DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2004/94

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# Contents

# Summary

Uppermost Neogene strata are not represented in onshore successions in Jylland, Denmark, due to Late Neogene up-lift and Holocene glacial erosion. Therefore, cuttings samples were palynologically prepared from the hydrocarbon exploration wells S-1 (2460'–1320') and Tove-1 (4280'–1340') in the Danish North Sea and analysed for dinoflagellate floras in order to provide better understanding of the Danish Neogene stratigraphy.

The chronology of the succession is estimated on the basis of the appearance and disappearance of selected dinoflagellate species and their age correlated stratigraphy in the North Atlantic realm.

A totally marine dinoflagellate flora is recorded in S-1, only in the uppermost part is dominated by terrestrial material. Based on the range tops of stratigraphically significant dinoflagellate species, the succession in S-1 is dated as Middle to Late Miocene of Langhian, Serravallian and Tortonian age. The succession correlates with the Upper Arnum -, Hodde - and Gram Formations onshore Jylland and with Sequences D, E and F in the Danish North Sea.

A corresponding dinoflagellate flora is recorded in Tove-1 followed by a narrow, presumed Messinian interval and a thick Pliocene succession (Zanclean–Piacenzian). Terrestrial organic matter dominates increasingly from the top Tortonian and the recovered dinoflagellate assemblages are restricted with respect to stratigraphic significant species. A marine dinoflagellate assemblage is only recovered in the uppermost strata of Late Pliocene age. The Messinian–Piacenzian succession correlates with Sequences G, H and I in the Danish North Sea.

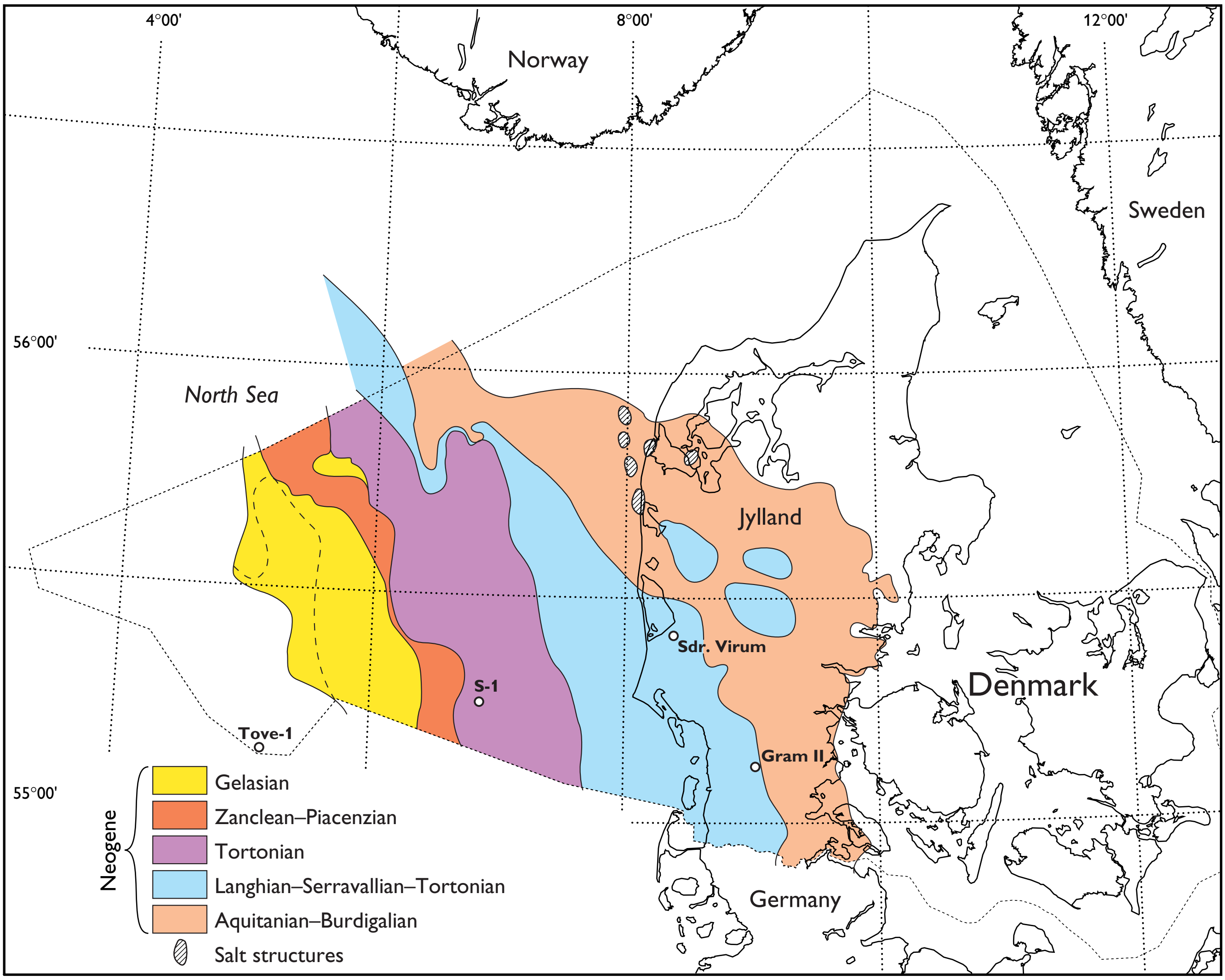



Figure 1: Map of the Neogene succession in the Danish region. Neogene is subcropping below the Quartenary cover and the strata become progressively older towards the north-east. Location of the offshore wells S–1 and Tove–1 are marked and the research wells onshore Jylland are also indicated.

# Introduction

Samples from the hydrocarbon exploration wells S-1 and Tove-1 in the Danish North Sea (Figure 1) have been selected and analysed for their content of dinoflagellate cysts in order to provide better understanding of the upper Neogene stratigraphy in the Danish region. Different research groups have applied foraminifer biostratigraphy to the Neogene succession in the North Sea with deviating results, which has created significant discrepancies in the subsequent seismic interpretation (Huuse *et al.* 2002; Japsen *et al.* 2002b).

The database for Neogene dinoflagellate stratigraphy, onshore Denmark, has increased significantly the last years by studies of the Geological Survey of Denmark and Greenland (GEUS). Analyses of the Neogene succession in drilled water wells and research/exploratory wells in Jylland were combined with studies of the stratigraphic limited, but abundant, exposures mainly along the east coast of Jylland (Dybkjær *et al.* 1999; Dybkjær & Rasmussen 2000; Piasecki 2001; Dybkjær *et al.* 2003; Piasecki *et al.* 2004); (Rasmussen 1996; Dybkjær 2004; Rasmussen in press (2004); Dybkjær 2004). New, refined biostratigraphy and a new sequence stratigraphic model have been evolved for the Neogene succession (Figure 2) (Rasmussen 2003; Rasmussen in press (2004); Rasmussen in print (2005)).

One important conclusion from these studies is that uppermost Miocene (Messinian) and Pliocene strata are not represented onshore Denmark in contrast to earlier statements (Figure 1) (Piasecki in print (2005)). The present study was therefore initiated to study the biostratigraphy of the youngest Neogene and to provide biostratigraphic data for seismic mapping of the Neogene successions in the Danish North Sea.

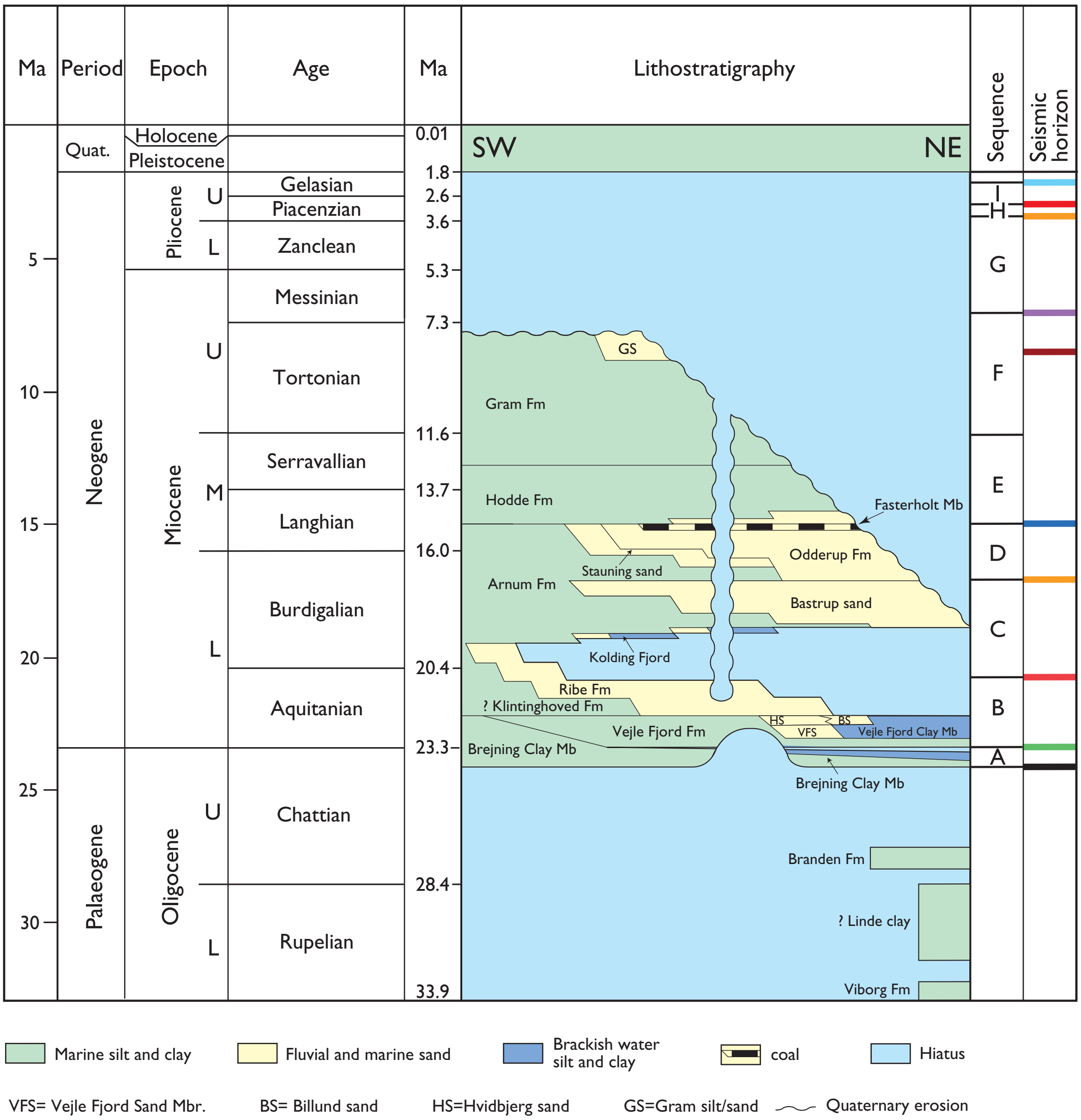



Figure 2: Miocene stratigraphy in the Danish region. The onshore lithostratigraphy is correlated with depositional sequences and seismic markers based on both on- and offshore data.

# Geological setting

The North Sea Basin was formed due to thermal subsidence after the formation of the Central Graben in the Jurassic (Ziegler 1982; Vejbæk 1992). The basin was open towards the north via a narrow strait between the Shetland Islands and Norway. The strait acted as a barrier so that the North Sea became brackish at times. The basin reached from Norway, along Scania to the Baltic region and North Germany. The southern margin passed through northern France and Belgium and towards the west, the basin margin followed eastern England and Scotland towards the Shetland Islands.

Maximum extension of the sea in this basin was in Late Cretaceous with deposition of chalk. The Alpine folding in Late Cretaceous – Paleocene affected the basin by inversion tectonics and probably uplift of the Fennoscandian Shield (Danielsen *et al.* 1995). The coastline prograded significantly from the north in the Eocene but Paleocene density deposits at the Ringkøbing-Fyn High (Danielsen *et al.* 1995) may indicate that progradation started already at that time.

The water depth was about 500–700 metres in the central part but significantly lower (0-100 metres) towards the east in the present Denmark (Hindsby *et al.* 1999).

The outbuilding of the slope-shelf system continued during the Oligocene (Michelsen *et al.* 1998). The Oligocene deposits were partly laid down as pro-deltaic deposits and partly as contourites (Hansen *et al.* 2004). Locally, turbidites deposition took place at the toe of the slope and on the basin floor. In the Miocene coastal plain deposits reached the Danish North Sea area and during the Aquitanian–Burdigalian three major progradations of deltas have been recorded (Figure 2) (Rasmussen *et al.* 2002). The deltas were predominantly wave-dominated (Rasmussen *et al.* 2004).

Marine transgression in the Langhian, Middle Miocene, and faulting of the Odderup Formation (Koch 1989) marked a significant phase of the basin development where the source of sediments also changed from northeast to east. At this time, Middle Miocene, the global climate was warm and the sea level was high so most of the Danish region was probably flooded. The following, Late Miocene, sea-level fall responds the global cooling but this was compensated by increased regional subsidence of the Danish region, so despite the generally falling sea level the marine flooding continued. Up to 400 metres of Upper Miocene sediments was deposited in mid-Jylland (Japsen *et al.* 2002a). Today, these sediments are only represented by the Gram Formation, which contains a rich marine fauna and flora. Late Neogene up-lift and Holocene glacial erosion have removed the younger sediments but they are preserved in parts in the present off-shore region e.g. the well Tove-1.

# Material

The hydrocarbon exploration wells S-1and Tove-1 were selected for analyses on the basis of seismic interpretation. S-1 is positioned 55° 30’ 57,0’’ N – 6° 55’ 17,8’’ E and Tove-1 is positioned 55° 15’ 17,3’’ – 5° 9’ 45,3’’ E in the Danish sector of the North Sea (Figure 1). Washed and dried cuttings material of fine-grained sediments was selected for preparation. Fourteen samples from 2460’–1320’ of S-1 (Appendix 1) and 40 samples from 4280’–1340’ of Tove-1 (Appendix 2) were selected from presumed Middle Miocene – Pliocene strata based on the correlation of significant seismic horizons. Approximately 20 gram of sediment have been prepared from each sample and sediment grains from 1 to 4 millimetres were used for analysis in order to minimise the content of caved material and mud contamination.

Methods

The samples have been prepared with standard palynological techniques. Hydrochloric and hydrofluoric acids removed mineral matter, and the organic content was oxidised with concentrated nitric acid and washed with potassiumhydroxide to remove humic material. The standard preparation process was followed by specific treatment of each sample such as filtering with 11 µm mesh size, ultrasonic bath, and swirling or heavy liquid separation. Four to five slides, representing the different steps in the preparation, were prepared for the analysis. The first slides were used mainly for evaluating the composition of the organic content and thermal maturity but all slides from each sample were scanned for stratigraphic significant taxa, which then were recorded on a record-sheet.

The recorded data are systematised in the program ”StrataBugs” and displayed in range-charts after first down-hole occurrence (Appendix 1–2). Three groups of palynomorphs are displayed separately: dinoflagellate cysts, acritarchs and (freshwater) algae. The diversity of the dinoflagellate flora is illustrated by the “absolute count” of specimens. Palaeoenvironmental and stratigraphic conclusions are also illustrated in the charts in the event list and in the stratigraphic columns. Stratigraphic important species are illustrated in plates 1–8. The photos are extracted from the MicroImage database at GEUS and are identified by their MI number.

# Stratigraphy

Neogene dinoflagellate stratigraphy has improved significantly in the last decade due to extensive studies especially in the North Atlantic region. The ODP/DSDP studies range from Baffin Bay and Labrador Sea to the Norwegian shelf in the north (Manum 1976; de Vernal & Mudie 1989a; de Vernal & Mudie 1989b; Head *et al.* 1989a; Head *et al.* 1989b; Head *et al.* 1989c; Manum *et al.* 1989; Poulsen *et al.* 1996; Smelror 1999; Williams & Manum 1999; Williams *et al.* 2004) (Figure 3). Further studies along the western margin of Europe provide data from the North-Atlantic mid-latitudes (Harland 1979; Edwards 1984).
De Verteuil and Norris (1996) created a break-through by their studies onshore eastern USA and studies of typesections in Italy also brought the Neogene dinoflagellate stratigraphy forward (Powell 1986; Zevenboom *et al.* 1994; Zevenboom 1995).
However, several of the comprehensive studies mentioned above do not include the uppermost Neogene. So, the recent studies of uppermost Miocene and Pliocene successions in the North Sea basin of United Kingdom and Belgium by M. Head and S. Louwye and co-authors are most relevant for the present analysis (Head 1996; Head 1997; Head 1998; Louwye & Laga 1998; Head & Norris 1999; Louwye 1999; Louwye *et al.* 1999; Louwye 2002; de Schepper *et al.* 2004; Louwye *et al.* 2004). The stratigraphic records and descriptions of many new species, restricted to the uppermost Neogene, have provided a significantly improved basis for Messinian – Pliocene dinoflagellate stratigraphy and for the understanding of the palaeoclimatic influence of the stratigraphy.

## Dinoflagellate stratigraphy of S-1

The dinoflagellate stratigraphy is described and discussed for “groups of samples” which are selected on the basis of common dinoflagellate assemblages, which are limited by significant changes in depositional environments and/or by seismic marker horizons. The stratigraphy is described downwards and the stratigraphic conclusions are based mainly on stratigraphic last occurrences (“tops”) because serious caving are evident at most levels. However, the (interpreted) stratigraphic lowermost occurrences of some species are also exploited in some cases (Figures 4–5).

### Samples from 1320’–2310’ (11 samples)

Depositional environment: Dominantly marine environment in the lower part to marginal marine in the upper part. The content of terrestrial material increases upwards from 1680’ and dominates totally from 1410’ and upwards, probably reflecting coastal progradation.

Dinoflagellate assemblage: *Spiniferites* spp. and *Operculodinium* spp. dominate the assemblage. *Labyrinthodinium truncatum* is very abundant in the lower part whereas *Habibacysta tectata* and *Bitectatodinium aborichiarum* are abundant in the upper part.

Other palynomorphs: The brackish to freshwater algae *Botryococcus* spp., *Pediastrum* spp. and *Mougeotia latevirens* are all most common in the upper part.

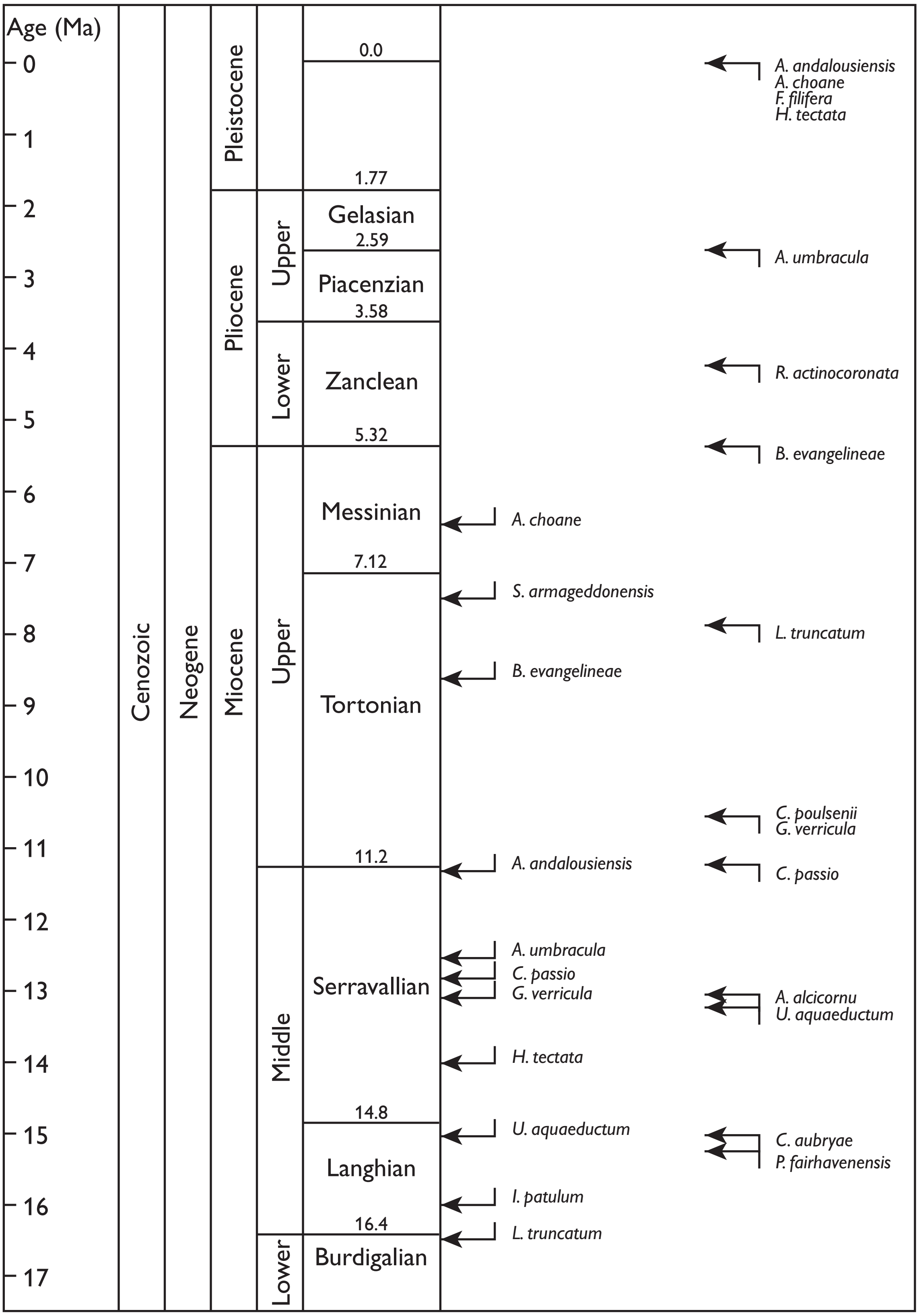



Figure 3: Appearances and disappearances of stratigraphic significant dinoflagellate cysts from the North Atlantic region based on Williams et al. 2004.

Stratigraphic events: *Barssidinium olymposum* and *B. pliocenicum* occur only in the uppermost sample and this is considered their stratigraphically first appearance. *Spiniferites solidago* are present up to the uppermost sample and this is considered the stratigraphically last occurrence. The stratigraphically last occurrences of *Labyrinthodinium truncatum* and *Bitectatodinium aborichiarum* are in sample 1680’ and the last occurrences of *Dapsilidinium pseudocolligerum* and *Spiniferites pseudofurcatus* are in 1890’. *Amiculosphaera umbraculum* appears stratigraphically from sample 2220’ whereas *Achomosphaera andalousiense* and *Cannosphaeropsis passio* appear from sample 2310’, the lowermost sample in this unit. *Cerebrocysta poulsenii* and *Palaeocystodinium miocaenicum* occur highest in this sample (Appendix 1).
*Labyrinthodinium truncatum* occurs latest at 7.85 Ma, *Amiculosphaera umbraculum* and *Achomosphaera andalousiense* appear at 11.3 Ma and *Cannosphaeropsis passio* appears at 12.8 Ma (Williams *et al.* 2004).

Age. Middle to Late Miocene, late Serravallian and Tortonian.

Correlation to standard nanno- and foraminifer stratigraphy: *Cannosphaeropsis passio* appears in NN6 and disappears in NN8 (de Verteuil & Norris 1996; Strauss *et al.* 2001; Williams *et al.* 2004). *Achomosphaera andalousiense* appears in basal NN9 (de Verteuil & Norris 1996) or already in NN6 in northern Germany (Strauss *et al.* 2001). The highest occurrence of *Cerebrocysta poulsenii* is in the NN9 (de Verteuil & Norris 1996). The common, highest occurrence of *Labyrinthodinium truncatum* and *Dapsilidinium pseudocolligerum* are in mid-NN11 (de Verteuil & Norris 1996). The highest occurrence of *Spiniferites pseudofurcatus* is located in NN11 (Strauss *et al.* 2001). Conclusively, these samples correlate with NN8 – midt-NN11, uppermost Serravallian to uppermost Tortonian.

Lithostratigraphy: The 11 samples from 1320’–2310’ correlates with the Gram Formation, onshore Jylland, Denmark (Appendix 1). The boundary to the underlying Hodde Formation is placed in 2320’ below the lowest sample. A seismic reflector does not indicate this boundary.

## Succession between 2310’ and 2400’

There are no samples from the interval between 2310’ and 2400’ but the succession in between can be stratigraphically limited and correlated based on the dinoflagellates in the samples above (2310’) and below (2400’).

Dinoflagellate assemblage: No records, the two samples are described respectively above and below.

Other palynomorphs: No records, the two samples are described respectively above and below.

Stratigraphic events: *Cannosphaeropsis passio* occurs only in sample 2310' and this is considered the stratigraphically last occurrence. *Achomosphaera andalousiense* appears stratigraphically in sample 2310'. The last occurrence of *Cousteaudinium aubryae* and Microdino sp.7 are in sample 2400' (Appendix 1).
*Cousteaudinium aubryae* disappears at 15.0 Ma, *Cannosphaeropsis passio* appears at 12.8 Ma and *Achomosphaera andalousiense* appears at 11.3 Ma (Williams *et al.* 2004).

Age. Middle Miocene, upper Langhian to Serravallian

Correlation to standard nanno- and foraminifer stratigraphy: *Cannosphaeropsis passio* disappears in NN8 (de Verteuil & Norris 1996; Strauss *et al.* 2001; Williams *et al.* 2004). *Achomosphaera andalousiense* appears in basal NN9 (de Verteuil & Norris 1996) or already in NN 6 in northern Germany (Strauss *et al.* 2001).

Lithostratigraphy: The blue seismic horizon of Rasmussen *et al.* in print (2005) at 2390' indicates the basis of the Hodde Formation. The succession between 2310'–2400' correlates with the basal Gram Formation, the Hodde Formation and topmost Arnum Formation, onshore Denmark (Appendix 1).

## Samples from 2400' – 2460' (3 samples)

Depositional environment: Dominantly marine

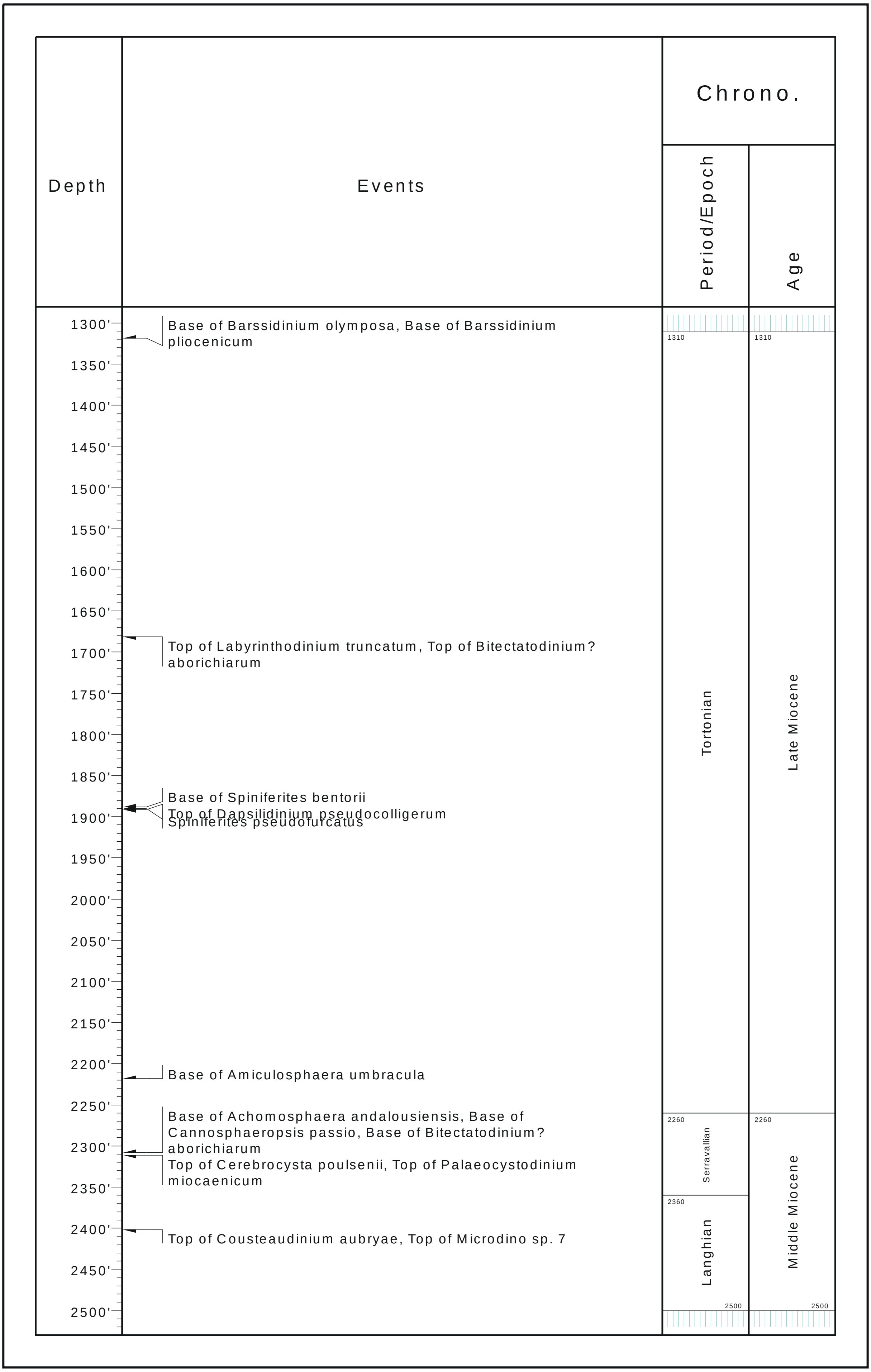
Dinoflagellate assemblage: *Spiniferites* spp. dominates the assemblage. *Cerebrocysta poulsenii*, *Labyrinthodinium truncatum*, *Melitasphaeridium choanophorum*, *Operculodinium* spp. and *Palaeocystodinium miocaenicum* are abundant to common.

Other palynomorphs: *Botryococcus* spp. is present.

Stratigraphic events: Highest stratigraphically occurrence of *Cousteaudinium aubryae*, Microdino sp. 7 and *Polysphaeridium zoharyi* in the uppermost sample. *Cerebrocysta poulsenii*, *Labyrinthodinium truncatum* and *Palaeocystodinium miocaenicum* are present (Appendix 1).
*Labyrinthodinium truncatum* appears at 16.5 Ma and *Cousteaudinium aubryae* disappears at 15.0 Ma (de Verteuil & Norris 1996; Williams *et al.* 2004).

Age. Middle Miocene, Langhian

Correlation to standard nanno- and foraminifer stratigraphy: *Cerebrocysta poulsenii* appears in basal NN5 (Langhian) in Germany where as *Palaeocystodinium miocaenicum* is reported to appear lower in upper NN4, (Burdigalian) (Strauss *et al.* 2001). *Cousteaudinium aubryae* disappears in upper NN5 (de Verteuil & Norris 1996). Conclusively, the samples correlate with NN5, Langhian.




Figur 4: List of stratigraphic significant dinoflagellate events in S-1 correlated with depths and stratigraphy.

Lithostratigraphy: The 3 samples from 2400'– 2460' correlates with Upper Arnum Formation onshore Denmark (Appendix 1). The seismic reflector in 2390' marks the upper boundary of the Arnum Formation.

## Dinoflagellate stratigraphy of Tove-1

### Samples 1340' – 1490' (3 samples)

Depositional environment: Near shore to marginal marine. The samples are dominated by terrestrial material and the brackish to freshwater algae *Botryococcus* spp. and *Pediastrum* spp. become very abundant in the upper part, probably reflecting progradation of the coast. Dinoflagellates occur mostly in the lowermost sample.

Dinoflagellate assemblage: *Spiniferites* spp. and *Habibacysta tectata* dominate in the lower part whereas *Operculodinium* spp. dominates in the upper part. *Achomosphaera* spp., *Filisphaera filifera* and *Operculodinium centrocarpum* are frequent. *Impagidinium multiplexum* occurs only in this unit. *Hystrichokolpoma rigaudiae* is present. *Operculodinium antwerpensis* and *Invertocysta lacrymosa* occur lowest in this unit. Several expectable, Pliocene dinoflagellate species are not recorded despite the relatively marine depositional environment of this unit.

Other palynomorphs: The brackish to freshwater algae *Botryococcus* spp. is common and *Pediastrum* spp. is abundant. The abundance of both algae increases upwards.

Stratigraphic events: The last occurrence of *Hystrichokolpoma rigaudiae*, *Invertocysta lacrymosa* and *Operculodinium antwerpensis* are reported in the Upper Pliocene, Piacenzian (Zevenboom 1995; Versteegh 1997; Head 1998). The first occurrence of *Impagidinium multiplexum* is reported from basal Upper Pliocene (Head 1998).
*Bitectatodinium tepikiense* is not recorded. In the North Sea it appears after the mid- Upper Pliocene cooling (approx. 2.6 Ma) (Head 1998).

Age: Early Late Pliocene, Piacenzian.

Correlation to standard nanno- and foraminifer stratigraphy: *Invertocysta lacrymosa* disappears in NN16, Piacenzian, (Versteegh 1997; Louwye *et al.* 2004)

Lithostratigraphy: Correlates with no successions onshore Denmark.

Sequence stratigraphy: The three samples correlate with the upper part of Sequence I (Appendix 2) of Rasmussen *et al.* in print (2005).

## Samples 1550' – 1640' (3 samples)

Depositional environment: Marginal marine. The samples are dominated by terrestrial material and dinoflagellates are relatively sparse. The upward increase in terrestrial material and corresponding decrease in dinoflagellates may reflect progradation of the coastal plain.

Dinoflagellate assemblage: Poor assemblage dominated by *Spiniferites* spp. and *Operculodinium* spp., both genera most frequent in the lowest sample. *Achomosphaera andalousiense* are present. *Barssidinium pliocenicum*, *Bitectatodinium raedwaldii* and *Tectatodinium pellitum* have highest occurrence in this unit.

Other palynomorphs: The brackish to freshwater algae *Botryococcus* spp. and *Pediastrum* spp. are present.

Stratigraphic events: The last occurrence of *Barssidinium pliocenicum*, *Bitectatodinium raedwaldii* and *Tectatodinium pellitum* are reported in the Upper Pliocene with a highest occurrence in the North Sea at the Piacenzian – Gelasian boundary, the mid Upper Pliocene at 2,6 Ma (Head 1998; Louwye *et al.* 2004).

Age: Earliest Late Pliocene, Piacenzian.

Correlation to standard nanno- and foraminifer stratigraphy: No direct correlation.

Lithostratigraphy: Correlates with no lithological units onshore Denmark.

Sequence stratigraphy: The three samples correlate with the lower part of Sequence I and are limited downwards by the red seismic horizon in (1650') (Appendix 2) of Rasmussen *et al.* in print (2005).

## Interval 1640' – 1790'

No samples are analysed from this interval which correlates with the upper part of Sequence H in Rasmussen *et al.* in print (2005).

## Samples 1790 '– 2330' (9 samples)

Depositional environment: Marginal marine to terrestrial. The samples are dominated of terrestrial material and dinoflagellates are relatively sparse. The upward increase in terrestrial material and corresponding decrease in dinoflagellates may reflect progradation of the coastal plain.

Dinoflagellate assemblage: The richest assemblage occurs in the lower part and is dominated by *Spiniferites* spp., *Operculodinium* spp. and *Achomosphaera andalousiense*. The abundance and diversity decrease rapidly upward and a poor assemblage characterised the most of this unit.

Other palynomorphs: The brackish to freshwater algae *Botryococcus* spp. and *Pediastrum* spp. are frequent in the lower part but become less frequent upwards.

Stratigraphic events: The poor to very poor dinoflagellate assemblage makes it difficult to recover the stratigraphic significant species, and to separate in *situ* dinoflagellates from reworked specimens. *Melitasphaeridium choanophorum* occurs for the last time in the basis of this interval, together with the top of common occurrence of *Invertocysta lacrymosa*. The last occurrences of these two species are reported in the Upper Pliocene (Head 1998).

Age: ?Late Pliocene, Piacenzian

Correlation to standard nanno- and foraminifer stratigraphy: No direct correlation.

Lithostratigraphy: Correlates with no lithological units onshore Denmark.

Sequence stratigraphy: The nine samples correlate with Sequence H (1805'– 2110') and the upper part (2110'–2330') of Sequence G (Appendix 2) of Rasmussen *et al.* in print (2005). Sequence H and G is separated by the orange seismic horizon at 2110'.

## Samples 2420' – 3290' (8 samples)

Depositional environment: Marginal marine environment. The samples are dominated by terrestrial material and the dinoflagellate assemblage is poor but more abundant than above. The upward increase in terrestrial material and corresponding decrease in dinoflagellates may reflect progradation of the coast.
Peak-abundance of the most common dinoflagellate species (*Spiniferites* spp., *Operculodinium* spp. and *Achomosphaera andalousiense*) in the samples 2410'–2520' at the top of this unit suggests a break in the overall upward increasing terrestrial dominance, e.g. a flooding event or a local shift of a delta lobe.

Dinoflagellate assemblage: *Spiniferites* spp., *Operculodinium* spp. and *Achomosphaera andalousiense* dominate the assemblage. *Spiniferites* spp. is slightly more abundant in the lower part of the unit whereas the abundance of *A. andalousiense* increases significant in the upper part to maximum abundance of this species. Diversity of the assemblage is low and decreasing upwards where as the abundance is relatively constant with an increase in the top.

Other palynomorphs: The brackish to freshwater algae *Botryococcus* spp. and *Pediastrum* spp. are frequent in the lower part but become less frequent upwards.

Stratigraphic events: *Ataxiodinium choane*? and *Reticulatosphaera actinocoronata* occurs for the last time in the lowermost part of the unit together with a maximum occurrence of *Operculodinium antwerpensis*. *Nematosphaeropsis lemniscata* occurs for the last time uppermost in the unit and *Melitasphaeridium choanophorum* occurs at the top. The relatively poor dinoflagellate assemblage makes it difficult to recover the stratigraphic significant species, and to separate in *situ* dinoflagellates from the reworked specimens.

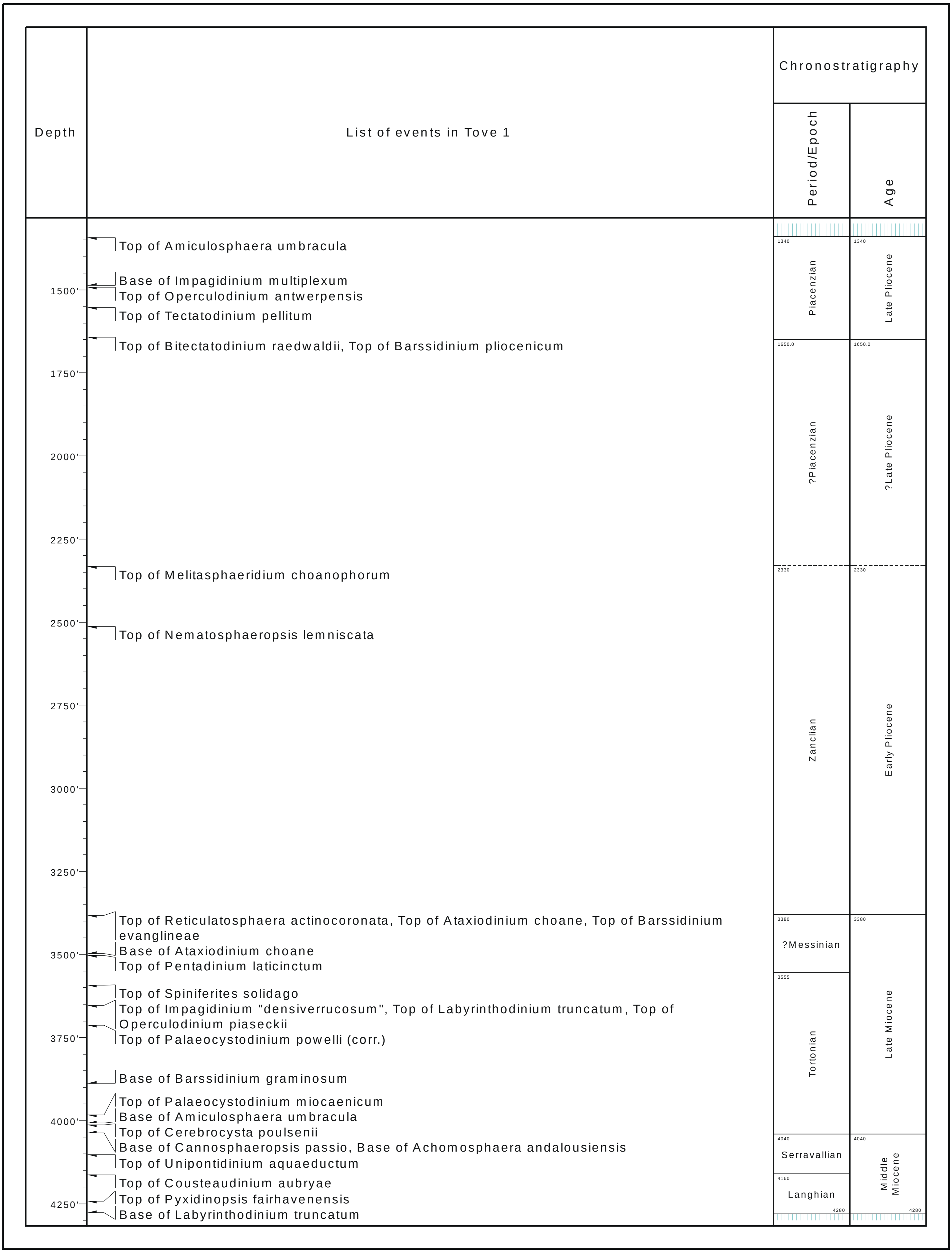



Figure 5: List of stratigraphic significant dinoflagellate events in Tove-1 correlated with depths and stratigraphy

*Melitasphaeridium choanophorum* is reported to occur for last time near the transition from Lower to Upper Pliocene (Head 1998).

Age: Early Pliocene, Zanclean.

Correlation to standard nanno- and foraminifer stratigraphy: *Reticulatosphaera actinocoronata* disappears in NN13, Zanclean, Lower Pliocene (Versteegh 1997; Louwye *et al.* 2004).

Lithostratigraphy: Correlates with no lithological units onshore Denmark.

Sequence stratigraphy: The eight samples correlates with the main, middle part of Sequence G, 2110'– 3555' (Appendix 2) of Rasmussen *et al.* in print (2005).

### Samples 3380' – 3500' (2 samples)

Depositional environment: Marginal to near shore marine environment e.g. prograding coastal plain. The samples are dominated of terrestrial material and the dinoflagellate assemblage is restricted.

Dinoflagellate assemblage: *Spiniferites* spp., *Operculodinium* spp. and *Operculodinium centrocarpum* dominate the assemblage. *Achomosphaera andalousiense*, *Barssidinium evangelineae* and *Operculodinium antwerpensis* are common. Diversity and density of the assemblage is low.

Other palynomorphs: The brackish to freshwater algae *Botryococcus* spp. and *Pediastrum* spp. are present.

Stratigraphic events: The occurrence of *Ataxiodinium choane*? is restricted to these samples. *Operculodinium antwerpensis* becomes common for the first time. *Barssidinium evangelineae* and *Reticulatosphaera actinocoronata* have their highest occurrences in the upper sample. The relatively poor dinoflagellate assemblage both in these samples and in the succession above makes it difficult both to recover the stratigraphic significant species, to distinguish *in situ* dinoflagellates from the reworked specimens and to pin point the precise last occurrence of taxa.
The appearance of *Ataxiodinium choane* is reported to be a stratigraphic marker for the mid-Messinian (6.45 Ma) in the North Atlantic region (Williams *et al.* 2004). The last occurrence of *Barssidinium evangelineae* is reported as a stratigraphical marker for top Messinian (5.32 Ma) in the North Atlantic region (Williams *et al.* 2004). Here it is contemporaneous with the last occurrence of *Reticulatosphaera actinocoronata* which is reported from the mid-Zanclean (4.18 Ma), Lower Pliocene.

Age: Late Miocene, Messinian?.

Correlation to standard nanno- and foraminifer stratigraphy: *Reticulatosphaera actinocoronata* disappears in NN13, Zanclean, Lower Pliocene (Versteegh 1997; Louwye *et al.* 2004).

Lithostratigraphy: Correlates with no lithological units onshore Denmark.

Sequence stratigraphy: The two samples correlate with the lowermost part of Sequence G, 2110'– 3555', (Appendix 2) and are limited downwards by the purple seismic horizon in 3555' of Rasmussen *et al.* in print (2005).

## Samples 3590' – 4040' (9 samples)

Depositional environment: Fully marine environment dominated by dinoflagellates and with increase of terrestrial material only in the uppermost part.

Dinoflagellate assemblage: Diversity and abundance of dinoflagellates are high. *Spiniferites* spp. and *Operculodinium* spp. dominates the assemblage. *Achomosphaera andalousiense* is locally very abundant. *Operculodinium centrocarpum* and *Lingulodinium machaerophorum* are common in most samples. *Barssidinium graminosum* and *Barssidinium evangelineae* are common throughout the upper part whereas *Impagidinium* "*densiverrucosum*" has a restricted range and a maximum in the upper part. Also *Nematosphaeropsis lemniscata* and *Invertocysta lacrymosa* have local maxima in the middle–upper part. *Habibacysta tectata* and *Labyrinthodinium truncatum* are common in the lowermost part.

Other palynomorphs: Freshwater algae are present in low numbers.

Stratigraphic events: Abundant *Achomosphaera andalousiense* and the species *Cannosphaeropsis passio* appear stratigraphically for the first time at the basis of this interval (above the top of *U. aquaeductum*) followed shortly by the first appearance of *Amiculosphaera umbraculum*. Successive stratigraphic last occurrences of *Cannosphaeropsis passio*, *Cerebrocysta poulsenii* and *Palaeocystodinium miocaenicum* (*P. "striatogranulosum"*) occur in the lowermost part of the unit. *Impagidinium "densiverrucosum" Barssidinium graminosum* and *Operculodinium antwerpensis* appear for the first time in the lower part of the interval whereas the upper part are characterised by the successive last occurrences of *Palaeocystodinium powellense*, *Impagidinium "densiverrucosum"*, *Labyrinthodinium truncatum*, *Operculodinium piaseckii*, *Spiniferites pseudofurcatus*, *Spiniferites solidago* and *Pentadinium laticinctum*.
The first appearance of *Cannosphaeropsis passio* and *Achomosphaera andalousiense* is reported in the upper Serravallian at 12.8 Ma and 11.3 Ma respectively. The last occurrence of *Cannosphaeropsis passio* is reported in the basal Tortonian at 11.3 Ma, the last occurrence of *Cerebrocysta poulsenii* is reported in the upper Tortonian at 10.9 Ma and the last occurrence of *L. truncatum* is reported in the upper Tortonian at 7.85 Ma, (Williams *et al.* 2004)

Age: Middle to Late Miocene, late Serravallian to Tortonian.

Correlation to standard nanno- and foraminifer stratigraphy: The range of *Cannosphaeropsis passio* is reported to be from NN6–NN8 (de Verteuil & Norris 1996). The first appearance of *Achomosphaera andalousiense* is reported from NN6 (Strauss *et al.* 2001) to NN8 (de Verteuil & Norris 1996). The last occurrence of *Cerebrocysta poulsenii* occurs in NN9, the last occurrence of *Palaeocystodinium* spp. is in NN10/NN11 and the last occurrence of *Labyrinthodinium truncatum* is in NN11 (de Verteuil & Norris 1996). Therefore, these samples correlate with NN6–NN11.

Lithostratigraphy: Correlates with the Gram Formation, onshore Denmark (Appendix 2) (Piasecki 1980; Piasecki *et al.* 2004)

Sequence stratigraphy: The nine samples correlate with Sequence F, 3555' – 3700', and uppermost sequence E, 3700'–4160', of Rasmussen *et al.* in print (2005). The brown seismic horizon occurs in 3500' (Rasmussen *et al.* in print (2005)).

## Samples 4040' – 4120' (2 samples)

Depositional environment: Fully marine environment dominated by dinoflagellates

Dinoflagellate assemblage: *Spiniferites* spp. dominates the assemblage where as *Operculodinium* spp. and *Operculodinium centrocarpum* are abundant. *Habibacysta tectata* and *Lingulodinium machaerophorum* are common in all samples. *Labyrinthodinium truncatum*, *Nematosphaeropsis lemniscata* and *Palaeocystodinium miocaenicum* are locally abundant.

Other palynomorphs: Freshwater algae do occur subordinately.

Stratigraphic events: *Unipontidinium aquaeductum* has highest occurrence at the top of this interval and the highest occurrence of *Apteodinium tectatum* and *Hystrichokolpoma "reducta"* are recorded here in. *Achomosphaera andalousiense* and *Cannosphaeropsis passio* are present but are considered caved due to consequent reports from the North Atlantic region that *U. aquaeductum* and *C. passio* do not occur stratigraphically associated (de Verteuil & Norris 1996; Piasecki *et al.* 2004).
The range of *U. aquaeductum* is reported to be from top Langhian at 15.4 My, to mid-Serravallian at 13.2 My (Williams *et al.* 2004) which is in accordance with the appearance of *Cannosphaeropsis passio* just above this unit (12.8 Ma).

Age: Middle Miocene, late Langhian to early Serravallian.

Correlation to standard nanno- and foraminifer stratigraphy: The range of *U. aquaeductum* is reported from NN5 to lowermost NN6 (de Verteuil & Norris 1996).

Lithostratigraphy: The succession from 4045' – 4160' correlates with the Hodde Formation, onshore Denmark (Piasecki 1980; Piasecki *et al.* 2004)

Sequence stratigraphy: Correlates with the lower part of Sequence E, 3700'–4160', in Rasmussen *et al.* in print (2005).

## Samples 4160’ – 4280’ (3 samples)

Depositional environment: Fully marine depositional environment with abundance of dinoflagellates.

Dinoflagellate assemblage: Rich and diverse assemblage of dinoflagellate cysts, which is dominated by *Spiniferites* spp., *Operculodinium centrocarpum*, *Operculodinium* spp. and *Lingulodinium machaerophorum*. *Labyrinthodinium truncatum*, *Palaeocystodinium miocaenicum*, *Polysphaeridium zoharyi* are common in this unit. Peak abundance of *Polysphaeridium zoharyi* occurs in the lower samples.

Other palynomorphs: Freshwater algae occur rarely.

Stratigraphic events: The last occurrence of *Cousteaudinium aubryae*, Microdino sp. 7 and *Tectatodinium* sp. 1 are recorded in the uppermost sample 4160´ and the last occurrence of *Pyxidinopsis fairhavenensis* occur just below in 4240’.
*Labyrinthodinium truncatum* and *Unipontidinium aquaeductum* are present in this interval.
Recently, Williams *et al.* (2004) reports that the first appearance of *Unipontidinium aqueductum* is coincident with the last occurrence of *Cousteaudinium aubryae*. However, an interval without the presence of any of these two species is consequently recorded between these two events in core- or outcrop material from Danish onshore successions (Piasecki 1980; Piasecki *et al.* 2004). The present combined occurrence of these two species is therefore considered mixing of cuttings or regular caving.
*Pyxidinopsis fairhavenensis* is reported to occur highest in the upper Langhian, 15.2 Ma (de Verteuil & Norris 1996; Williams *et al.* 2004). *Cousteaudinium aubryae* is reported to occur for the last time close to the Langhian–Serravalian boundary at 15 Ma (de Verteuil & Norris 1996; Williams *et al.* 2004). *L. truncatum* appears close to the Burdigalian–Langhian boundary (de Verteuil & Norris 1996; Williams *et al.* 2004).

Age: Middle Miocene, Langhian.

Correlation to standard nanno- and foraminifer stratigraphy: The first occurrence of *L. truncatum* is correlated to mid-NN4 and the last occurrence of *C. aubryae* is correlated to lower NN5 (de Verteuil & Norris 1996). Therefore, the unit correlates with NN4–NN5.

Lithostratigraphy: The interval from 4061’ – 4280’ correlates with the uppermost Arnum Formation, onshore Denmark. The last occurrences of *C. aubryae,* Microdino sp. 7 and *Tectatodinium* sp. 1 have been recorded in the uppermost Arnum Formation in several wells onshore Denmark (Piasecki *et al.* 2004; Piasecki & Rasmussen 2004). Similarly, the peak occurrence of *Polysphaeridium zoharyi* in 4280’ and 4240’ correlates well with corresponding *P. zoharyi*-maxima close to the last occurrence of *C. aubryae* in the uppermost Arnum Formation onshore Denmark.

Sequence stratigraphy: Correlates with the upper Sequence D, 4045’– (4280’) in (Rasmussen *et al.* in print (2005)).

# Conclusions

The wells are biostratigraphically dated. The analysed succession of S-1 (2460'–1320') comprises Middle – Upper Miocene sediments from Langhian, Serravallian and Tortonian. The studied succession correlates with the uppermost Arnum Formation (2500'–2390'), probably with the Hodde Formation (2390'–2320') and with the Gram Formation (2320'–1310'). The lower succession are deposited in a fully marine environment until sample 1680' from which terrestrial material becomes more and more dominant probably reflecting deposition in front of a prograding coast.

The analysed succession of Tove-1 comprises Middle Miocene – Upper Pliocene sediments. Langhian, Serravallian and Tortonian are identified. A limited, but probably Messinian succession has been located. The Pliocene succession comprises Lower Pliocene and Upper Pliocene. A Zanclean, a probable Piacenzian and a definite Piacenzian succession are recognised.
The studied succession correlates with the uppermost Arnum Formation (4280'–4160'), the Hodde Formation (4160'–4045') and the Gram Formation (4045'–3555') of the Danish onshore succession. The lower boundary of the Hodde Formation and the upper boundary of the Gram Formation are identified by seismic reflectors, blue and purple respectively, and correlates with Sequence F of Rasmussen *et al.* in print (2005) (Figure 2). Seismic reflectors divide the following higher succession into 3 units corresponding to depositional sequences. The lower Sequence G (3555'–2110') comprises ?Messinian, Zanclean (Lower Pliocene) to Piacenzian? (lowermost Upper Pliocene) strata. Sequence H (2110'–1650') comprises a Piacenzian succession, lower part of the Upper Pliocene. Sequence I comprises a definitive Piacenzian succession, lower part of the Upper Pliocene. No Gelasian succession has been identified.
The Arnum Formation, the Hodde Formation and most of the Gram Formation are deposited in a fully marine environment. The fraction of terrestrial material in the organic matter increases in the upper Gram Formation and becomes abundant throughout Sequence G and totally dominating in Sequence H probably reflecting deposition in front of a prograding coastal plain. The full Arnum, Hodde, Gram, Sequence G and H succession represents one major flooding – progradation cyclus. The upper Sequence H is not represented by any samples because it is a coarse-grained sand. Sequence I comprises two small depositional cycles both represented by a restricted marine flora in the lower part which becomes terrestrial dominated in the upper part.

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# Illustrations

## Figure captions

Figure 1: Map of the Neogene succession in the Danish region. Neogene is subcropping below the Quartenary cover and the strata become progressively older towards the north-east. Location of the offshore wells S–1 and Tove–1 are marked and the research wells onshore Jylland are also indicated.

Figure 2: Miocene stratigraphy in the Danish region. The onshore lithostratigraphy is correlated with depositional sequences and seismic markers based on both on- and offshore data.

Figure 3: Appearances and disappearances of stratigraphic significant dinoflagellate cysts in the North Atlantic region based on Williams *et al.* (2004).

Figure 4: List of stratigraphic significant dinoflagellate events in S-1 correlated with depths and stratigraphy.

Figure 5: List of significant dinoflagellate events in Tove-1 correlated with depths and stratigraphy.

## Appendix 1

Distribution chart of the palynological fossils in samples analysed from the S-1 well. The first column shows the depth scale. The chronostratigraphy and the age interpretation are followed by the correlation of the succession to lithologically units onshore, the gamma log and selected dinoflagellate events.
The stratigraphic distribution of dinoflagellates, acritarchs and other algae are shown separately. The succession of recorded species is arranged after their down-hole appearances. The colours light green (terrestrial), dark green (marginal marine), light blue (near shore marine) and dark blue (dominantly marine) illustrate the interpretation of the palaeo-depositional environment. The variations in dinoflagellate diversity are illustrated in red.

## Appendix 2

Distribution chart of the palynological fossils in samples analysed from the Tove-1 well. The first column shows the depth scale. The chronostratigraphy and the age interpretation are followed by the correlation of the succession to lithologically units onshore Denmark or in the Danish North Sea, the gamma log and selected dinoflagellate events.
The stratigraphic distribution of dinoflagellates, acritarchs and other algae are shown separately. The succession of recorded species is arranged after their down-hole appearances. The colours light green (terrestrial), dark green (marginal marine), light blue (near shore marine) and dark blue (dominantly marine) illustrate the interpretation of the palaeo-depositional environment. The variations in dinoflagellate diversity are illustrated in red.

## Plate 1

Magnification of the dinoflagellates is approximately x 680. The size is indicated by the 25 µm long bar.
MI numbers refer to records in the MicroImage database at GEUS.

Figures 1–2: *Operculodinium piaseckii* from 1890’in S-1. MI 14.383.

Figure 3. *Palaeocystodinium golzowense* from 4280’ in Tove-1. MI 13.879.

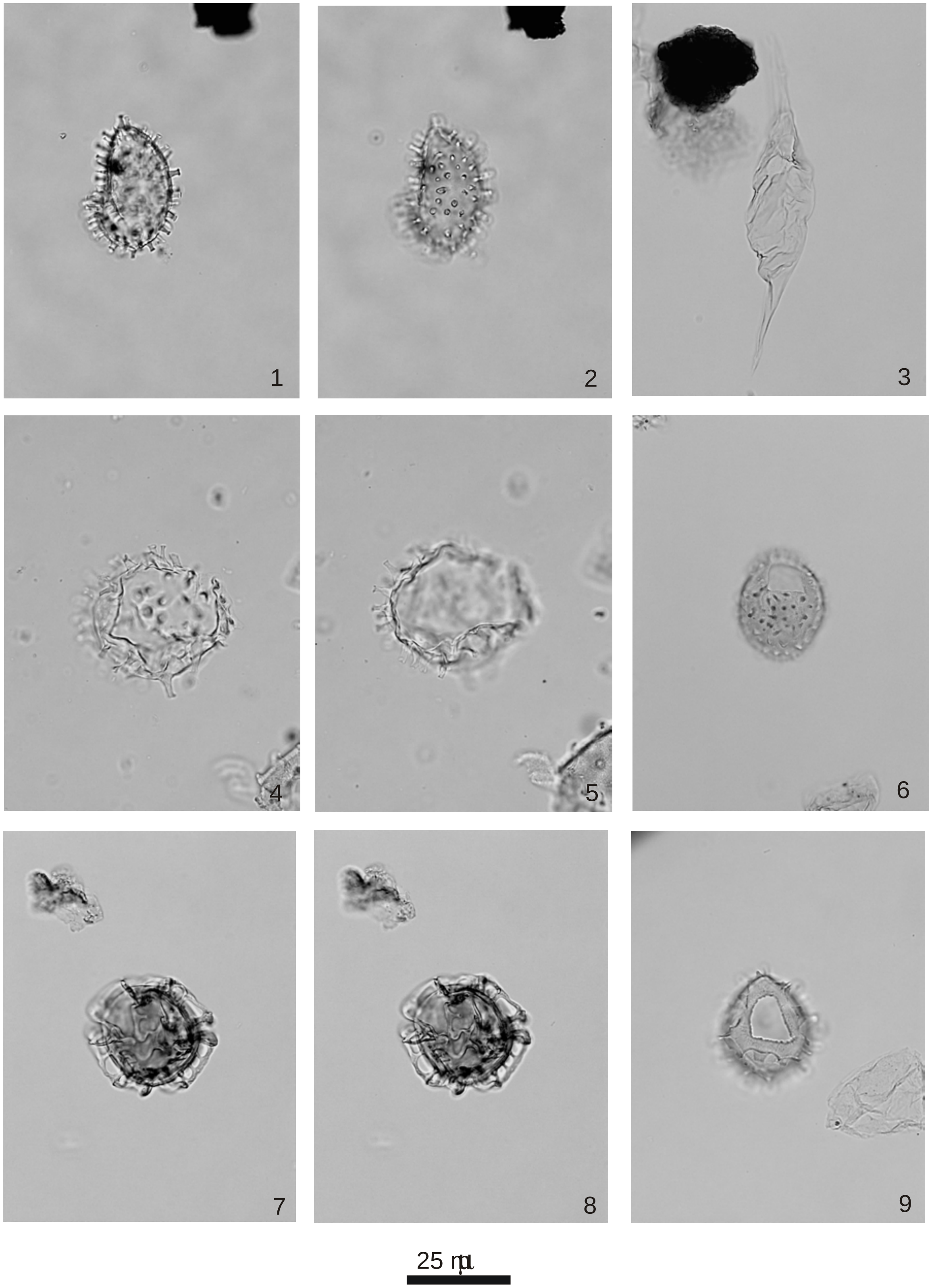
Figures 4–5: *Polysphaeridium zoharyi* from 2430’ in S1. MI 14.384.

Figure 6: *Pyxidinopsis fairhavenensis* from 4240’ in Tove-1. MI 13.896.

Figures 7-8: *Unipontidinium aquaeductum* from 3380’ in Tove-1. MI 13.891.

Figure 9: *Cerebrocysta poulsenii* from 2400’ in S-1. MI13.827.

Plate 1



## Plate 2

Magnification of the dinoflagellates is approximately x 680. The size is indicated by the 25 μm long bar.
MI numbers refer to records in the MicroImage database at GEUS.

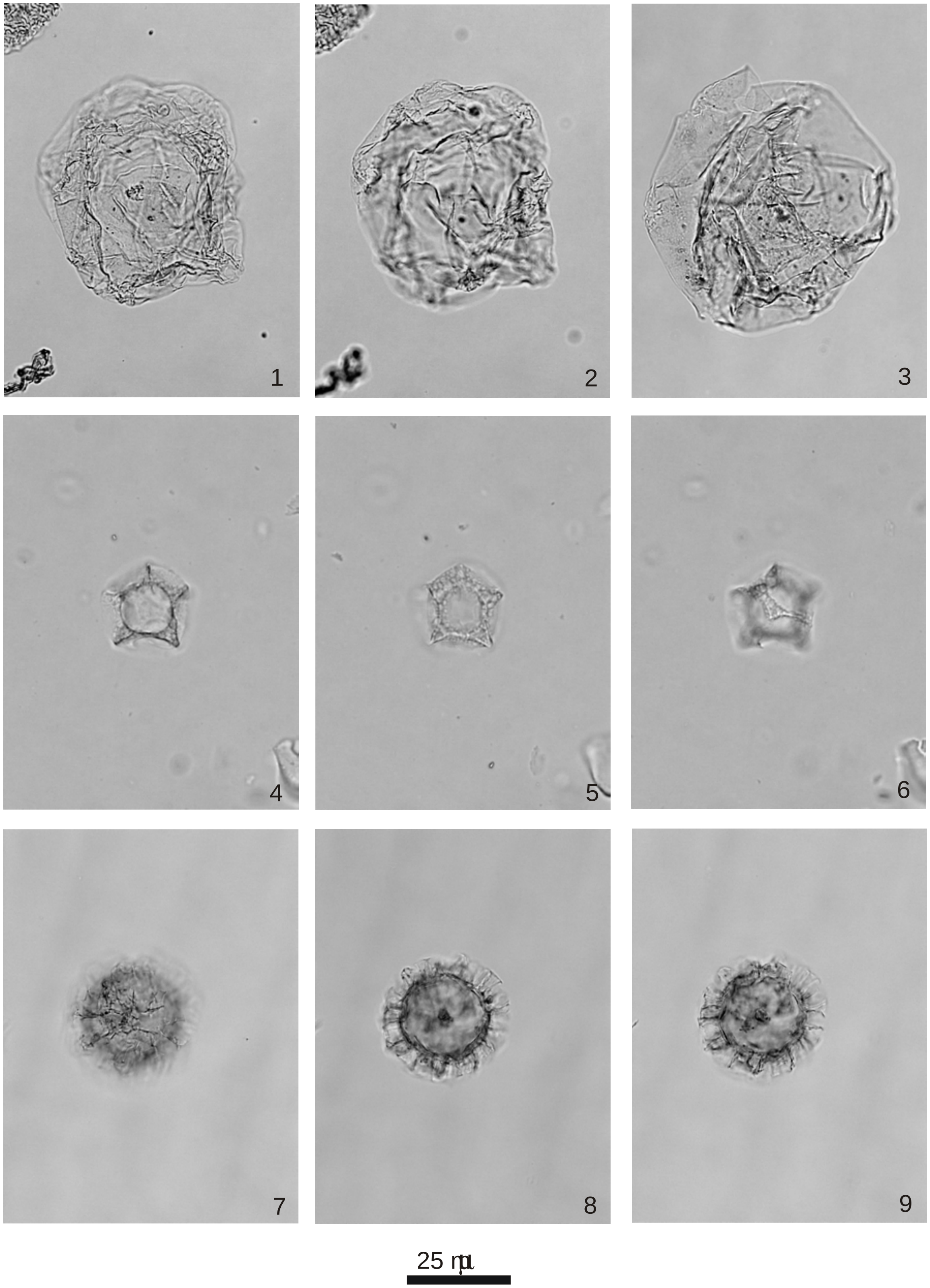
Figures 1–2: *Cousteaudinium aubryae* from 4240’ in Tove-1. MI 14.381.

Figure 3: *Cousteaudinium aubryae* from 4280’ in Tove-1. MI 14.382.

Figures 4–6: Microdino sp.7 from 2460’ in S-1. MI 14.385.

Figures 7–9: *Labyrinthodinium truncatum* from 4160’ in Tove-1. MI 14.378.

Plate 2



## Plate 3

Magnification of the dinoflagellates is approximately x 680. The size is indicated by the 25 µm long bar.
MI numbers refer to records in the MicroImage database at GEUS. Figures 1–2 and 4–5 illustrate relevant species with specimens from other localities.

Figure 1: *Bitectatodinium? aborichiarum* from 25.58 meter in Sdr. Vium research well, Jylland, Denmark, MI 13.086.

Figure 2: *Bitectatodinium? aborichiarum* from 25.58 meter in Sdr. Vium research well, Jylland, Denmark. MI12.268.

Figure 3: *Melitasphaeridium choanophorum* from 4120’ in Tove-1. MI 14.377.

Figure 4: *Gramocysta verricula* from 13.0 meter in Gram II research well, Jylland, Denmark. MI 11.657.

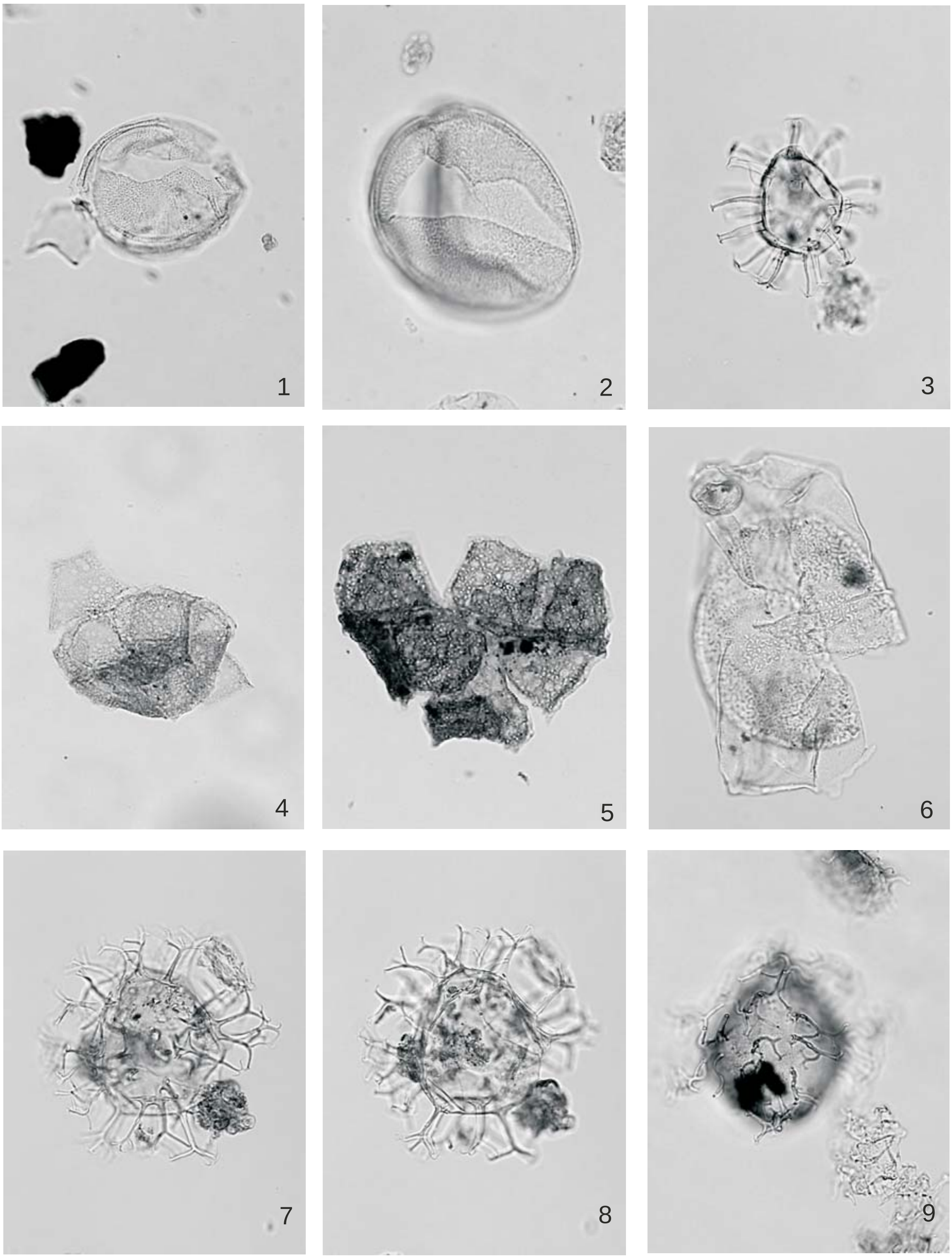
Figure 5: *Gramocysta verricula* from16.0 meter in Gram II research well, Jylland, Denmark. MI 11.669.

Figure 6: *Hystrichosphaeropsis obscura* from 4010’ in Tove-1. MI 14.374.

Figures 7–8: *Spiniferites solidago* from 4100’ in Tove-1. MI 14.376.

Figure 9: *Spiniferites solidago* from 4040’ in Tove-1. MI 14.375.

Plate 3




25 m

## Plate 4

Magnification of the dinoflagellates is approximately x 680. The size is indicated by the 25 μm long bar.
MI numbers refer to records in the MicroImage database at GEUS.

Figure 1–3: *Cannosphaeropsis passio* from 4040’ in Tove-1. MI 13.883.

Figure 4: *Achomosphaera andalousiense* from 4040’ in Tove-1. MI 13.885.

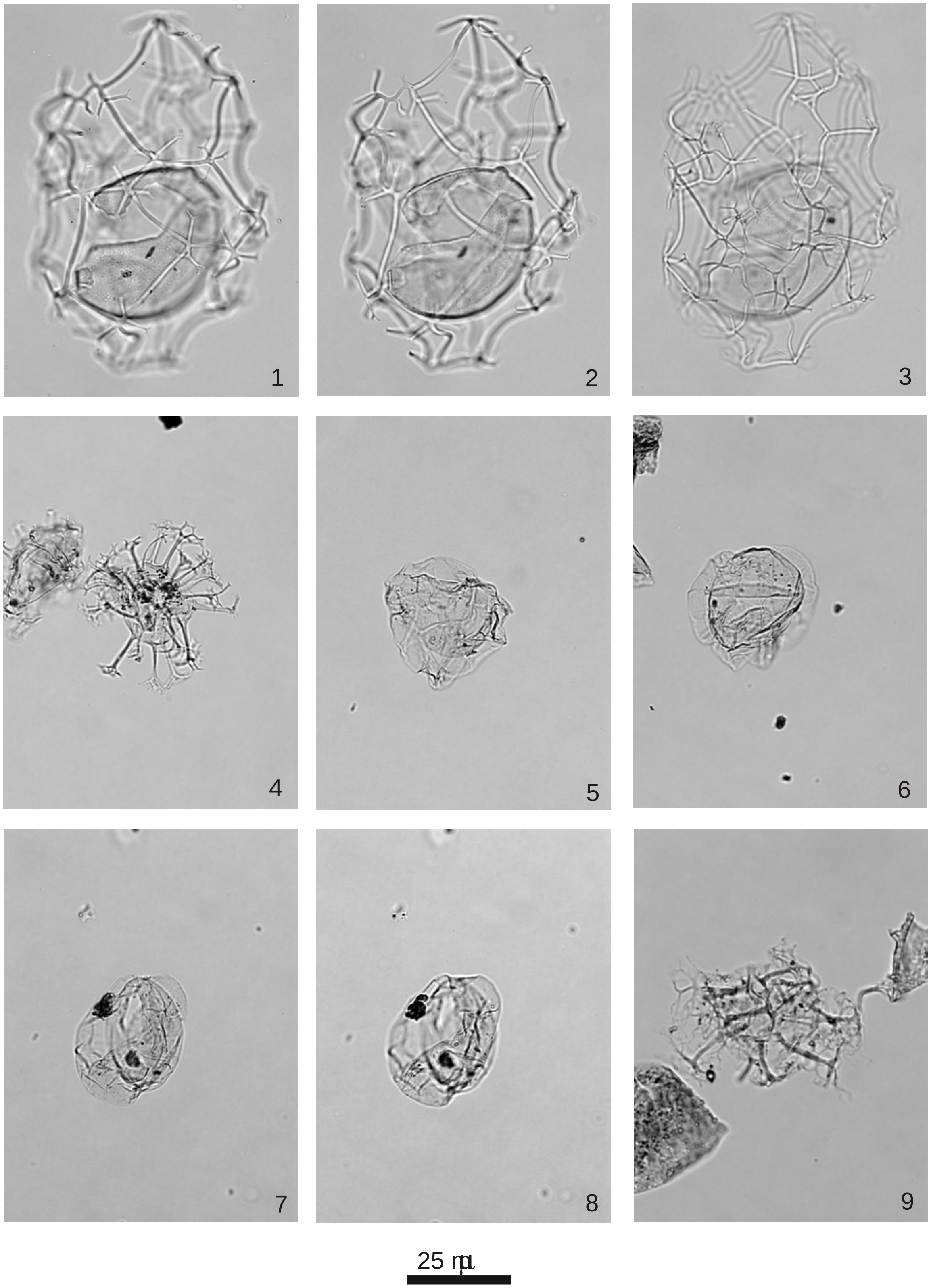
Figure 5: *Ataxiodinium choane*? from 3140’ Tove-1. MI 14.365.

Figure 6: *Ataxiodinium choane*? from 3500’ in Tove-1, MI 14.367.

Figures 7–8: *Ataxiodinium choane*? from 3500’ in Tove-1. MI14.368.

Figure 9: *Reticulatosphaera actinocoronata* from 3740’ in Tove-1. MI 14.396.

# Plate 4



## Plate 5

Magnification of the dinoflagellates is approximately x 680. The size is indicated by the 25 μm long bar.
MI numbers refer to records in the MicroImage database at GEUS. Figures 6, 8–9 illustrate relevant species with specimens from other localities.

Figure 1: *Impagidinium ”densiverrucosum”* from 3800’ in Tove-1. MI 14.371.

Figures 2–3: *Pentadinium laticinctum* from 3740’ in Tove-1. MI 14.370.

Figure 4: *Palaeocystodinium powellense* from 4010’ in Tove-1. MI 13.943.

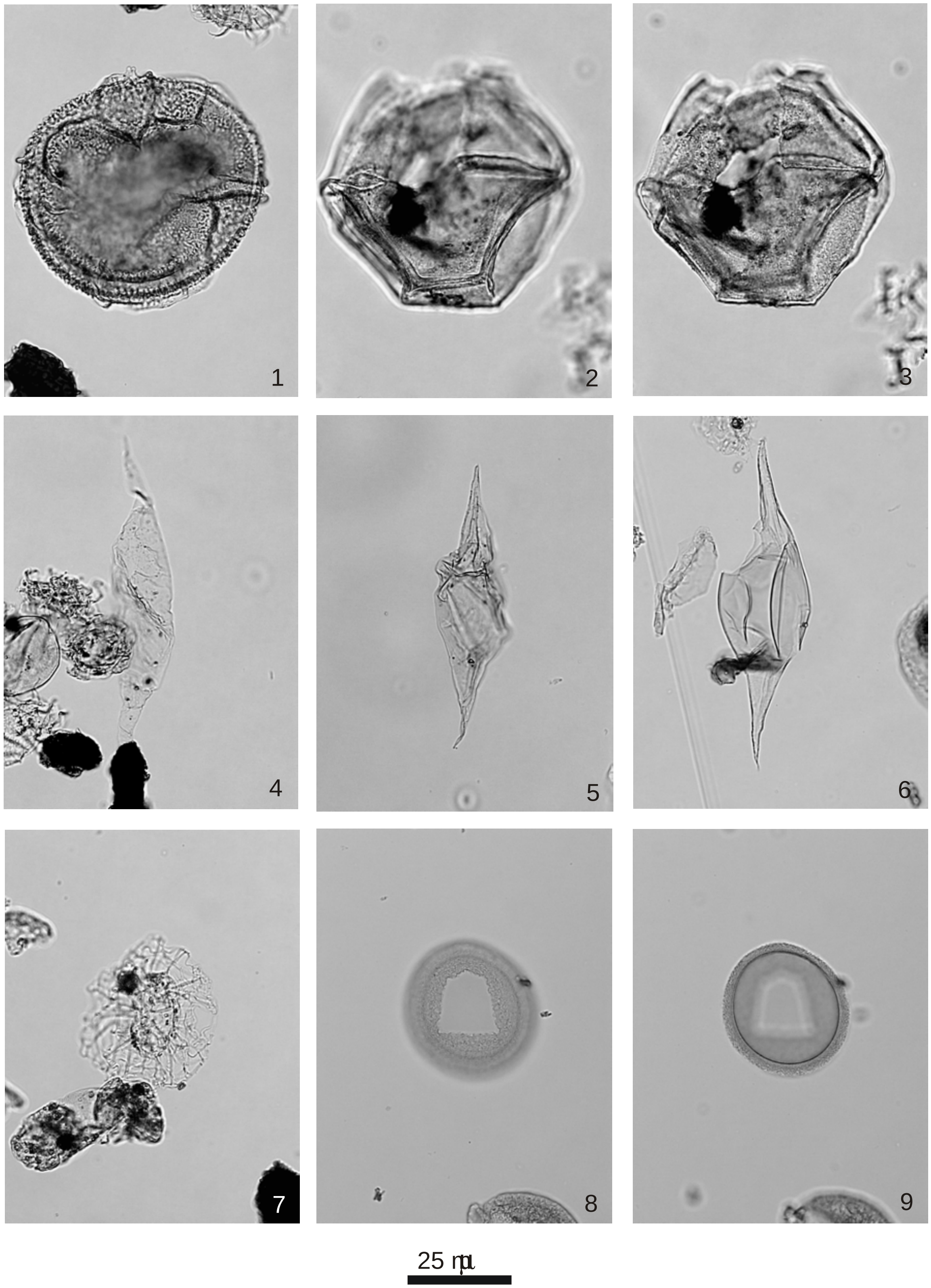
Figure 5: *Palaeocystodinium miocaenicum* from 4100’ in Tove-1. MI 14.185.

Figure 6: *Palaeocystodinium miocaenicum* from Sdr. Vium research well in Jylland, Denmark. MI 13.517.

Figure 7: *Nematosphaeropsis lemniscata* from 3800’ in Tove-1. MI 14.372.

Figure 8–9: *Tectatodinium pellitum* from 25.58 meter in Sdr. Vium research well, Jylland, Denmark. MI 12.514.

Plate 5



## Plate 6

Magnification of the dinoflagellates is approximately x 680. The size is indicated by the 25 μm long bar.
MI numbers refer to records in the MicroImage database at GEUS.

Figure 1: *Habibacysta tectata* from 4160' in Tove-1. MI 14.380.

Figure 2: *Habibacysta tectata* from 1640' in Tove-1. MI 14.360.

Figure 3: *Filisphaera filifera* from 1400' in Tove-1. MI 14.258.

Figure 4: *Filisphaera filifera* from 2750' in Tove-1. MI 14.361.

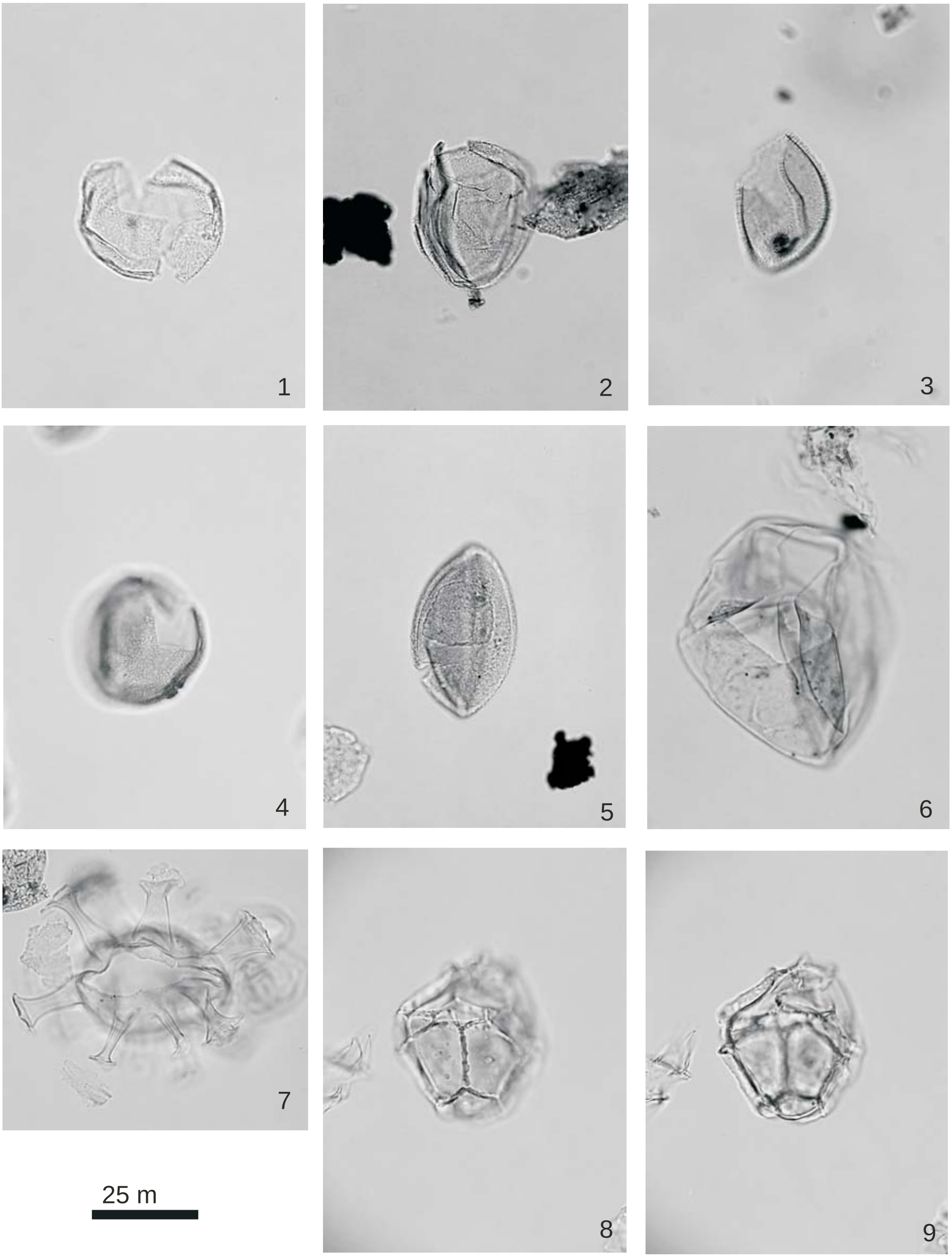
Figure 5: *Bitectatodinium raedwaldii* from 1640' in Tove-1. MI 14.259.

Figure 6: *Bitectatodinium serratum* from 3140' in Tove-1. MI 14.362.

Figure 7: *Hystrichokolpoma "reducta"*? from 1490' in Tove-1. MI 13.848.

Figure 8: *Impagidinium* sp. A Wrenn & Kokinos 1986 from 4160' in Tove-1. MI 13.878.

Plate 6



## Plate 7

Magnification of the dinoflagellates is approximately x 680. The size is indicated by the 25 μm long bar.
MI numbers refer to records in the MicroImage database at GEUS.

Figures 1–2: *Barssidinium evangelineae* from 3650’ in Tove-1. MI 13.889.

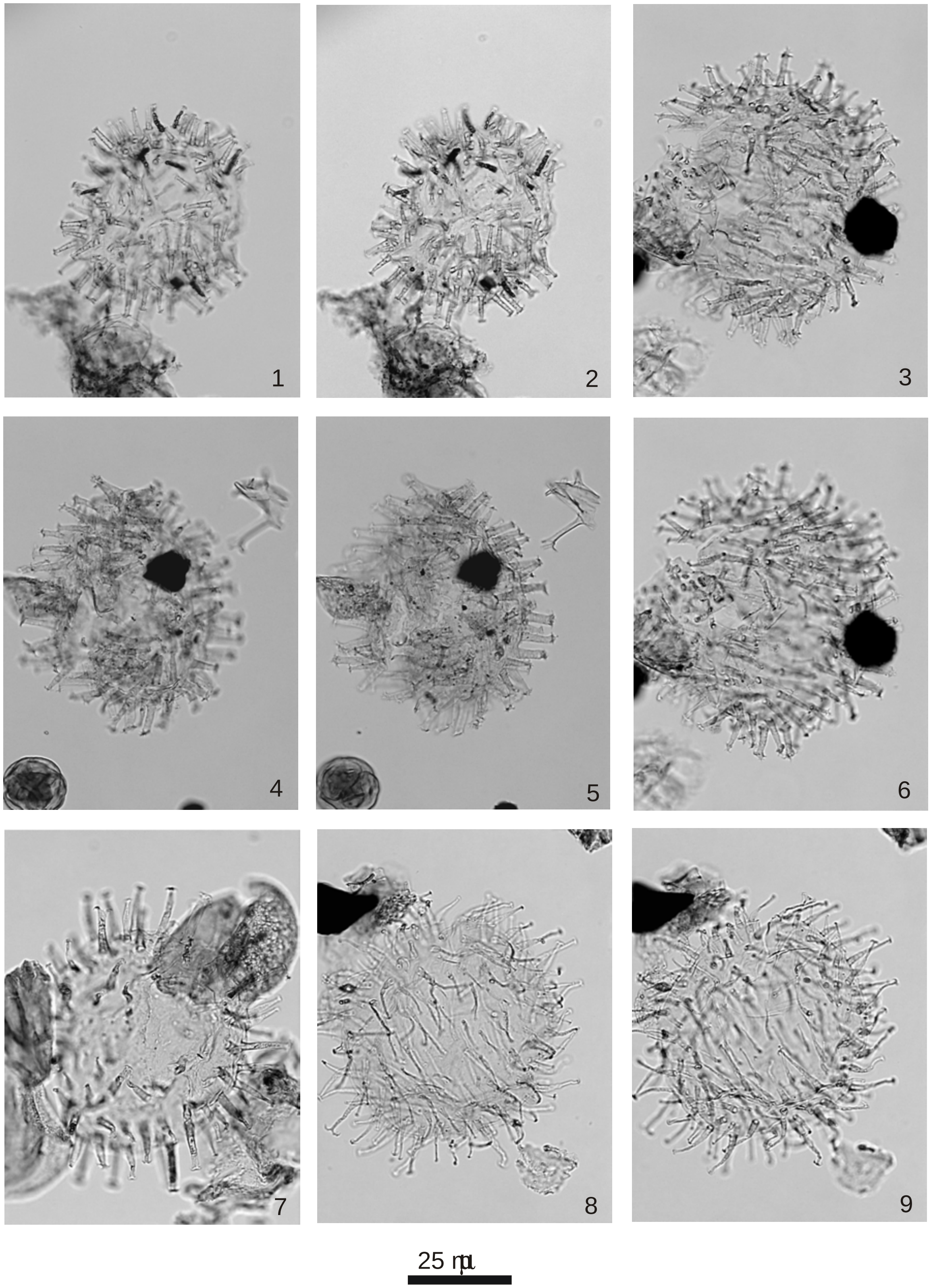
Figures 4–6: *Barssidinium evangelineae* from 3500 in Tove-1. MI 13.844.

Figures 3 & 6: *Barssidinium pliocenicum* from 3500’ in Tove-1. MI 13829.

Figure 7: *Barssidinium pliocenicum* from 3140’ in Tove-1. MI 14364

Figures 8–9: *Barssidinium graminosum* from 3500’ in Tove-1. MI 14.366.

Plate 7



## Plate 8

Magnification of the dinoflagellates is approximately x 680. The size is indicated by the 25 μm long bar.
MI numbers refer to records in the MicroImage database at GEUS.

Figure 1: *Amiculosphaera umbraculum* from 1340’ in Tove-1. MI 13.899.

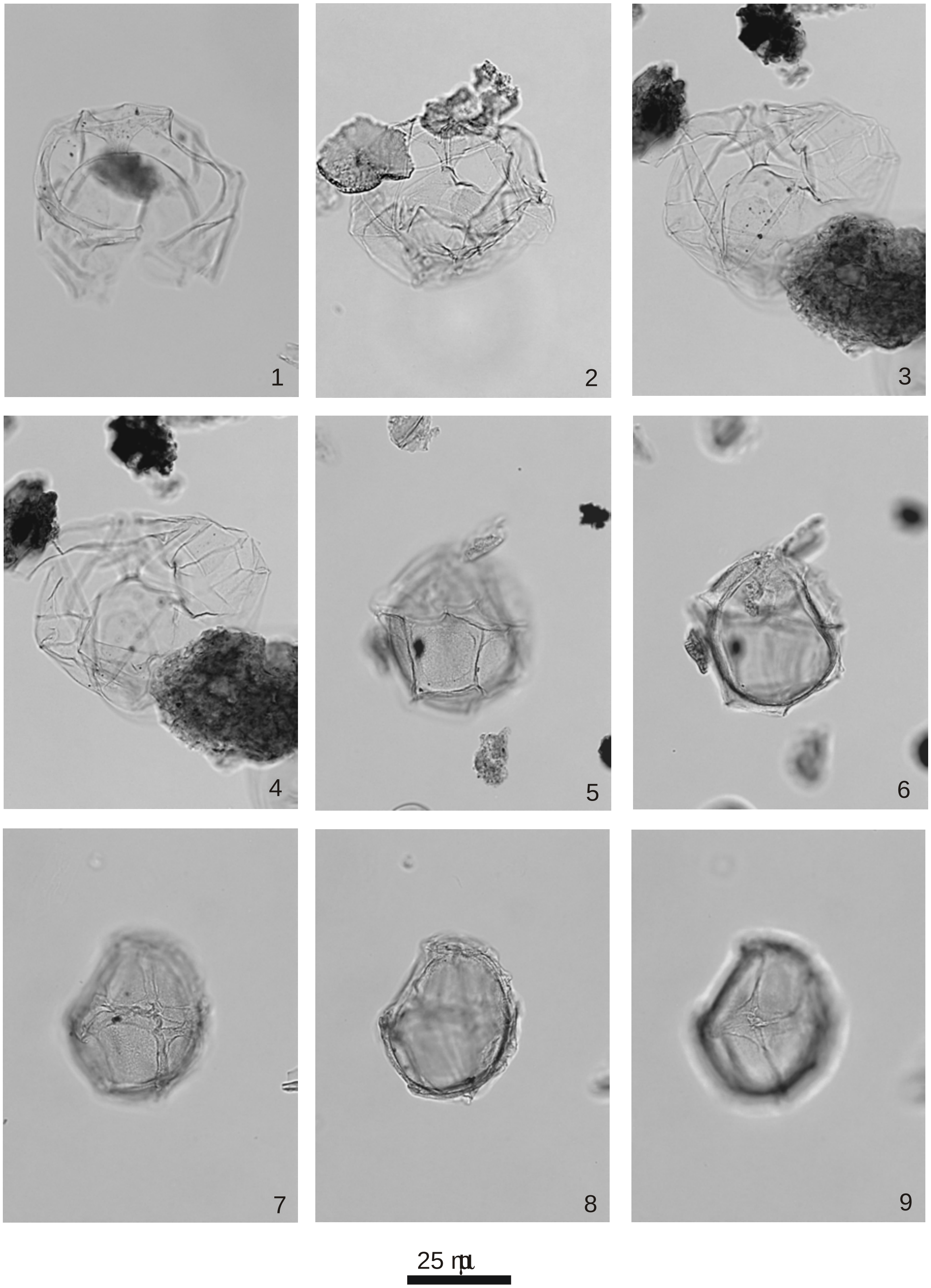
Figure 2: *Amiculosphaera umbraculum* from 3140’ in Tove-1. MI 14.363.

Figures 3–4: *Amiculosphaera umbraculum* from 1340’ in Tove-1. MI 13.898.

Figures 5–6: *Impagidinium multiplexum* from 1490’ in Tove-1. MI 13.846.

Figures 7–9: *Impagidinium multiplexum* from 1490’ in Tove-1. MI 13.847.

# Plate 8



# Well Name : S-1

Operator : Chevron Petrol. Comp. Spudded : 06 February 1975
Well Code : S-1 Completed : 14 April 1975
Lat/Long : 55°30' 57.00"N 6°55' 17.80"E
Interval : 1312' - 2503' Neogene dinoflagellate stratigraphy......
Scale : 1:2000 S. Piasecki & E. S. Rasmussen
Chart date: 20 October 2004 GEUS Report 2004/94: APPENDIX 1

# S-1

GEUS
Report file no.
Enclosure
25678 (01/02)

GEUS
Copenhagen

APPENDIX 1

**Well Name : TOVE-1**

Operator : Chevron Petroleum Company
Well Code: TOVE-1
Lat/Long : 55°15' 17.30"N 5° 9' 45.30"E
Interval : 1300' - 4300'
Scale : 1:2000
Chart date: 14 October 2004

Neogene dinoflagellate stratigraphy....
S. Piasecki & E. S. Rasmussen
GEUS Report 2004/94: APPENDIX 2

# TOVE-1

GEUS Copenhagen



APPENDIX 2