sand is in thin laminas and a few very thin beds, maximum a couple of centimeters. Only a thin section of prodeltaic deposits are present in the Nordkapp Basin core with dominance of planar parallel laminated silt and shales with distinctively more bioturbation compared to the other areas.



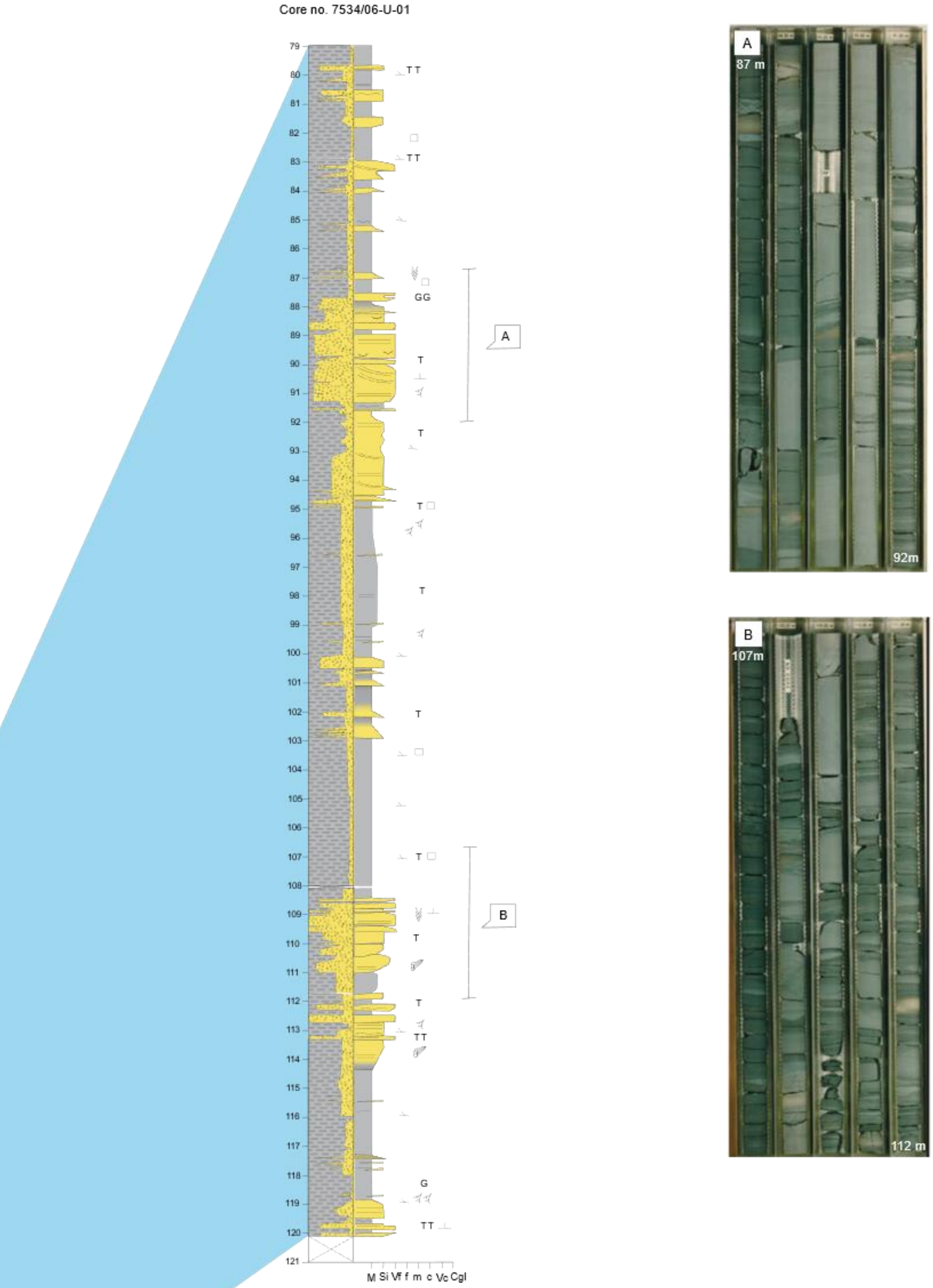


Figure 6.4:Facies association 5- Prodelta/offshore transition.
A) Interlayered bedding overlaid by low-angled cross-stratification overlaid by mudstone. B) Interlayered bedding overlaid by mudstone.

Discussion and interpretation

The prodelta environment is located seaward from the delta front and is closely associated with the prograding delta system. Proximal to the delta front, typical deposits are planar to lenticular laminated silts, whereas away from the delta front deposits are more dominated by clays with less textural stratification (Reineck and Singh, 1980). Prodeltaic deposits share many similarities with deposits from the offshore transition zone, and the two different environments may be difficult to distinguish. In this case prodelta is chosen as a facies association based on previous studies of the Kobbe Formation (Klausen et al., 2017), where seismic and core studies are integrated, and the findings shows clinoform geometries that have developed due to delta progradation. In addition, coarsening upward intervals at Sentralbanken High might be indicative of episodes of delta progradation, and thus favor prodelta deposits above offshore transition zone deposits.

Sediment supply to prodelta areas and offshore transition zones are to large degree controlled by storms, hyperpycnal flows or hypopycnal plumes. Background sedimentation during fair weather is normally restricted to settling of suspended mud and fines. During storm events, coastal areas typically gets eroded and sediments are transported basinwards and deposited in areas that normally are mud prone (Eide et al., 2015). A typical tempestite are often recognized by an abrupt change of lithology with an erosional boundary to underlying deposit. Wave oscillation ripples often overlays hummocky cross-stratification or swaley cross-stratification, reflecting waning phases of the storm (Suter, 2006). None of the studied cores show hummocky cross-stratification. The sand and silt are either planar laminated or rippled, which suggests a distal position of the prodelta deposits at the Svalis Dome and the Nordkapp Basin. A distal position of the prodelta is also supported by the very limited input of sand, especially at the Svalis Dome, which might indicate a long transport path from the sediment supplier. Alternatively, very thin beds of sand can be related to vague storm intensity (Myrow, 1992), and not be related to the distance of the sediment source. The cross-stratified sandstone interval from the Svalis Dome possibly resembles some sort of offshore bar deposits.

The laminated siltstones with gradational sandstone laminae are herein interpreted to represent deposition from either turbidity currents or storm activity. Both mechanisms are capable of producing such structures (Walker, 1984, Myrow, 1992), and most likely a combination of the two mechanisms are responsible for the beds. The observed gravity faults and Minor normal faults and slump structures might reflect slope instability, which might occur during rapid delta progradation and sedimentation, or movement above a muddy substrate (Elliott, 1978), but it is important to state that occurrence of these structures are rare, and that such mechanisms probably not were dominant.

6.3.2. FA 6: Outer shelf

Observations

Outer shelf deposits are mostly composed of dark grey mudstone (facies L) but are also found together with muddy siltstone with sandstone intercalations (facies K) where the facies association transitions to prodelta/offshore transition deposits (FA 5). This transition is gradual at both the upper and lower boundary. Outer shelf facies association is only found in the core from Sentralbanken High in between prodelta/offshore transition deposits. Since most of the facies association constitutes of facies L, the observations are described under facies.

Discussion and interpretation

Outer shelf environments are calm and low energetic environments which primarily are subjected to pelagic and hemipelagic deposition of mud. Few physical processes are active at the outer shelf, and the sedimentation rate is slow. Particles settles under the influence of gravity if bottom and turbidity currents are absent (Stow et al., 1996). This facies association consists almost exclusively of mud, only rarely the mudstone is interrupted by silt laminas. An exception is in the transition to prodelta/offshore transition facies association. The long continuous section witnesses a long period of slow accumulation rates at the sea floor. The beds with slightly larger grainsize are pervasively calcite cemented and possible primary depositional structures are not to be recognized. The mechanism for transportation and deposition of these beds are thus uncertain, but some possible transport mechanism for coarser grained material in deep-water regions are contour currents at the sea bottom possibly due to cooling and sinking of surface waters (Stow et at., 1996), traction currents, subaqueous debris flows or turbidity currents.

The mudstones are dark and visible bioturbation is sparse, but the facies association is still separated from the outer restricted shelf (FA 7). The section without visible lamination might have been subjected to intense bioturbation, which if the case would indicate a much more favorable environment at the sea floor compared to facies association 3.3. Nevertheless, since the only observed trace fossil is *Chondrites*, the sea bottom waters are interpreted to have a relatively low oxygen content, but not as low as in the outer restricted shelf.

6.3.3. FA 7: Outer restricted shelf

Observations

The facies association is composed solely of facies M, dark phosphoritic rich shale. The outer restricted shelf facies association is considered the most distal of all facies associations. It has many similarities to facies association 3.2 (outer shelf), and most likely origin from a morphologically similar system, but show evidence of slightly different conditions by the significantly higher abundance of phosphate nodules and pelagic fossils. Outer restricted shelf deposits are found only at the Svalis Dome in one continuous thick interval totally without disruption.

Discussion and interpretation

The outer shelf is located in the most distal and deepest part of the continental shelf. These environments predominantly constitute successions of mud. As established from the facies the dark organic rich mudstones with phosphate nodules represent suspension settling in a calm environment with similar physical conditions as described for the outer shelf (FA 6).

Deposition of black organic rich shales is favored if surface-water productivity is high or if terrestrial plant material is supplied in large quantities (Stow et al., 1996). How much organic carbon that are being produced depends on how much that will accumulate on the sea floor, sediment particle size, sedimentation rate and the oxygen content at the sea floor. (Demaison and Moore, 1980).

To preserve organic material in shelf sediments, some sort of protection from oxidative processes is needed (Sueter, 2006). The waters need to have a low relative concentration of dissolved oxygen, which can be facilitated by processes described in facies M. Stratification of the water column might occur due to salinity, density and temperature contrasts creates layers that prevents water circulation and possibly leading to anoxia. Poorly oxygenated bottom conditions are usually not sites of extensive benthic colonization. Trace fossils or other signs of benthic fauna have not been observed in the cores from the Svalis Dome, which supports the interpretation of a low oxygenated environment. The high values of total organic content of up to 9% (Mørk and Elvebakk 1999), occurrence of pyrite and phosphorite nodules suggests deposition in an anoxic environment. The whole interval has relatively high TOC values, and maintenance of anoxic conditions require absence of current activity and turbulence, limited reworking of sediments and a low rate of deposition (Reineck and Singh, 1980). This together with the dominance of clay deposits implies a long period with low accumulation rates with limited sediment influx from surrounding areas.

7. Discussion

Thirteen facies and seven facies associations have been defined in three areas in the southwestern Barents Sea. The facies are ascribed to three different formations where each of the formations show different characteristics. The depositional environments are partly discussed under facies associations where the various environments are interpreted and discussed individually based on the vertical distribution of facies. This chapter will have a broader focus, and possible causes for transitions between the various depositional environments of the studied cores will be discussed considering previous studies of both sedimentology and delta geometries. The vertical distribution of facies will be discussed in terms of possible depositional processes that can have affected the deposition such as waves, tides, storms, fluvial input and pelagic deposition and pedogenic processes. Since the three locations not are located closely and have significantly different characteristics, the depositional environment for each area will first be evaluated separately. Secondly the south to north evolution of the study areas will be discussed and attempted to put in a more regional context. Parts of the Kobbe Formation and Steinkobbe Formation are of approximately the same age (Late Olenekian-Anisian) (Lundshien et al., 2014), and the respective formations development and relationship will thus be emphasized.

7.1. Facies distribution and depositional environment

7.1.1. Nordkapp Basin

The Kobbe Formation which overall constitutes the most proximal facies observed show a steady shallowing upwards regressive trend in the Nordkapp Basin. The base of the core consists of deposits associated with prodeltaic to shallow marine environments and were deposited at the inner shelf. This is supported by the presence of graded to laminated siltstones and a moderately occurrence of glauconite. If Glauconite is found in place, the mineral is usually associated with marine deposits and implies low sedimentation rates (Nichols, 2009). It is thus suggested that limited sediments were supplied to the system during deposition of the lower proportions of core 7323/05-U-06. Above the deposits are of marginal marine character and composed of tidal flat associated deposits and a tidally influenced channel. Tides and fluvial processes are regarded as the two most important factors concerning transportation and distribution of sediments implied by the frequent occurrence of heterolithic bedding, mud drapes, channelized deposits and fluid mud. Marginal marine facies associations are overlaid by coastal plain deposits which are comprised of facies associated with floodplains and distributary areas and minor distributary channels. Observations of paleosols, coal and coal shales suggest a transition to conditions with frequent subaerially exposure possibly with a relatively warm and humid climate indicated by the presence of kaolinite in the paleosols (Sheldon and Tabors, 2009). However, it might have been periods with more arid conditions supported by the occurrence of a horizon rich in calcite nodules and lack of kaolinite in certain paleosols.

Overall the stacking of facies and facies associations implies a progressively shallower environment upwards in the core with facies developing from distal to proximal. Only at approximately 39 m in core 7237/05-U-06 the continuous shallowing upwards succession shows signs of sudden marine incursion where tidal flat associated facies are overlaid the subaerial coastal plain deposits. The tidal flat sediments are here comprised of more sand compared to what is found lower down in the same core. This might reflect a higher input of sediments, which can be related to stronger tidal currents or more sand transported from the fluvial system. The tidal flat facies association and deposits from the floodplains and interfluvial areas are interpreted to be closely linked and minor changes of the morphology or water level would most likely lead to a switch between the two facies associations (Reading and Levell, 1996). Possible reasons for this facies change could be changes in the pathways of the fluvial system which could modify the geomorphology of the system, or it may represent a period of slightly higher water level which could be the case if sedimentation increases and the basin fills up.

As stated, a regressive trend is dominant for core 7230/05-U-06. The facies that are found stacked are regarded as naturally replacements as the water level drops or a basin gets infilled. The only punctuation of this regressive trend other than what was discussed above is the siderite conglomerates which frequently occur. The sandy matrix of the conglomerates occasionally contains glauconite, which could imply a marine origin, at least for the matrix. However, glauconite is also found in tidally influenced channel associated deposits and might thus also be a product of erosion of marine sediments as a channel cuts down and erode underlying strata. It is therefore proposed that the core material have been deposited during a steady period of regression with punctuation by occasional floodings.

Klausen et al. (2017) Refer to the Kobbe Formation in the Nordkapp Basin as a mud-rich platform edge delta. Deltas are fundamentally regressive in nature with most of the sediments derived from rivers (Bhattacharya, 2006). Typically, delta successions are recognized by progressively shallower facies and are usually coarsening upwards as the delta prograde. Extensive sand deposits are not found within the deposits in the Nordkapp Basin other than what has been associated with channelized deposits, and the succession is lacking a sandy delta front. Thicker sand units are mostly deposited around moth bars and are thus often of limited lateral extent (Reading and Collinson, 2006), especially if the sediments not are redistributed by waves or longshore currents. The absence of a sandy delta front in the succession might thus be related to the position to a distributary fluvial system at the base of the core and a reorganization of the fluvial system might have taken place later at the onset of the channelized deposits that are found positioned on top of the shallow marine- prodeltaic deposits. Alternatively, it might represent some sort of bypass of sediments which could be the case in regressive settings where the platform gets subaerially exposed which allows sediments to get bypassed and form a delta complex at the platform margin. Platform-margin deltas are interpreted from seismic in the western Barents Sea with topsets with limited accommodation space where most of the sediments bypassed the delta platform (Glørstad-Clark et al., 2011).

The strong tidal signals and the occurrence of channelized deposits thereby implies that tides and fluvial processes probably were the two most controlling factors regarding sedimentation and modification of the geometry in the upper part of the delta.

7.1.1 Sentralbanken High

The mudstone interval from core 7535/06-U-05 has in the literature been ascribed to both Steinkobbe and Kobbe formations. In Lundschien et al. (2014) the mudstones are correlated and ascribed to Steinkobbe Formation whereas in Riis et al. (2008) Kobbe Formation is used for the same core. The deposits from the core from Sentralbanken High are herein suggested to belong to Steinkobbe Formation due to the greater similarity of deposits in the core from Svalis Dome compared to with the Kobbe Formation that are found in Sentralbanken High.

The lowermost unit in the core from Sentralbanken High is palynologically dated as late Olenekian (Riis et al., 2008) and assigned to the Klappmyss Formation of Worsley et al. (1988). Coarsening upward sequences are observed with sandstone beds internally fining upwards but appears more frequently. Altogether these beds comprise coarsening upward units. However, it is somewhat uncertain whether they all are coarsening upwards due to the lack of distinct boundaries. It might also be that some of the sequences are fining upwards and represents periods of reduction of sediment supply instead of increased supply. Lundschien et al. (2014) noted the possibility for auto cyclic switches of deltaic lobes in a large deltaic system based on subtle variations in depositional settings of core 7523/06-U-01 and an adjacent core (7532/02-U-01) also from Sentralbanken High. The coarsening and/or fining upwards units might thus be related to the dynamic nature of the delta and possibly represent progradation of deltaic lobes and changes of the pathways in the deltaic fluvial system. However, storms and turbidity currents are suggested as the most important factors of deposition and transportation of sediments, and an increase of the frequency and thickness of storm beds or turbidites could possibly reflect a closer position of the sediment source.

Lack of extensive bioturbation and low diversity ichnofauna were by Riis et al. (2008) suggested to represent reduced oxic conditions or rapid sedimentation. Limited access to oxygen is supported by the presence of *Chondrites* (Bromely and Ekdale, 1984) which are found in abundance in the part of the core ascribed to Klappmyss Formation. One possibility is that low sedimentation rates and relatively low oxic conditions were dominant and periodically got interrupted by more rapid deposition by sediment laden incursions in terms of storms or turbidity currents.

It is a marked change in lithology at the boundary between Klappmyss and Steinkobbe formations with a sudden deepening of facies with transition from interbedded silt and mudstones to dark mudstone. The former prodeltaic conditions are replaced with what has been interpreted as deep outer shelf conditions below storm wave basis. Upwards, the mudstones grades into interbedded mudstones, siltstones and thin sandstones with similarities to deposits of Klappmyss Formation. This indicates an upward increase of energy level and testifies deposition in a shallower environment within the reach of storm influence.

Overall the majority core 7523/06-U-01 is suggested deposited in a slightly shallower environment compared to the lithologies from the Svalis Dome. Possibly also with somewhat better water circulation, supported by thin beds and laminae of silt in the mudstones of Steinkobbe Formation. If these silt laminas are products of turbidity currents, mixing of waters is likely, and could possibly have created better ventilation and supplied the water with oxygen. Processes influencing deposition are most likely the same for both areas, but conditions at Sentralbanken High are interpreted to be somewhat less anoxic in comparison supported by the slightly lighter color of sediments, lack of prominent lamination, which could reflect bioturbation of the strata and more frequent interruptions of silt laminas during deposition of the mudstone.

7.1.2. The Svalis Dome

Like at Sentralbanken High an abrupt deepening of facies occurs at the transition between Klappmyss Formation and Steinkobbe Formation. The storm and/or current affected prodelta deposits are sharply overlaid by black organic rich shales. This formation boundary represents a transgressive surface (Mørk and Elvebakk 1999).

As established in facies and facies association, Steinkobbe Formation have been interpreted to origin in a deep basin with limited access to oxygen, deposited on a restricted shelf. Similar lithologies are observed on land at eastern Spitsbergen, there represented by Botneheia Formation (Mørk et al., 1982). However, deposition of black organic rich shales started slightly later in these areas (Vigran et al., 2014, Mørk et al, 1999) and continued throughout the Middle Triassic. Turbidity currents and/or storms are thought to be the responsible mechanisms for deposition of the laminated silts in the Klappmyss Formation displayed as frequently occurring graded beds with fining upwards lamination. After the transgression the distance from the sediment source to the shelf probably became too long for turbidity currents to reach and too deep for significant affection by storm waves. If the basin is deep and mechanisms capable of transporting sediment in to the basin is limited, accumulation rates are slow and mostly constrained to pelagic deposition. This is observed by the long section of laminated mud. If the offshore area is deep, it would require larger changes in the relative sea level to switch to other facies compared to the more proximal low gradient areas seen in the Nordkapp Basin. Minor changes in sea level will not necessarily be detectable in such deep facies, so the black shales have either been deposited in a relatively deep environment too far from the sediment source or, alternatively, the possible delta have not prograded much during this period, so that sediment supply were reduced.

The overall trend of the log is a sudden deepening in the transition from Klappmyss Formation to Steinkobbe Formation followed by more input of sand and silt towards the top of core 7323/07-U-01. The continuous deposition of black shale then became periodically interrupted by laminated silt beds and thinner laminas of very fine sand, and the characteristic occurrence of phosphate nodules were to large degree exchanged by siderite nodules and thin siderite cemented beds. Two possible causes for the deposition of the thin sand and silt beds are considered. i) Infill of the deep basin due to a prograding delta feeding the system with sediments leading to a shallower basin. ii) Rapid deposition or steepening of the delta slope which could create an unstable slope more prone to subaqueous debris flows.

7.2. Potential mechanisms responsible for the regressive trend of Steinkobbe Formation

In the Early Triassic the Barents Sea region was an underfilled epicontinental basin. During Early and Middle Triassic, the basin was gradually infilled with sediment sources located in the south and southeast, probably supplied by the Ural Mountains and the Baltic Shield (Glørstad-Clark et al., 2011, Høy and Lundschien, 2011, Worsley, 2008). Clinoforms prograded into the basin and were formed in series of transgressive and regressive events, resulting in the formation of sequence boundaries. At Sentralbanken High and the Svalis Dome transgressive events are observed at the formation boundaries between Klappmyss and Steinkobbe formations. After the transgression, Steinkobbe Formation seems to shallow upwards. Four hypotheses are here proposed to explain the regressive style observed in all cores: *i)* Fluctuation of the sea water level leading to a shallower basin with greater possibilities for sediment supply. *ii)* Reduction of accommodation space due to reduced subsidence of the basin. *iii)* Reduced accommodation space due to progradation of clinoforms gradually filling the basin. *iv)* A period of more frequent and/or heavier storms capable of resuspend and transport sediments at greater depths. Hypothesis *ii* and *iv* are restricted to the cores from Sentralbanken High and the Svalis Dome since the depositional pattern in the upper part of the delta are considered more dynamic and related to the fluvial input and because evidence of storm activity not is prominent from the Nordkapp Basin core. These factors could by themselves of in combination be responsible for the observed shallowing upwards successions observed. Which of the scenarios that are the most likely and/or have influenced the most are uncertain, but reduced accommodation space due to increased sediment supply from the deltaic system is favored supported by the general trend of the transgressive-regressive cycles proven to coexist all over Svalbard, the Barents Sea (Mørk and Smelror, 2001). The same trend is seen at Svalbard where Vikinghøgda Formation is overlaid by organic rich shales of the Botneheia Formation (Mørk et al., 1999).

It is not observed strong evidence of delta progradation in the cores of any of the three areas. For a delta to prograde the system must be fed with sediments from a fluvial system and prograde as sediment supply accumulates laterally. This commonly results in a coarsening upward succession. Evidence of a fluvial system exists in the Nordkapp Basin where fine cross-stratified and rippled sands are associated with channelized deposits. This proves the presence of an active fluvial system that possibly could supply sediments to a delta. As previously noted, the intervals that witnesses periods of increased and decreased sediment supply could be related to the proximity to the delta front, but these are only minor changes and not prominent signals. Steinkobbe Formation in the Svalis Dome is considered deposited too deep and too far away from a possible delta front to have been considerably affected by possible progradation.

Mørk and Smelror (2001) proposed that Triassic sequence boundaries mainly were controlled by eustasy, although tectonic might have influenced the sea level. Global tectonics are suggested as the main driving forces for the formation of these boundaries (Embry, 2006). The regressive nature after the creation of a sequence boundary might thus reflect a stepwise development of the deltaic system in the south-east. Bravaisberget Formation and Botneheia Formation in the Svalbard region show the same regressive nature of the deposits (Karajewski et al., 2007, Vigran et al., 2011), but had had a sediment source from Greenland in the west during this period (Mørk et al., 1982).

7.3. Lateral relationship

7.3.1. Local perspective

According to Høy and Lundschien (2011), Triassic clinoform sequences gets successively younger towards northwest, which means that a connection between the deposits from the Nordkapp Basin and the Svalis Dome not are unlikely. The slightly shallower nature of the deposits from Sentralbanken High in comparison to at the Svalis dome might indicate that the delta had prograded further in north-east as illustrated in the palaeogeographic evolution model of Lundschien et al. (2014) (Fig 2.3).

The three wells are correlated by Lundschien et al. (2014) and indicates that the onset of the Steinkobbe formation started earlier at the Svalis Dome than at Sentralbanken High, but the general shallowing upwards trend is the same for both areas. It is important to take into consideration that the distance between the wells are relatively long and data from only one core in an area not are sufficient to draw solid conclusions about the previous conditions in general. Rough assumptions can be made, but there will be a large gap where the lithology is unknown between the areas.

The Kobbe Formation in the Nordkapp Basin show the most proximal trend in the eastern and south eastern segments of the basin where well 7530/05-U-06 is located (Klausen et al., 2017). More distal deltaic deposits are documented in the central and western parts where marine processes dominated deposition. Klausen et al. (2017) interpreted the deltaic systems of the Kobbe Formation as normal regressive with increasingly more heterolithic and marine dominated deposits basinward on the delta plain. Seismic studies have proven the presence of clinoforms that have developed in a series of transgressive-regressive stages (Glørstad-Clark et al., 2011, Klausen et al., 2017) on both the platform and at the platform edge. The clinoterm topsets have been observed to typically be bounded toward the deeper basin by an offlap break leading into a slope separating the platform from the basin. The lower half of the Kobbe Formation might represent deposition on clinoform topset, whereas Klappmyss Formation possibly represents the separating slope. Steinkobbe Formation at both localities where it is present show the most distal facies and are suggested to represent basinal deposition or the bottomset of a delta. The core material used as basis for this study is alone not sufficient to draw certain conclusions whether the sediments were deposited in such platform-margin geometries, but the northward deepening of facies and the regressive nature of Kobbe and Steinkobbe Formations supports the interpretations of a deltaic system building out from the south-east.

7.3.2. Regional perspective

A western sediment source from the Greenland area is proposed for the Anisian Bravaisberget Formation at western Spitsbergen (Mørk et al., 1982, Riis et al., 2008). The most distal part of Kobbe Formation has many similarities to Bravaisberget Formation (Mørk et al., 1999) of western Svalbard. In the Carnian there was an overall transgression in the Barents Shelf, and the open marine deposits were replaced with a widespread coastal plain stretching from Novaya Zemlya to the Hammerfest Basin, and deposition of the Snadd Formation which started in Ladinian. (Riis et al., 2008, Smelror et al., 2009). The prograding delta system from the south-east did not reach Svalbard before the Late Carnian and the youngest of the clinoform successions might have extended as far as north of Kvitøya (Høy and Lundschien, 2011), and possibly also as far as to the Sverdrup Basin in Arctic Canada (Lundschien et al., 2014, Klausen et al., 2015). On Svalbard these deposits are represented by the De Geerdalen Formaition, an onshore equivalent of the Snadd Formation (Worsley et al., 1988, Klausen et al., 2015). Together the Late Triassic deposits at Svalbard and the Barents Shelf represents a late stage of the infill of the Barents Sea. The studied cores are thus representative for the early stages of the Triassic infilling of the Barents Sea.

8. Conclusions

- The Middle Triassic Kobbe Formation were deposited in a shallow marine to a coastal plain environment and show a steady regressive development of facies where the lowermost part contains facies that are common in shallow marine environments and the upper half have facies that is characteristic for a coastal plain environment including paleosols and coal.
- Channelized deposits indicate that an active fluvial system was present, probably capable to supply sediment to a delta. Strong tidal and fluvial signals suggest that tides and fluvial processes were the main factors regarding deposition and distribution of sediments of the upper part of the delta.
- The dark mudstone which comprise a significant interval of core 7523/06-U-01 (Sentralbanken High) is herein suggested to belong to Steinkobbe Formation and not Kobbe Formation due to the greater similarities to the black organic rich shale.
- Steinkobbe Formation were deposited at a relatively deep shelf at both Sentralbanken High and the Svalis Dome after a transgression separating the formation from the underlying Klappmyss Formation.
- At both Sentralbanken High and the Svalis Dome conditions were anoxic, but at Sentralbanken High it is indications of a slightly less anoxic environment.
- Facies are deepening towards north which is in accordance with theories of north-westerly prograding clinoforms developing as an extensive delta was building out across the Barents Sea, and it is suggested that the studied deposits represent the early phases of the Triassic infill of the Barents Sea.

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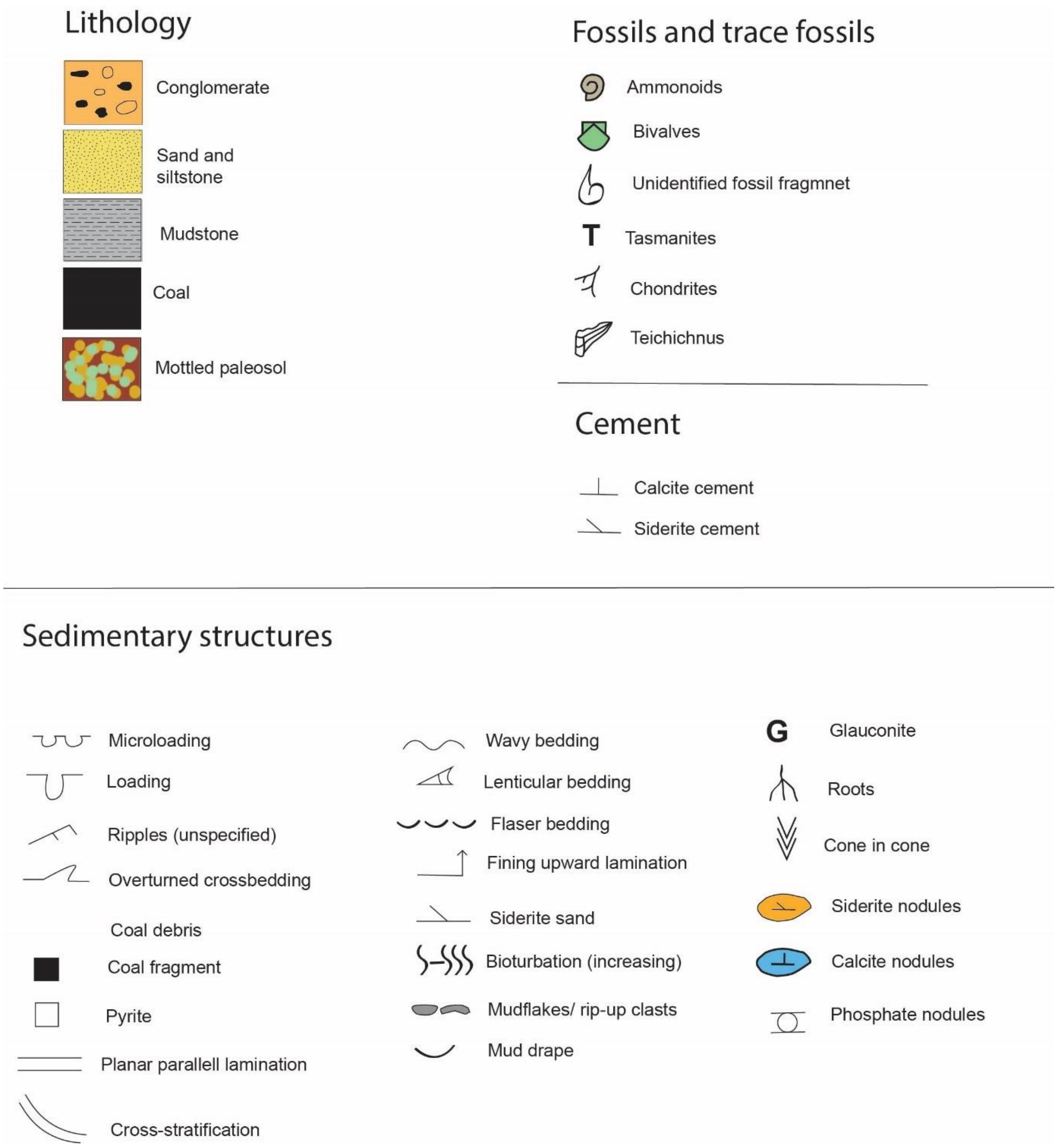
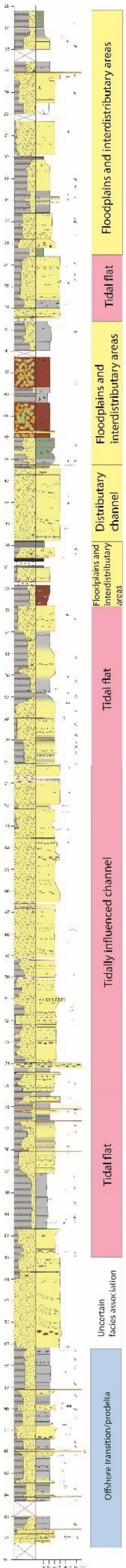
10. Appendix

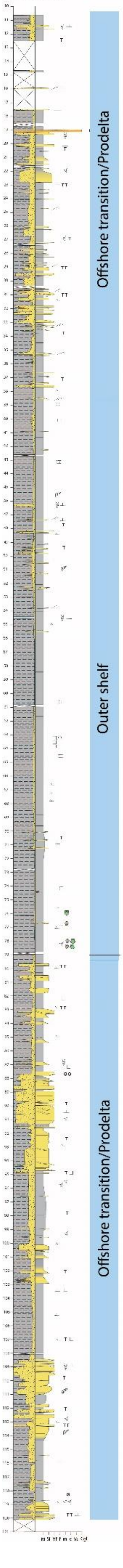
Appendix A: Legend for logged sections

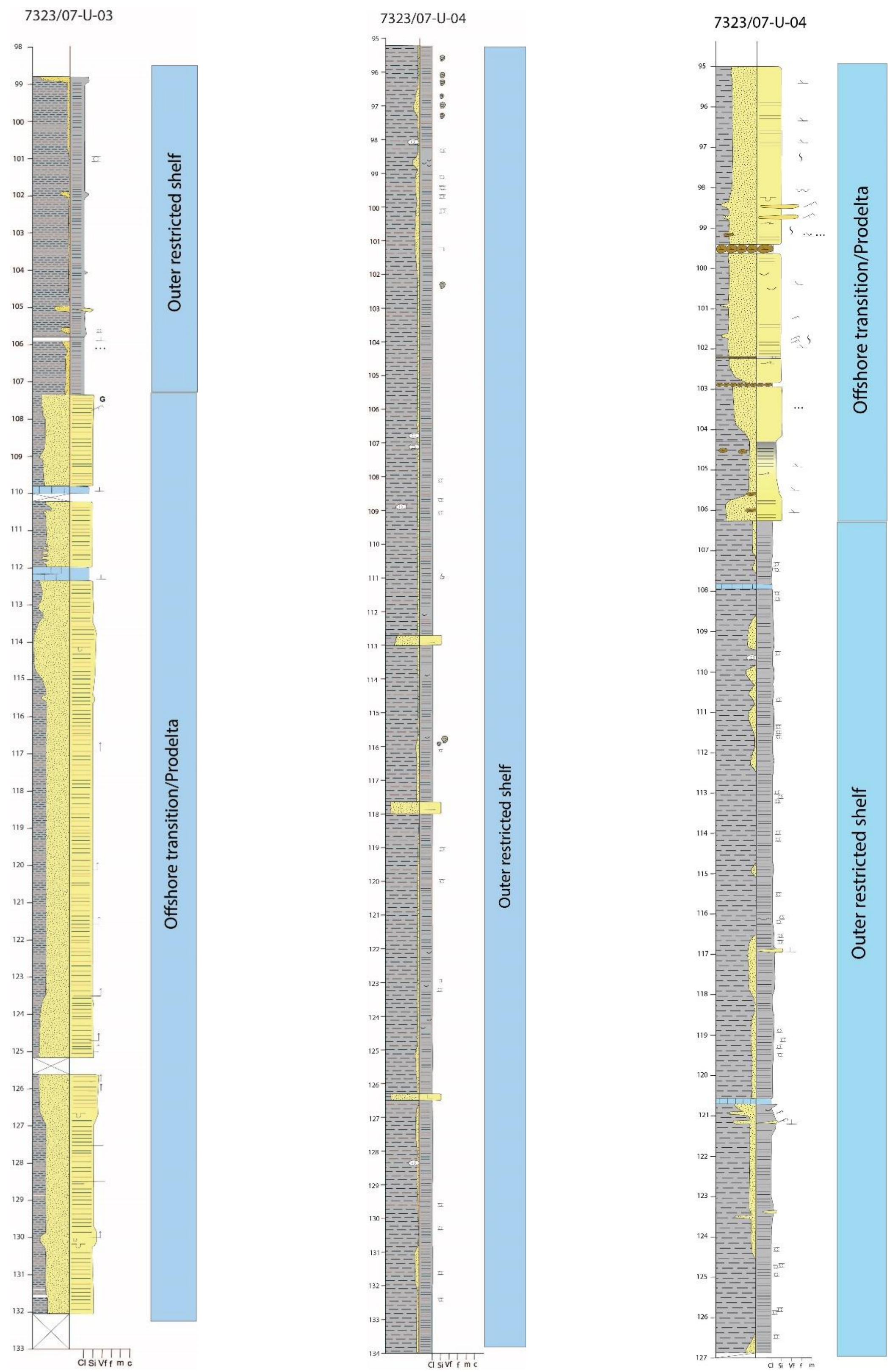


Appendix B: Distribution of facies associations

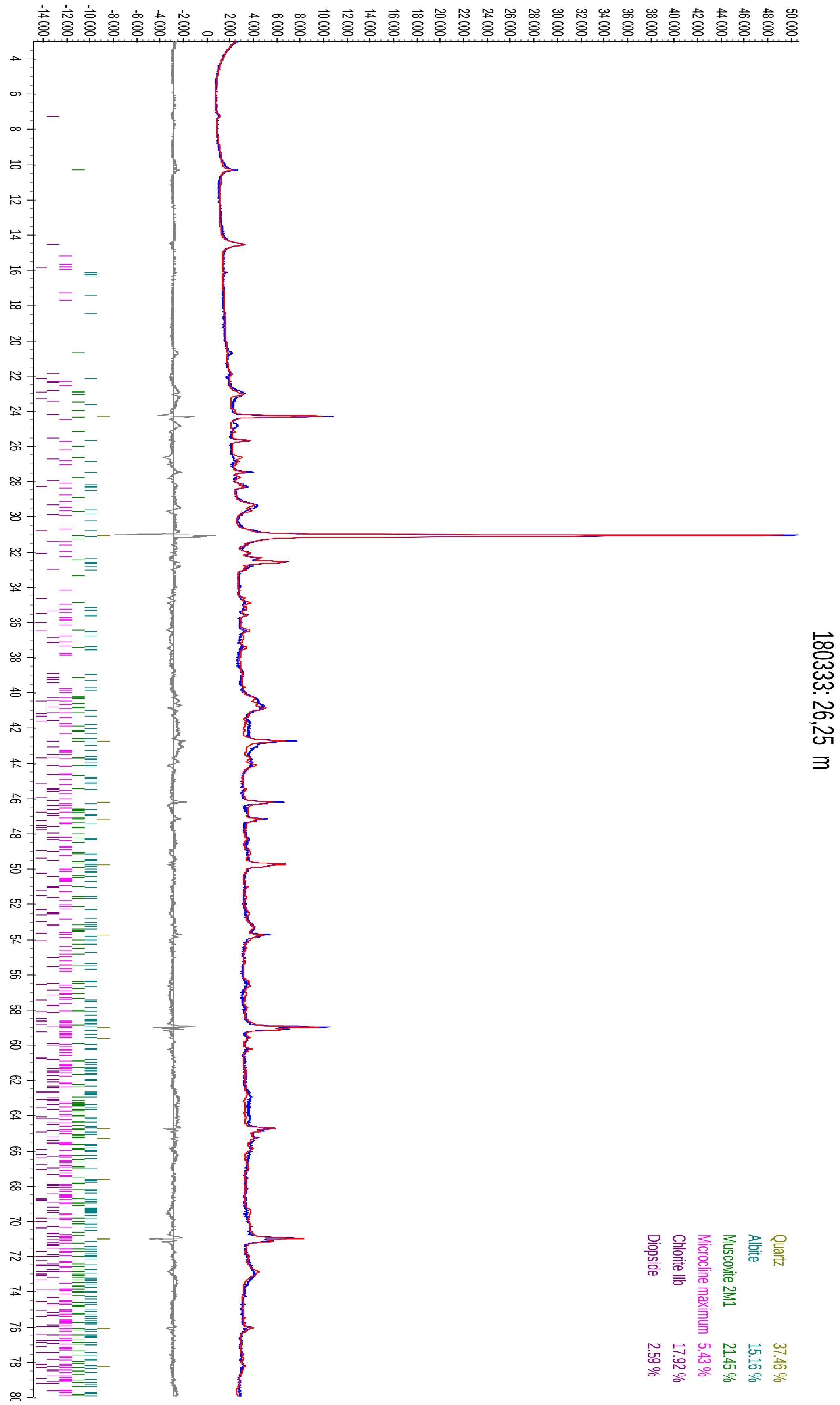


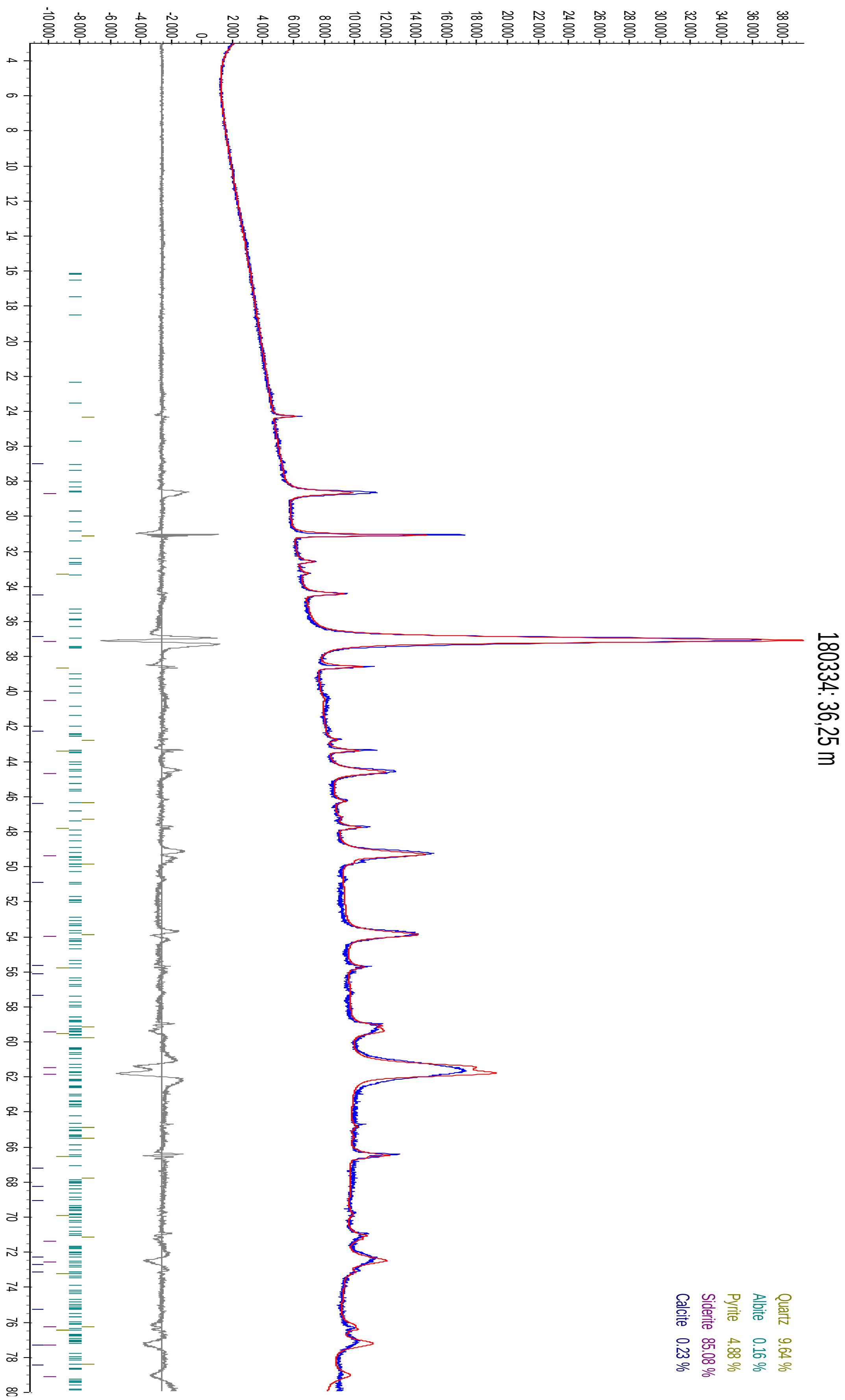
7523/06-U-01

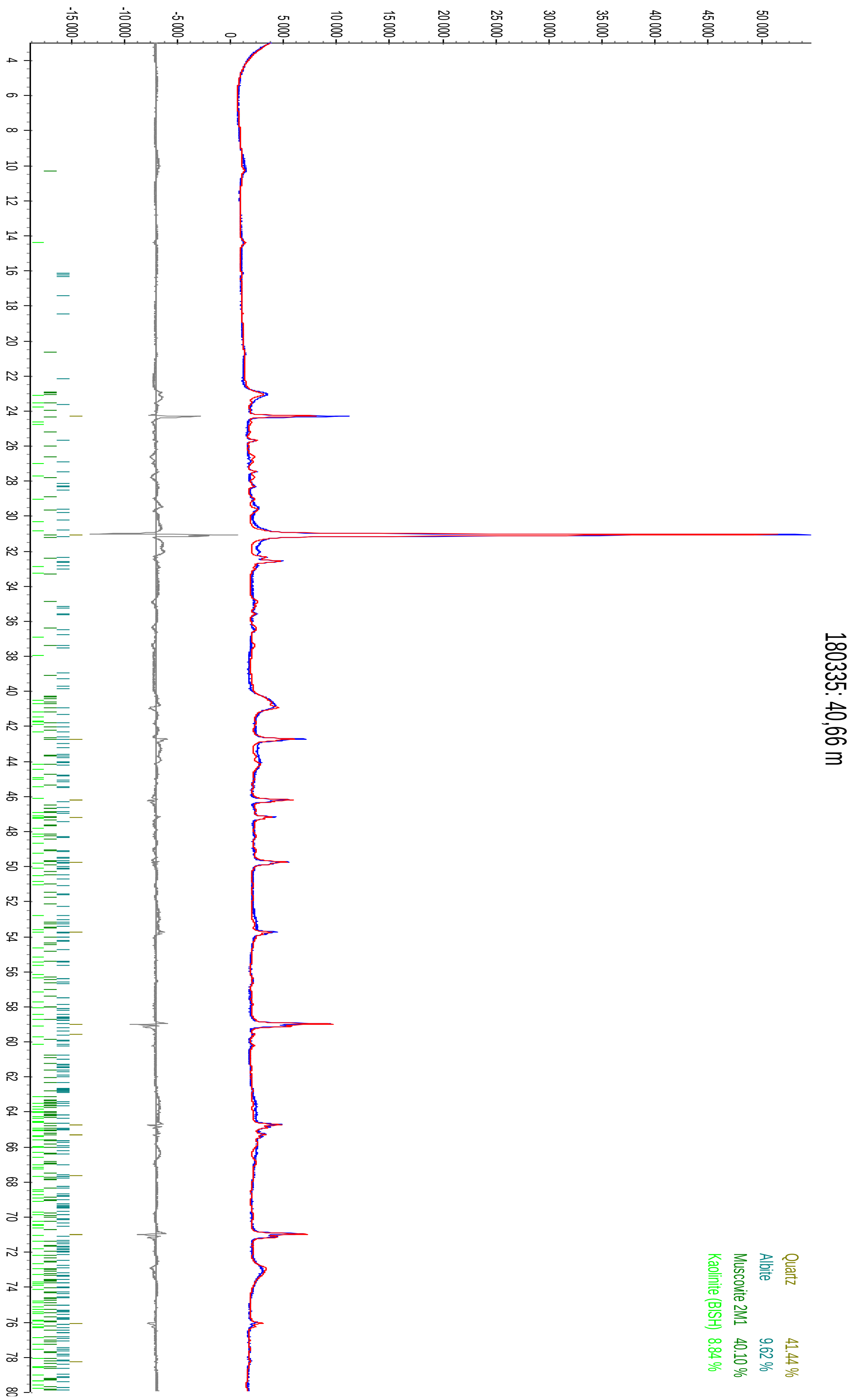

Offshore transition/Prodelta
Outer shelf
Offshore transition/Prodelta


7323/07-U-03
Outer restricted shelf
Offshore transition/Prodelta
Cl Si Vf f m c
7323/07-U-04
Outer restricted shelf
Cl Si Vf f m c
7323/07-U-04
Offshore transition/Prodelta
Outer restricted shelf
Cl Si Vf f m

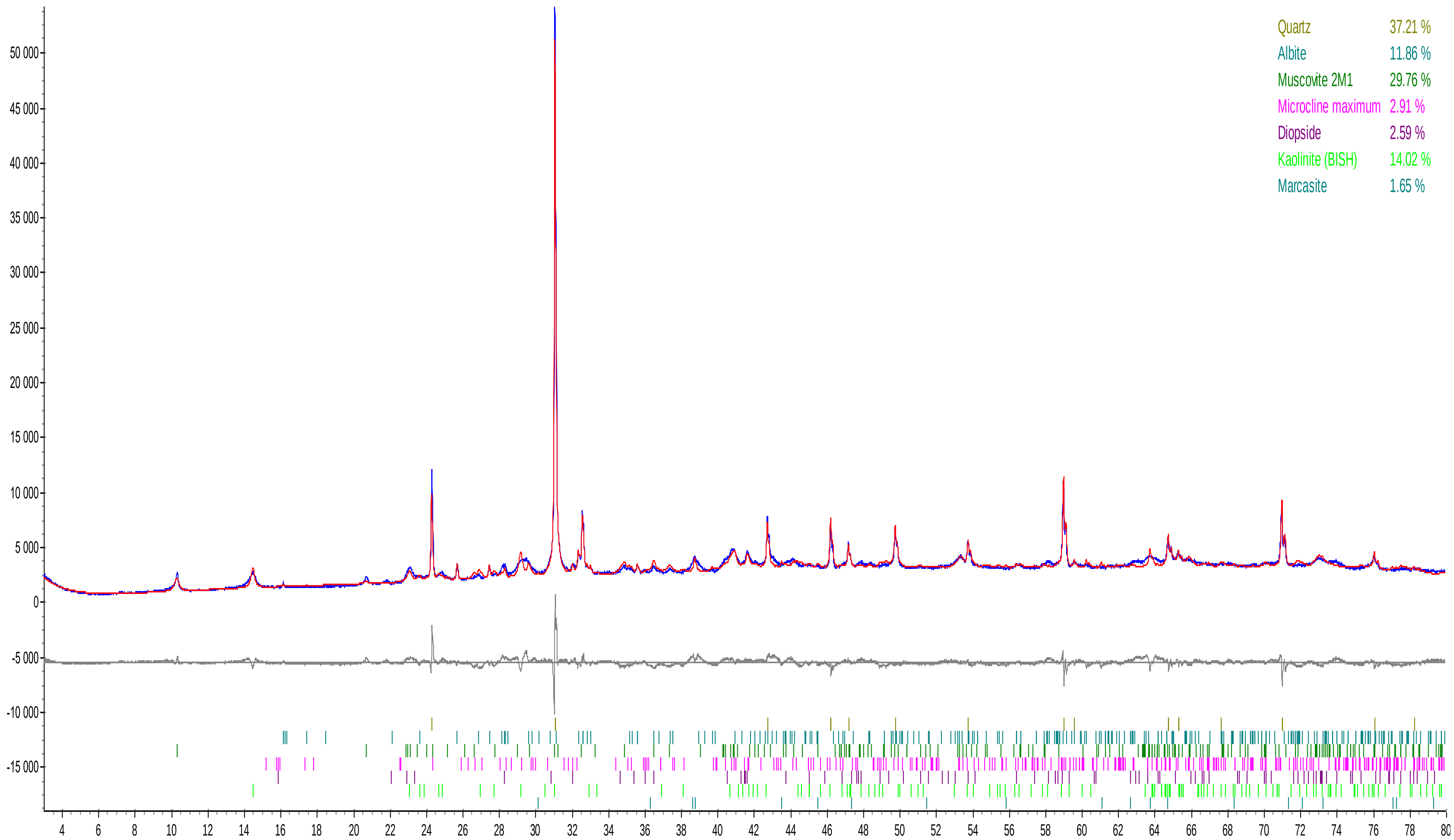
Appendix C: XRD results



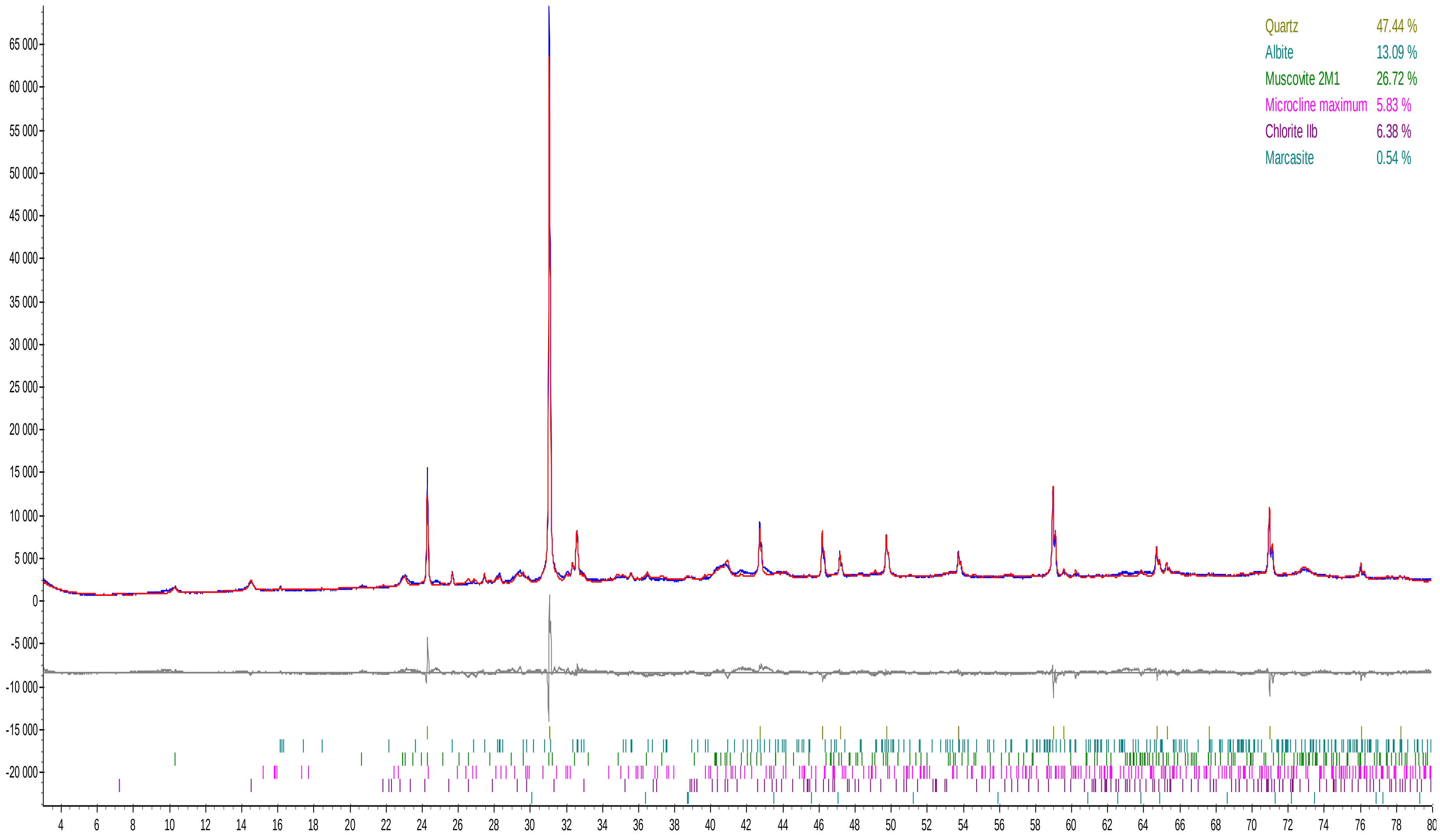

180334: 36,25 m
Quartz 9.64 %
Albite 0.16 %
Pyrite 4.88 %
Siderite 85.08 %
Calcite 0.23 %

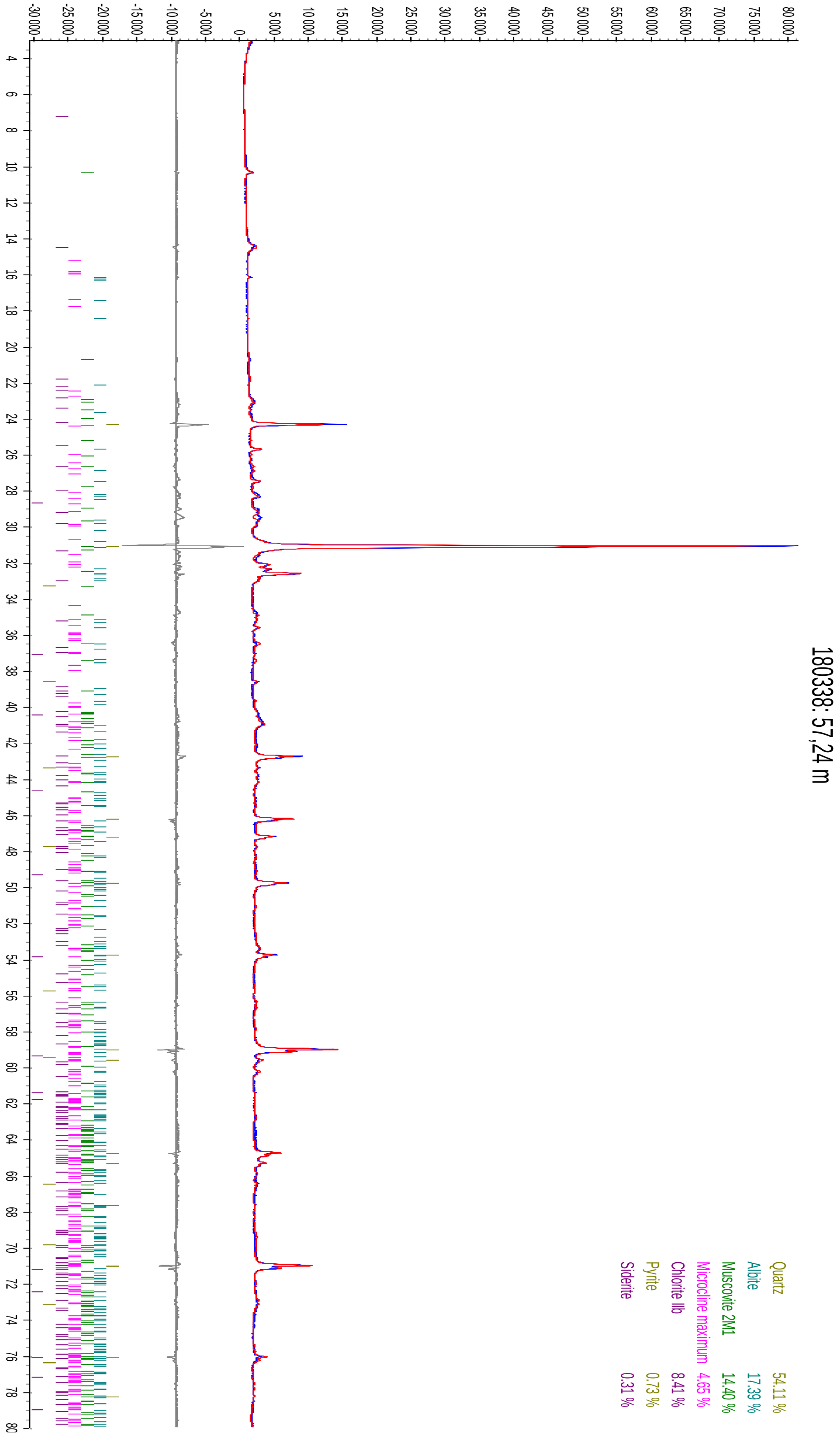

180335: 40,66 m
Quartz 41,44 %
Albite 9,62 %
Muscovite 2M1 40,10 %
Kaolinite (BISH) 8,84 %

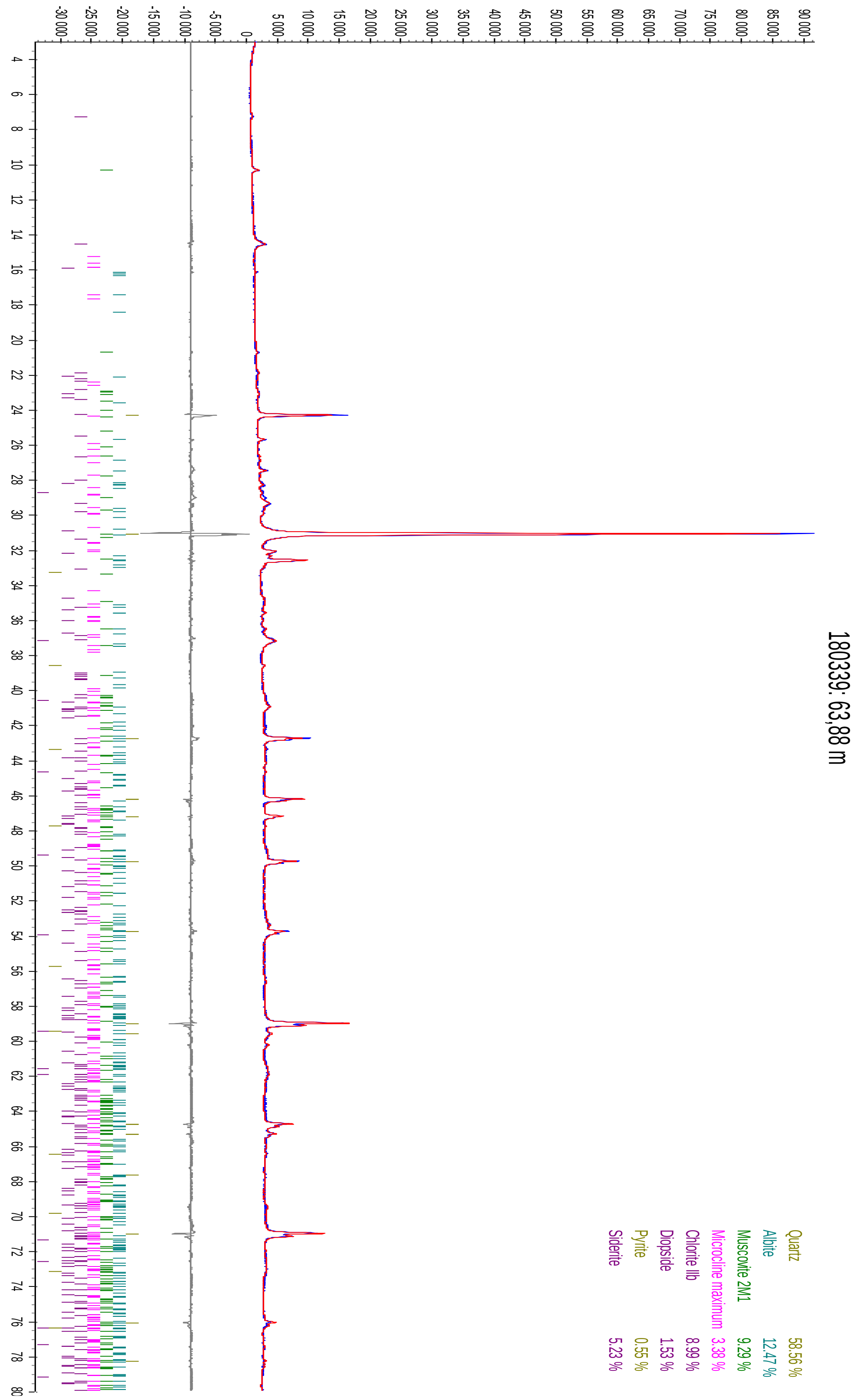
180336: 43,90 m

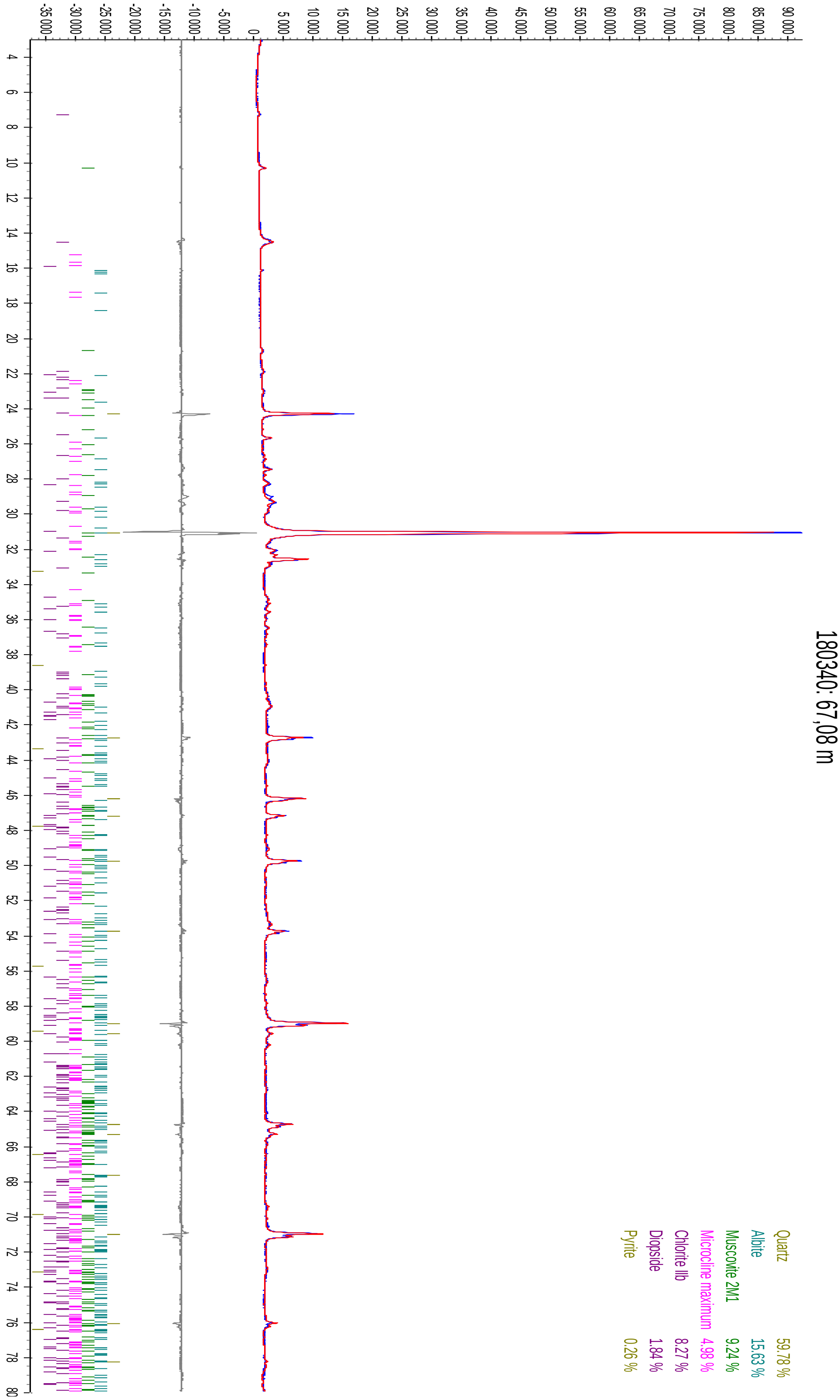


180337: 52,48 m




180338: 57,24 m
Quartz 54.11 %
Albite 17.39 %
Muscovite 2M1 14.40 %
Microcline maximum 4.65 %
Chlorite IIb 8.41 %
Pyrite 0.73 %
Siderite 0.31 %


180339: 63,88 m
Quartz 58.56 %
Albite 12.47 %
Muscovite 2M1 9.29 %
Microcline maximum 3.38 %
Chlorite IIb 8.99 %
Diopside 1.53 %
Pyrite 0.55 %
Siderite 5.23 %


180340: 67,08 m
Quartz 59.78 %
Albite 15.63 %
Muscovite 2M1 9.24 %
Microcline maximum 4.98 %
Chlorite IIb 8.27 %
Diopside 1.84 %
Pyrite 0.26 %