Environmental significance and taxonomy of well preserved foraminifera from Upper Jurassic – Lower Cretaceous hydrocarbon seep carbonates, central Spitsbergen

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Five hydrocarbon seep carbonate structures in the upper part of the Slottsmøya Member (Agardhfjellet Formation) in central Spitsbergen have been sampled and processed for foraminiferal study. The carbonates have been found to contain excellently preserved agglutinated assemblages, in contrast to the diagenetically deformed assemblages in the adjacent shales. In total 15 genera and 35 agglutinated species are recognised in the palaeoseeps. The pristine condition of the foraminiferal tests allows for detailed morphological documentation of 21 species, the following six which are proposed as new: *Reophax pyriloculus*, *Haplophragmoides perlobatus*, *Labrospira lenticulata, Ammobaculites deflectus, Ammobaculites knorringensis and Textularia pernana*. Depositional environment of the carbonate palaeoseeps is interpreted to be similar to that of a normal marine shelf, as opposed to the previously documented restricted (hypoxic) environment of the adjacent shales. Morphogroup analysis of assemblages in the palaeoseeps reveals that over 89% of genera in the seep carbonate bodies are categorised as surficial/shallow infaunal to deep infaunal. The same morphogroup component in the shale succession only makes up 31.5% of the total genera. A gradual shift can be seen in the shale assemblages from almost exclusively epifaunal morphogroups in the lower part to a dominating surficial to infaunal component in the samples closest to the palaeoseep stratigraphic levels, which translates to an upwards decreasing oxygen level trend. The foraminifera date the palaeoseeps as late Volgian – late Ryazanian, and the ages for each seep structure are constrained by previously reported associated ammonite occurrences. Some species of foraminifera occurring in the palaeoseeps are possible candidates for extended stratigraphic ranges.

Keywords: ***foraminifera, Spitsbergen, hydrocarbon seeps, Jurassic, Cretaceous***

INTRODUCTION

In the Upper Jurassic shales of the Slottsmøya Member of the Agardhfjellet Formation on Svalbard, 15 carbonate bodies interpreted as fossil hydrocarbon seeps were discovered during field work focused on excavation of marine reptile skeletons (Hammer et al. 2011; Hurum et al. 2012). Text-fig. 1 shows the location of the study area within Spitsbergen and Text-fig. 2 illustrates the age relationships and lithostratigraphic framework of the Slottsmøya Member. The carbonate structures represent one of few locations globally where seep build-ups of Jurassic and Cretaceous age have been found and the first ones in Spitsbergen, making them the northernmost occurrences overall (Campbell and Bottjer 1993; Campbell 2006; Hammer et al. 2011). An initial report introducing the foraminiferal assemblages in the seep carbonate bodies was published by Hjálmarsdóttir et al. (2012). In the current paper we present a detailed documentation of the excellently preserved agglutinated assemblages, including their palaeoecology, taphonomy, and taxonomic composition.

Extensive foraminiferal research has been carried out on the Upper Jurassic to Lower Cretaceous strata of Spitsbergen in recent years but up until now it has been focused mainly on shale successions from the Agardhfjellet and Rurikfjellet formations comprising the Janusfjellet Subgroup (e.g. Løfaldli and Nagy 1980; 1983; Nagy and Basov 1998). A study of the foraminiferal content of the shales composing the Slottsmøya Member was also conducted and is used here for the comparison to the palaeoseep assemblages in terms of taxonomic content, depositional environment, and taphonomy.

GEOLOGICAL SETTING

The sections of the Slottsmøya Member with the analysed carbonate bodies are located in the Central Mesozoic Basin of Spitsbergen. The member represents the upper part of the Agardhfjellet Formation, which together with the overlying Rurikfjellet Formation comprise the Janusfjellet Subgroup (Callovian – Hauterivian) belonging to the Adventdalen Group (Text-fig. 2). The stratigraphy and facies development of the group in central Spitsbergen is discussed in several papers (e.g. Orvin 1940; Parker 1967; Major and Nagy 1972; Dypvik et al. 1991a). The lithostratigraphy of the group is outlined and revised by Mørk et al. (1999) both on Spitsbergen and in the Barents Sea.

At Janusfjellet and Knorringfjellet (Text-fig. 1), the Slottsmøya Member is ca. 75 meter thick. It consists mainly of organic rich, fine grained, dark grey shales with local occurrences of black paper shale, red to yellowish siderite concretions, siderite and dolomite interbeds, as well as the seep carbonate bodies (Dypvik et al. 1991a; Hammer et al. 2011; Collignon and Hammer 2012). The depositional environment of the Slottsmøya Member has been interpreted as a low-energy open marine shelf in a Boreal benthic oxygen deficient setting (Nagy et al. 1988; Dypvik et al. 1991b). Sedimentation rate in the member was low, with an upwards decreasing trend to the Myklegardfjellet Bed, and a possible shallowing-up episode in the area is indicated by upwards increasing foraminiferal diversity, upwards decreasing TOC, and numerous upward coarsening parasequences in the upper part of the Wimanfjellet Member (Birkenmajer et al. 1982; Nagy and Basov 1998; Hryniewicz et al. 2012). Presence of a condensed interval is however assumed in the upper part of the Slottsmøya Member, occurring at similar levels as the hydrocarbon seep bodies (Collignon and Hammer 2012). The recognition of a condensed interval suggests that sedimentation rates were especially low during a short time period, possibly as a result of a sea-level rise leading to an abrupt transgression of the shoreline. Previous age determinations of the palaeoseeps and the Slottsmøya Member based on ammonites, palynomorphs and agglutinated foraminifera suggest that they are early Volgian to late Ryazanian in age (Nagy and Basov 1998; Mørk et al. 1999; Wierzbowski et al. 2011; Hjálmarsdóttir et al. 2012; Dalseg et al. 2016a and b).

Hydrocarbon seeps in modern day settings are reported from shallow to deep water sites where hydrocarbon rich fluids leak onto the seafloor (e.g. Judd and Hovland 2009). The seeping hydrocarbon is mainly methane, both of thermogenic and biogenic origin, deriving from underlying organic rich sediments. The methane released is oxidised within the shallow subsurface by a process of anaerobic oxidation of the methane, which increases alkalinity and facilitates the precipitation of methane-derived authigenic carbonates (Peckmann and Thiel 2004). The fossil hydrocarbon structures sampled for foraminifera for this paper are of a thermogenic origin as indicated by carbon isotope signatures (Hammer et al. 2011). The palaeoseeps were so-called cold seeps, indicating that they were fuelled by fluids with temperatures not or slightly exceeding the average temperatures of the bottom waters (Campbell 2006; Hammer et al. 2011).

Collignon and Hammer (2012) presented a lithological log of the Slottsmøya Member from Janusfjellet (Text-fig. 3). It shows that the seep carbonate bodies were all found between the *Dorsoplanites* bed and the Myklegardfjellet Bed in the upper part of the member. In the Sassenfjorden outcrop belt where the palaeoseeps were encountered, excavations have revealed a rich Boreal Lagerstätte, containing a diverse invertebrate fauna as well as abundant and excellently preserved plesiosaur and ichthyosaur remains (Hurum et al. 2012). Several papers have recently been published on the macro invertebrate faunas discovered in the palaeoseeps and the surrounding Slottsmøya shales (e.g. Wierzbowski et al. 2011; Holmer and Nakrem 2012; Hryniewicz et al. 2012; Hammer et al. 2013; Sandy et al. 2014; Hryniewicz et al. 2014 and 2015; Kaim et al. 2017; Rousseau et al. 2018), as well as palynological studies on the carbonate palaeoseeps and adjacent shales (Dalseg et al. 2016a and b). A microfacies analysis was published by Hryniewicz et al. (2012). These studies in combination provide a rare opportunity to analyse the palaeoseeps in stratigraphic and palaeoenvironmental contexts along with sedimentation and diagenetic processes.

MATERIAL AND METHODS

Five carbonate seep bodies were selected for foraminiferal study and detailed information about their locations is listed in Table 1. The two palaeoseeps at Janusfjellet have been labelled 2009-03 and 2009-04, while the three located at Knorringfjellet were marked as 2007-01, 2007-02 and 2007-03, giving an indication of the year and order of their discovery (Text-fig. 1, Table 1).

The method of extracting the agglutinated foraminifera from the lithified carbonates was to immerse the sample pieces into weak acetic acid until an adequate amount of the rock was dissolved. The goal of using this method was to extract microfossils for a cross-discipline study involving foraminifera and phosphatic microfossils such as vertebrate teeth and lingulid brachiopods (Holmer and Nakrem 2012). This acetic acid dissolution technique is described by Jeppsson et al. (1999). The limestone samples ranged from 1.50 – 7.65 kg in weight and were digested for 5-6 days in 10-15% acetic acid, with the procedure repeated if necessary. After acid digestion, the residues were wet sieved with grid sizes from 90 - 500µm. Samples were dried at 50 degrees Celsius and then split with a custom made sample-splitter to achieve more manageable quantities for picking. The foraminifera were then handpicked from all grain sizes with a wet brush and glued onto numbered squares in slides. Approximately 200 agglutinated specimens were picked from each sample and percentages of each species calculated (Appendix 1). The restriction on numbers of foraminifera picked was that two of the samples did not contain more specimens (2007-01 and 2009-03).

All but four of the shale samples studied are from a section at Janusfjellet, close to seep 2009-04. The last four samples were collected at a different occasion to that of the main set of shale samples, and their meter levels are not fully comparable with the positions of the others. This is due to differences in zero-level (base) of the Slottsmøya Member used for each set of samples, and problems in determining the boundaries of the Myklegardfjellet. These additional samples are therefore identified with the prefix A. The extraction of foraminifera from shales was facilitated by the tenside method (Nagy 2005). The dry rock samples are first crushed by a mortar or a machine to produce <5-mm sized pieces. The sediment is placed in a beaker and fully immersed in a 3:1 ratio mixture of tenside (Rewoquat) and methanol. The sample is left at room temperature for 3-4 days with occasional stirring to soften the sediment, and then washed and sieved. The procedure is repeated if the sample is not sufficiently disintegrated. Material from the shale samples was used only for comparison with the seep assemblages, and has therefore not received detailed taxonomic documentation in this paper. Quantitative data is available in Appendix 2. An alphabetical list of all species discovered in both sample sets is presented in Appendix 3.

Photography for the seep foraminifera was performed under conventional reflected light using a Leica M205C microscope with a Leica MC170 HD camera, and Leica Application Suite V4.3 software. The software was used to take stacks of photographs from different focus levels on the fossils, which were then processed through Adobe Photoshop Lightroom Classic CC (version 7.2) and Adobe Photoshop CC (version 19.1.2). This method proved to be especially efficient for photography of the more spherical fossils, where optimal focus was achieved on the whole fossil. The method however needs refining when photographing very large foraminifera. This creates a considerable distance between the first and last focus point of the fossil, which can result in the edges of the fossil becoming less sharp than desirable. The shale foraminifera were photographed under reflected light with a Leica DC 500 camera attached to a Leica MZ16 A microscope. The same processing method was used as for the seep foraminifera, but the software was ACDSee 6.0 and Helicon Focus Photo Software (V5.1). SEM photography was performed with Hitachi S3600N in a low vacuum mode with secondary electrons (SE) and backscattered electrons (BSE) in 3D mode. All figured material is housed in the palaeontological collections of the Natural History Museum, University of Oslo. This work and the nomenclatural acts it contains have been registered in ZooBank, the online registration system for the ICZN. The ZooBank LSIDs (Life Science Identifiers) can be resolved and the associated information viewed through any standard web browser by appending the LSID to the prefix http://zoobank.org/. The LSID for this publication is: urn:lsid:zoobank.org:pub:3F29FC70-67D6-4BF4-AF02-48818093298C.

STRATIGRAPHY

The shale sample interval analysed in this paper has been tentatively placed on the log from Collignon and Hammer (2012) in Text-fig. 3. Due to the homogenous nature of the shales in the Slottsmøya Member, logs usually rely on conspicuous beds as field markers such as the Myklegardfjellet Bed and the *Dorsoplanites* Bed. Zero level is placed at a marker bed indicating the upper boundary of the lowermost part of the member, while the base is placed roughly 22 meters below. The sampled shale extends from near the base of the Slottsmøya Member to its uppermost part just below the Myklegardfjellet Bed. There is a certain degree of difficulty placing the Myklegardfjellet Bed properly in the stratigraphy without extensive excavation. The bed has a diffuse vertical extent in the field at Janusfjellet owing to its boundaries commonly being covered in scree. The bed itself or parts of it are also potentially down-slumped or intermixed with the surrounding shales because of its dominant lithology of soft yellow to reddish clays.

When the shale samples were acquired for the present study, the *Dorsoplanites* Bed was defined between 20.89 and 21.7 meters in the measured succession. In the log of Collignon and Hammer (2012; Text-fig. 3) of the Slottsmøya Member the *Dorsoplanites* bed is however identified at 27 meters. These differences in the measured values imply that the positions in our study are about 6.5 meters below those in Collignon and Hammer (2012). In spite of this inconsistency with the shale sample levels, they are all regarded as located below the Myklegardfjellet Bed. This is confirmed by distinct differences in lithology between the Slottsmøya Member and the Rurikfjellet Formation, and the fact that the Rurikfjellet foraminiferal assemblages are clearly different from those of the underlying Slottsmøya Member (Nagy et al. 1990a).

The palaeoseeps are indicated as mound-like objects in Text-fig. 3, although it is not known how they appeared at the time of formation. It is probable that some of the sampled palaeoseeps are not preserved exactly *in situ* as many of the original build-ups appear in the field as slumped and weathered blocks of carbonate (Text-fig. 4), detached from the original seep body (Hryniewicz et al. 2015). This leads to the conclusion that the palaeoseeps were not necessarily formed where they appear in the stratigraphy today, and discussing each palaeoseep as a stratigraphic entity in a succession, is not feasible or reasonable. It is worth noting that since sampling in 2007, palaeoseeps 2007-02 and 2007-03 have been eroded away due to land sliding in the north eastern slopes of Knorringfjellet (Hryniewicz et al. 2015). All of the carbonate seep bodies are however interpreted to appear underneath the Myklegardfjellet Bed, as no record of large carbonate concretions has ever been reported within or above this bed (Birkenmajer 1980; Dypvik et al. 1992).

The age of the Myklegardfjellet Bed has been a topic of discussion, since Dypvik et al. (1992) confined the age of the upper part of the Agardhfjellet Formation to the Volgian only, leaving the Myklegardfjellet Bed as basal Ryazanian in age. Basov et al. (1997) concluded a similar stratigraphic interpretation based on ammonites. These conclusions conflict with the ages interpreted (also from ammonites) in Wierzbowski et al. (2011) for the seep carbonate structures found beneath Myklegardfjellet Bed (late Volgian – late Ryazanian). Therefore the Ryazanian is expressed to have an uncertain extent in our Text-fig. 3. An important feature of the uppermost part of Slottsmøya Member is that the sedimentation rates were very low, and a condensed interval is interpreted to occur at the same levels as the seep carbonate bodies (Collignon and Hammer 2012). Reduced sedimentation rates with 4.2 to 5.3m/my are previously calculated for the Upper Volgian to Ryazanian interval by Nagy and Basov (1998, fig. 9).

Even though the ammonites in the study of Wierzbowski et al. (2011) represent the most complete biostratigraphical record so far of the Upper Volgian to uppermost Ryazanian in Spitsbergen, they propose a hiatus between the Chetae Zone and Maynci-Sibiricus Zone in the Sassenfjorden area. This might possibly be caused by tectonic activity and is also contemporary with the interpreted condensed interval in the Slottsmøya Member. A new ammonite zone was established by Kiselev et al. (2018), the Volgidiscus singularis Zone, which reaches from the base of the Chetae Zone to slightly above the base of the Ryazanian. This new zone can be directly correlated with uppermost horizons of the Volgian Substage in the Urals, Northern Siberia, England and the North and Barents Seas, and the authors suggest that there is no hiatus at the boundary between the Volgian and Ryazanian. Spitsbergen has not been studied for evidence of this zone, as far as we are aware of.

RESULTS

Main features of foraminiferal assemblages

In the five palaeoseep samples, a total of 15 genera and 35 agglutinated species are recognised, 12 of which are cited under open nomenclature. The open nomenclature specimens are commonly broken or are not common enough to warrant a precise identification. The occurrences of species in each seep body are presented in Text-fig. 5, in a stratigraphic framework based on ammonite occurrences from Wierzbowski et al. (2011). Illustrations of 21 species are given in Plates 1-5. The foraminiferal content of the seep carbonates is composed of a dominant agglutinated component and a rather diversified but seemingly subordinate calcareous component belonging to the suborder Lagenina (Hjálmarsdóttir et al. 2012). These various calcareous taxa are observed only in thin sections from the seep carbonates. Shales of the Agardhfjellet Formation are strongly lithified (Løfaldli and Nagy 1983; Nagy et al. 1990a) and require the special tenside method to free foraminifera from the matrix. The method is however ineffective on limestones (Nagy 2005). While processing the palaeoseep samples no crushing was performed beforehand to reduce the size of the rock pieces as is common with shale processing. It was feared that this would affect the completeness of the tests and result in loss of some of the more fragile taxa observed during preliminary processing. This approach led to increased digestion time in the acetic acid because of larger sample size. The procedure may have resulted in the dissolution of all calcareous forms which are therefore only observable in thin section of the carbonates, as no free calcareous tests have been found in the residue (Hjálmarsdóttir et al. 2012).

A range chart for taxa occurring in the shale sample succession is presented in Text-fig. 6, and selected species are illustrated in Plates 6 and 7. A total of 26 genera and 59 species were identified in the shale samples and all are agglutinated except for one, *Ceratolamarckina* aff. *levinae* (Dain 1980), which is aragonitic and represented by only two specimens. A biozonation presented by Nagy and Basov (1998) is applied to the foraminiferal fauna occurring at each shale level, to elucidate their stratigraphic positions.

The agglutinated assemblages occurring in the seeps are of Boreal nature, and most taxa are closely related or identical to species previously reported from siliciclastic sediments (mainly shales and mudstones) of Spitsbergen, the Barents Sea and Siberia (e. g. Dain 1972; Nagy et al. 1988; Bulynnikova et al. 1990; Nagy and Basov 1998; Marinov and Zakharov 2001; Nikitenko 2009). Close similarities are also observed with species from the North-American Arctic and the North Sea (e. g.

Tappan 1955; Wall 1983; Nagy et al. 1990a; Nagy and Johansen 1991). Below is a description of the foraminiferal content together with ammonite and dinocyst occurrences in each palaeoseep. Information about ammonites is from Wierzbowski et al. (2011) and dinocyst occurrences are from Dalseg et al. (2016b).

Palaeoseep assemblages

Palaeoseep 2007-01

Ammonites occurring in this carbonate body include *Tollia* (*Tollia*) *tolli* Pavlow 1914 and *Surites* (*Bojarkia*) *tzikwinianus* (Bogoslovsky 1896) as documented by Wierzbowski et al. (2011). These species date the palaeoseep as being close to the Ryazanian - Valanginian boundary, (e.g. Schulgina 1969; Surlyk 1978; Mesezhnikov 1984), and thus indicate that this is the youngest of the five palaeoseeps studied. Dinoflagellate cysts found in the seep that are consistent with this age determination (Dalseg et al. 2016b) include *Tubotuberella apatela* (Cookson and Eisenack 1960), *Escharisphaeridia rudis* Davies 1983, *Sirmiodinium grossii* Alberti 1961 and *Wallodinium krutzchii* (Alberti 1961).

Rich occurrences of the foraminiferal species *Recurvoides obskiensis* Romanova 1960 and *Schleiferella vallata* (Nagy and Basov 1998) characterise this sample. The age of *R. obskiensis* is latest Volgian-late Ryazanian in Spitsbergen, while *S. vallata* has a wide range by occurring sporadically in the middle Volgian, but with higher abundances in the late Volgian to late Ryazanian. *Gaudryina gerkei* (Vasilenko 1951) has been reported from Ryazanian – Valanginian strata in Central Siberia, and both *G. gerkei* and *Gaudryina rostellata* Nagy and Basov 1998 are common in Ryazanian strata of Spitsbergen and Siberia. Additional foraminiferal occurrences supporting a Ryazanian age are *Schleiferella schleiferi* (Sharovskaja 1966), *Orientalia baccula* Schleifer 1968 and *Recurvoides paucus* Dubrovskaja 1962.

Foraminifera with previously reported ranges deviating from ages determined by ammonites are: *Ammobaculites praegoodlandensis* Bulynnikova 1972, *Ammoglobigerina canningensis* (Tappan 1955), *Bulbobaculites elongatulus* (Dain 1972), *Glomospira oxfordiana* Sharovskaja 1966, *Schleiferella emeljanzevi* (Schleifer 1966), *Trochammina praerosacea* Nagy and Basov 1998, *Trochammina rosacea* Zaspelova 1948. These species have previously only been found in older strata, of mostly Volgian ages.

Palaeoseep 2007-03

An assemblage including the ammonite *Surites* (*Bojarkia*) *tzikwinianus* occurs in this carbonate body, constricting the age to the Tzikwinianus Zone of the late Ryazanian.

The foraminiferal fauna is closely similar to that of palaeoseep 2007-01, supporting a late Ryazanian age. *Calyptammina praegyroidiniformis* (Bystrova and Kossitskaja 1984) occurs only in this sample. While it has only been found in Volgian strata in Spitsbergen, its reported range is Ryazanian – Valanginian in Canada and Siberia (Wall 1983; Bystrova 1984; Nagy & Basov 1998).

Palaeoseep 2009-03

Ammonites found within the carbonates include *Surites* (*Surites*) *spasskensis* (Nikitin 1888), *S.* (*S.*) aff. *spasskensis* and *Borealites* (*Pseudocraspedites*) sp. indicating a late Ryazanian age (Subquadratus subzone of the Analogus zone) (Wierzbowski et al. 2011). Reported dinoflagellate cysts (Dalseg et al. 2016b) agreeing with this age determination include *Tubotuberella apatela*, *Escharisphaeridia rudis*, *Sirmiodinium grossii*, *Wallodinium krutzchii*, *Cleistosphaeridium* sp. and *Atopodinium haromense* Thomas and Cox 1988.

This carbonate body contains similar foraminiferal assemblages as 2007-01 and 2007-03. The occurrence of *Gaudryina rostellata*, *Gaudryina gerkei*, *Recurvoides obskiensis*, *Schleiferella schleiferi,* and *Recurvoides paucus* indicate an age of early to late Ryazanian, supporting the ammonite dating. *Trochammina praerosacea*, *Ammoglobigerina canningensis* and *Trochammina rosacea* also occur here as in palaeoseeps 2007-01 and 2007-03, which suggests that they might range into younger strata than previously documented.

Palaeoseep 2007-02

The co-occurrence of the ammonites *Craspedites (Craspedites) okensis* (d'Orbigny 1845) and *C.* (*Taimyroceras*) *originalis* Schulgina 1969 (Wierzbowski et al. 2011) is indicative of the Originalis Subzone of the upper part of the Okensis Zone, earliest late Volgian (Zakharov and Rogov 2008 and references therein).

Many of the same foraminiferal species occur here as in the younger palaeoseeps, indicating a discrepancy where the foraminifera indicate a younger age than the ammonites for this palaeoseep. Foraminiferal species with ranges coincident with the age indicated by the ammonites (earliest late Volgian) are *Trochammina praerosacea*, *Schleiferella vallata* and *Trochammina rosacea*.

Palaeoseep 2009-04

Records of ammonites, e.g. *Kachpurites* sp. (Wierzbowski et al. 2011), which occur in the Okensis Subzone of the Okensis Zone, lowermost upper Volgian on the Russian Platform (Zakharov and Rogov 2008 and references therein), indicate that this is the oldest palaeoseep, and also very close to palaeoseep 2007-02 in age. Dinoflagellate cysts identified in the palaeoseep that agree with this age determination (Dalseg et al. 2016b) include *Kallosphaeridium* sp. and *Cleistosphaeridium* sp.

Foraminifera in this palaeoseep show an age range of late Volgian – late Ryazanian. *Recurvoides obskiensis* is not found in this sample, but species such as *Gaudryina rostellata* and *Gaudryina gerkei* still occur here, indicating a Ryazanian age. Foraminifera supporting an earliest late Volgian age are *Trochammina praerosacea, Schleiferella emeljanzevi* and *Schleiferella vallata*. *Trochammina annae* Levina 1972, which occurs only in this palaeoseep, has a poorly documented range in Spitsbergen, but is reported from middle Volgian deposits of Western and Northern Siberia (Bulynnikova 1990).

The ages of foraminifera and ammonites largely agree, although the foraminifera exhibit wider stratigraphic ranges of the seep structures than the ammonites. This is in accordance with the general observation that benthic foraminifera have considerably wider stratigraphic ranges than ammonites. The discrepancy might also be the result of reworking of the seep sediments, extremely low sedimentation rates at the palaeoseep sites, or diachronous distribution in different sedimentary basins (Kaminski and Geroch 1992; Hjálmarsdóttir et al. 2012). The most likely explanation of conflicting ages is that the previously reported stratigraphic ranges of foraminiferal species are not fully defined and can be altered by future research, or the ranges established in other basins are divergent from those in Spitsbergen. The local dinoflagellate cyst biostratigraphy (Dalseg et al. 2016b) is in an overall accordance with the foraminiferal ages, although the diversity of dinocysts is generally low, and few age-diagnostic species are encountered. The ranges of the dinocysts in Russia and the Barents Sea are the closest to the ages determined by ammonites, while dinocysts ranges in the UK and Greenland seem older.

Distribution of genera

The occurrences of selected genera in each palaeoseep are presented in Text-fig. 7. The most abundant genera are *Recurvoides, Schleiferella, Ammobaculites, Ammoglobigerina, Gaudryina* and *Labrospira. Recurvoides* is the genus with the highest average abundance in all the samples (12.8%), while the highest abundance in a single sample is that of *Ammobaculites* (2009-04, 41.5%). *Schleiferella* has the second highest average abundance of 10.2%. Genera that only occur in the palaeoseeps are *Reophax* and *Orientalia*. Generic distribution in the shale succession is presented in Text-fig. 8. Here the most abundant genera are *Calyptammina, Haplophragmoides, Trochammina,* *Ammodiscus* and *Schleiferella*. The genus with the highest average abundance in all samples is *Calyptammina* (29.4%), closely followed by *Haplophragmoides* (28.9%). The genus with the highest abundance in a single sample is *Trochammina,* with 95.5% in sample at -5.73m. Down section in the shale succession, *Trochammina* becomes increasingly dominant, replacing genera such as *Haplophragmoides, Recurvoides, Labrospira, Ammobaculites,* and *Gaudryina*, which only occur in the upper part of the succession. *Schleiferella* shows a distinct decline down section, while *Ammodiscus* has its peak abundance around the middle of the section, as well as *Calyptammina.* Genera which only occur in the shale succession are *Agardhella, Arenoturrispirillina, Ceratolamarckina*, *Cribrostomoides, Eomarssonella, Kutsevella, Polychasmina, Ryiadhella, Thuramminoides, Tolypammina,* and *Verneuilinoides. Calyptammina* is very abundant in some of the shale samples, by attaining over 60% in sample at 19.57m. In the seeps we only find a single specimen of this genus, in palaeoseep 2007-03. Similarly, *Ammodiscus* reaches over 50% in abundance in sample at 14.44m in the shales, while only a single specimen occurs in the palaeoseeps (2009-04). *Haplophragmoides* occurs in all palaeoseep samples with an average abundance of 1.9% (max 2.9%) while in the uppermost part of the shale section it has an average of 28.9% (max 57.3% in sample at 39.12m), but then disappears in lower levels.

Species diversity and dominance

Foraminiferal species diversity indices were calculated for the five palaeoseep samples. The indices used were the alpha-index (Fisher et al. 1943), and the information function H index (Shannon 1948). The alpha-index ranges from 3.7 – 5.7, and H values from 2.1 – 2.5. The same statistical methods were applied to the shale sample set adjacent to carbonate seep 2009-04 and the results can be seen in Text-fig. 9. The shales exhibit alpha-index values ranging from 0.7 – 3.8, and H values 1.2 – 2.4. Diversity in the shales decreases down section. This is best seen in the Fisher alpha values, which are at maximum in samples near the top (3.60 in sample A41.10 and 3.79 in sample at 37.41m) while near the base of the member they reach a minimum of 0.67 in sample at -5.73m and 0.89 in sample at -7.81m.

Dominance in both sets of samples was calculated using the Simpson dominance in the PAST software (Hammer et al. 2001). The dominance of species in the palaeoseep samples varies between 0.17 and 0.11, with a mean of 0.14. The dominance in the shale samples varies from 0.11 – 0.45, with a mean of 0.24. Text-fig. 10 illustrates the relationship between the diversity indices and dominance in the shale samples. It is evident that there is an inverse relationship between these measures best seen in sample points at 39.12, 27.03, 4.39 and -5.73 meters, where a high value of dominance is recorded together with a low value of one or both diversity indices.

It is worth noting, that more fragile and hollow taxa which are found in the palaeoseep samples are not seen in the shale material. Agglutinated foraminifera from lithified shales however, tend to be more mechanically resistant than the surrounding sediment, owing to an increased tendency of cementation by precipitation of silica in the porous test wall. It is therefore questionable if the fragile taxa observed in the seep samples are destroyed during mechanical processing of the shale succession samples, or if they did not occur there originally and their absence has not biased the diversity.

PALAEOECOLOGY

While the agglutinated diversity values of the palaeoseep samples indicate a rather restricted environment (Text-fig. 9; Murray 1973), it has to be kept in mind that there is a significant calcareous component in these assemblages as recorded from thin sections (Hjálmarsdóttir et al. 2012), and with the addition of this data the diversity would in fact be higher. It is reasonable to assume that the alpha diversities are in reality entirely above 5 for the palaeoseep assemblages, which are regarded as typical values for modern normal marine shelf faunas usually dominated by calcareous taxa (Murray 1973). In contrast to the interpreted normal marine shelf environment for the carbonate seep bodies, the values for the shales indicate a restricted environment (Text-fig. 9). Similarly low diversities are well documented previously in organic rich shales of the Agardhfjellet Formation of Spitsbergen (Nagy et al. 1990a; Nagy and Basov 1998). The dominance values for the palaeoseeps are quite low, which supports the interpretation for normal marine conditions (Sen Gupta and Machain-Castillo 1993). The dominance in the shale samples is however higher, supporting the interpretation of a more restricted palaeoenvironment.

There are two alternative explanations of the marked faunal differences between the seep carbonates and the surrounding shales: 1) Calcareous foraminifera were originally present in the shales, but this carbonate component became dissolved *post mortem* or during diagenetic processes, and only the agglutinated group is preserved intact. Conversely, both the agglutinated and calcareous taxa are preserved in the seep carbonates, due to adequate pH conditions and rapid carbonate precipitation; 2) The depositional environment of the shales was hypoxic and potentially somewhat acidic and these factors prevented living calcareous foraminifera from thriving. The seeps meanwhile formed refuges for calcareous species by providing more oxygenated and adequate pH conditions leading to enhanced life conditions and preservation of calcareous taxa. The faunal difference between the hydrocarbon seep bodies and the shales forming the main body of the Slottsmøya Member therefore warrants the question of whether or not the absence of calcareous taxa from the shales is an original feature or the result of post-depositional diagenesis. Important observations in this context are: 1) belemnite rostra preserved with the originally fibrous texture of calcite occur in the shales; 2) echinoderm fragments (calcite) are common in and around the *Dorsoplanites* Bed; 3) in the shale samples, pyrite internal moulds of calcareous foraminifera are not found but are observed for agglutinated tests. Consequently, it is apparent that at least some carbonate is preserved in the shales.

To elucidate the faunal and environmental differences between the palaeoseeps and the surrounding shales, it is important to consider the environmental adaptation of the calcareous faunal component of the seeps carbonate bodies recognised in thin sections by Hjálmarsdóttir et al. (2012, fig. 5). This component is heavily dominated by the suborder *Lagenina,* represented by *Astacolus* sp. 1, *A*. sp. 2, *Lenticulina* sp. 1, *Marginulina* sp. 1, *Marginulinopsis* sp. 1, *Lingulina* sp. 1 and *Bullopora?* sp. 1. The suborder *Robertinina* occurs more rarely, and is represented by *Epistomina* sp. 1 and *E.* sp. 2. A relevant study concerning the calcareous component was carried out in the Jurassic North Sea Basin by Nagy et al. (1990b), comparing foraminiferal assemblages referred to normal marine shelf to hypoxic and hyposaline (marginal marine) environments. Assemblages regarded as normal marine were heavily dominated by *Lagenina* and showed alpha values above 5, while the two types of restricted assemblages (hypoxic and hyposaline) were dominated by, or consisted entirely of agglutinants with alpha values below 5. In modern faunas, *Lagenina* occurs in very low amounts, mainly in normal marine environments where it is replaced by the suborder *Rotaliina.* Thus, the distribution trends of *Lagenina* suggest that the palaeoseeps might have formed patches of normal shelf-like conditions providing refuges for calcareous foraminifera (mainly *Lagenina)* on a more or less hypoxic shelf populated by agglutinants.

PRESERVATION AND TAPHONOMY

Several intact morphological features which can be a crucial part of taxonomical determination (e.g. visible aperture details, true cross section, shape of sutures), can be seen in many of the foraminiferal specimens from the palaeoseeps. This high level of preservation therefore provides an excellent opportunity to observe these features in many taxa commonly found in much more reduced states. An example is *Schleiferella schleiferi* (Plate 1, figs 2a-c and 3a-c; Plate 5, fig. 3) and related species here referred to the same genus. In several publications using more poorly preserved material, these species are referred to *Evolutinella* Mjatliuk 1971 typified by an interiomarginal aperture at the base of the apertural wall. Excellently preserved specimens of these species from the seep carbonates reveal an areal aperture with bordering lip (Plate 1, figs 1c, 5c, 4, 6c; Plate 5, figs 1-4), features commonly obscured by compression or sediment infill. Based on this apertural development combined with general test morphology, this and related species are here referred to *Schleiferella* Bulynnikova 1971. Our material also enables observation of apertural features of species such as *Ammobaculites praegoodlandensis, Recurvoides paucus*, *Recurvoides obskiensis*, *Ammoglobigerina canningensis* and *Trochammina rosacea* (see Plates 1-5). The material also allows for erection of six new species; *Reophax pyriloculus*, *Haplophragmoides perlobatus*, *Labrospira lenticulata, Ammobaculites deflectus, Ammobaculites knorringensis and Textularia pernana*, which are described in detail in the systematic palaeontology part of this paper.

The difference in preservation of the agglutinated foraminiferal tests between the seep carbonate bodies and adjacent shales is obvious, as illustrated in Text-fig. 11. The majority of the tests in the shales are found in varying states of compression or irregular deformation, which in many cases renders the tests unidentifiable at species, genus or even higher level. This poor preservation is a common feature of agglutinated faunas in many sedimentary basins and is reported by several studies of Middle Jurassic – Early Cretaceous faunas of Svalbard (Nagy et al. 1988; Nagy et al. 1990a; Nagy and Basov 1998). The low quality preservation of shale foraminifera is attributed to compaction of the fine-grained mixture of clay minerals, silt grains and organic matter by dewatering of the original sea bed mud during burial.

While the mud surrounding the palaeoseeps is fine-grained and easily compacted, the most common microfacies in the carbonate seep bodies is peloidal packstone, and they are therefore more enriched in coarser grains (Hryniewicz et al. 2012). This is owing to processes such as autochthonous mineral formation, prolonged exposure to sea bed conditions, and removal of some of the finer grained material from the permeable sediment by currents (Hryniewicz et al. 2012). The larger grains in the palaeoseeps have therefore shielded the foraminiferal tests from any compaction. It is also assumed that compaction was overall rather restricted or absent in the Sassenfjorden seep carbonate bodies due to early diagenesis, and the porosity was not significantly altered (Hammer et al. 2011). In addition to the lack of compaction and grain size differences, the authigenic precipitation of carbonate at the seep site was a large contributing factor to excellent test preservation. This process led to early cementation of the sediments in the palaeoseeps and carbonate precipitation in the chamber lumen of foraminifera, which additionally protected the tests from any compaction (Hjálmarsdóttir et al. 2012).

Palaeoseeps as substrates for foraminifera

According to Bayon et al. (2009), a hard crust or layer commonly forms at active methane seep sites during carbonate precipitation. The surface of our palaeoseeps when they were active was probably not continuously covered with a hard crust, but formed a patchy system of precipitated carbonate with softer sediments in between, where surficial foraminifera could graze, and shallow to deep infaunal foraminifera were able to burrow. This assumption is supported by the chunky irregular structure of the seep carbonates, easily fractured by modern weathering. Further supporting the idea of non-cemented interstitial zones is the occurrence of the deep burrowing brachiopod *Lingula* reported from the seep carbonate bodies by Holmer and Nakrem (2012). The soft areas might also have acted as intermittent conduits for bubbles of methane leading to mixing of oxygenated water into the sediment providing adequate conditions for the normal marine faunal component represented by calcareous foraminifera.

MORPHOGROUP ANALYSIS

Morphogroups as environmental proxies

The concept of integrating test morphologies, life habitats, and feeding habits to categorise morphological types of foraminifera was introduced by Jones & Charnock (1985) based on modern examples. In subsequent studies the concept was developed to interpret aspects of ancient environments such as substrate, oxygenation and food supply (e.g. Nagy 1992; Tyszka 1994; Bak 2004; Szydlo 2004; Reolid et al. 2008; Setoyama et al. 2011). A level of subjectivity is however to be observed in interpreting foraminiferal living habits. Several studies have concluded that foraminiferal species can move vertically within the sediment and horizontally over the sea bed surface, to exploit different food sources or migrate to a microenvironment with a particular oxygen concentration (e.g. Alve and Bernhard 1995; Gooday and Rathburn 1999; Murray and Alve 2011). Jorissen et al. (1998) were even more critical towards microhabitat interpretations and concluded that it was almost impossible to tell whether a species that prefers the topmost level of the sediment is epifaunal or shallow infaunal.

Morphological units defined by test shape and chamber arrangement, as applied in this study, are assumed to reflect the adaptation of foraminiferal taxa to certain environmental conditions. This approach makes it possible to draw conclusions as to the ancient living habits and environments of different foraminiferal genera. Morphogroup categorization by genera is beneficial in several ways: 1. The analysis allows reliable comparison of assemblages of different ages by reducing the effect of taxonomical divergence, caused by evolution (Nagy 1992); 2. Arranging taxa into morphogroups reduces the number of variables, which simplifies analyses and comparisons; 3. Taxonomic determinations to genus level (instead of species) are sufficient and allow inclusion of maximum amount of data.

The morphogroup categorization used in this study is a modified version of that facilitated by Nagy et al. (2009) where a detailed description of each morphological category is available. Morphogroup assignments of species in the present paper are listed in Appendix 3 and statistics for each morphogroup are given in Appendix 4. For a further data reduction, the morphogroups are arranged into the following three faunal components reflecting their ancient lifestyles (Text-fig. 12): Epifauna, including morphogroups A, B, D1, E; Surficial-shallow infauna, with morphogroups C1, D2; Shallow-deep infauna containing morphogroups C1, C3. These categories (Text-fig. 13) provide an adequate basis for comparison of morphological developments both in the palaeoseeps and adjacent shales.

Many studies agree that the most important factors for microhabitat control of foraminifera are oxygen concentration and food availability (e.g. Bernhard 1986; Corliss and Emerson 1990; Jorissen et al. 1995; Van der Zwaan 1999). The critical oxygen range for foraminifera is from anoxia (zero dissolved oxygen) to dysoxia (9-45 µM) whereas oxic seawater is above 45 µM dissolved oxygen, where there is no stress for foraminifera (Murray 2006). When organic matter settles on the seafloor it is decomposed by bacteria which use oxygen. When the oxygen in the environment is depleted, the bacteria start consuming other oxidised compounds such as nitrates, sulphates and phosphates, consequently producing ammonia, hydrogen sulphide and other toxic compounds (Murray 2006), creating quite a hostile environment.

The TROX model of Jorissen et al. (1995) explains foraminiferal microhabitat preferences in terms of downward organic flux, i.e. availability of food, and oxygen. Under high organic flux (eutrophic environment), oxygen consumption is high and penetration of infaunal species is shallow since the redox zone is shallow as well. This is most common in shallow marine settings, where infaunal foraminiferal species are shallow (Murray 2006). Deeper infaunal penetration is made possible in more mesotrophic environments because of more stable conditions between oxygen consumption and influx of organic matter, resulting in a redox zone that lies deeper within the sediments. This is most often the case in shelf or upper slope environments (Murray 2006). In an extreme case of decreased organic flux (oligotrophic environment), food availability within the sediment becomes the limiting factor, hindering deep infaunal penetration. This setting is most common in deep marine environments and foraminifera re predominantly epifaunal or very shallow infaunal (Murray 2006).

Contrasting morphogroups of palaeoseeps and adjacent shales

As displayed in Text-fig. 12 and compiled in Table 2, there is a striking difference in the morphogroup distribution pattern between the palaeoseep samples and the shale sample succession. In the shale samples the epifaunal component (e.g. *Ammodiscus* and *Trochammina*) forms on average 68.3% (range 5.9 – 100%) while in the palaeoseeps it makes up on average only 10.8% (range 2.9 – 22.4%). The seep carbonate assemblages are heavily dominated by the surficial-shallow infaunal component with an average of 73.7% (range 60.0 – 87.9%) typified by *Schleiferella*, *Recurvoides* and *Labrospira*. In addition, a significant shallow-deep infaunal component also occurs with an average of 15.6% (range 8.8 – 23.9%), including genera such as *Reophax* and *Gaudryina*. The combined occurrence of these two essentially infaunal components makes up on average 89.3% of the palaeoseep assemblages. The same components only make up 31.5% on average in the shales. It has to be kept in mind however, that the stratigraphic levels of the seeps coincide with the uppermost shale sample levels (Text-fig. 3) and only represent around the topmost 10 meters of the Slottsmøya Member. Therefore a direct comparison of the whole morphogroup content between the palaeoseep and shale samples is not optimal.

The distribution of epifauna and surficial to shallow and deep infauna in the carbonate seep bodies reflects a rather stable environment where neither oxygen nor food availability are a restricting factor. The deep infaunal microhabitat penetration is facilitated by the availability of metabolisable organic matter in the deeper sediment layers and sufficient amounts of dissolved oxygen. The dominant ratios of surficial-shallow infauna and the presence of deep infauna could suggest that the environment was mesotrophic, and indicative of shelf or upper slope conditions (Jorissen et al. 1995; Murray 2006). This is in agreement with the diversity analysis, supporting a normal marine palaeoenvironment. An aspect of the surficial – deep infaunal palaeoseep foraminiferal component is that the calcareous foraminifera (only observable in thin section) could alter the ratios between morphogroups if taken into account. The observed calcareous genera and their morphological allocations are as follows: *Bullopora* and *Epistomina*, epifaunal; *Lenticulina* and *Astacolus* (involute), surficial-shallow infaunal; *Lingulina*, *Marginulina, Marginulinopsis* and *Astacolus* (evolute), shallow-deep infaunal (Nagy et al. 2009; Reolid et al. 2008; Rita et al. 2016).

For the shale succession, it is important to note the clear shift in ratios from almost exclusively epifaunal morphogroups in the lower part of the shale succession (up to sample at 21.70m) to dominating surficial to infaunal microhabitats in the uppermost samples close to the Myklegardfjellet Bed and the levels of the carbonate seep bodies (Text-fig. 12). According to the TROX model, this would suggest that in the palaeoenvironment of the lowermost part of the Slottsmøya Member either organic matter was plentiful resulting in scarce oxygen within the sediments (shallow marine setting), or there was a lack of organic matter within the sediments (deep marine). The depositional environment for the Slottsmøya Member has previously been described as an open marine shelf

(Nagy et al. 1988; Dypvik et al. 1991b), which rules out deep marine setting. This increase in the organic flux beyond eutrophic settings, leads to an increased consumption of oxygen in the benthic environment, and to a shallowing of the oxygenated sediment layer. All oxygen is consumed at the sediment surface rendering deeper sediment layers anoxic and just as under exceptionally oligotrophic conditions, all benthic foraminifera will be found at the sediment-water interface. The epifaunal component in the shales in our study consists largely of *Trochammina* (morphogroup D1), a genus known to dominate in hypoxic black shales (Reolid et al. 2014; Nagy 2016). In accordance with this, non-bioturbated paper shales occur at ca. 10 intervals in the sampled shale succession (Text-fig. 3). Therefore, the dominance of the epifauna in the lower shale levels could be explained by the fact that the typical infaunal microhabitats were void of oxygen, and the foraminifera lived only as epifauna.

The shift from epifaunal genera to surficial-shallow infaunal in the shales upwards in the section should then reflect a decrease in TOC and an increase in oxygen. This is in agreement with previous studies which have concluded that TOC is fluctuating but decreasing in the upper part of the Agardhfjellet Formation (Nagy et al. 1988; Dypvik et al. 1991b). The latest studies focusing on the Slottsmøya Member (Collignon and Hammer 2012; Koevoets et al. 2018) reveal however that TOC is variable but slightly increasing in the uppermost part of the member, culminating in a condensed interval which coincides with the palaeoseep levels. This was supported by black beds both in the field and in the cores, a dramatic reduction in benthic fauna but increase in pelagic fauna (fish and onychites), a slight increase in elemental proxies for low oxygen, high sulphur content, and sulphur bacterial filaments (*Trichichnus*) (Hammer 2018, written comm.). In Text-fig. 14, Fisher-alpha diversity results from the shale succession in our study and TOC (%) from the study of Collignon and Hammer (2012) are plotted together for each sample. It is clear that both are increasing upwards but have inverse relationships, where high TOC values coincide with low foraminiferal diversity and samples with higher diversities exhibit lower TOC values.

A shoaling development of the depositional basin while the Slottsmøya Member was formed is suggested by lithological and faunal evidence in several studies (Birkenmajer et al. 1982; Nagy and Basov 1998; Nagy et al. 2009). Collignon and Hammer (2012) recorded an overall fining upwards trend of sediments in the Slottsmøya Member until about 42 m, where a coarsening up succession continues to the top of the member, suggesting a shallowing event. Our morphogroup analysis suggests that in the base of the Slottsmøya Member sea level was shallow, and as the epifaunal genera lower down were replaced by surficial to infaunal genera up section, sea level rose. This is then in conflict with the established shallowing in the area.

In the context of both seep and shale microhabitats it is important to note that burrowing macrofauna transports oxygen into deeper layers of sediments, making it possible for foraminifera to live deeper even if the overall oxygen levels are low (Jorissen et al. 1995; Murray 2006). It has previously been established that burrowing macrofauna was plentiful in the Slottsmøya Member. Lingulid brachiopods (Holmer and Nakrem 2012) as well as shallow to deep burrowing bivalves constituted almost 80% of the whole macrofauna in the palaeoseeps (Hryniewicz et al. 2015).

COMPARISONS WITH MODERN SEEP ASSEMBLAGES

Comparisons between Jurassic – earliest Cretaceous and modern foraminiferal assemblages are seriously hampered by the extensive taxonomical changes, which took place mainly during the Late Cretaceous and Paleogene. A particularly important development was the extreme reduction of suborder Lagenina (forming almost the whole calcareous Svalbard seep component), which was replaced by the development and strong expansion of suborder Rotaliina, occupying the same habitats (Murray 2006). A major problem is also finding data on modern equivalents to the Boreal Spitsbergen palaeoseeps, formed as carbonate build ups in a black shale background environment. It is nevertheless of interest to examine how foraminifera behave in modern seep environments to better understand the palaeoecology of our own foraminifera from the palaeoseeps.

The few studies that have looked into the abundance and dominance of foraminifera in active seep environments as opposed to their non-seep adjacent environments revealed that the diversities tend to decline closer to or in the seeps (Bernhard et al. 2001; Lobegeier and Sen Gupta 2008). Some studies also look at the taxonomical differences between hydrocarbon seep environments and their adjacent sediments, and they arrived at diverging conclusions. While some authors agree that there are differences (e.g. Rathburn et al. 2000; Lobegeier and Sen Gupta 2008), others conclude that the foraminiferal fauna in the seeps are merely a sub-set of the faunas in the non-seep surroundings (e.g. Jones 1993; Bernhard et al. 2001; Martin et al. 2007). Lobegeier and Sen Gupta (2008) suggest that the dominance differences in non-seep areas and seeps can be tied to a post mortem mixing of species from different microhabitats, which might elevate the diversity at some sites and cause the differences.

Although all the above mentioned studies (and the present study) agree that no seep-endemic taxa of foraminifera have been found, that does not mean that they could not exist, and a recent study from New Zealand might have found the first seep-indigenous foraminifera (Hayward et al. 2011). An extinct, extremely rare species of benthic foraminifera, *Amphimorphinella butonensis*, was found in large numbers in a patch of siltstone surrounding a Miocene concretionary carbonate body, described as a fossil methane seep. This species has only been reported once before, from a Miocene muddy limestone in Indonesia, which is believed to be associated with hydrocarbon seepage.

It is not difficult to imagine that the presence of H_2S at hydrocarbon seep sites means that diversity and abundance of foraminiferal species is reduced compared to adjacent environments with more oxygen. Many studies have however found that assemblages occurring at seep sites tend to contain species that are adapted to high organic low oxygen environments, and some of them might even be able to live in the dysoxic, sulfidic environments, at least for some time (Sen Gupta et al. 1997; Rathburn et al. 2000; Bernhard et al. 2001; Hill et al. 2003). Bernhard (1996) demonstrated that foraminifera may be microaerophiles and not facultative anaerobes, which means that they can inhabit sites with either little or no oxygen and presence of H_2S for a limited amount of time. These dare-devil species therefore try to live in the hostile environment in order to take advantage of the high food supply. This fact might have an effect on the application of the TROX model, which assumes that foraminifera cannot live as infauna in oxygen-deprived sediments. No anaerobic species of foraminifera have however been found (Fenchel and Finlay 1995), and long term exposure to these harsh environments eventually leads to the death of the organism (Murray 2006).

All of the aforementioned studies agree that foraminifera seem to be drawn to abundant availability of food (mainly bacteria) at cold hydrocarbon seep sites, and that their abundance might even increase at sites with higher methane supply (Torres et al. 2003; Rathburn et al. 2000). Many studies mention *Beggiatoa* bacterial mats as the source of food (e.g. Sen Gupta et al. 1997; Panieri 2006; Lobegeier and Sen Gupta 2008) and remains of bacterial mat material from a seep site have been found in vacuoles in the protoplasm of the benthic foraminifera *Chilostomella ovoidea* collected in the Santa Barbara Basin (Bernhard and Reimers 1991).

ENVIRONMENTAL MODEL

The carbonate bodies in Sassenfjorden, interpreted as having been formed at hydrocarbon seeps (Hammer et al. 2011) in late Volgian to early Ryazanian times, were precipitated in an epicontinental sea spread over a relatively large area and at roughly the same stratigraphic interval within the Slottsmøya Member (Hryniewicz et al. 2015). Previous studies on the surrounding shales of the Slottsmøya Member indicate by sedimentological and micropalaeontological evidence that it was deposited in restricted yet open marine shelf environment at water depths between 100-300m, where the main restricting factor was hypoxia associated with low pH, alternating with periodic conditions of increased oxygenation of the sea bed (Dypvik et al. 1991b; Nagy and Basov 1998;

Dypvik et al. 2002; Nagy et al. 2009). In the uppermost part of the Slottsmøya Member where the palaeoseeps occur, the depositional conditions are still relatively unknown, and conflicting information has been published on the TOC and oxygenation trends. As previously discussed, stratigraphy of the Myklegardfjellet Bed is also difficult to decipher and the palaeoenvironment of the bed is still an enigma.

The palaeoseeps acted as a biotope on the shelf for increased biological activity due to enhanced food availability (Hammer et al. 2011, Hryniewicz et al. 2015), with *Beggiatoa* bacterial mats attracting diverse foraminiferal life. Foraminifera lived on and in the seabed (surficial/shallow infaunal to deep infaunal), but very few genera were living above the seabed (epifaunal). The palaeoseeps formed refuge areas for calcareous foraminiferal species by providing adequate pH conditions and oxygen levels as opposed to the surrounding shelf. The carbonate bodies might have been elevated topographical areas on the sea bottom, able to provide improved oxygen conditions as opposed to the adjacent shales. Additionally, vertical movement of seeping gases through the water column might have created current activity, increasing bottom water oxygenation. The conditions on the surrounding shelf were inhospitable for calcareous foraminifera due to relatively high organic influx during deposition of the organic-rich shales, creating somewhat hypoxic and acidic conditions overall.

Carbonate isotopic data from the palaeoseeps reveals that authigenic carbonate was formed close to the seafloor at the seep sites, resulting in early cementation of the sediment (hardgrounds) (Hammer et al. 2011). The hardgrounds acted as a protective encapsulation around the foraminifera after their death, shielding the tests from compaction and deformation. Little diagenetic alteration is assumed to have taken place in the area of the palaeoseeps after burial (Hammer et al. 2011). The lack of compaction further prevented any subsequent destruction to the foraminifera, yielding excellently preserved foraminiferal tests which can be studied in much detail.

SYSTEMATIC PALAEONTOLOGY

A total of 15 genera and 35 species are recognised in the seep samples, and 21 of these are illustrated in Plates 1 – 5. In the shale samples 26 genera and 59 species are identified, 18 of which are illustrated in Plates 6 and 7.

The morphology and taxonomy of 21 species are discussed in this chapter, with descriptions of six new species. All of the figured and described specimens are housed in the palaeontological type collection of the Natural History Museum, University of Oslo. In this paper we follow the classification of Loeblich and Tappan (1988).

Family HORMOSINIDAE Haeckel 1894

Subfamily REOPHACINAE Cushman 1910

Genus *Reophax* de Montfort 1808

Reophax pyriloculus Hjálmarsdóttir, Nakrem and Nagy n. sp.

Plate 1, figures 7 – 10.

Reophax aff. *metensis* HJÁLMARSDÓTTIR et al. 2012, fig. 7P.

Etymology: The name combines the Latin words *pyrum* (pear) and *loculus* (compartment) used in reference to the pear-like outline of the chambers.

Material: 24 specimens from seeps 2007-01, 2007-02, and 2007-03 from Knorringfjellet, central Spitsbergen.

Holotype: PMO 233.715.

Type locality and level: Seep 2007-01, Knorringfjellet.

Diagnosis: Chambers pyriform, added along a curved axis. Test wall loosely cemented and exhibits a pattern.

Description: The test is elongate, uniserial, in specimens of more than two chambers becoming loosely uniserial as more chambers added along a curved axis. The chambers are pyriform, a shape most evident in the last chamber, and increase rapidly in size as added, tapering to a neck. Our material consists of specimens with mostly one to two chambers, with a single specimen achieving four chambers. The wall of the test is very coarse grained, but delicate and easily broken. The neck, which is not commonly preserved whole, is long (ca. 1/2 length of last chamber) and tubular to slightly conical and commonly finer grained than the rest of the test. The position of the neck is asymmetrical, and therefore the basal part of the new chamber is not centered around the neck of the preceding chamber. The sutures are formed between the lateral base of the new chamber and the shoulder preceding the neck on the previous chamber. The sutures are distinct and depressed, and in specimens where a shift in growth direction is observed, become oblique. The aperture is terminal and rounded at the end of the neck.

Dimensions (mm): Measurements are based on 19 specimens from seeps 2007-01, 2007-02, and 2007-03 from Knorringfjellet, central Spitsbergen. Width is the widest point of the test. Length is the length of the whole test, with all chambers included in multilocular specimens. The width of the apertural neck was measured but due to the neck commonly being broken at various lengths, it was not possible to ascertain an average width.

	Mean	Min	Max

Length:	0.72	0.30	1.25
Width:	0.39	0.25	0.60

Remarks: The occurrence of this species in the carbonate seep bodies provides the best evidence for the absence of compaction. Even though the tests of *Reophax pyriloculus* are very coarse grained, they are delicate and empty inside. The low amount of cement and coarse wall material make the test very fragile, and therefore relatively few specimens survived the processing procedure intact, even though care was taken. The special pattern commonly seen on the tests are cavities most likely left after dissolution of carbonate. Among described species, *R. pyriloculus* resembles *Reophax metensis*, but because of its different chamber shape it is described as new here. Single chambered specimens of *R. pyriloculus* resemble *Lagenammina*, but without confirmation of the presence of an apertural area of the penultimate chamber it is impossible to separate these forms.

Occurrence: Reophax pyriloculus occurs in seeps 2007-03, 2007-01, and 2007-02, of late Volgian – late Ryazanian age. It is not found in the shale sample succession.

Family HAPLOPHRAGMOIDIDAE Maync 1952

Genus *Schleiferella* Bulynnikova 1971

Remarks: The generic name *Schleiferella* was originally introduced by Bulynnikova (1971) for strongly evolute planispiral species with *Haplophragmoides* (?) *schleiferi* Sharovskaja 1966 as type species. Based on its evolute shape and supposed position of its aperture at the base of the apertural face, *H.*? *schleiferi* and similar evolute taxa were usually included in the genus *Evolutinella* Mjatliuk. Subsequently, this was the case with the Spitsbergen species *Evolutinella schleiferi, E. emeljanzevi* and *E. vallata* as indicated in the synonymy lists below.

The present analysis of well-preserved specimens from hydrocarbon seep carbonates revealed that the type species of *Schleiferella, S. schleiferi* differs from *Evolutinella* by its sub-elliptical aperture with a bordering lip in lower part of the apertural face, and its somewhat irregularly planispiral inner whorls visible in some species. Consequently, the three Spitsbergen species previously referred to *Evolutinella* are here transferred to *Schleiferella*. The areal aperture with bordering lips and the somewhat irregular inner whorls with streptospiral tendency suggest a connection with *Recurvoides*. This is particularly apparent when comparing *S. schleiferi* to species of *Recurvoides* with planispiral outer whorl as *R. anabarensis* Basov 1985 from the Middle Jurassic of Siberia. The irregularly coiled inner whorls might be interpreted as a phylogenetic remnant of a streptospiral coiling.

Schleiferella emeljanzevi (Schleifer 1966)

Plate 1, figures 1a-c; Plate 5, figure 4.

Haplophragmoides (?) *emeljanzevi* SHAROVSKAJA 1966, p. 58, pl. 3, figs 1-5.

Haplophragmoides emeljanzevi BASOV 1968, p. 113, pl. 20. figs 2a-b. – NAGY et al. 1990a, p. 991, pl. 2, figs 8-10

Evolutinella emeljanzevi NAGY and BASOV 1998, p. 243, pl. 3, figs 1-2. – HJÁLMARSDÓTTIR et al. 2012, figs 6M-N, 8A-B.

Description: Test is typically large, planispiral biumbilicate, evolute, and has a lobate periphery with 12-14 chambers in the final whorl. Inner whorls somewhat irregularly wound. Chambers are sub-trapezoidal in outline, increase gradually in size as added with latest chambers having a tendency to be more inflated than preceding ones. Sutures are depressed and rather wide. Aperture is an areal elongate slit close to the base of the apertural wall and has a bordering lip which is observed in well preserved specimens. Test wall is smooth and fine-grained. Very little to no compression is present in our material.

Occurrence: *E. emeljanzevi* occurs in seeps 2007-01, 2007-03 and 2009-04, of late Volgian – late Ryazanian age. Similar ranges are reported from Western and Central Siberia.

Schleiferella schleiferi (Sharovskaja 1966)

Plate 1, figures 2a-c, 3a-b and 4; Plate 5, figure 3.

Haplophragmoides (?) *schleiferi* SHAROVSKAJA 1966, 61, pl. 4, figs 1-7.

Haplophragmoides schleiferi SHAROVSKAJA 1968, figure in stratigraphic table. – LØFALDLI and NAGY 1983, p. 100, pl. 1, figs 8-9.

Schleiferella schleiferi BULYNNIKOVA 1971, p.14.

Evolutinella schleiferi NAGY and BASOV 1998, pl. 3, figs 3-4. – HJÁLMARSDÓTTIR et al. 2012, figs 7J, M.

Description: *Schleiferella schleiferi* has a planispiral test with an almost smooth periphery. Its whorl thickness is smaller than that of other *Schleiferella* species. There are two morphologies in the present material, involute (Plate 1, figs 2a-c) and evolute (Plate 1, figs 3a-b). The evolute specimens have a wide umbilicus with a slight degree of depression, three visible whorls, and a reduced chamber length. The involute specimens possess a disc-like appearance with a somewhat elevated umbilical shoulder, and only the two last whorls are seen. Both end members have 12-13 chambers in the last whorl, increasing slowly in size as added. In both morphologies the chambers are sub-triangular to sub-trapezoidal, and the sutures depressed, well-defined and somewhat dark. Some specimens reveal slightly irregularly coiled inner whorls resembling streptospiral chamber arrangement. Test is fine grained and smooth. Aperture is an oval areal opening on the apertural face, with a lip bordering the whole opening preserved in many specimens.

Occurrence: S. schleiferi has been reported from the Volgian and Ryazanian of Western and Central Siberia (Sharovskaja 1966; 1968; Saks 1975), the upper Volgian of Western Siberia (Bulynnikova *et al.,* 1990), and middle Volgian – lower Ryazanian in north Central Siberia (Bulynnikova et al. 1990). In southern Spitsbergen *S. schleiferi* occurs in Volgian strata (Løfaldli and Nagy 1983) and in central Spitsbergen it is common in lower – upper Ryazanian (Nagy and Basov 1998). In the present study, *S. schleiferi* occurs in the three youngest seeps, 2007-01, 2007-03 and 2009-03, of Ryazanian age.

Schleiferella vallata (Nagy and Basov 1998)

Plate 1, figures 5a-c and 6a-c; Plate 5, figure 1-2; Plate 6, figures 1a-b.

Cribrostomoides? sp. 2 WALL 1983, pl. 4, figs 39-40.

Haplophragmoides infracalloviensis Dain 1948 LØFALDLI and NAGY 1983, p. 100, pl. 1, figs 4-5.

Haplophragmoides sp. 2 NAGY et al. 1990a, p. 292, pl. 3, figs 3-6.

Evolutinella vallata NAGY and BASOV 1998, p. 235, pl. 2, figs. 14-29 and pl. 8, figs 10-13. – HJÁLMARSDÓTTIR et al. 2012, figs 6A-D.

Description: This species is planispiral, biumbilicate, and has a large test with a smooth periphery. It comprises two end-member morphologies with various intermediate forms between involute shapes (Plate 1, figs 5a-c) and evolute (Plate 1, figs 6a-c). The evolute specimens have an umbilical area that shows maximum one half of the penultimate whorl. Involute specimens attain a larger whorl thickness than the evolute ones, and are circular in outline, while evolute specimens tend to have a sub-elliptical outline. The involute group shows an asymmetrical coiling of the inner whorl. Number of chambers in the final whorl varies from 11-14 in both end members. Sutures are rather narrow but distinct and thick in some specimens. Aperture is commonly visible as an elongate slit close to the base of final chamber, and in most specimens a well-developed lip can be seen around the opening. Test wall is fine to medium grained and typically smooth.

Remarks: Specimens from the studied material are preserved with no apparent compression. Evolute forms of *S. vallata* resemble *S. emeljanzevi* (Schleifer 1966) but have a smoother periphery and thicker whorls. The involute specimens of *S. vallata* have a deeper umbilical area than *S. emeljanzevi.* The involute form of *S. vallata* resembles *Cribrostomoides*? sp. 2 recorded by Wall (1983) from the upper Volgian of the Sverdrup Basin. The asymmetrical coiling of the inner whorl is most pronounced in Plate 1 figs. 5a-b, less clearly seen in Plate 1 figs 6a-b.

Occurrence: In central Spitsbergen, *S. vallata* has been reported from middle Volgian to Ryazanian strata (Nagy and Basov 1998). The species occurs in high numbers in all palaeoseeps (except seep 2009-04), which are of middle Volgian – earliest Ryazanian age.

Genus *Haplophragmoides* Cushman 1910

Haplophragmoides perlobatus Hjálmarsdóttir, Nakrem and Nagy n. sp.

Plate 2, figures 4a-c.

Etymology: The name is derived from Latin *per* (strongly) and *lobatus* (lobate), in reference to the strongly lobate periphery of the five chambers in the last whorl.

Material: 11 specimens from seeps 2007-02 and 2009-04, Knorringfjellet and Janusfjellet, central Spitsbergen.

Holotype: PMO 233.719.

Type locality and level: Seep 2009-04, Janusfjellet.

Diagnosis: Test strongly lobate. Last whorl irregularly coiled.

Description: The test is planispirally enrolled and involute, with occasional specimens being slightly evolute on one side. Test is biumbilicate, with a distinct and deep umbilical depression on the involute side. The species has five to five and a half chambers in the last whorl, increasing rapidly in size as added. The last whorl is irregularly coiled, converging to the evolute side. Chambers show no to only slight compression, are inflated and triangular to sub-triangular, with each chamber becoming more inflated than preceding ones. Sutures are straight, distinct and depressed. Test is fine grained with smooth exterior and highly lobate margin. Aperture is a short equatorial slit at the base of the apertural face, and is not visible in all specimens.

Dimensions (mm): Measurements are made from 12 whole specimens from samples 2007-02 and 2009-04.

	Mean	Min	Max
Height:	0.23	0.18	0.31
Width:	0.19	0.14	0.25
Umbilical diameter:	0.03	0.02	0.04

Remarks: H. perlobatus is similar to *H. loeblichi* Dain, but the chambers in our species expand more rapidly and the periphery is more lobate. *H. perlobatus* also has fewer chambers in the last whorl than the Siberian species, which has six to eight chambers.

Occurrence: *H. perlobatus* occurs in seep samples 2007-02, 2007-03 and 2009-04, of late Volgian – late Ryazanian age.

Genus *Labrospira* Höglund 1947

Labrospira lenticulata Hjálmarsdóttir, Nakrem and Nagy n.sp.

Plate 2, figures 1a-c, 2a-c and 3a-b; Plate 5, figures 5-6; Plate 6, figures 2a-b.

Haplophragmoides goodenoughensis (Chamney) 1969 NAGY et al. 1990a, p. 991. pl 3, fig. 1.

Labrospira aff. *goodenoughensis* (Chamney) 1969 HJÁLMARSDÓTTIR et al. 2012, figs 6J-L.

Etymology: Overall shape of the species is lenticular.

Material: 79 specimens from all sampled seeps at Janusfjellet and Knorringfjellet, central Spitsbergen.

Holotype: PMO 221.394.

Type locality and level: Seep 2007-01, Knorringfjellet.

Diagnosis: 13-15 cuneate chambers in last whorl. Raised umbilical area. Sutures dark and show a sigmoidal bend. Well-developed apertural lip. Test is large.

Description: Test is large, distinctly lenticular with a subacute to narrowly rounded periphery. It is involute planispiral and biumbilicate. The species has a distinctly elevated middle area around a narrow but relatively deep umbilical depression. Some specimens have a wider umbilical area, but do not show previous whorls. The last whorl has 13-15 cuneate chambers which very gradually increase in size and often become distorted because of the elevated middle area. The last one to two chambers are usually more inflated than the preceding ones. Sutures are distinctively dark and thick, somewhat depressed, radiating outwards with a marked sigmoidal bend. They are thicker and more visible on the elevated central area in well-preserved specimens. Aperture is an oval to slit-like areal opening slightly above the base of the apertural wall, with a well-developed bordering lip. Wall is agglutinated of fine grained material, and margin is smooth to somewhat lobate in the outermost chambers.

Dimensions (mm): Based on 23 specimens from seep 2009-03, Janusfjellet, central Spitsbergen.

	Mean	Min	Max
Largest diameter:	0.80	0.47	1.25
Smallest diameter:	0.68	0.39	1.14
Umbilical diameter:	0.11	0.05	0.23
Thickness:	0.41	0.23	0.60

Remarks: L. lenticulata is similar to *Haplophragmoides goodenoughensis* originally described by Chamney (1969) from the Barremian of Arctic Canada. In both species the central area of the flanks surrounding the umbilicus is typically elevated. A significant feature of *L. lenticulata* is its sigmoidal sutures contrasting to the straightly radiating sutures of *H. goodenoughensis.* Other differences between these two species include the more inflated test with rounded periphery, fewer (9-12) and longer chambers, lower umbilical elevation, and coarser grained wall of *H. goodenoughensis.* In *L. lenticulata* the sigmoidal course of sutures is even traceable in the compressed specimen (from shales) figured by Nagy et al. (1990a pl. 3, fig. 1). Diffuse appearance of sigmoidal sutures of the specimen in Plate 2 figs 2a-b of this study seems to be caused by moderate diagenetic deformation. *Labrospira goodenoughensis* reported by Fowler and Braun (1993) from the Lower Cretaceous of Arctic Canada is closely similar to *L. lenticulata* by its elevated umbilical area, smooth periphery and large number of chambers (up to 15). The main differences between these two species are the straightly radiating (instead of sigmoidal) sutures and the coarser wall of the Canadian species. The present species also resembles *Labrospira*? *mutabila* Bulynnikova described in Bulynnikova et al. (1990) from the Cretaceous of Western Siberia, but the Russian species has a more open umbilical area, slightly fewer chambers and more lobate periphery, which might be exaggerated by compression. *L. lenticulata* also bears a resemblance *to Cribrostomoides infracretaceous* Mjatliuk (in Bulynnikova et al. 1990). The latter species has a slightly elevated central part, but fewer chambers in the last whorl and its sutures are less distinct. *L. lenticulata* also resembles *Cribrostomoides goodenoughensis* (Chamney) figured by Wall (1983) from Arctic Canada, but the chambers in the Canadian species are larger and fewer in the last whorl and the sutures are not as distinct.

Occurrence: L. lenticulata occurs in all seep samples, late Volgian to late Ryazanian in age. It is especially abundant in sample 2009-03, which is late Ryazanian in age. The species was previously reported as *Haplophragmoides goodenoughensis* from the upper Volgian to Ryazanian of central and eastern Spitsbergen (Nagy et al. 1990a).

Family LITUOLIDAE de Blainville 1827

Subfamily AMMOMARGINULININAE Podobina 1978

Genus *Ammobaculites* Cushman 1910

Ammobaculites praegoodlandensis Bulynnikova 1972

Plate 3, figures 5a-c.

Ammobaculites praegoodlandensis BULYNNIKOVA 1972, p. 124-127, pl. 1. – BULYNNIKOVA et al. 1990, p. 67, pl. 85, figs 4-5; pl. 86, figs 1-5; pl. 112, figs 1-2. – NAGY and BASOV 1998, p. 237, pl. 3, figs 19-26, pl. 8, figs 8-9.

Kutsevella praegoodlandensis (Bulynnikova) DAIN 1978 p. 132.

Description: Test is planispiral in earlier stages, but shows a tendency to uncoil in the last one or two chambers. Planispiral part is evolute, biumbilicate, with lobate periphery and with 8-10 chambers in the last whorl. Chambers are triangular to sub-triangular, and increase rapidly in size as added. Wall has an intermediate grain size and a rather rough surface compared to other species in the assemblage. Sutures are somewhat narrow but depressed. Aperture is rounded and terminal, commonly observable in the present material. In some specimens the aperture is located on a subconical projection of the last chamber, but in others it is simply an areal opening.

Occurrence: In northern part of Central Siberia, *A. praegoodlandensis* occurs in the upper Volgian – Ryazanian interval and is reported from the Ryazanian of Western Siberia (Bulynnikova et al. 1990). In central Spitsbergen the species occurs in levels corresponding to the middle-upper Volgian transition (Nagy and Basov 1998). It is found in seeps 2007-03 and 2007-01, of late Ryazanian age.

Ammobaculites deflectus Hjálmarsdóttir, Nakrem and Nagy n.sp.

Plate 2, figures 5a-b, 6a-b, 7a-b, 8a-b and 9a-b; Plate 5, figure 7.

Ammobaculites sp. 1 HJALMARSDOTTIR *et al.* 2012*,* fig. 7N-O.

Etymology: The name is derived from Latin *deflectere* (to turn or bend aside) in reference to the obliquely bent uncoiling of the test.

Material: 38 specimens from all carbonate palaeoseeps sampled.

Holotype: PMO 221.405.

Type locality and level: Seep 2007-01, Knorringfjellet.

Diagnosis: Distinct curve against coiling direction of the uniserial portion in mature specimens.

Description: This species has an initial planispiral, biumbilicate, evolute coil with the previous whorl visible. The last whorl of the coil has five to seven triangular to sub-triangular chambers which rapidly increase in size, before uncoiling into a loosely uniserial portion. The chambers in the planispiral part are circular to sub-circular in cross section. The distinct uniserial section shows a tendency to curve against the initial coiling direction. The number of chambers in the uniserial part varies between one and six, most commonly two. Chambers in the uniserial part increase gradually in size, becoming more barrel-shaped with larger width than height in later chambers. The last chamber is more inflated and spherical than the preceding ones, containing a terminal and rounded aperture on a small indistinct neck. Sutures are narrow and depressed. Our material contains both macrospheric (Plate 2, figs 5a-b) and microspheric (Plate 2, figs 6a-9b) specimens. The wall of the macrospheric tests is made up of much larger grains than those of the microspheric specimens, leading to a very rough surface. Because of the size of the grains and lack of compaction, the tests are normally empty inside, making them quite fragile and easily broken. The tests of the microspheric forms are however much finer-grained and are more commonly found intact.

Dimensions (mm): Measurements are from 30 specimens from samples 2007-01, 2007-02, 2009-03 and 2009-04.

	Mean	Min	Max
Length:	0.47	0.27	1.05
Width uniserial portion:	0.16	0.10	0.33
Width planispiral portion:	0.24	0.12	0.45

Remarks: The species has quite varying morphologies, perhaps explained by the difference in the agglutinated grain size. The morphological variance can be explained step-wise by growth stages: 1) The uniserial part of the test is not yet developed, but the last chamber of the planispiral stage is inflated and reveals signs of uncoiling (Plate 2, figures 6a-b); 2) The uniserial part is formed and consists of one to two chambers but has not yet deflected (Plate 2, figs 7a-b); 3) The uniserial stage has three to four chambers and the last one to two chambers show signs of bending against the initial coiling direction. Some of the specimens seem to start to bend immediately after the uncoiling starts (Plate 2, figs 7a-b), while others straighten out more gradually (Plate 2, figs 8a-b); 4) The uniserial stage of the test has 4 or more chambers and the deflection is clear (Plate 2, figs 9a-b). The tests comprising finer material have achieved more numerous chambers in our material and therefore have reached the deflection step of the test evolution, while the coarser grained tests are commonly still in step one or two.

By its bent uniserial portion, *Ammobaculites deflectus* shows some similarity to *Carteriella manelobasensis* Haig and McCartain 2010 described from the Triassic of Timor. The well-preserved *A. deflectus* differs clearly from the Timor species by the symmetrical position of its uniserial part relative to the coil, a well-developed uniserial portion of four chambers, and a small terminal aperture at the top of a pyriform final chamber with a small indistinct neck, as is usual in numerous species of *Ammobaculites.*

Occurrence: The species is found in all seep carbonate bodies, which have an age range of late Volgian – late Ryazanian.

Ammobaculites knorringensis Hjálmarsdóttir, Nakrem and Nagy n.sp.

Plate 3, figures 1a-b, 2a-b, 3a-b and 4a-b; Plate 5, figures 8-9.

Etymology: The name *knorringensis* refers to Knorringfjellet in central Spitsbergen where carbonate palaeoseep 2007-01 is located, from which the type species is recovered.

Material: 134 specimens from all palaeoseeps sampled.

Holotype: PMO 233.724.

Type locality and level: Seep 2007-02, Knorringfjellet.

Diagnosis: Initial planispiral part, with final whorl wider or of same width as the uniserial stage.

Description: The test is made up of an initial planispiral part and a subsequent uniserial stage. The planispiral stage consists of four to five chambers in its final whorl is commonly wider or of the same width as the widest part of the uniserial portion. The uniserial portion is straight, with a circular chamber cross-section, more or less parallel sided and consists of one to seven barrel-shaped chambers having a larger width than height. The last one to two chambers become more inflated and rounded. Sutures are narrow and depressed. Aperture is terminal and rounded, positioned on the last chamber of the uniserial stage. Wall is medium grained.

Dimensions (mm): Measurements are from 55 specimens from samples 2007-02, 2007-03 and 2009-04.

	Mean	Min	Max
Length:	0.46	0.20	0.82
Width of uniserial section:	0.13	0.09	0.22
Width of planispiral section:	0.17	0.11	0.32

Remarks: The initial planispiral coil typically has a symmetrically positioned first chamber. *Ammobaculites knorringensis* is superficially similar to *Bulbobaculites elongatulus*, but has a planispiral initial coil, and is smaller in size.

Occurrence: A. knorringensis occurs in all seep samples with especially large numbers in the older seep bodies 2007-02 and 2009-04, which are late Volgian – late Ryazanian in age.

***Ammobaculites* sp. 1**

Plate 3, figures 7a-c.

Description: Test is planispiral and biumbilicate with a relatively narrow umbilicus, which is usually obscured by sediment. Chamber cross section is sub-triangular, with five to six chambers in the last whorl. Chambers increase gradually in size, the last of which is more inflated and rounded than the preceding ones. Aperture is round, terminal and areal, commonly observable in our material. Sutures are depressed but narrow. Wall has an intermediate grain size and a rather rough surface.

Remarks: This species bears resemblance to *A. praegoodlandensis* but has fewer chambers in the last whorl, more closed umbilical area and no apparent tendency to uncoil. This is perhaps caused by the juvenile stage morphology of the observed specimens. The species has not been described as new because of the low numbers of specimens recovered.

Occurrence: Ammobaculites sp. 1 occurs only in the oldest seep, 2009-04, of late Volgian in age.

Family AMMOSPHAEROIDINIDAE Cushman 1927

Subfamily RECURVOIDINAE Alekseychik-Mitskevitch 1973

Genus *Recurvoides* Earland 1934

Recurvoides obskiensis Romanova 1960

Plate 3, figures 8a-c; Plate 5, figure 10; Plate 7, figures 1a-c and 2.

Recurvoides obskiensis In: GLAZUNOVA et al. 1960, p. 55, pl. 44, figs 1-8. – PUTRJA 1967, p. 53, pl. 7, figs 5-6. – SOUAYA 1976, p. 268, pl. 2, figs 3, 5. – NAGY et al. 1990a, p. 993, pl.3 figs. 13-16. – BULYNNIKOVA et al. 1990, p. 30, pl. 73, fig. 5, pl. 74 fig. 1. – NAGY and BASOV 1998, pl. 5, figs 6-7. – HJÁLMARSDÓTTIR et al. 2012, figs 4C-D, 6G-I.

Description: This species has a sub-circular to elliptical test outline, with 12-14 chambers of trapezoidal to triangular shape in the last whorl. The sutures are radiating, thick and distinct, but very slightly depressed to flush with the test surface. Test is streptospiral in early growth stages but changes the coiling to planispiral in later stages at 90° angle from previous whorls. The last chamber is larger than the preceding ones, and has a sub-spherical to oval shape. Test wall is smooth, of fine-grained material. Aperture is sub-spherical and areal within the apertural wall. A lip is seen around the aperture in well preserved specimen.

Remarks: *Recurvoides obskiensis* has quite a wide range of morphologies, and if specimens are poorly preserved, it makes determination difficult. Some specimens in the present material are clearly elliptical in outline, while others are sub-circular. *R. obskiensis* is most similar to *Recurvoides praeobskiensis* Dain and Bulynnikova (in Bulynnikova et al. 1990), but the latter species has more whorls and lower chambers.

Occurrence: The species occurs in uppermost Volgian – upper Ryazanian strata in central Spitsbergen (Nagy and Basov 1998). It is reported from upper Ryazanian – lower Valanginian strata in Western Siberia and Valanginian beds from the north Yenisei Khatanga trough of Central Siberia (Bulynnikova et al. 1990). *Recurvoides obskiensis* occurs in large numbers in the youngest seep bodies (2007-01 and 2007-03) and in lower quantities in seep 2007-02. These palaeoseeps are of late Volgian – late Ryazanian age.

Recurvoides paucus Dubrovskaja 1962

Plate 3, figures 9-11; Plate 5, figure 11.

Recurvoides paucus DUBROVSKAJA 1962, p. 70, pl. 1, figs 7a, b, v. – BULYNNIKOVA 1967, p. 59, pl. 8, figs 7-11. – NAGY et al. 1990a, p. 994, pl. 4, figs 5-7. – HJÁLMARSDÓTTIR et al. 2012, figs. 7H-I.

Description: Test is medium sized, globular to oval in outline, streptospirally coiled. Chambers are of various but mostly rounded shapes: globular, sub-globular, sub-rhomboid, triangular, and sub-trapezoid. Earlier chambers are smaller and typically more rounded than subsequent ones. Wall is fine-grained and no compression of tests is observed. Aperture is typical of *Recurvoides*, with a visible lip in well preserved specimens.

Remarks: In the present material, specimens of *R. paucus* show a wide array of morphologies: some bear resemblance to *Orientalia baccula* but with a less tapered test, while others have a random streptospiral arrangement of the chambers.

Occurrence: In Western Siberia, *R. paucus* is found in Ryazanian – Valanginian deposits (Bulynnikova 1967), and in Ryazanian strata in the western part of north Central Siberia (Bulynnikova et al. 1990). In central Spitsbergen, it has been reported from uppermost Volgian – upper Ryazanian strata (Nagy and Basov 1998). In the present study, *R. paucus* is found in seeps 2007-01, 2007-03 and 2009-03, which have all been dated as late Ryazanian.

Family AMMOBACULINIDAE Saidova 1981

Genus *Bulbobaculites* Maync 1952

Bulbobaculites elongatulus (Dain 1972)

Plate 3, figures 6a-b; Plate 7 figures 6a-b.

Haplophragmium elongatulum DAIN 1972, p. 69, pl. 18, figs 8-10.

Bulbobaculites elongatum BULYNNIKOVA *et al.* 1990, pl. 24, figs 8-10.

Bulbobaculites elongatulus NAGY and BASOV 1998, p. 240, pl. 5, figs 8-11. – HJÁLMARSDÓTTIR *et al.* 2012, figs 6E-F.

Description: Test has a streptospiral, rounded initial coil of subglobular chambers which increase slowly in size. The initial coil is followed by a straight uniserial portion of five to six chambers, which widens towards aperture. Chambers in the uniserial part are barrel shaped and wider than high, except the last chamber which is sub-spherical to ovoid. Sutures are narrow but depressed. Aperture is terminal, rounded and on a short neck. Test wall is fine-grained.

Occurrence: B. elongatulus occurs in seep 2007-01 of late Ryazanian age. Previously reported from the Late Kimmeridgian in Spitsbergen (Nagy and Basov 1998).

Family TROCHAMMINIDAE Schwager 1877

Subfamily TROCHAMMININAE Schwager 1877

Genus *Ammoglobigerina* Eimer and Fickert 1899

Ammoglobigerina canningensis (Tappan 1955)

Plate 4, figures 3a-c; Plate 5, figure 14.

Trochammina globigeriniformis (Parker and Jones) BARTENSTEIN and BRAND 1937, p. 189, pl. 1A, fig. 21, pl. 4, fig. 13, pl. 5, fig. 76. – CIFELLI 1959, p. 290, pl. 1, figs 23-24.

Trochammina canningensis TAPPAN 1955, p. 49, pl. 14, figs 15-19. – HJÁLMARSDÓTTIR *et al.* 2012*:* figs 7E-G.

Trochammina (?) ex. gr. *canningensis* Tappan DAIN 1972, pl. 13, figs 1-2.

Ammoglobigerina canningensis NAGY and JOHANSEN 1991*,* p. 22, pl. 3, figs 15-18.

Description: Test is small and subspherical. It is composed of five to seven chambers, which are arranged in a trochospiral pattern, with more chambers visible on the dorsal side. Chambers are subglobular and increase rapidly in size as added. Sutures are thin and slightly depressed. Wall is finely agglutinated and thin. Aperture is an interiomarginal arch.

Remarks: This species has thin walls, is not compressed and commonly found without infill. Some specimens have coarser grained walls which make the test almost translucent.

Occurrence: A. canningensis is present in all seep samples of the current study, spanning the late Volgian – late Ryazanian. Previously reported from the Callovian – early Volgian of Spitsbergen (Nagy et al. 1990a).

Genus *Trochammina* Parker and Jones 1859

Trochammina annae Levina in Dain 1972

Plate 3, figures 14a-b.

Trochammina annae DAIN 1972, pl. 26, figs 1-4, pl. 29, fig. 10. – *Trochammina annae* BULYNNIKOVA et al. 1990, Pl. 34, figs 3-5 and 10-12. – NAGY et al. 1995, Pl. 4, figs 13-15.

Description: Test is small, thin-walled, low trochospiral and flattened. Only two whorls are visible in the present material, with five to six chambers in the last whorl. Chambers increase rapidly in size as added and in the last whorl they are much larger than preceding ones. On the spiral side the chambers are rounded quadrangular, while on the umbilical side they are rounded triangular. Sutures are thin and depressed. Margin is lobate. Aperture is not visible.

Remarks: The specimens of *T. annae* in the present assemblages are very small, as in the material reported in the papers referred to above. This makes observation of details difficult.

Occurrence: Trochammina annae only occurs in the oldest seep, 2009-04, which has been dated as late Volgian. In Western Siberia its range is late Kimmeridgian- Volgian (Bulynnikova et al. 1990). In

Thakkola, Nepal, *Trochammina annae* is reported from the upper Nupra Formation, where it occurs in Volgian assemblages with some Early Cretaceous aspects (Nagy et al. 1995).

Trochammina rosacea Zaspelova 1948

Plate 3, figures 12a-b; Plate 5, figure 13.

Trochammina rosacea ZASPELOVA 1948, p. 202, pl. 2, figs 1a-b. – SHAROVSKAJA 1961, p. 33, pl. 2, figs 4a-c; pl. 3, figs 1a, b, 2-4. – DAIN 1972, pl. 28, fig. 7. – BULYNNIKOVA et al. 1990, p. 90, pl. 34 fig. 6, pl. 92, figs 15-16.

Description: Test is small and low trochoid, consisting of two and a half to three whorls. In the last whorl, six rounded trapezoidal to subtriangular chambers are visible, increasing rapidly in size as added. Sutures are depressed but narrow, and backwards curved on the spiral side and radiating on the umbilical side. Aperture is an interiomarginal extraumbilical-umbilical arch. Wall is fine grained and periphery is lobate.

Remarks: *T. rosacea* is similar to *T. praerosacea* but differs by its rapidly expanding chambers, kidney-shaped last chamber, and its lower dorsal spire. The sutures in *T. rosacea* are also more inclined backwards on the spiral side than in *T. praerosacea*.

Occurrence: In western and Central Siberia, *T. rosacea* occurs in Volgian deposits (Sharovskaja 1968; Dain 1972; Saks 1975), and in upper Volgian strata in West and North Siberia (Bulynnikova et al. 1990). *T. rosacea* occurs in all seep samples except for 2009-04. Their age is late Volgian – late Ryazanian.

Trochammina praerosacea Nagy and Basov 1998

Plate 3, figures 13a-c; Plate 4, figures 1a-b; Plate 5, figure 12; Plate 6, figures 6a-b, 7a-b and 9a-b.

Trochammina rosacea Zaspelova NAGY et al. 1990a*,* 995, pl. 5, figs 3-6.

Trochammina praerosacea NAGY and BASOV 1998, 242, pl. 5, figs 12-26. – HJÁLMARSDÓTTIR et al. 2012, figs 7K-L.

Description: *T. praerosacea* has a low to moderately high trochospiral test, with an expanded final chamber which protrudes ventrally. Dorsal side is subconical with all chambers of three to four whorls visible. Ventral side flattened with only the last whorl of six to seven chambers visible. Umbilical depression is commonly obscured by sediment. Sutures are depressed, inclined backwards on the spiral side, and straightly radiating on the umbilical side. Margin is slightly lobate. Wall is finely agglutinated. Aperture is an interiomarginal umbilical – extraumbilical arch, but is commonly obscured.

Occurrence: In the present material, the species is found in all seep carbonate bodies, of late Volgian – late Ryazanian age. Previously reported from the early Volgian – earliest late Volgian in Spitsbergen (Nagy and Basov 1998).

Family PROLIXOPLECTIDAE Loeblich and Tappan 1985

Genus *Orientalia* Bykova 1947

Orientalia baccula Schleifer 1968

Plate 4, figures 2a-b.

Orientalia (?) *baccula nomen nudum* SCHLEIFER 1968, fig. in stratigraphic table.

Arenobulimina cf. *torula* Tappan SOUAYA 1976, p. 276, pl. 4, fig. 5. – LØFALDLI and NAGY 1983, p. 101, pl. 2, fig. 9.

Arenobulimina sp. 2 WALL 1983, pl. 5, figs 16-17.

Arenobulimina sp. 1 NAGY et al. 1990a, p. 997, pl. 6, fig. 9.

Orientalia (?) *baccula* Schleifer BULYNNIKOVA et al. 1990, p. 104, pl. 95, figs 3-4. – AZBEL and GRIGYALIS 1991, pl. 68, figs 11a-v.

Orientalia baccula Schleifer NAGY and BASOV 1998, p. 246, pl. 7, figs 1-4.

Description: The test is spiral to serial and expands rapidly towards the final chambers. The early trochospiral stage has six or more chambers, while later growth stages show sub-parallel rows of four to six chambers. The present material contains specimens of four to five whorls. Chambers increase gradually in size as added, in early stage rounded and later evolving into rounded rhomboidal shapes. The last whorl consists of chambers with an oval-rounded or sub-spherical outline. Sutures are straight, thick, and depressed. Test is fine grained. The aperture is slit-like, but fully or partly obscured in all specimens in the present material.

Remarks: The species occurs in relatively small numbers in the seep samples, but it has a very distinct appearance and good preservation.

Occurrence: O. baccula is found in seeps 2007-01, 2007-03, and 2009-03 of late Ryazanian age. It is reported from the eastern part of the Sverdrup Basin from Ryazanian-Valanginian strata (Wall 1983), from the early Ryazanian in south-eastern Barents Sea (Basov et al. 1989), and from the late Volgian of Central Siberia (Sharovskaja 1968; Bulynnikova et al. 1990). Previously reported from the late Volgian-Ryazanian of Spitsbergen (Nagy and Basov 1998).

Family VERNEUILINIDAE Cushman 1911

Subfamily VERNEUILININAE Cushman 1911

Genus *Gaudryina* d'Orbigny 1839

Gaudryina gerkei (Vasilenko 1951)

Plate 4, figures 4a-b and 5a-b; Plate 7, figure 9.

Verneuilina gerkei VASILENKO 1951, 62, pl. 1, figs 7-8.

Gaudryina gerkei SHAROVSKAJA 1968, figure in stratigraphic table. – BULYNNIKOVA et al. 1990, 109, pl. 96, figs 4-6, pl. 112, fig. 3. – NAGY and BASOV 1998, p. 248, pl. 7, figs 10-12, pl. 8, figs 25-27. – HJÁLMARSDÓTTIR *et al.* 2012*,* figs 7C-D.

Description: The test is medium sized, narrow, starting to slightly bend, with triserial and evolving into biserial chamber arrangement. The biserial part typically forms more than a half of the test length. A distinct feature of the species is a bend of the test about at half to one-third length from the proloculus, which is observed in most specimens. It occurs where the chamber arrangement changes from triserial to biserial. Sutures are commonly depressed and thick. Test is fine grained and rounded in cross section. Aperture is a low arch at the base of final chamber.

Occurrence: G. gerkei is found in all studied seep bodies, dated as late Volgian – late Ryazanian. In central Spitsbergen, it occurs in the Ryazanian (Nagy and Basov 1998) and in Siberia its range is recorded as Ryazanian – Valanginian (Bulynnikova et al. 1990).

Gaudryina rostellata Nagy and Basov 1998

Plate 4, figures 6a-b and 7a-b; Plate 7, figures 8a-b.

Gaudryina aff. *milleri* Tappan, 1955 NAGY et al. 1990a, p. 996, pl. 6, figs 1-4.

Gaudryina gerkei (Vasilenko, 1951) BULYNNIKOVA et al. 1990, p. 109, pl. 96, figs 4, 6.

Gaudryina rostellata NAGY and BASOV 1998, p. 250, pl. 7, figs 13-14, pl. 8, figs 29-34. – HJÁLMARSDÓTTIR et al. 2012, figs 7A-B.

Description: The species starts with triserial but evolves into biserial chamber arrangement. Specimens with short test commonly do not reach the biserial growth stage. Tests vary in degree of flaring, and the shorter specimens are commonly wider than the long ones. Sutures are somewhat depressed but narrow. Test has a sub-triangular early portion which tapers strongly, and sub-elliptical later portion which tapers gently. Wall is fine to medium grained. Aperture is a low arch at the base of final chamber.

Remarks: *G. rostellata* is closely related to *G. gerkei* (Vasilenko 1951), but is more robust and has a wider and more flaring test outline. Early chambers tend to show a brownish colour in some specimens, which is attributed to organic material forming wall cement or inner lining of the chambers.

Occurrence: G. rostellata occurs in Ryazanian sediments in Western Siberia (Bulynnikova et al. 1990). In central Spitsbergen, it occurs in the Ryazanian, and defines the *G. rostellata* zone of Nagy and Basov (1998). In the present material the species is present in all palaeoseeps, with the age range of late Volgian – late Ryazanian.

Family TEXTULARIIDAE Ehrenberg 1838

Subfamily TEXTULARIINAE Ehrenberg 1838

Genus *Textularia* Defrance 1824

Textularia pernana Hjálmarsdóttir, Nakrem and Nagy n.sp.

Plate 4, figures 8a-b, 9a-c, 10 and 11a-b; Plate 5, figure 15.

Textularia sp. 1 HJÁLMARSDÓTTIR et al. 2012, Fig. 8, D-E.

Etymology: The name comes from the Latin prefix *per* (very) and Greek *nanos* (dwarf), in reference to the small size of the species.

Material: 22 specimens from palaeoseeps 2007-03 and 2009-04.

Holotype: PMO 233.726.

Type locality and level: Seep 2007-03, Knorringfjellet.

Diagnosis: Test small and fine grained. Adventitious chamber against the first pair of chambers.

Description: Test is very small compared to the rest of the agglutinated assemblage and biserial throughout. The preservation of many of the specimens makes it possible to observe the "adventitious third chamber against the first pair of chambers" as described by Loeblich and Tappan (1988, p. 173), found in the microspheric generation of the genus. This extra chamber gives the appearance of an initial planispiral arrangement, which is in many cases wider than the start of the biserial part. In the biserial section the chambers increase gradually in size as added, and are rounded to sub-rounded in early stages, getting more elongate to sub-rectangular towards the aperture. The test has six to seven pairs of biserial chambers and the last one or two are semi-circular and more inflated than earlier ones. Wall material varies between tests of different sizes; smaller specimens are fine grained while larger specimens are medium-grained. Sutures are depressed and of medium width, getting slightly more oblique and more depressed between later chambers. Aperture is a low arch at the base of the final chamber.

Dimensions: Many of the specimens are broken, lacking the initial chambers. These specimens were excluded from the measurements. Measurements include 16 individuals, from samples 2007-03 and 2009-04.

	Mean	Min	Max
Length:	0.29	0.15	0.46
Widest point:	0.10	0.07	0.13
Narrowest point:	0.03	0.02	0.04

Remarks: The presence of a constriction between the initial wider section and the following biserial section is the cause for the initial section commonly being broken off from some of the specimens. In many specimens there is a bend about ⅓ – ½ of the way from the proloculus (Plate 4, figs 8a-b and 10). This is more commonly seen in smaller specimens, and could be a preservation artefact. *Textularia pernana* is similar to *Spiroplectammina navarroana* Cushman, but does not have a planispiral initial coil, and is considerably smaller.
Occurrence: Textularia pernana is found in seep 2007-01 and seep 2009-04 of late Volgian – late Ryazanian age.

CONCLUSIONS

The hydrocarbon seep carbonate bodies of the Slottsmøya Member (Agardhfjellet Formation) contain uniquely well preserved foraminiferal assemblages including the six new species *Reophax pyriloculus*, *Haplophragmoides perlobatus*, *Labrospira lenticulata, Ammobaculites deflectus, Ammobaculites knorringensis and Textularia pernana*. The excellent preservation without any apparent test deformation is due to authigenic precipitation of carbonate that led to early cementation of the sediment. This preservation has made it possible to improve existing taxonomic descriptions, and provide high-quality illustrations for future research.

Well-preserved ammonite faunas occurring in the seeps constrain age assignments for the five seep carbonate bodies. The ages indicated by ammonites are in the interval early late Volgian – latest Ryazanian. The foraminiferal assemblages generally agree with these age determinations, although some species have older reported ages than those suggested by the ammonites. These discrepancies could be due to reworking of the seep sediments, low sedimentation rates at the seep sites, or diachronous distribution between sedimentary basins. The most likely explanation however, is that some of the foraminiferal species might be candidates for extended stratigraphic ranges.

The excellent preservation of the agglutinated foraminiferal taxa in the palaeoseeps contributes to palaeoecological interpretation of the assemblages. Statistical analysis based on diversity indices concludes that close to normal marine environments are indicated by the seep foraminifera. In contrast, the adjacent shale assemblages reveal a restricted environment, attributed to a slightly hypoxic and somewhat acidic shelf with periodically increased oxygenation linked to influx of sediments. High dominance of the semi-infaunal morphogroup in the seep carbonates suggests more oxygenated palaeoenvironment conditions at the seep sites, while dominance of the surficial morphogroup in the shales is in accordance with overall hypoxia on the surrounding shelf.

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Text-figure, Table and Plate captions:

Text-fig. 1. Location map of the hydrocarbon seep carbonates in Sassenfjorden outcrop area, central Spitsbergen. Geology modified from Dallmann et al. (2001).

Text-fig. 2. Lithostratigraphic subdivision and age relationships of the Middle Jurassic to Lower Cretaceous succession of central Spitsbergen. Position of hydrocarbon seep carbonate bodies is depicted in the stratigraphy by black hemispherical symbols.

Text-fig. 3. Lithological column showing stratigraphical relationships between seep carbonate bodies (dome-shaped symbols) and the adjacent shale succession within the Slottsmøya Member. Modified from Collignon and Hammer (2012).

Text-fig. 4. Picture of seep 2007-01 in the field. Photo by Hans Arne Nakrem.

Text-fig. 5. Distribution of foraminiferal species in the analysed palaeoseep samples portrayed in a stratigraphic framework based on ammonites by Wierzbowski et al. (2011), and modified after Hjálmarsdóttir et al. (2012).

Text-fig. 6. Range chart of foraminiferal species in the analysed shale samples, assigned to foraminiferal zones by Nagy and Basov (1998).

Text-fig. 7. Percentage distribution of selected foraminiferal genera in the palaeoseeps.

Text-fig. 8. Percentage distribution of selected foraminiferal genera in the shale succession.

Text-fig. 9. Plot of agglutinated foraminiferal diversity indices comparing assemblage values of seep carbonate bodies and adjacent shales. Calcareous species found in thin sections of the carbonate seep bodies are not included in the calculations.

Text-fig. 10. Diversity indices and dominance in the shale succession. Calcareous species found in thin sections in the seep carbonates are not included in the calculations.

Text-fig. 11. Comparison of species preserved in seep carbonates to species in adjacent shales in the Volgian to Ryazanian of Spitsbergen. **A-B**: PMO 221.559. **C**: PMO 221.412. **D**: PMO 221.580. **E**: PMO

221.395. **F**: PMO 221.394. **G**: PMO 221.579. **H-I**: PMO 221.558. **J-K**: PMO 221.590. **L-M**: PMO 221.575. **N**: PMO 221.595 SAME AS PLATE 7 FIGS 6A-6B. **O**: PMO 221.398. **P**: PMO 221.399. **Q-R**: PMO 221.588. **S-T**: PMO 221.571. **U-V**: PMO 221.597. **W-X**: PMO 221.389. **Y**: PMO 221.598. **Z-ZZ**: PMO 221.392. Magnifications vary – figures only for comparison of preservation.

Text-fig. 12. Ratios of morphogroups in the seep and shale samples according to life style.

Text-fig. 13. Interpreted lifestyles of foraminiferal morphogroups and their subgroups relative to sediment habitat illustrated by examples: *Reophax pyriloculus* (C1) and *Gaudryina rostellata* (C3) represent shallow to deep infaunal lifestyle; *Bulbobaculites elongatulus* (C2) has a shallow infaunal lifestyle; *Schleiferella emeljanzevi* (D2) shows an epifaunal to potentially shallow infaunal habitat; *Trochammina praerosacea* (D1) depicts a epifaunal lifestyle; *Ammodiscus zaspelovae* (E) shows a epifaunal to phytal lifestyle. Modified from Nagy et al. (2009).

Text-fig. 14. TOC (%) and alpha diversity values of the shale succession. Uppermost shale levels with the prefix A are not included as TOC information is not available for these. TOC values from Collignon and Hammer (2012).

Table 1. Seep sample identifications, map coordinates, and ages according to ammonite datings in Wierzbowski et al. 2011.

Table 2. Comparison of percentages of foraminiferal lifestyle groups and their associated morphogroups in the shale and seep carbonate samples. For full documentation of the morphogroups for each species see Appendix 3. For detailed clarification of each morphogroup, see Nagy et al. 2009.

Appendix 1. Quantitative data on the palaeoseep agglutinated foraminifera content.

Appendix 2. Quantitative data on the foraminifera content in the shale sample succession.

Appendix 3. Alphabetical list of all species in this study, with information about Plate figures and morphogroup assignment.

Plate 1. Specimens from seep carbonate bodies, shown in reflected light. All scale bars are 100 µm. **1a-c.** *Schleiferella emeljanzevi*, PMO 221.385, from seep 2007-01. **2a-c.** *Schleiferella schleiferi*,

involute form PMO 221.403, from seep 2007-01. **3a-b.** *Schleiferella schleiferi*, evolute form PMO 221.404, from seep 2007-01; **4.** *Schleiferella schleiferi*, evolute form PMO 231.528, from seep 2007-01. **5a-c.** *Schleiferella vallata*, involute form PMO 231.526, from seep 2007-01. **6a-c** *Schleiferella vallata*, evolute form PMO 231.527, from seep 2007-02. **7.** *Reophax pyriloculus* PMO 233.715 from seep 2007-01. **8.** *Reophax pyriloculus* PMO 233.716 from seep 2007-01. . **9.** *Reophax pyriloculus* PMO 233.717 from seep 2007-02. **10a-b.** *Reophax pyriloculus,* PMO 233.718, from seep 2007-01.

Plate 2. Specimens from seep carbonate bodies, shown in reflected light. All scale bars are 100 µm. **1a-c**. *Labrospira lenticulata*, PMO 221.394, from seep 2007-01. **2a-c.** *Labrospira lenticulata*, PMO 231.518, from seep 2007-01. **3a-b**. *Labrospira lenticulata*, PMO 221.395, from seep 2007-01. **4a-c.** *Haplophragmoides perlobatus* PMO 233.719 from seep 2009-04. **5a-b.** *Ammobaculites deflectus*, macrospheric PMO 231.534, from seep 2009-04. **6a-b.** *Ammobaculites deflectus* PMO 233.720 from seep 2009-04. **7a-b.** *Ammobaculites deflectus* PMO 233.721 from seep 2009-03. **8a-b.** *Ammobaculites deflectus* PMO 233.722 from seep 2009-04. **9a-b.** *Ammobaculites deflectus* PMO 221.405, from seep 2007-01.

Plate 3. Specimens from seep carbonate bodies, shown in reflected light. All scale bars are 100 µm. **1a-b.** *Ammobaculites knorringensis* PMO 233.723 from seep 2009-04. **2a-b.** *Ammobaculites knorringensis* PMO 233.724 from seep 2007-02. **3a-b.** *Ammobaculites knorringensis* PMO 231.535, from seep 2007-01. **4a-b.** *Ammobaculites knorringensis* PMO 233.725 from seep 2007-02. **5a-c.** *Ammobaculites praegoodlandensis* PMO 221.576, from seep 2007-01. **6a-b.** *Bulbobaculites elongatulus* PMO 221.399, from seep 2007-01. **7a-c.** *Ammobaculites* sp. 1 PMO 221.577, from seep 2007-02. **8a-c.** *Recurvoides obskiensis* PMO 231.521, from seep 2009-03. **9.** *Recurvoides paucus* PMO 231.524, from seep 2007-03. **10.** *Recurvoides paucus* PMO 221.400 from seep 2007-01. **11.** *Recurvoides paucus* PMO 221.401, from seep 2007-01. **12a-b.** *Trochammina rosacea* PMO 231.532 from seep 2007-01. **13a-c.** *Trochammina praerosacea* PMO 221.571, from seep 2007-02. **14a-b.** *Trochammina annae* PMO 231.533, from seep 2009-04.

Plate 4. Specimens from seep carbonate bodies, shown in reflected light. All scale bars are 100 µm. **1a-b.** *Trochammina praerosacea* PMO 231.530, from seep 2007-01. **2a-b.** *Orientalia baccula* PMO 231.525, from seep 2007-01. **3a-c.** *Ammoglobigerina canningensis* PMO 221.388, from seep 2007-01. **4a-b.** *Gaudryina gerkei* PMO 231.519, from seep 2009-03. **5a-b**. *Gaudryina gerkei* PMO 231.520, from seep 2007-03. **6a-b**. *Gaudryina rostellata* PMO 231.522, from seep 2007-02. **7a-b.** *Gaudryina rostellata* PMO 231.523, from seep 2007-02. **8a-b.** *Textularia pernana* PMO 233.726 from seep 2007-

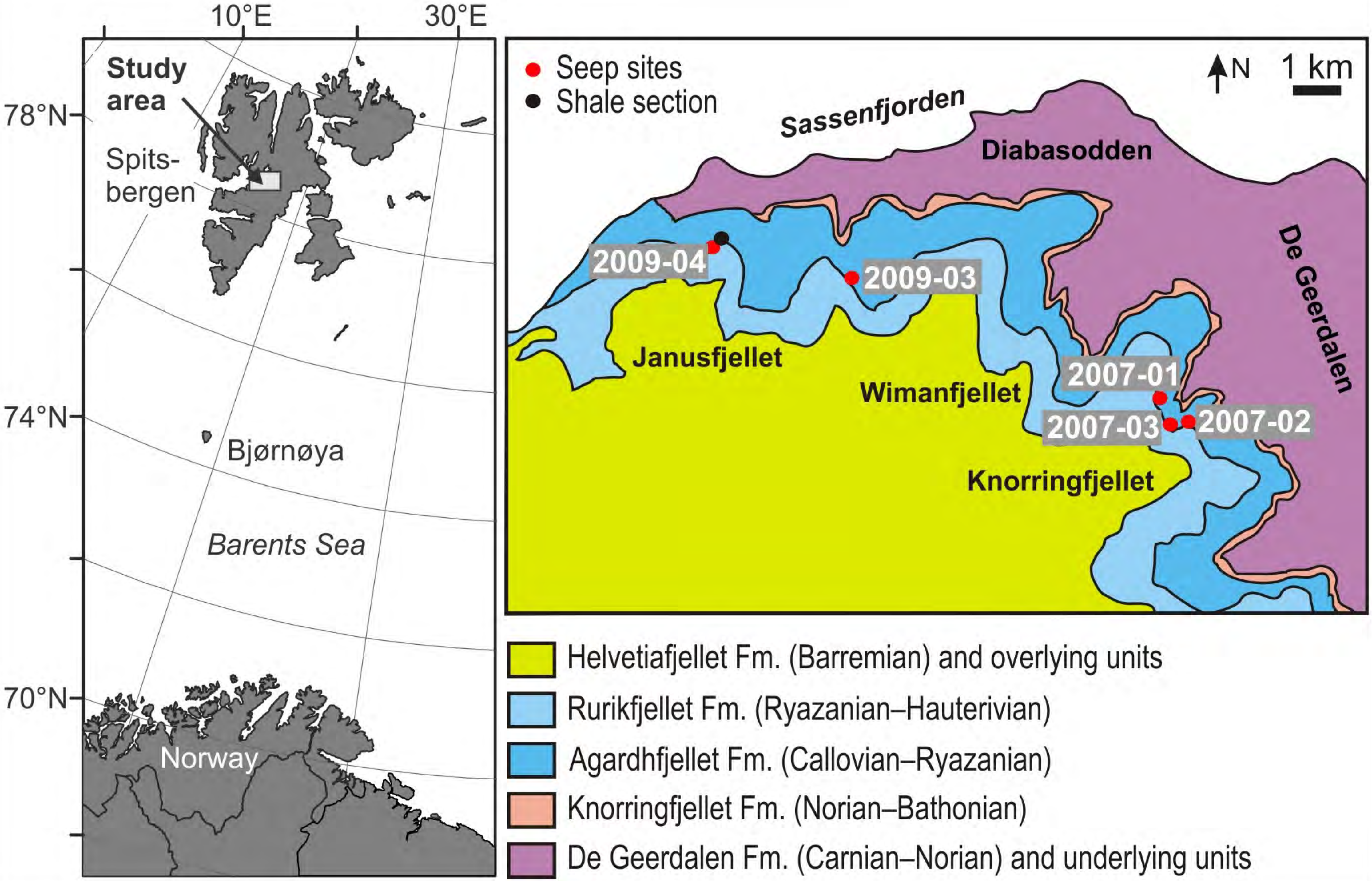
03. **9a-c.** *Textularia pernana* PMO 233.727 from seep 2009-04. **10.** *Textularia pernana* PMO 233.728 from seep 2009-04. **11a-b.** *Textularia pernana* PMO 233.729 from seep 2009-04.

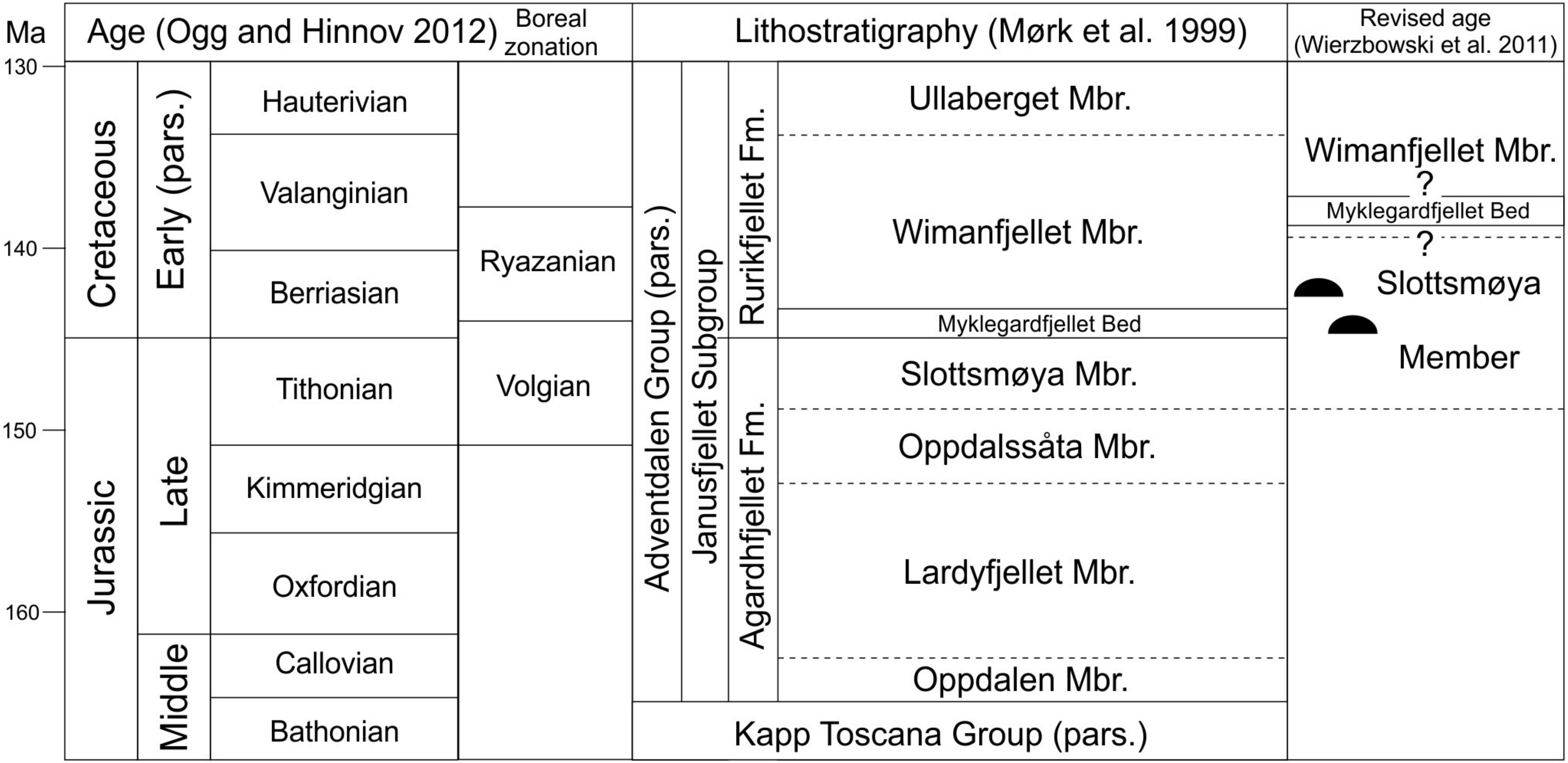
Plate 5. SEM photos of apertures of selected species in hydrocarbon seep carbonates. **1.** *Schleiferella vallata*, involute specimen PMO 231.526, from seep 2007-01.**2.** *Schleiferella vallata*, evolute specimen PMO 231.527, from seep 2007-02. **3.** *Schleiferella schleiferi* PMO231.528, from seep 2007-01. **4.** *Schleiferella emeljanzevi* PMO 221.385, from seep 2007-01. **5.** *Labrospira lenticulata* PMO 221.394, from seep 2007-01. **6.** *Labrospira lenticulata* PMO 231.518, from seep 2007-01. **7.** *Ammobaculites deflectus* PMO 233.721 from seep 2009-03. **8.** *Ammobaculites knorringensis* PMO 233.730 from seep 2007-02. **9.** *Ammobaculites knorringensis* PMO 233.731 from seep 2007-02. **10.** *Recurvoides obskiensis*, PMO 231.521, from seep 2009-03.
11. *Recurvoides paucus*, PMO 231.524, from seep 2007-03. **12.** *Trochammina praerosacea*, PMO 231.532, from seep 2007-02. **13.** *Trochammina rosacea*, PMO 231.531, from seep 2007-01. **14.** *Ammoglobigerina canningensis*, PMO 221.388, from seep 2007-01. 15. *Textularia pernana* PMO 233.729 from seep 2009-04.

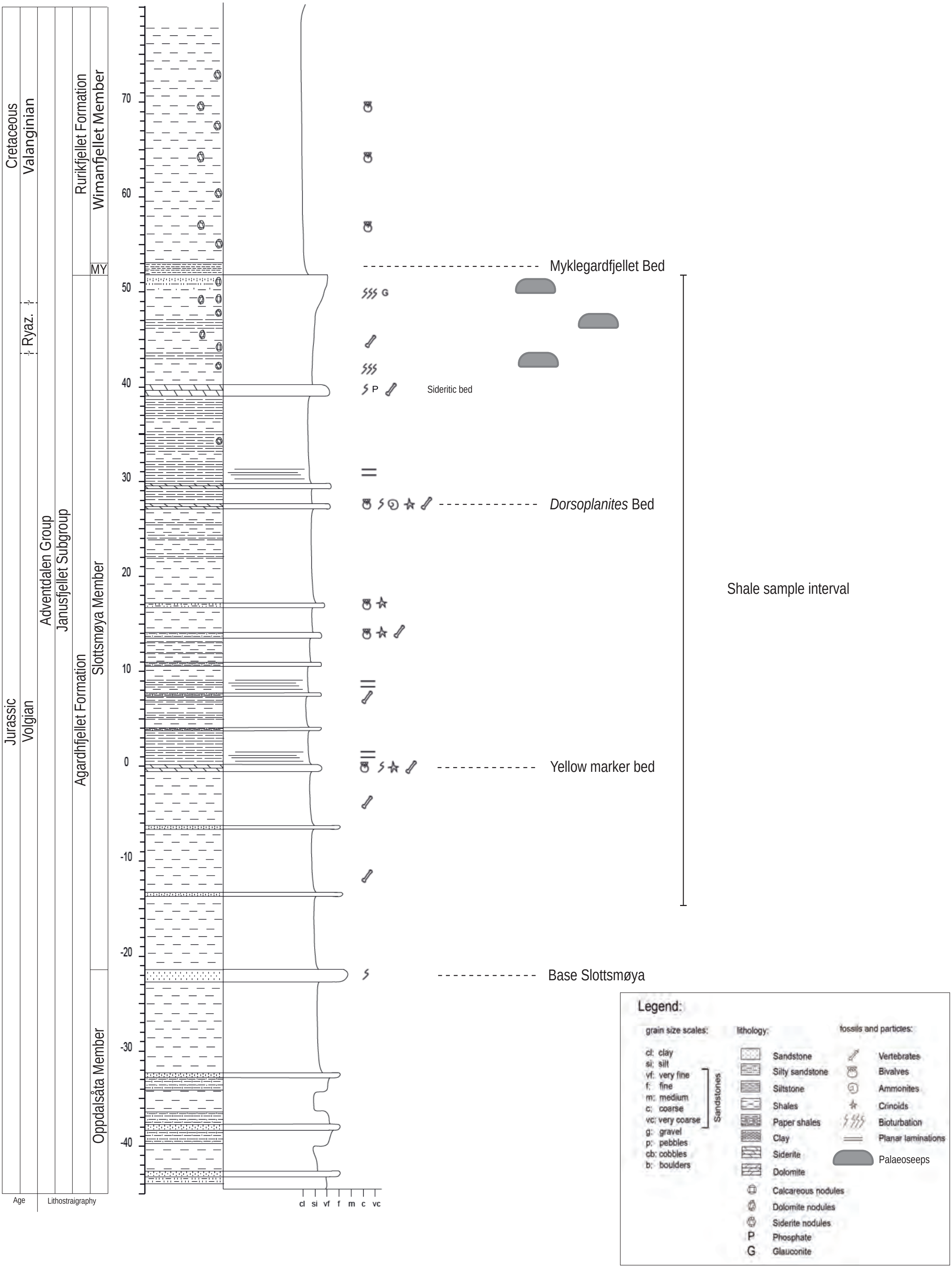
Plate 6. Specimens from shales adjacent to seep bodies, shown in reflected light. All scale bars are 100 µm. **1a-b.** *Schleiferella vallata*, PMO 221.579, from level A35.40m. **2a-b**. *Labrospira lenticulata*, PMO 221.580, from level A35.40m. **3a-b.** *Evolutinella volossatovi,* PMO 221.581, from level 33.02m. **4a-b.** *Haplophragmoides* aff. *incognitus*, PMO 221.582, from level A35.4m. **5a-b.** *Trochammina* aff. *misinovi*, PMO 221.583, from level A35.40m. **6a-b.** *Trochammina praerosacea*, PMO 221.584, from level -2.55m. **7a-b.** *Trochammina praerosacea*, PMO 221.585 from level -2.55m. **8a-b.** *Trochammina septentrionalis*, PMO 221.587, from level 14.44m. **9a-b.** *Trochammina praerosacea*, PMO 221.586, from level 14.44m. **10a-b.** *Trochammina* aff. *kosyrevae*, PMO 221.588, from level 14.44m**. 11a-b .** *Trochammina* aff. *kosyrevae*, PMO 221.589, from level 14.44m.

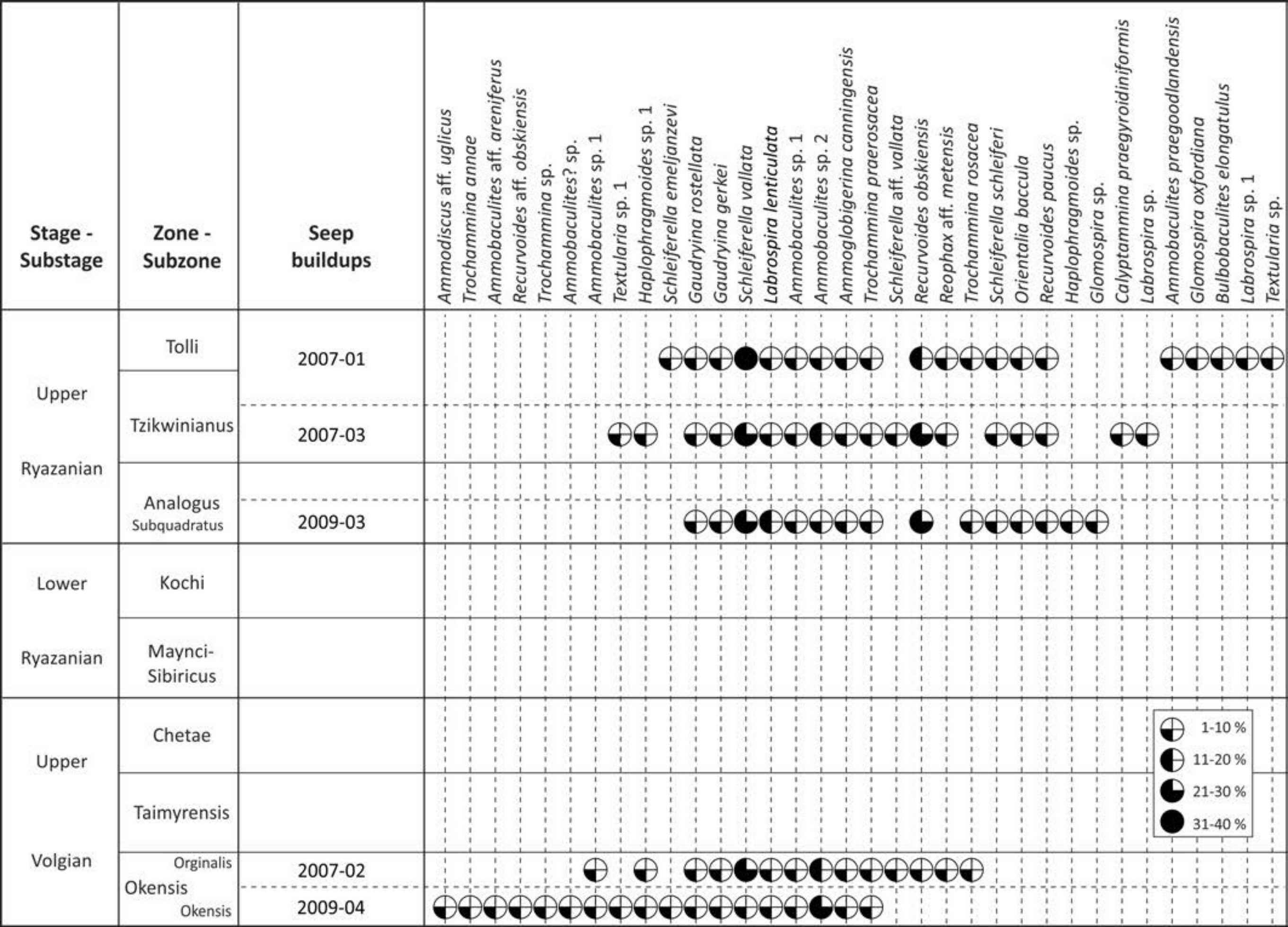
Plate 7. Specimens from shales adjacent to seep bodies, shown in reflected light. All scale bars are 100 µm. **1a-b.** *Recurvoides obskiensis*, PMO 221.590, from level A37.5m. **2.** *Recurvoides obskiensis*, PMO 221.591, from level A41.10m. **3a-b.** *Agardhella placula*, PMO 221.592, from level -2.55m. **4a-b**. *Calyptammina praegyroidiniformis*, PMO 221.593, from level 33.02m. **5a-b.** *Calyptammina praegyroidiniformis*, PMO 221.594, from level 33.02m. **6a-b.** *Bulbobaculites elongatulus*, PMO 221.595, from level A35.40m. **7a-b.** *Kutsevella pseudogoodlandensis*, PMO 221.596, from level A41.10m. **8a-b.** *Gaudryina rostellata*, PMO 221.597, from level A41.10m. **9.** *Gaudryina gerkei*, PMO 221.598, from level A41.10m. **10a-b.** *Ammodiscus zaspelovae*, PMO 221.559, from level 33.02m. **11.**

Arenoturrispirillina jeletskyi, PMO 221.600, from level -2.55m. **12.** *Ammodiscus* aff. *uglicus*, PMO 221.601, from level -2.55m.


10°E
30°E
78°N
74°N
70°N
Study area
Spits-bergen
Bjørnøya
Barents Sea
Norway
Seep sites
Shale section
N
1 km
Sassenfjorden
Diabasodden
De Geerdalen
2009-04
2009-03
Janusfjellet
Wimanfjellet
2007-01
2007-03
2007-02
Knorringfjellet
Helvetiafjellet Fm. (Barremian) and overlying units
Rurikfjellet Fm. (Ryazanian–Hauterivian)
Agardhfjellet Fm. (Callovian–Ryazanian)
Knorringfjellet Fm. (Norian–Bathonian)
De Geerdalen Fm. (Carnian–Norian) and underlying units

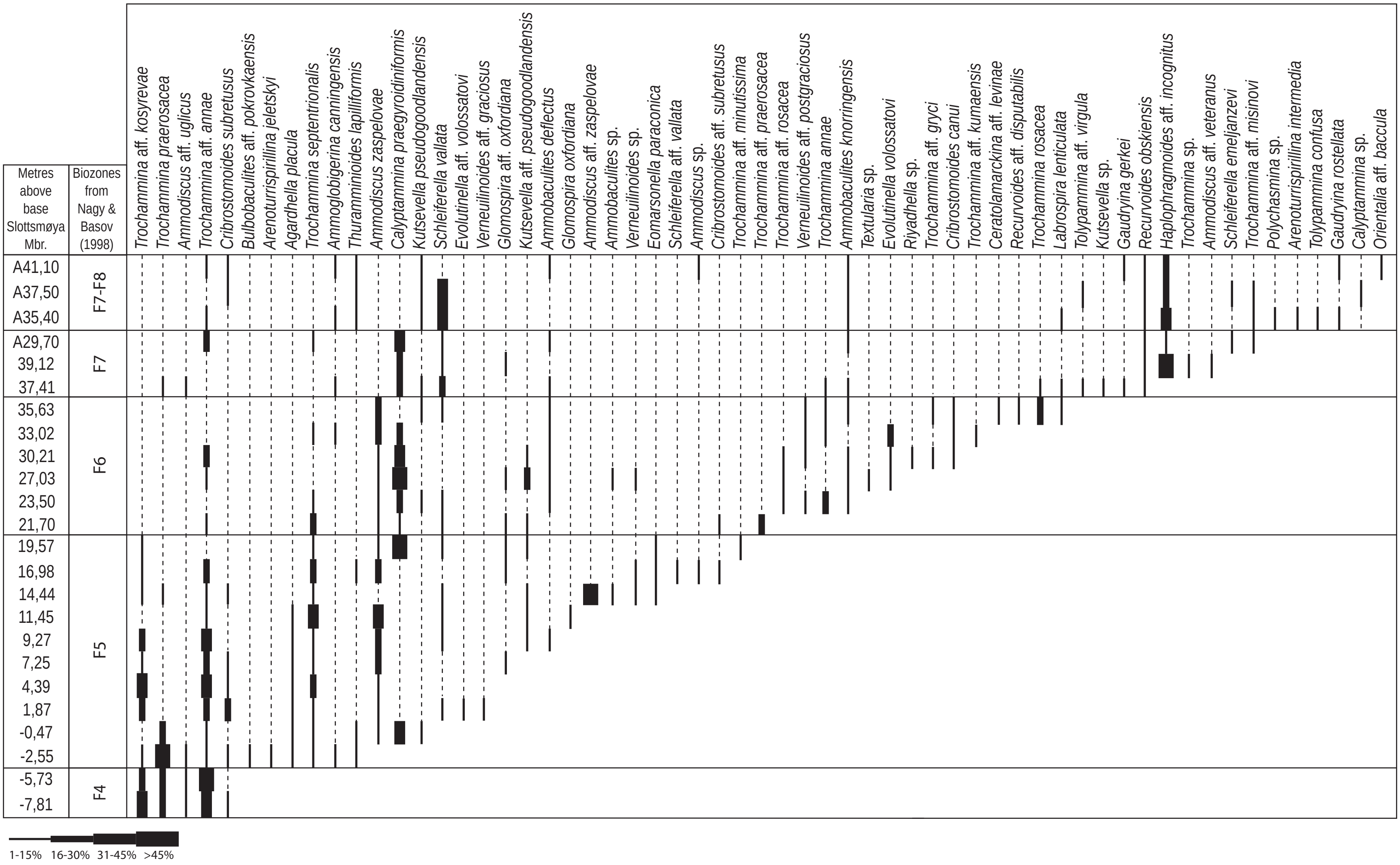

Ma
Age (Ogg and Hinnov 2012)
Boreal zonation
Lithostratigraphy (Mørk et al. 1999)
Revised age (Wierzbowski et al. 2011)
130
140
150
160
Cretaceous
Early (pars.)
Hauterivian
Valanginian
Berriasian
Jurassic
Late
Middle
Tithonian
Kimmeridgian
Oxfordian
Callovian
Bathonian
Ryazanian
Volgian
Adventdalen Group (pars.)
Janusfjellet Subgroup
Rurikfjellet Fm.
Agardhfjellet Fm.
Ullaberget Mbr.
Wimanfjellet Mbr.
Myklegardfjellet Bed
Slottsmøya Mbr.
Oppdalssåta Mbr.
Lardyfjellet Mbr.
Oppdalen Mbr.
Kapp Toscana Group (pars.)
Wimanfjellet Mbr.
?
Myklegardfjellet Bed
?
Slottsmøya Member


Cretaceous
Valanginian
Jurassic
Volgian
Ryaz.
Adventdalen Group
Janusfjellet Subgroup
Rurikfjellet Formation
Wimanfjellet Member
MY
Agardhfjellet Formation
Slottsmøya Member
Oppdalsåta Member
Age
Lithostraigraphy
70
60
50
40
30
20
10
0
-10
-20
-30
-40
cl si vf f m c vc
G
P
Sideritic bed
Myklegardfjellet Bed
Dorsoplanites Bed
Yellow marker bed
Base Slottsmøya
Shale sample interval
Legend:
grain size scales:
cl: clay
si: silt
vf: very fine
f: fine
m: medium
c: coarse
vc: very coarse
g: gravel
p: pebbles
cb: cobbles
b: boulders
Sandstones
lithology:
Sandstone
Silty sandstone
Siltstone
Shales
Paper shales
Clay
Siderite
Dolomite
Calcareous nodules
Dolomite nodules
Siderite nodules
P Phosphate
G Glauconite
fossils and particles:
Vertebrates
Bivalves
Ammonites
Crinoids
Bioturbation
Planar laminations
Palaeoseeps

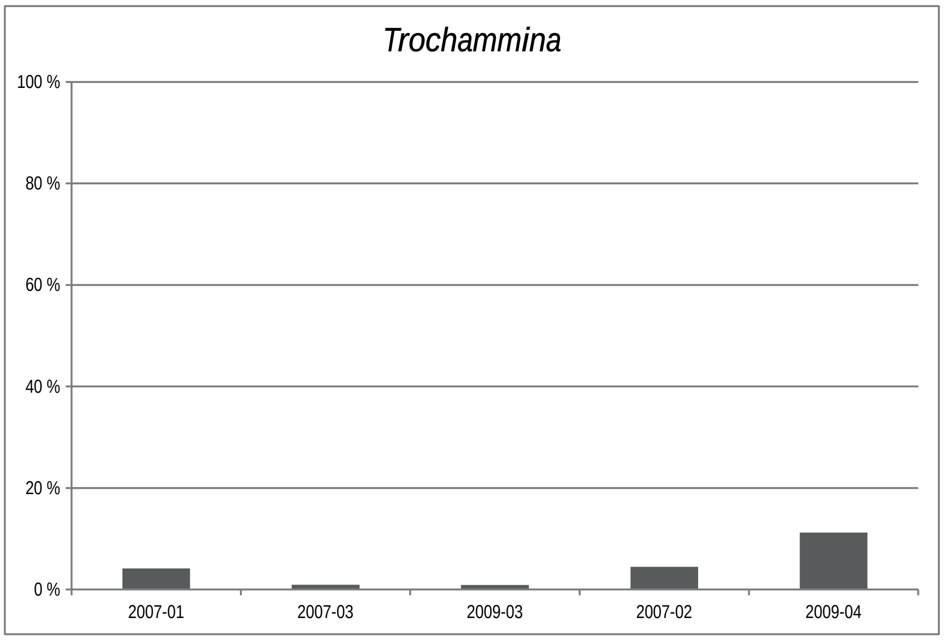


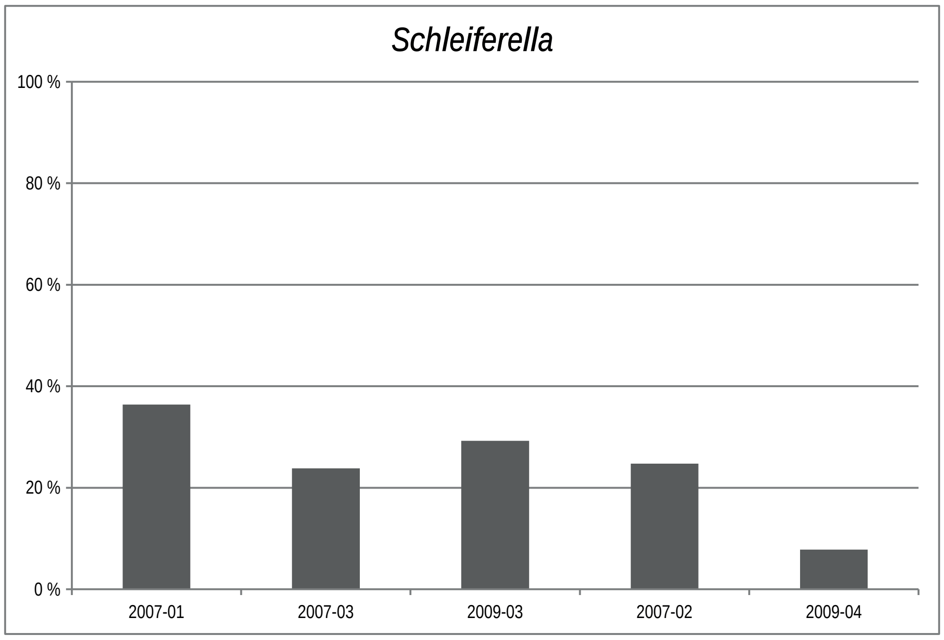
Stage - Substage	Zone - Subzone	Seep buildups	*Ammodiscus* aff. *uglicus*	*Trochammina annae*	*Ammobaculites* aff. *areniferus*	*Recurvoides* aff. *obskiensis*	*Trochammina* sp.	*Ammobaculites*? sp.	*Ammobaculites* sp. 1	*Textularia* sp. 1	*Haplophragmoides* sp. 1	*Schleiferella emeljanzevi*	*Gaudryina rostellata*	*Gaudryina gerkei*	*Schleiferella vallata*	*Labrospira lenticulata*	*Ammobaculites* sp. 1	*Ammobaculites* sp. 2	*Ammoglobigerina canningensis*	*Trochammina praerosacea*	*Schleiferella* aff. *vallata*	*Recurvoides obskiensis*	*Reophax* aff. *metensis*	*Trochammina rosacea*	*Schleiferella schleiferi*	*Orientalia baccula*	*Recurvoides paucus*	*Haplophragmoides* sp.	*Glomospira* sp.	*Calyptammina praegyroidiniformis*	*Labrospira* sp.	*Ammobaculites praegoodlandensis*	*Glomospira oxfordiana*	*Bulbobaculites elongatulus*	*Labrospira* sp. 1	*Textularia* sp.
Upper Ryazanian	Tolli	2007-01										◔	◔	◔	●	◔	◔	◔	◔	◔		◑	◔	◔	◔	◔	◔					◔	◔	◔	◔	◔
	Tzikwinianus	2007-03								◔	◔		◔	◔	◕	◔	◔	◑	◔	◔	◔	◕	◔		◔	◔	◔			◔	◔					
	Analogus Subquadratus	2009-03											◔	◔	◕	◑	◔	◔	◔	◔		◕		◔	◔	◔	◔	◔	◔							
Lower Ryazanian	Kochi																																			
	Maynci-Sibiricus																																			
Upper Volgian	Chetae																																			
	Taimyrensis																																			
	Okensis Orginalis	2007-02							◔		◔		◔	◔	◕	◔	◔	◑	◔	◔	◔	◔	◔	◔												
	Okensis Okensis	2009-04	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔	◑	◔	◔																

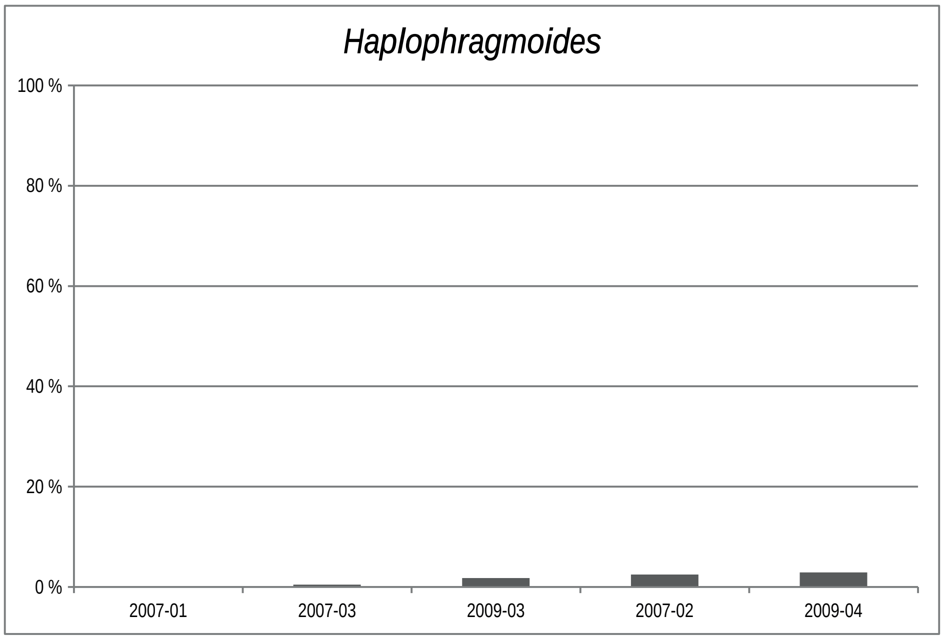
◔ 1-10 %
◑ 11-20 %
◕ 21-30 %
● 31-40 %

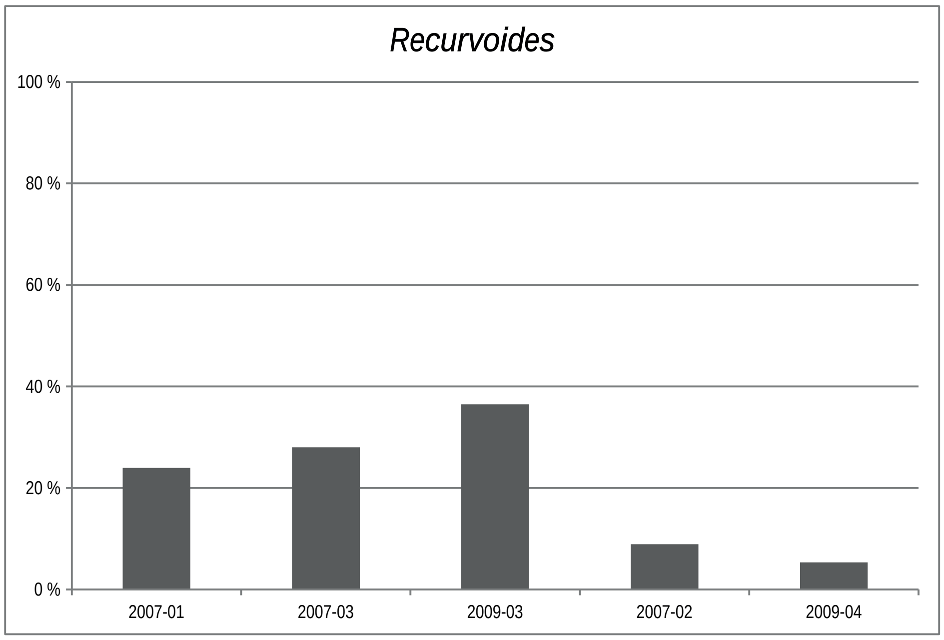

Metres above base Slottsmøya Mbr.
Biozones from Nagy & Basov (1998)
Trochammina aff. *kosyrevae*
Trochammina praerosacea
Ammodiscus aff. *uglicus*
Trochammina aff. *annae*
Cribrostomoides subretusus
Bulbobaculites aff. *pokrovkaensis*
Arenoturrispirillina jeletskyi
Agardhella placula
Trochammina septentrionalis
Ammoglobigerina canningensis
Thuramminoides lapilliformis
Ammodiscus zaspelovae
Calyptammina praegyroidiniformis
Kutsevella pseudogoodlandensis
Schleiferella vallata
Evolutinella aff. *volossatovi*
Verneuilinoides aff. *graciosus*
Glomospira aff. *oxfordiana*
Kutsevella aff. *pseudogoodlandensis*
Ammobaculites deflectus
Glomospira oxfordiana
Ammodiscus aff. *zaspelovae*
Ammobaculites sp.
Verneuilinoides sp.
Eomarsonella paraconica
Schleiferella aff. *vallata*
Ammodiscus sp.
Cribrostomoides aff. *subretusus*
Trochammina aff. *minutissima*
Trochammina aff. *praerosacea*
Trochammina aff. *rosacea*
Verneuilinoides aff. *postgraciosus*
Trochammina annae
Ammobaculites knorringensis
Textularia sp.
Evolutinella volossatovi
Riyadhella sp.
Trochammina aff. *gryci*
Cribrostomoides canui
Trochammina aff. *kumaensis*
Ceratolamarckina aff. *levinae*
Recurvoides aff. *disputabilis*
Trochammina rosacea
Labrospira lenticulata
Tolypammina aff. *virgula*
Kutsevella sp.
Gaudryina gerkei
Recurvoides obskiensis
Haplophragmoides aff. *incognitus*
Trochammina sp.
Ammodiscus aff. *veteranus*
Schleiferella emeljanzevi
Trochammina aff. *misinovi*
Polychasmina sp.
Arenoturrispirillina intermedia
Tolypammina confusa
Gaudryina rostellata
Calyptammina sp.
Orientalia aff. *baccula*
A41,10
A37,50
A35,40
F7-F8
A29,70
39,12
37,41
F7
35,63
33,02
30,21
27,03
23,50
21,70
F6
19,57
16,98
14,44
11,45
9,27
7,25
4,39
1,87
-0,47
-2,55
F5
-5,73
-7,81
F4
1-15%
16-30%
31-45%
>45%

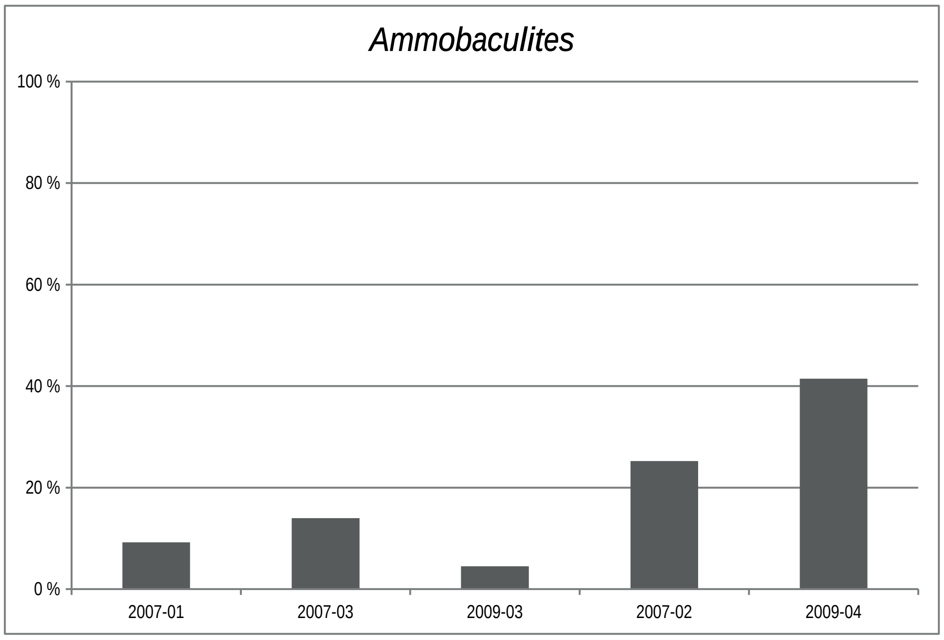
Seep samples

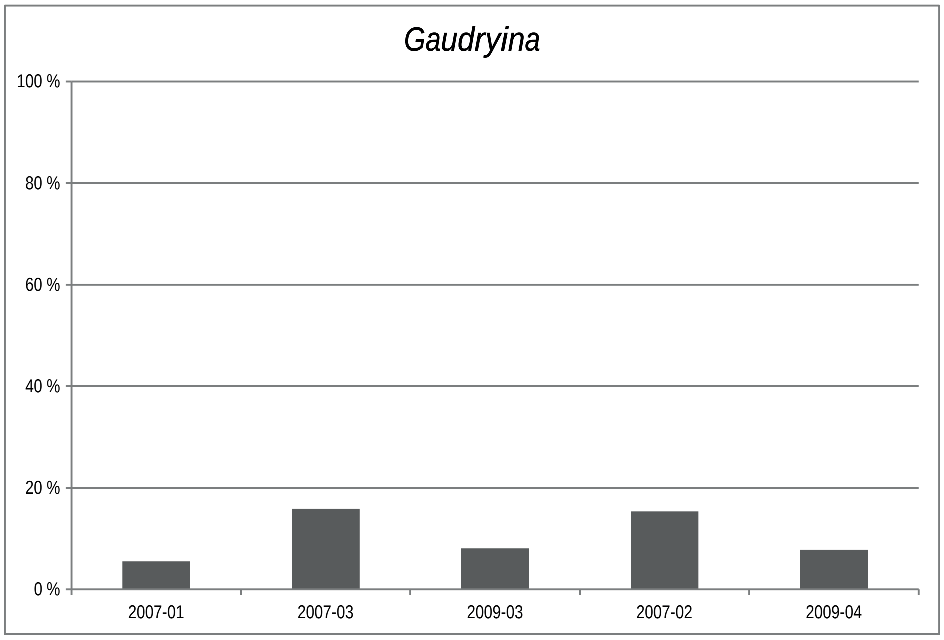




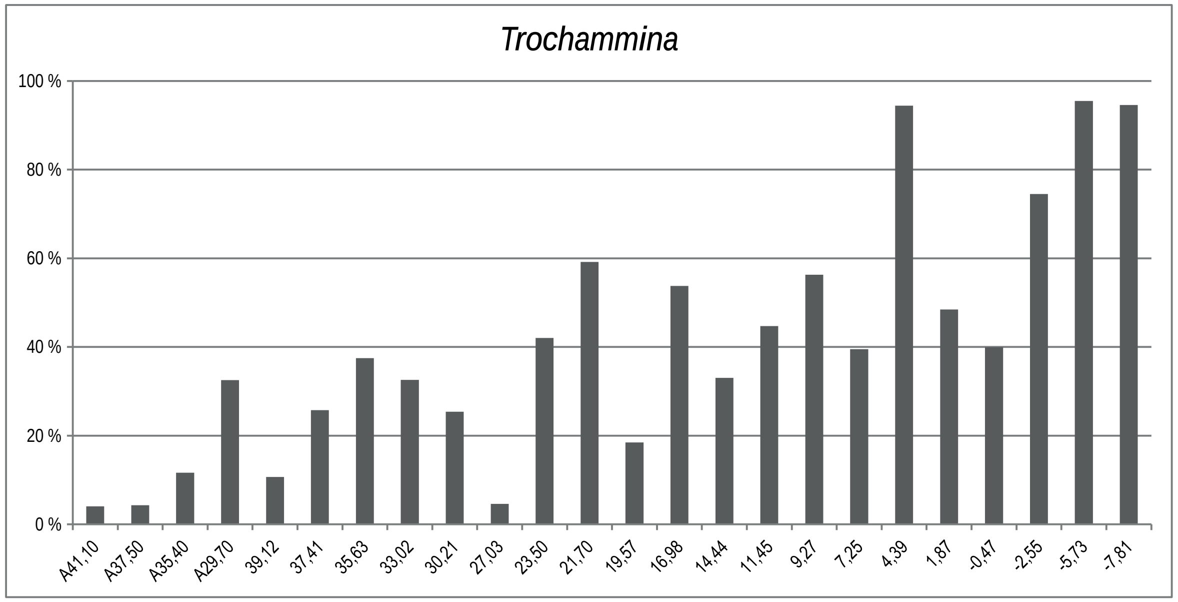


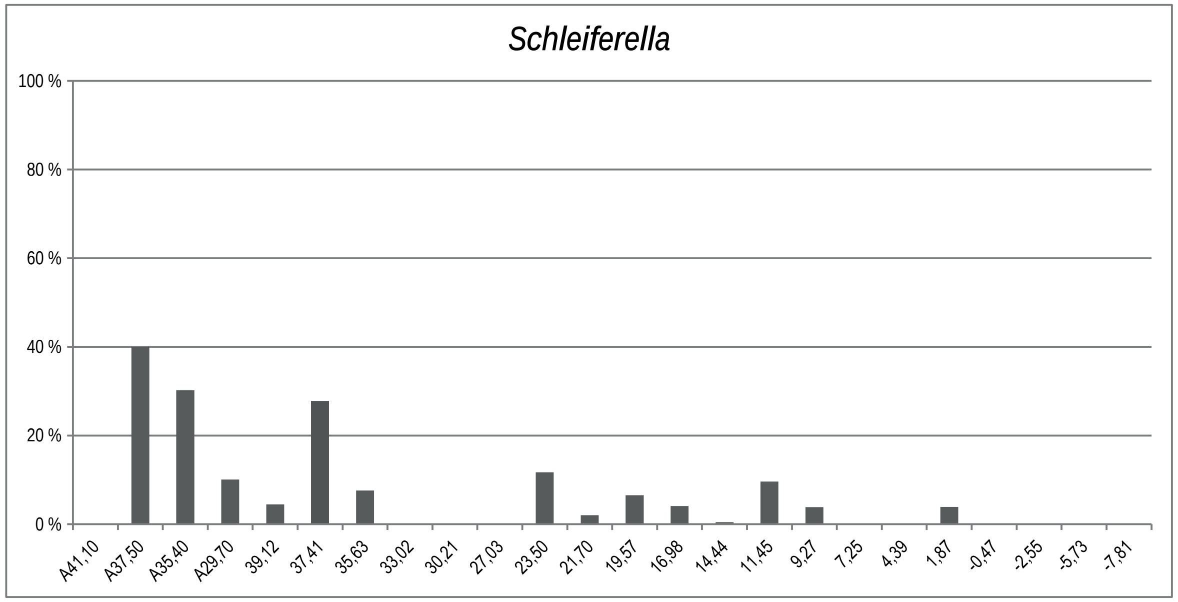


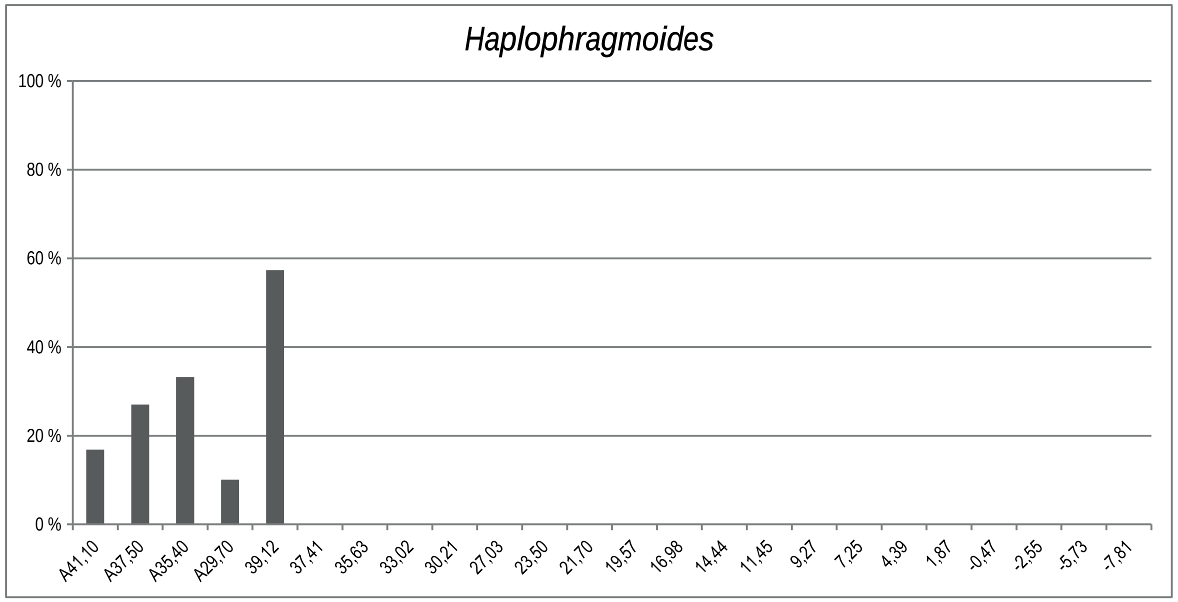


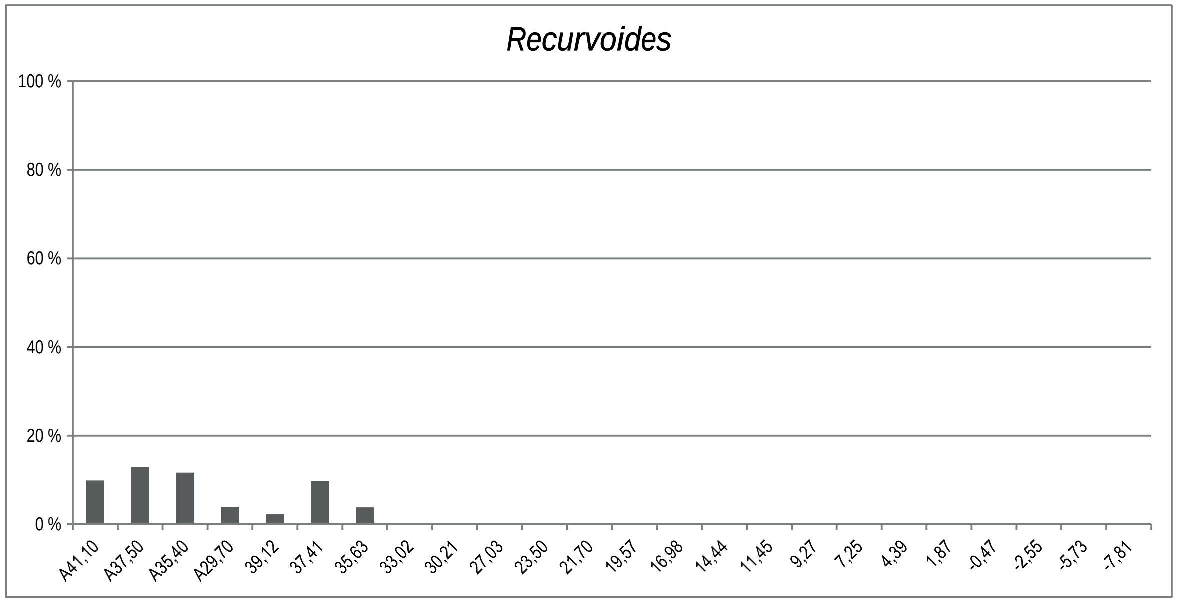


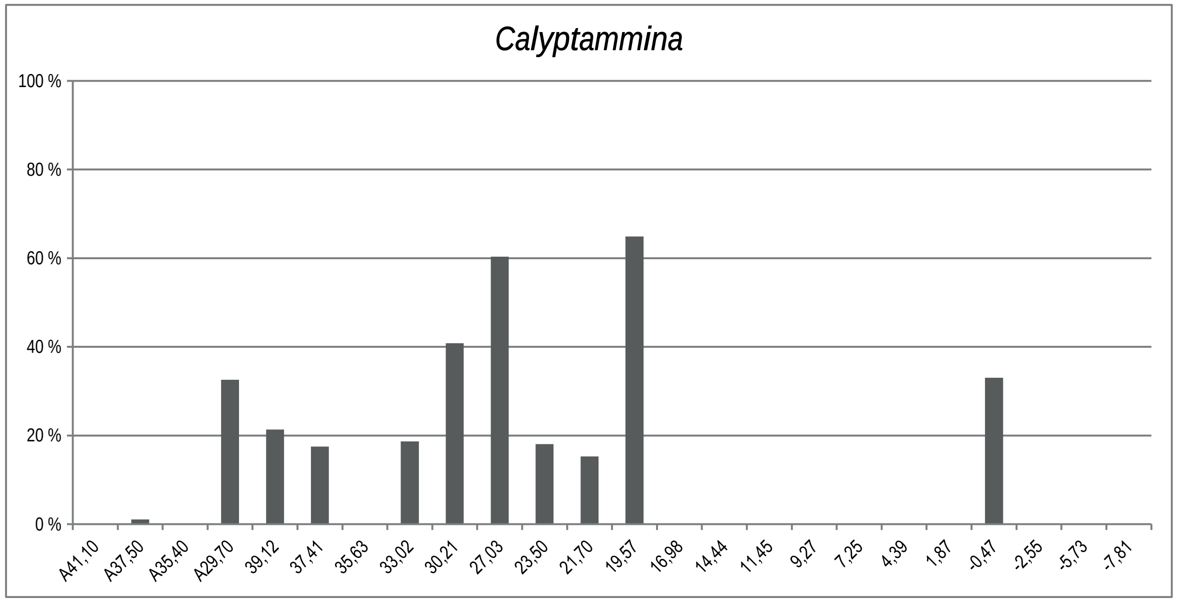
Shale samples

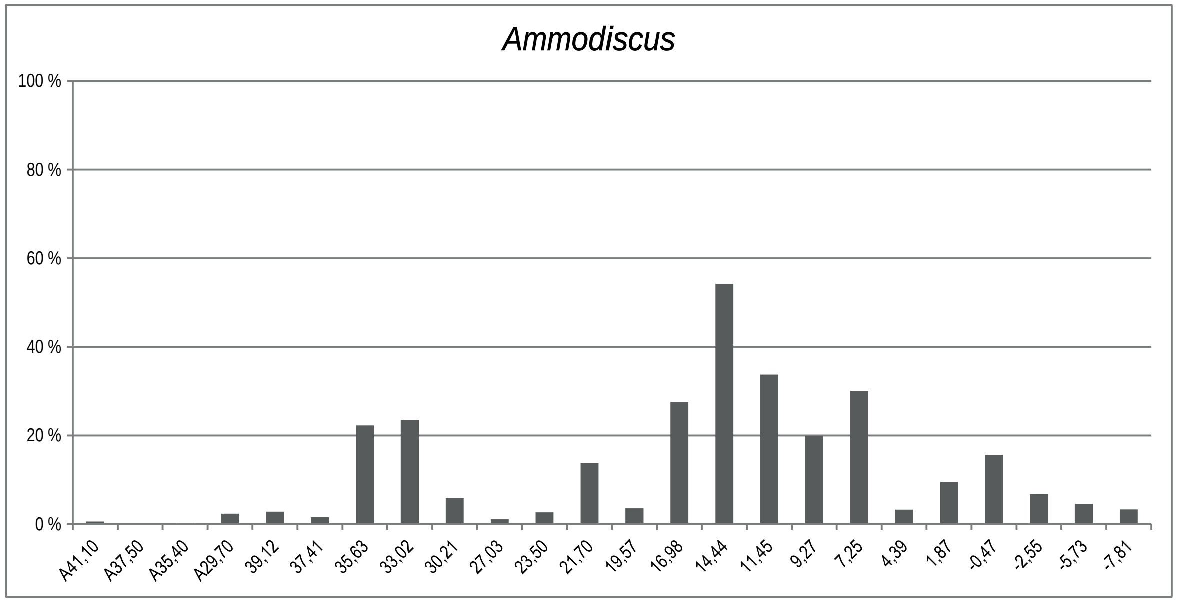

Trochammina

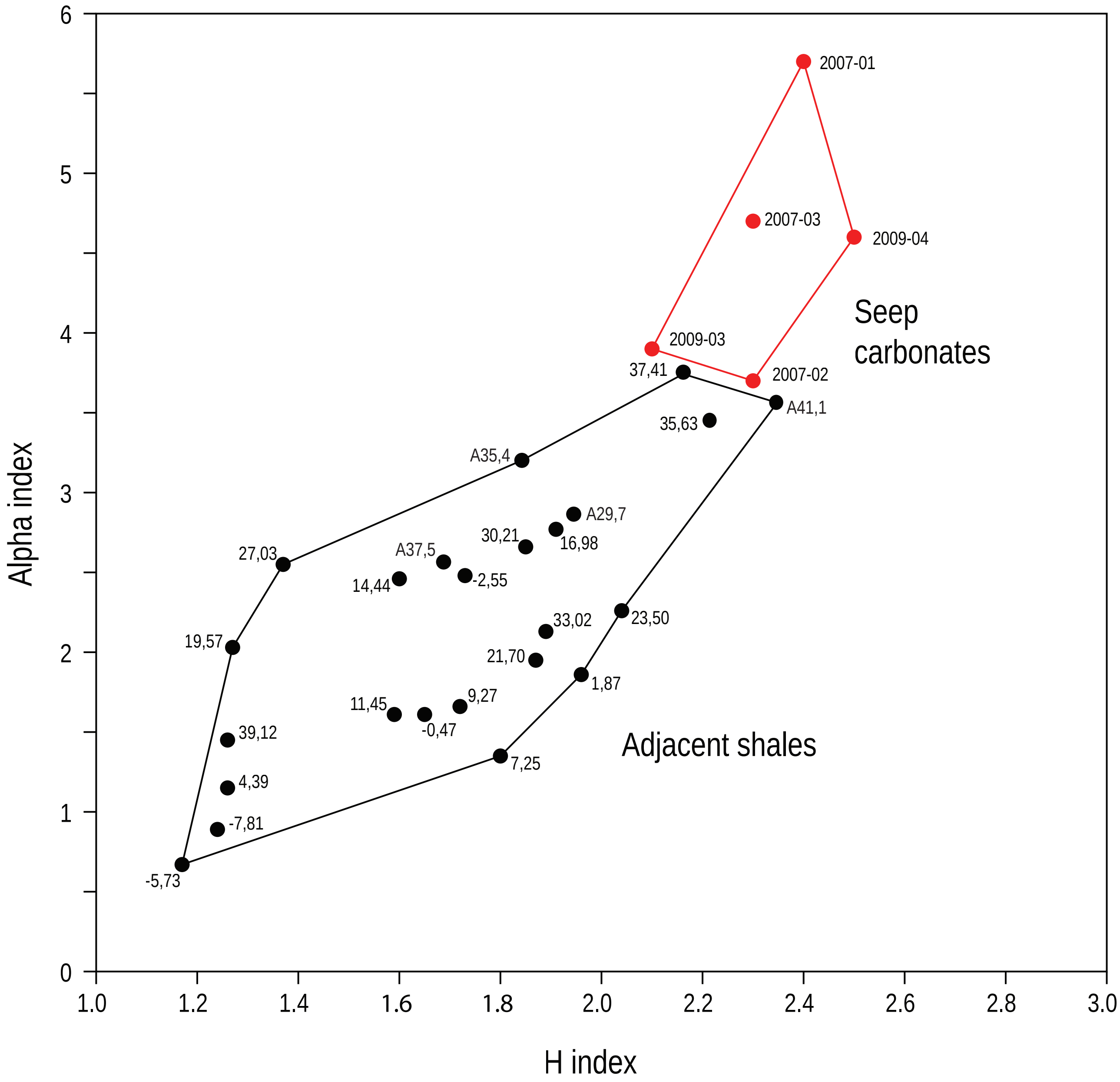

Schleiferella


Haplophragmoides

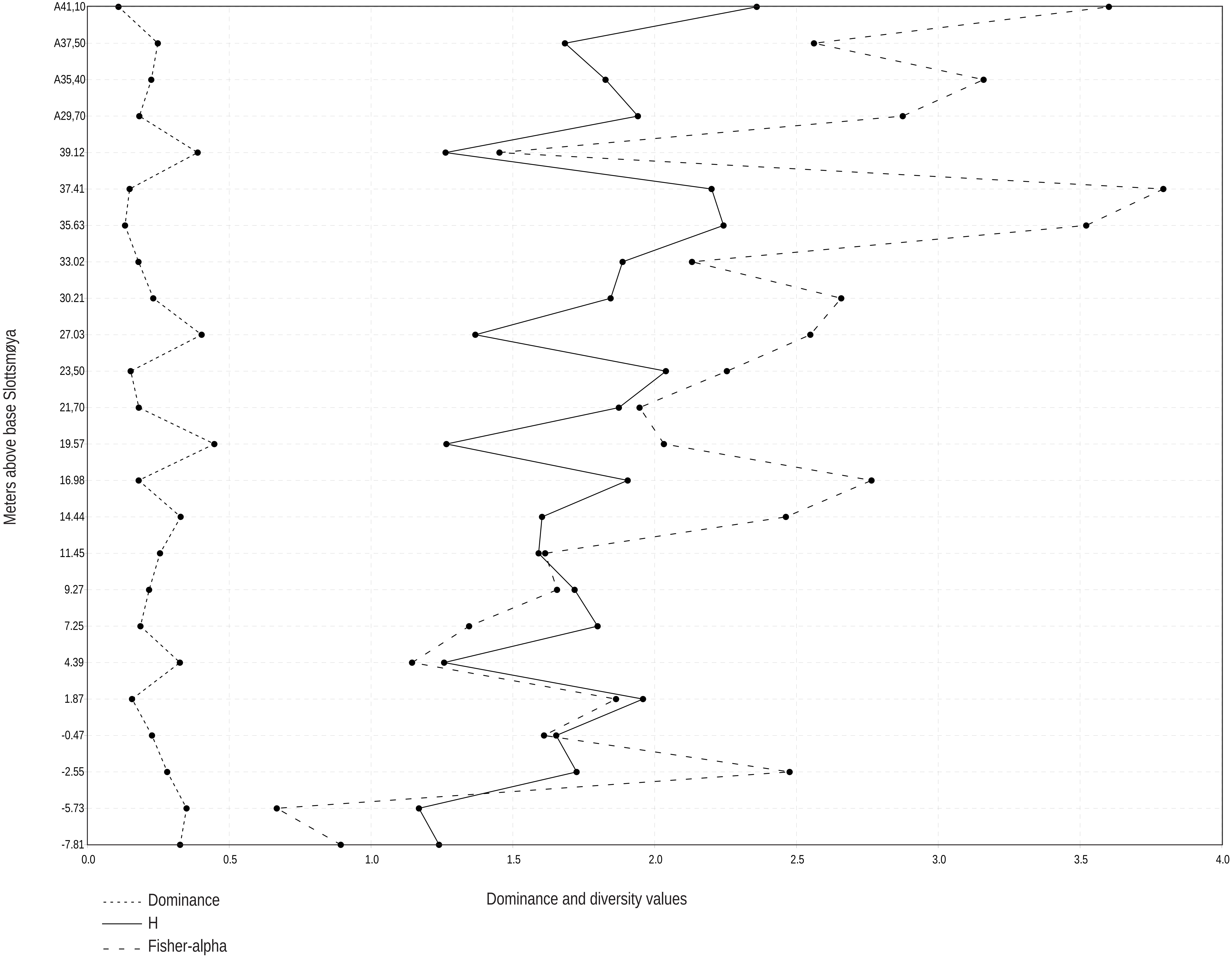

Recurvoides

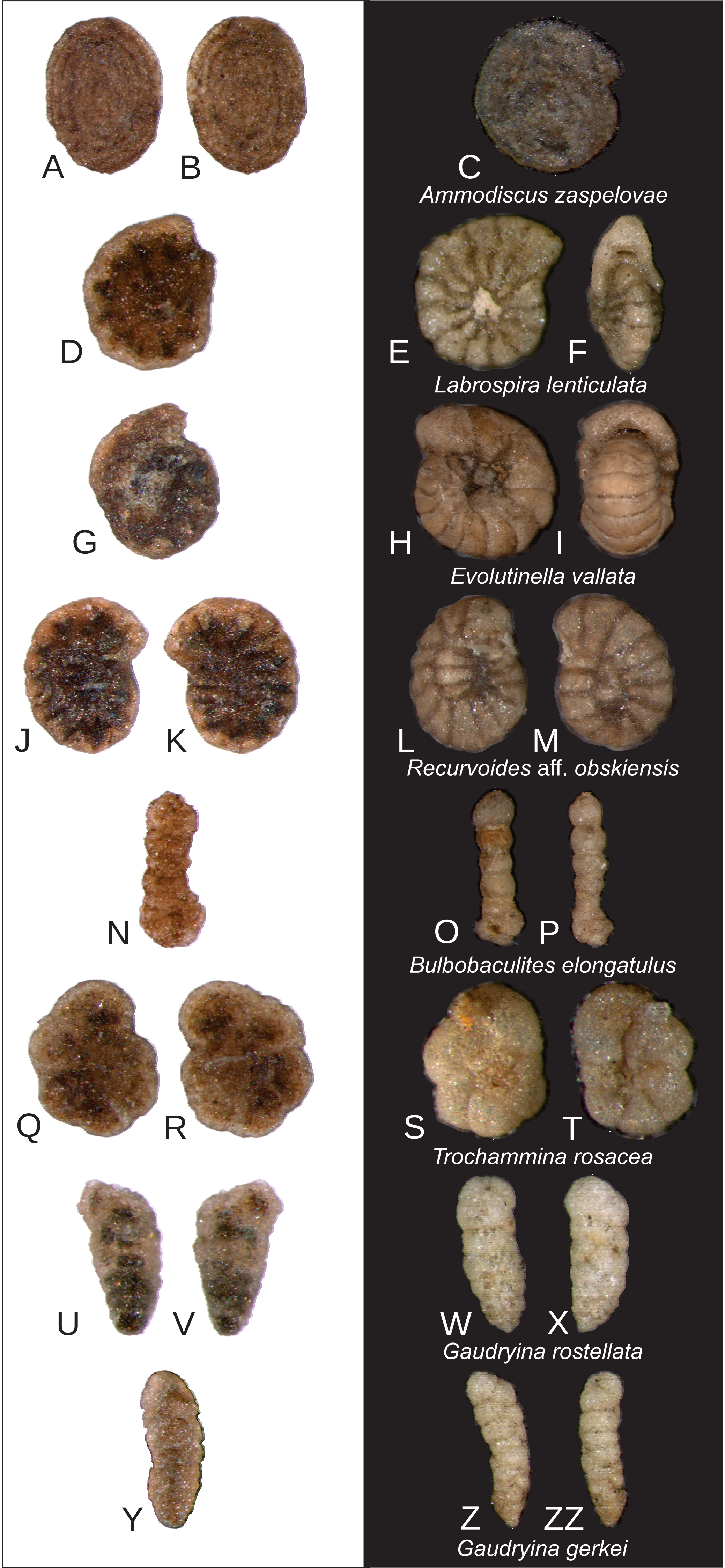

Calyptammina

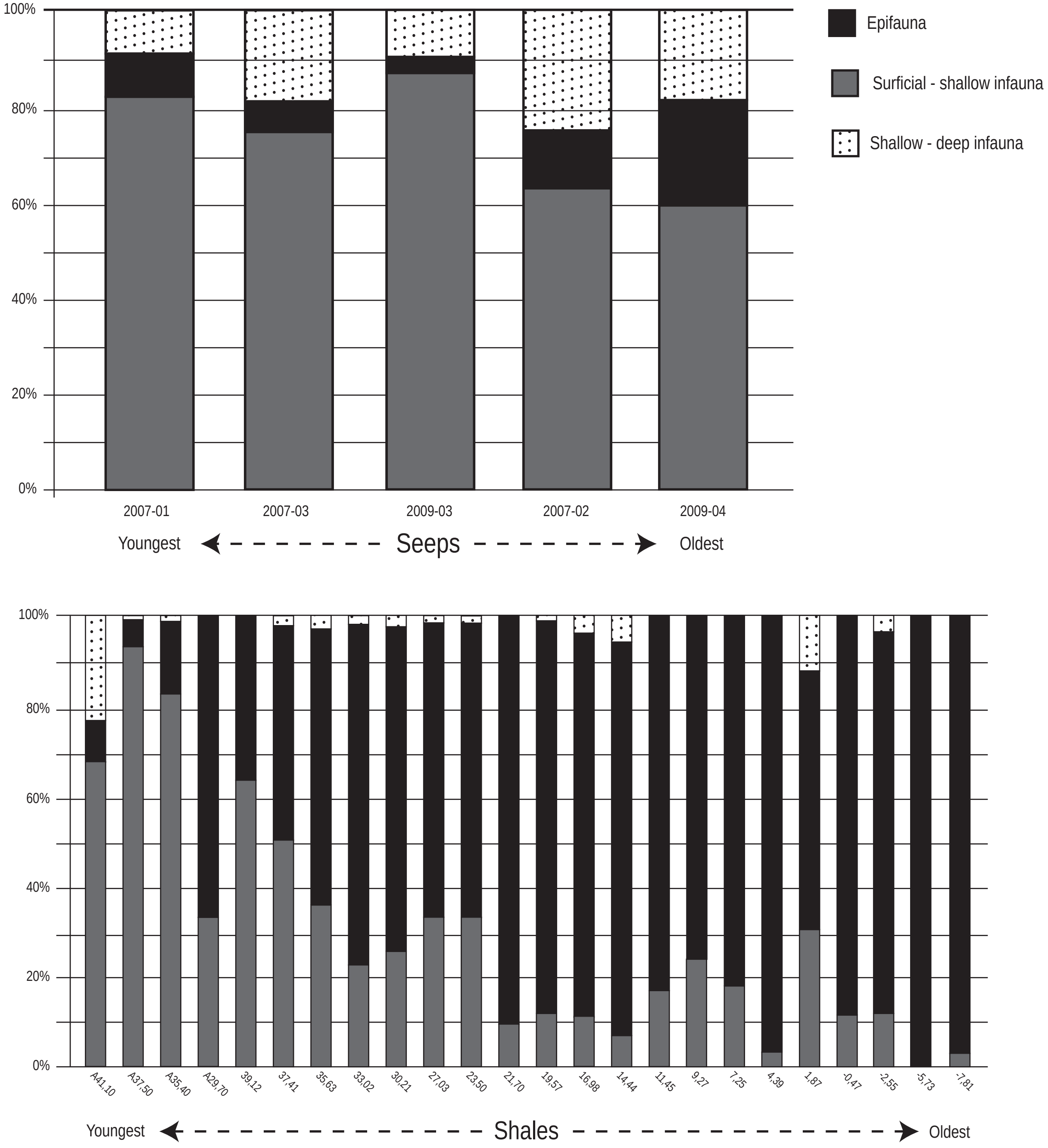

Ammodiscus



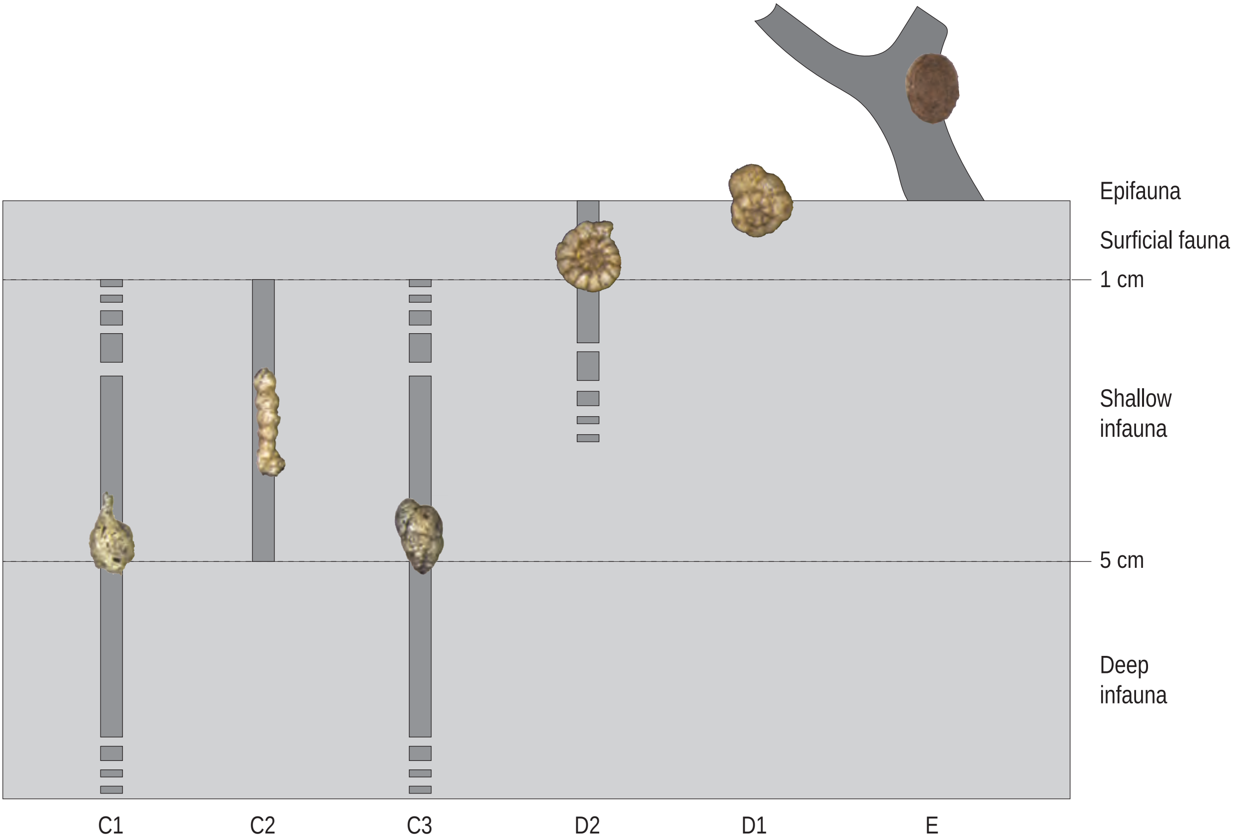
Alpha index
H index
0
1
2
3
4
5
6
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
2007-01
2007-03
2009-04
2009-03
2007-02
Seep carbonates
37,41
A41,1
35,63
A35,4
A29,7
30,21
16,98
27,03
A37,5
14,44
-2,55
33,02
23,50
19,57
21,70
1,87
11,45
9,27
-0,47
39,12
Adjacent shales
7,25
4,39
-7,81
-5,73

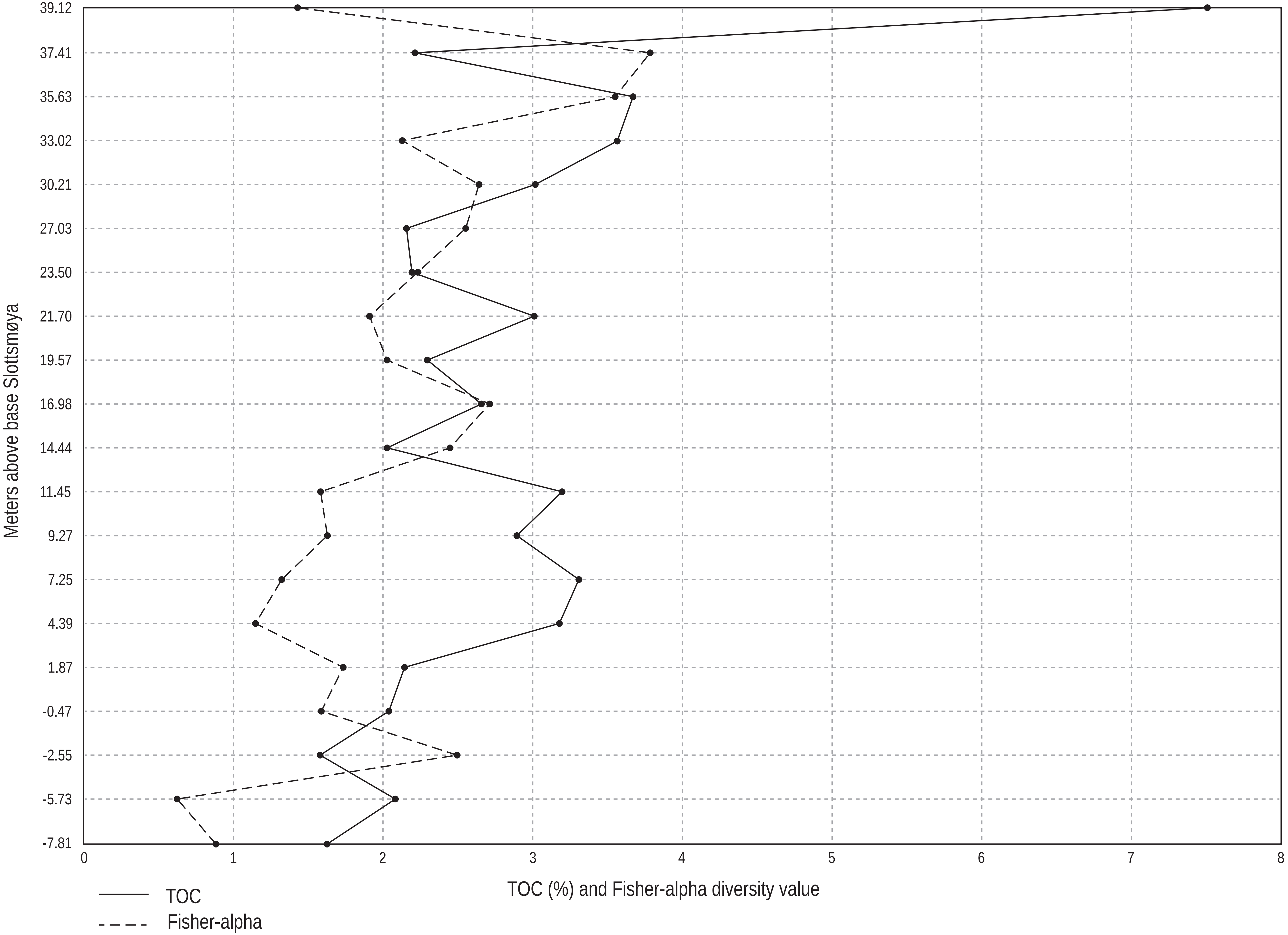

Meters above base Slottsmøya
A41,10
A37,50
A35,40
A29,70
39.12
37.41
35.63
33.02
30.21
27.03
23,50
21,70
19.57
16.98
14.44
11.45
9.27
7.25
4.39
1.87
-0.47
-2.55
-5.73
-7.81
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Dominance and diversity values
Dominance
H
Fisher-alpha


A
B
C
Ammodiscus zaspelovae
D
E
F
Labrospira lenticulata
G
H
I
Evolutinella vallata
J
K
L
M
Recurvoides aff. obskiensis
N
O
P
Bulbobaculites elongatulus
Q
R
S
T
Trochammina rosacea
U
V
W
X
Gaudryina rostellata
Y
Z
ZZ
Gaudryina gerkei



100%
80%
60%
40%
20%
0%
2007-01
2007-03
2009-03
2007-02
2009-04
Youngest
Seeps
Oldest
Epifauna
Surficial - shallow infauna
Shallow - deep infauna
100%
80%
60%
40%
20%
0%
A41,10
A37,50
A35,40
A29,70
39,12
37,41
35,63
33,02
30,21
27,03
23,50
21,70
19,57
16,98
14,44
11,45
9,27
7,25
4,39
1,87
-0,47
-2,55
-5,73
-7,81
Youngest
Shales
Oldest


Epifauna
Surficial fauna
1 cm
Shallow infauna
5 cm
Deep infauna
C1
C2
C3
D2
D1
E


Meters above base Slottsmøya
39.12
37.41
35.63
33.02
30.21
27.03
23.50
21.70
19.57
16.98
14.44
11.45
9.27
7.25
4.39
1.87
-0.47
-2.55
-5.73
-7.81
0
1
2
3
4
5
6
7
8
TOC (%) and Fisher-alpha diversity value
TOC
Fisher-alpha

Seep ID	Map coordinates	UTM coordinates	Seep ID used in Hammer et al. 2011; Hryniewicz et al. 2012; 2015	Meters above sea level	Age
2007-01	N78° 18.831' E16° 10.981'	33 X 526748 8693666	9	434	Late Ryazanian
2007-02	N78° 18.563' E16° 12.596'	33 X 527367 8693181	13	450	Late Volgian
2007-03	N78° 18.558' E16° 12.520'	33 X 527338 8693170	12	457	Late Ryazanian
2009-03	N78° 20.013' E15° 56.404'	33 X 521220 8695766	5	326	Late Ryazanian
2009-04	N78° 20.223' E15° 50.765'	33 X 519093 8696124	3	254	Late Volgian

Faunal components		Epifauna %	Surficial - shallow infauna %	Shallow - deep infauna %
Morphogroups		A, B, D1, E	C2, D2	C1, C3
Seeps	Average	10.8	73.7	15.6
	Range	2.9 - 22.4	60.0 - 87.9	8.8 - 23.9
Shales	Average	68.3	29.2	2.3
	Range	5.9 - 100	0.0 - 93.5	0.0 - 21.5

	2007-01		2007-03		2009-03		2007-02		2009-04	
Species	Count	%	Count	%	Count	%	Count	%	Count	%
Ammobaculites aff. *areniferus*									8	3,9
Ammobaculites deflectus	3	1,4	3	1,4	6	2,7	5	2,5	21	10,2
Ammobaculites knorringensis	12	5,5	27	12,6	4	1,8	36	17,8	55	26,8
Ammobaculites praegoodlandensis	5	2,3								
Ammobaculites sp. 1							10	5,0	1	0,5
Ammobaculites ? sp.									2	1,0
Ammodiscus aff. *uglicus*									1	0,5
Ammoglobigerina canningensis	10	4,6	11	5,1	3	1,4	17	8,4	22	10,7
Bulbobaculites elongatulus	5	2,3								
Calyptammina praegyroidiniformis			1	0,5						
Gaudryina gerkei	7	3,2	15	7,0	8	3,6	21	10,4	8	3,9
Gaudryina rostellata	5	2,3	19	8,9	10	4,5	10	5,0	8	3,9
Glomospira oxfordiana	1	0,5								
Glomospira sp.					1	0,5				
Haplophragmoides perlobatus			1	0,5			5	2,5	6	2,9
Haplophragmoides sp.					4	1,8				
Labrospira lenticulata	19	8,8	18	8,4	35	15,8	4	2,0	3	1,5
Labrospira sp.			1	0,5						
Labrospira sp. 1	3	1,4								
Orientalia baccula	1	0,5	1	0,5	3	1,4				
Recurvoides aff. *obskiensis*									11	5,4
Recurvoides obskiensis	41	18,9	51	23,8	66	29,7	18	8,9		
Recurvoides paucus	11	5,1	9	4,2	15	6,8				
Reophax pyriloculus	5	2,3	2	0,9			17	8,4		
Schleiferella aff. *vallata*			4	1,9			1	0,5		
Schleiferella emeljanzevi	2	0,9							6	2,9
Schleiferella vallata	66	30,4	41	19,2	47	21,2	49	24,3	10	4,9
Scleiferella schleiferi	11	5,1	6	2,8	18	8,1				
Textularia pernana			2	0,9					20	9,8
Textularia sp.	1	0,5								
Trochammina annae									6	2,9
Trochammina praerosacea	7	3,2	2	0,9	1	0,5	4	2,0	11	5,4
Trochammina rosacea	2	0,9			1	0,5	5	2,5		
Trochammina sp.									6	2,9
Sample	**2007-01**		**2007-03**		**2009-03**		**2007-02**		**2009-04**	
Individuals	217		214		222		202		205	
Taxa	21		18		16		15		18	
Dominance	0,14		0,14		0,17		0,12		0,11	
H	2,4		2,3		2,1		2,3		2,5	
Fisher alpha	5,7		4,7		3,9		3,7		4,6	

Meters above base Slottsmøya	**A41,10**		**A37,50**		**A35,40**		**A29,70**		**39,12**		**37,41**		**35,63**		**33,02**		**30,21**		**27,03**		**23,50**		**21,70**		**19,57**		**16,98**		**14,44**		**11,45**		**9,27**		**7,25**		**4,39**		**1,87**		**-0,47**		**-2,55**		**-5,73**		**-7,81**	
Species	Count	%	Count	%	Count	%	Count	%	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**
Agardhella placula																															8	3,5	10	4,9	20	8,2	3	1,4	21	9,1	11	4,8	15	7,2				
Ammobaculites *deflectus*	8	4,7	6	3,2			1	0,8			4	2,1	4	2,2	7	3,0	11	4,6	10	3,6	15	8,0											3	1,5														
Ammobaculites knorringensis	16	9,3			13	3,6	10	7,8			10	5,2	18	9,8			15	6,3	12	4,3	20	10,6																										
Ammobaculites sp.																			21	7,5									4	1,9																		
Ammodiscus aff. *uglicus*											3	1,6																															14	6,7	12	4,5	8	3,3
Ammodiscus aff. *veteranus*					1	0,3	3	2,3	5	2,8																																						
Ammodiscus aff. *zaspelovae*																													115	54,3																		
Ammodiscus sp.	1	0,6																									1	0,7																				
Ammodiscus zaspelovae													41	22,3	54	23,5	14	5,8	3	1,1	5	2,7	27	13,8	6	3,6	39	26,9			77	33,8	41	19,9	73	30,0	7	3,3	22	9,5	36	15,7						
Ammoglobigerina canningensis	8	4,7			8	2,2					2	1,0			3	1,3																											3	1,4				
Arenoturrispirillina intermedia					2	0,6																																										
Arenoturrispirillina jeletskyi																																											6	2,9				
Bulbobaculites aff. *pokrovkaensis*																																											2	1,0				
Calyptammina sp.			2	1,1																																												
Calyptammina praegyroidiniformis							42	32,6	38	21,4	34	17,5			43	18,7	98	40,8	169	60,4	34	18,1	30	15,3	109	64,9															76	33,0						
Ceratolamarckina aff. *levinae*													2	1,1																																		
Cribrostomoides aff. *subretusus*																							4	2,0			9	6,2																				
Cribrostomoides canui													9	4,9	8	3,5	14	5,8																														
Cribrostomoides subretusus	20	11,6	3	1,6																									5	2,4					25	10,3	2	0,9	39	16,9			6	2,9			5	2,1
Eomarsonella paraconica																									1	0,6	1	0,7	3	1,4																		
Evolutinella aff. *volossatovi*																																							1	0,4								
Evolutinella volossatovi															37	16,1	3	1,3	1	0,4																												
Gaudryina gerkei	6	3,5									3	1,6																																				
Gaudryina rostellata	24	14,0			1	0,3																																										
Glomospira aff. *oxfordiana*									2	1,1									1	0,4			4	2,0	2	1,2	6	4,1							29	11,9												
Glomospira oxfordiana																															7	3,1																
Haplophragmoides aff. *incognitus*	29	16,9	50	27,0	120	33,2	13	10,1	102	57,3																																						
Kutsevella aff. *pseudogoodlandensis*																	19	7,9	47	16,8			11	5,6	8	4,8			5	2,4	11	4,8	28	13,6														
Kutsevella pseudogoodlandensis	25	14,5	16	8,7	6	1,7					1	0,5	3	1,6							12	6,4																			14	6,1						
Kutsevella sp.											7	3,6																																				
Labrospira lenticulata					12	3,3					3	1,6	12	6,5																																		
Orientalia aff. *baccula*	2	1,2																																														
Polychasmina spp.					1	0,3																																										
Recurvoides aff. *disputabilis*													7	3,8																																		
Recurvoides obskiensis	17	9,9	24	13,0	42	11,6	5	3,9	4	2,3	19	9,8																																				
Riyadhella sp.																	1	0,4																														
Schleiferella aff. *vallata*																											6	4,1																				
Schleiferella emeljanzevi			3	1,6			1	0,8																																								
Schleiferella vallata			71	38,4	109	30,2	12	9,3	8	4,5	54	27,8	14	7,6							22	11,7	4	2,0	11	6,6			1	0,5	22	9,7	8	3,9					9	3,9								
Textularia sp.																			1	0,4																												
Thuramminoides lapilliformis	5	2,9	1	0,5	1	0,3																					1	0,7													1	0,4	7	3,4				
Tolypammina aff. *virgula*			1	0,5							4	2,1																																				
Tolypammina confusa					3	0,8																																										
Trochammina aff. *annae*	7	4,1			18	5,0	24	18,6									51	21,3	9	3,2			20	10,2			28	19,3	24	11,3	24	10,5	72	35,0	50	20,6	87	40,5	51	22,1	26	11,3	24	11,5	130	48,9	100	41,7
Trochammina aff. *gryci*													7	3,8			3	1,3																														
Trochammina aff. *kosyrevae*																									22	13,1	19	13,1	24	11,3			37	18,0	35	14,4	77	35,8	49	21,2			25	12,0	61	22,9	82	34,2
Trochammina aff. *kumaensis*															5	2,2																																
Trochammina aff. *misinovi*			8	4,3	24	6,7	16	12,4																																								
Trochammina aff. *minutissima*																									5	3,0																						
Trochammina aff. *praerosacea*																							39	19,9																								
Trochammina aff. *rosacea*																	7	2,9	4	1,4	19	10,1																										
Trochammina annae											23	11,9	30	16,3	55	23,9					50	26,6																										
Trochammina praerosacea											8	4,1																	12	5,7											63	27,4	102	49,0	63	23,7	45	18,8
Trochammina rosacea											19	9,8	32	17,4																																		
Trochammina septentrionalis							2	1,6							15	6,5					10	5,3	57	29,1	4	2,4	31	21,4	10	4,7	78	34,2	7	3,4	11	4,5	39	18,1	12	5,2	3	1,3	4	1,9				
Trochammina sp.									19	10,7																																						
Verneuilinoides aff. *graciosus*																																							27	11,7								
Verneuilinoides aff. *postgraciosus*													4	2,2	3	1,3	4	1,7			1	0,5																										
Verneuilinoides sp.																			2	0,7							4	2,8	9	4,3																		

Sample	**A41,10**	**A37,50**	**A35,40**	**A29,70**	**39,12**	**37,41**	**35,63**	**33,02**	**30,21**	**27,03**	**23,50**	**21,70**	**19,57**	**16,98**	**14,44**	**11,45**	**9,27**	**7,25**	**4,39**	**1,87**	**-0,47**	**-2,55**	**-5,73**	**-7,81**	**Min**	**Max**	**Mean**
Individuals	168	185	361	129	178	194	183	230	240	280	188	196	168	145	212	227	206	243	215	231	230	208	266	240	145	280	214,0
Taxa	14	11	15	11	7	15	14	10	12	12	10	9	9	11	11	8	8	7	6	9	8	11	4	5	4,0	15,0	9,9
Dominance	0,11	0,25	0,23	0,18	0,39	0,15	0,13	0,18	0,23	0,40	0,15	0,18	0,45	0,18	0,33	0,26	0,22	0,19	0,33	0,16	0,23	0,28	0,35	0,33	0,11	0,45	0,24
H	2,36	1,68	1,83	1,94	1,26	2,20	2,24	1,89	1,85	1,37	2,04	1,87	1,27	1,91	1,60	1,59	1,72	1,80	1,26	1,96	1,65	1,73	1,17	1,24	1,17	2,36	1,73
Fisher alpha	3,60	2,56	3,16	2,88	1,45	3,79	3,52	2,13	2,66	2,55	2,26	1,95	2,03	2,77	2,46	1,61	1,66	1,35	1,15	1,86	1,61	2,48	0,67	0,89	0,67	3,79	2,21

Taxon	**Seep**	**Shale**	**Figured**	**Morpho-group**
Agardhella placula Nagy & Basov 1998		X	Plate 7 figs 3a-b	C2
Ammobaculites aff. *areniferus* Nagy & Basov 1998	X			C2
Ammobaculites praegoodlandensis Bulynnikova 1972	X		Plate 3 figs 5a-c	C2
Ammobaculites sp.		X		C2
Ammobaculites deflectus n. sp.	X	X	Plate 2 figs 5a-b, 6a-b, 7a-b, 8a-b, 9a-b Plate 5 fig. 7	C2
Ammobaculites knorringensis n. sp.	X	X	Plate 3 figs 1a-b, 2a-b, 3a-b, 4a-b Plate 5 figs 8-9	C2
Ammobaculites sp. 1	X		Plate 3 figs 7a-c	C2
Ammodiscus aff. *uglicus* Ehreemeva 1972	X	X	Plate 7 fig. 12	E
Ammodiscus aff. *veteranus* Kosyreva 1972		X		E
Ammodiscus aff. *zaspelovae* 1972		X		E
Ammodiscus sp.		X		E
Ammodiscus zaspelovae Kosyreva 1972		X	Plate 7 figs 10a-b	E
Ammoglobigerina canningensis (Tappan 1955)	X	X	Plate 4 figs 3a-c Plate 5 fig. 14	D1
Arenoturrispirillina intermedia Chamney 1971		X		E
Arenoturrispirillina jeletskyi Chamney 1971		X	Plate 7 fig. 11	E
Bulbobaculites aff. *pokrovkaensis* Kosyreva 1972		X		C2
Bulbobaculites elongatulus (Dain 1972)	X		Plate 3 figs 6a-b Plate 7 figs 6a-b	C2
Calyptammina praegyroidiniformis (Bystrova & Kossitskaja 1984)	X	X	Plate 7 figs 4a-b, 5a-b	D1
Calyptammina sp.		X		D1
Ceratolamarckina aff. *levinae* Dain 1980		X		E
Cribrostomoides aff. *subretusus* Nagy & Basov 1998		X		D2
Cribrostomoides canui (Cushman 1929)		X		D2
Cribrostomoides subretusus Nagy & Basov 1998		X		D2
Eomarssonella paraconica Levina 1972		X		C3
Evolutinella aff. *volossatovi* (Sharovskaja 1966)		X		D2
Evolutinella volossatovi (Sharovskaja 1966)		X	Plate 6 figs 3a-b	D2
Gaudryina gerkei (Vasilenko 1951)	X	X	Plate 4 figs 4a-b, 5a-b Plate 7 fig. 9	C3

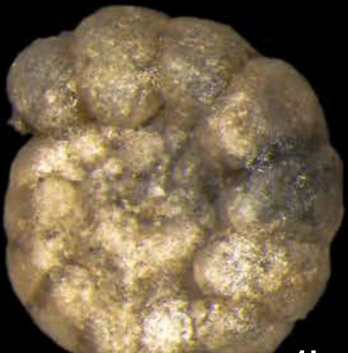
Gaudryina rostellata Nagy & Basov 1998	X	X	Plate 4 figs 6a-b, 7a-b Plate 7 figs 8a-b	C3
Glomospira aff. *oxfordiana* Sharovskaja 1966		X		E
Glomospira oxfordiana Sharovskaja 1966	X	X		E
Glomospira sp.	X			E
Haplophragmoides aff. *incognitus* Bulynnikova 1990		X	Plate 6 figs 4a-b	D2
Haplophragmoides sp.	X			D2
Haplophragmoides perlobatus n. sp.	X		Plate 2 figs 4a-c	D2
Kutsevella aff. *pseudogoodlandensis* (Mjatliuk 1973)		X		C2
Kutsevella pseudogoodlandensis (Mjatliuk 1973)		X	Plate 7 figs 7a-b	C2
Kutsevella sp.		X		C2
Labrospira lenticulata n. sp.	X	X	Plate 2 figs 1a-c, 2a-c, 3a-b Plate 5 figs 5-6 Plate 6 figs 2a-b	D2
Labrospira sp.	X			D2
Labrospira sp. 1	X			D2
Orientalia aff. *baccula* Schleifer 1990		X		C3
Orientalia baccula Schleifer 1990	X		Plate 4 figs 2a-b	C3
Polychasmina sp.		X		C1
Recurvoides aff. *disputabilis* Dain 1972		X		D2
Recurvoides aff. *obskiensis* Romanova 1960	X			D2
Recurvoides obskiensis Romanova 1960	X	X	Plate 3 figs 8a-c Plate 5, fig. 10 Plate 7 figs 1a-c, 2	D2
Recurvoides paucus Dubrovskaja 1962	X		Plate 3 figs 9-11 Plate 5 fig. 11	D2
Reophax pyriloculus n. sp.	X		Plate 1 figs 7 – 10	C1
Riyadhella sp.		X		C3
Schleiferella aff. *vallata* Nagy & Basov 1998	X	X		D2
Schleiferella emeljanzevi (Schleifer 1966)	X	X	Plate 1 figs 1a-c Plate 5 fig. 4	D2
Schleiferella schleiferi (Sharovskaja 1966)	X		Plate 1 figs 2a-c, 3a-b, 4 Plate 5 fig. 3	D2
Schleiferella vallata Nagy & Basov 1998	X	X	Plate 1 figs 5a-c, 6a-c Plate 5 fig. 1-2 Plate 6 figs. 1a-b	D2
Textularia sp.	X	X		C3
Textularia pernana n. sp.	X		Plate 4 figs 8a-b, 9a-c, 10 , 11a-b Plate 5 fig. 15	C3

Thuramminoides lapilliformis Nagy & Basov 1998		X		C1
Tolypammina aff. *virgula* Kosyreva 1972		X		B
Tolypammina confusa Dain 1972		X		B
Trochammina aff. *annae* Levina 1972		X		D1
Trochammina aff. *gryci* Tappan 1955		X		D1
Trochammina aff. *kosyrevae* Levina 1972		X	Plate 6 figs 10a-b, 11a-b	D1
Trochammina aff. *kumaensis* Levina 1972		X		D1
Trochammina aff. *minutissima* Dain 1972		X		D1
Trochammina aff. *misinovi* Levina 1972		X	Plate 6 figs 5a-b	D1
Trochammina aff. *praerosacea* Nagy & Basov 1998		X		D1
Trochammina aff. *rosacea* Zaspelova 1948		X		D1
Trochammina annae Levina 1972	X	X	Plate 3 figs 14a-b	D1
Trochammina praerosacea Nagy & Basov 1998	X	X	Plate 3 figs 13a-c Plate 4, figs 1a-b Plate 5 fig. 12 Plate 6 figs 6a-b, 7a-b, 9a-b	D1
Trochammina rosacea Zaspelova 1948	X	X	Plate 3 figs. 12a-b Plate 5 fig. 13	D1
Trochammina septentrionalis Sharovskaja 1961		X	Plate 6 figs 8a-b	D1
Trochammina sp.	X	X		D1
Verneuilinoides aff. *graciosus* Kosyreva 1972		X		C3
Verneuilinoides aff. *postgraciosus* Komissarenko 1986		X		C3
Verneuilinoides sp.		X		C3

Sample	**B**	**C1**	**C2**	**C3**	**D1**	**D2**	**E**
2007-01	0,0	2,3	11,5	6,5	8,7	70,6	0,5
2007-02	0,0	8,5	25,4	15,4	13,0	37,9	0,0
2007-03	0,0	0,9	14,0	17,3	6,5	61,3	0,0
2009-03	0,0	0,0	4,5	9,5	2,4	83,4	0,5
2009-04	0,0	0,0	42,4	17,6	21,9	17,6	0,5

Sample	**B**	**C1**	**C2**	**C3**	**D1**	**D2**	**E**
A41,10	0,0	2,9	28,5	18,6	8,7	38,4	0,6
A37,50	0,5	0,5	11,9	0,0	5,4	81,6	0,0
A35,40	0,8	0,6	5,3	0,3	13,9	78,4	0,8
A29,70	0,0	0,0	8,5	0,0	65,1	24,0	2,3
39,12	0,0	0,0	0,0	0,0	32,1	64,0	3,9
37,41	2,1	0,0	11,3	1,6	44,3	39,2	1,6
35,63	0,0	0,0	13,6	2,2	37,5	22,8	23,4
33,02	0,0	0,0	3,0	1,3	52,6	19,6	23,5
30,21	0,0	0,0	18,8	2,1	66,3	7,1	5,8
27,03	0,0	0,0	32,2	1,1	65,0	0,4	1,4
23,50	0,0	0,0	25,0	0,5	60,1	11,7	2,7
21,70	0,0	0,0	5,6	0,0	74,5	4,1	15,8
19,57	0,0	0,0	4,8	0,6	83,3	6,6	4,8
16,98	0,0	0,0	0,0	3,5	53,8	10,4	31,7
14,44	0,0	0,0	4,3	5,7	33,0	2,8	54,3
11,45	0,0	0,0	8,3	0,0	44,7	9,7	36,8
9,27	0,0	0,0	19,9	0,0	56,3	3,9	19,9
7,25	0,0	0,0	8,2	0,0	39,5	10,3	42,0
4,39	0,0	0,0	1,4	0,0	94,4	0,9	3,3
1,87	0,0	0,0	9,1	11,7	48,5	21,2	9,5
-0,47	0,0	0,0	10,9	0,0	73,0	0,0	15,7
-2,55	0,0	3,4	8,2	0,0	76,0	2,9	9,6
-5,73	0,0	0,0	0,0	0,0	95,5	0,0	4,5
-7,81	0,0	0,0	0,0	0,0	94,6	2,1	3,3


1a


1b


1c


7


2a


2b


2c


8


3a


3b


4


9


5a

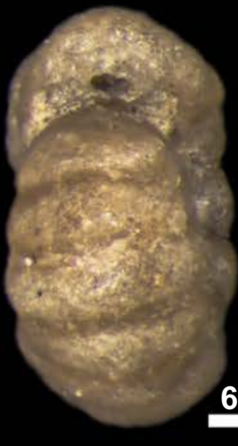

5b


5c

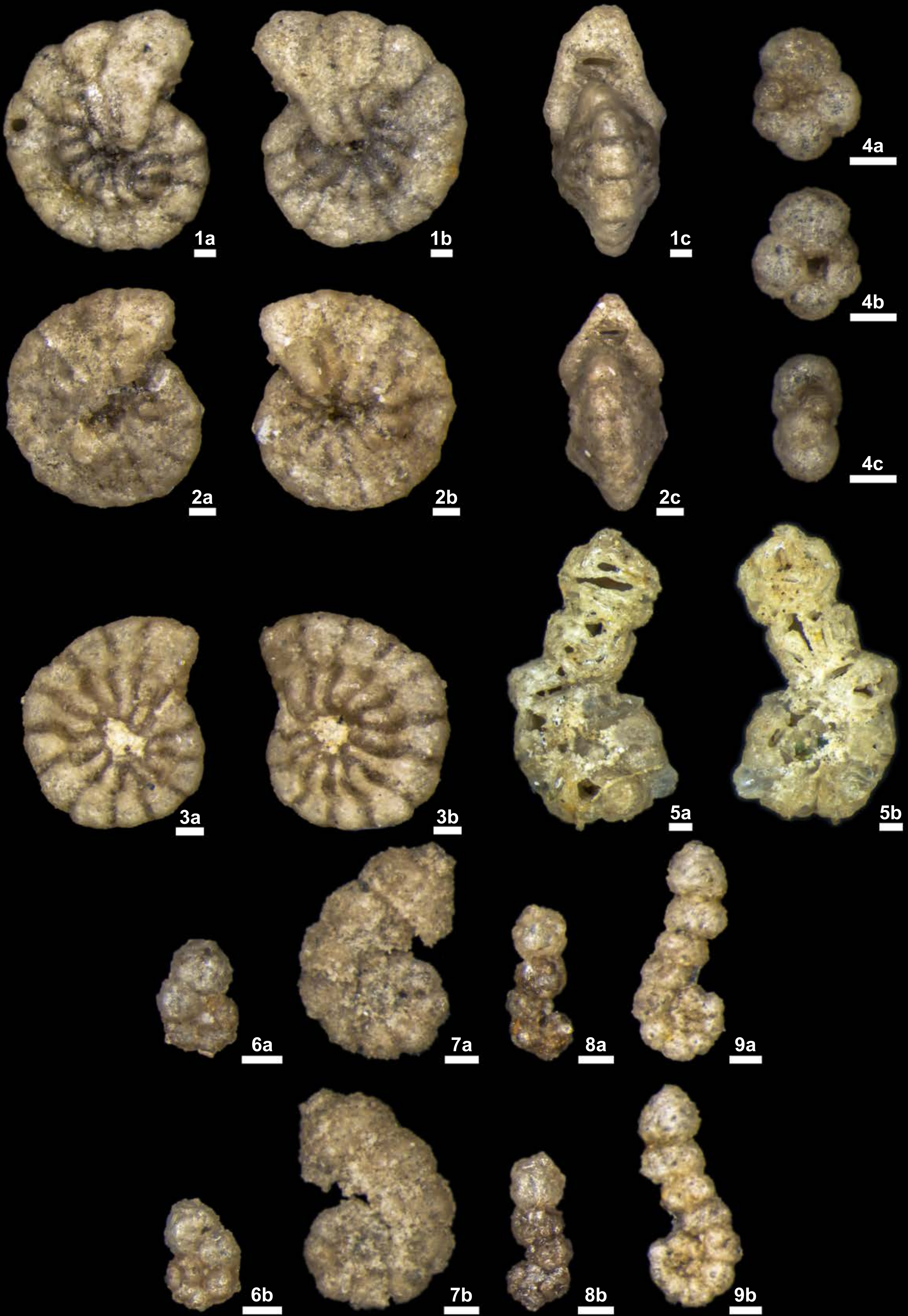

10a


6a


6b


6c


10b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1b
1c
4a
4b
2a
2b
2c
4c
3a
3b
5a
5b
6a
7a
8a
9a
6b
7b
8b
9b


1a
1b
2a
2b
3a
3b
4a
4b
5a
5b
5c
6a
6b
7a
7b
7c
8a
8b
8c
9
10
11
12a
12b
13a
13b
13c
14a
14b


1a
1b
2a
2b
3a
3b
3c
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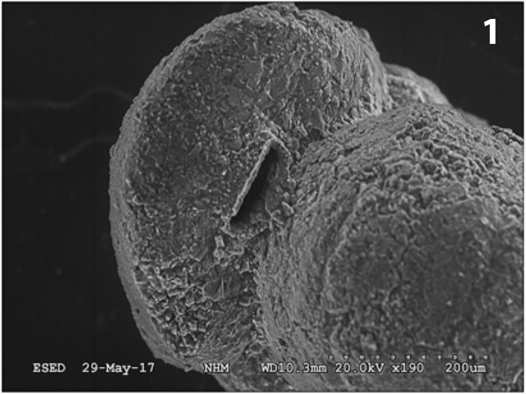
9c
10
11a
11b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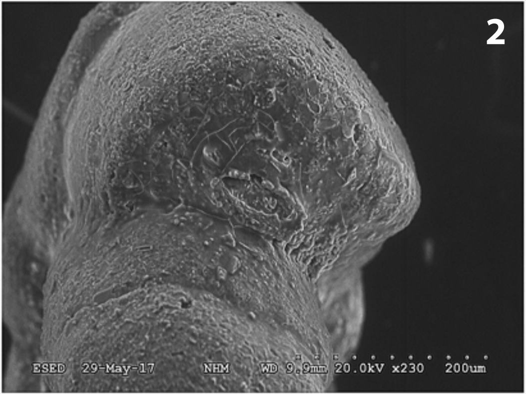
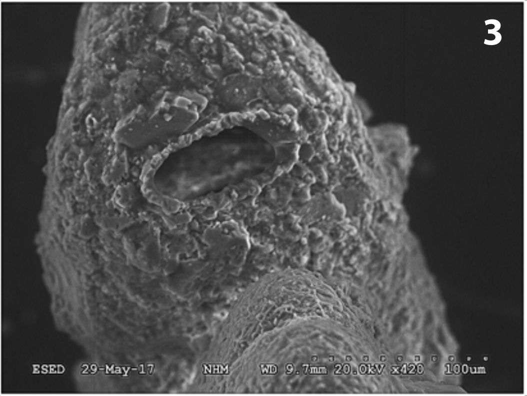

2
ESED 29-May-17 NHM WD 9.9mm 20.0kV x230 200um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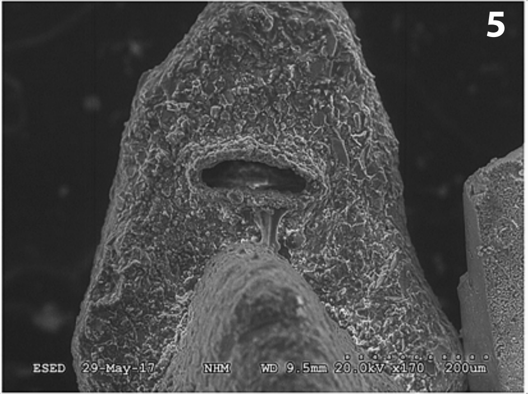
ESED 29-May-17 NHM WD 9.7mm 20.0kV x420 100um


4
ESED 29-May-17 NHM WD 9.5mm 20.0kV x190 200um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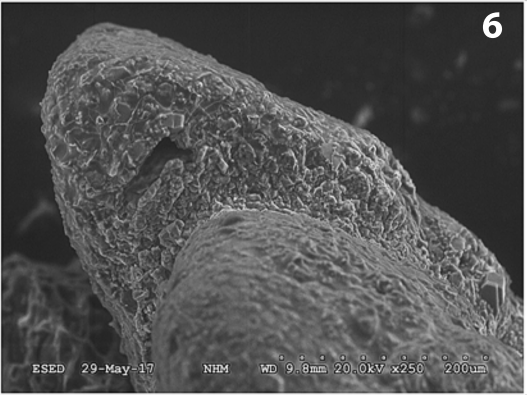
ESED 29-May-17 NHM WD 9.5mm 20.0kV x170 200um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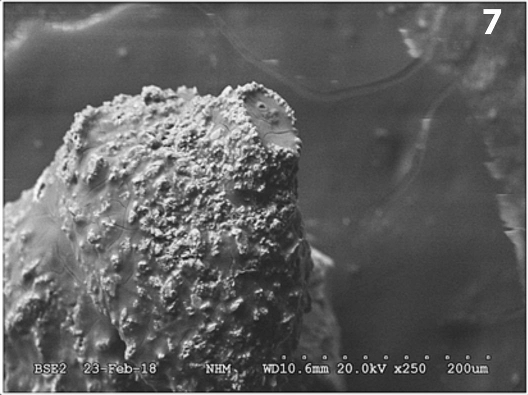
ESED 29-May-17 NHM WD 9.8mm 20.0kV x250 200um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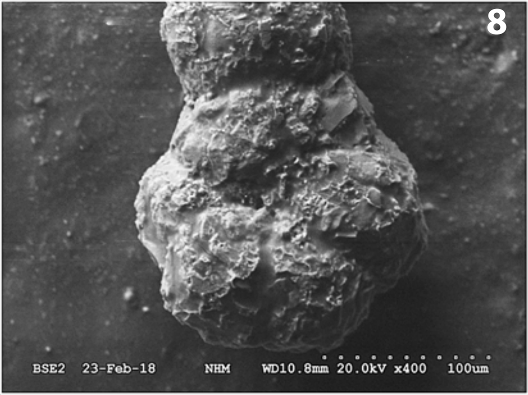
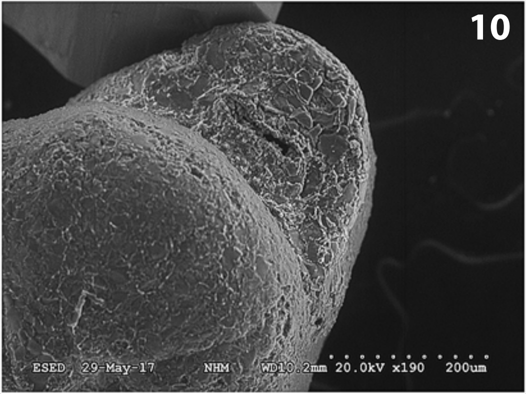
BSE2 23-Feb-18 NHM WD10.6mm 20.0kV x250 200um


8
BSE2 23-Feb-18 NHM WD10.8mm 20.0kV x400 100um


9
BSE2 23-Feb-18 NHM WD10.7mm 20.0kV x350 100um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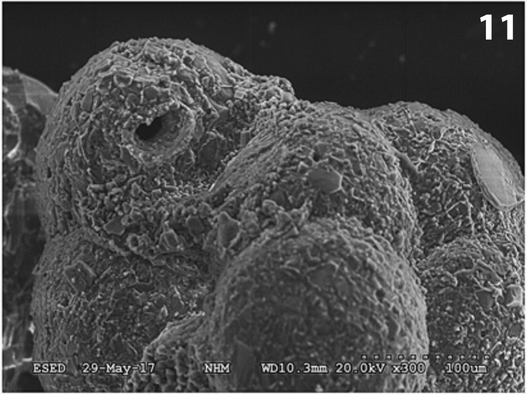
ESED 29-May-17 NHM WD10.2mm 20.0kV x190 200um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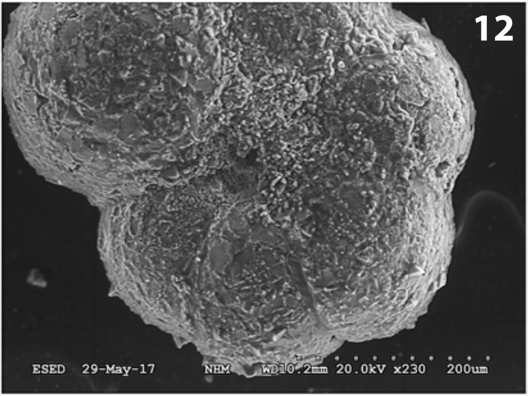
ESED 29-May-17 NHM WD10.3mm 20.0kV x300 100um


12
ESED 29-May-17 NHM WD10.2mm 20.0kV x230 200um


13
ESED 29-May-17 NHM WD10.4mm 20.0kV x350 100um


14
ESED 29-May-17 NHM WD10.4mm 20.0kV x350 100um


15
BSE2 23-Feb-18 NHM WD10.8mm 20.0kV x300 100um


1a


1b


2a


2b

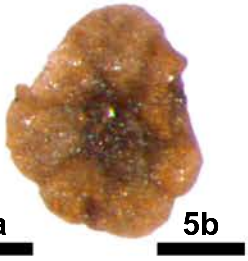

3a


3b


4a

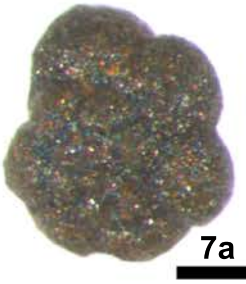

4b


5a


5b


6a


6b

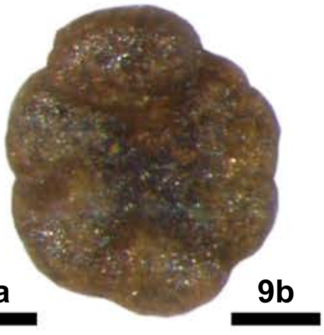

7a


7b

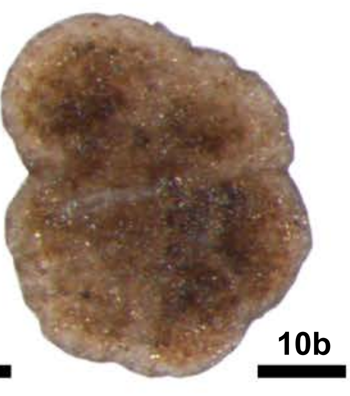

8a


8b


9a


9b


10a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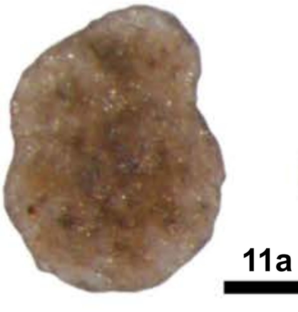
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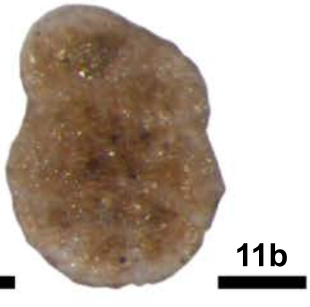
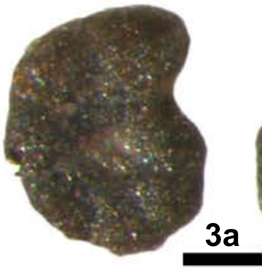

11b


1a


1b

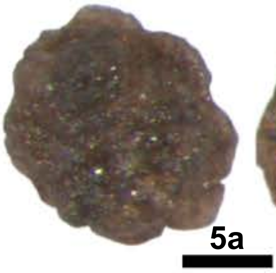

2


3a


3b


4a


4b


5a


5b


6a


6b


7a


7b


8a


8b


9


10a


10b


11


12