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Late Jurassic to Early Cretaceous dinoflagellate cysts from the Eastern Gulf of Mexico:

Facilitating future exploration and development activities in the basin

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Abstract

The Late Jurassic to Early Cretaceous strata of the Eastern Gulf of Mexico (EGoM) are one of the world's major hydrocarbon reserves. However, there is a lack of published palynology studies from these strata. This research aimed to fill that data gap by producing a biostratigraphy based on dinoflagellate cyst assemblages using data collected from three wells around the EGoM: VK117, DC353 and CH265.

The Gulf of Mexico is a structurally complex area in terms of its tectonic setting. This unusual depocentre therefore requires a well age-constrained biostratigraphy to be established to enable correlation of strata and structures around the EGoM basin. Rich assemblages of palynomorphs, dominated by dinoflagellate cysts, have been recovered from 175 samples taken from the three wells. These have been analysed using a transmitted light microscope to collect the palynofacies data, as well as systematically describing 164 dinoflagellate cyst species and collate quantitative data concerning their occurrence/abundance. These data were then compared to adjacent locations to produce a working biostratigraphy of the EGoM.

Further analysis of the palynodebris and palynomorphs has presented information concerning the depositional environments. These data were interpreted using a Tyson Ternary Kerogen Plot (AOM–phytoclasts–palynomorphs) and compared to a Ternary Liptinite–Vitrinite–Inertinite Kerogen Plot to indicate hydrocarbon source potential of the surrounding rocks.

The kerogen associations indicated by the Ternary plots for two wells were then compared to the Palynomorph Darkness Index (PDI). To test the robustness of the PDI calculations and if they can be used as an alternative indicator of thermal maturity using a dinoflagellate cyst (*Sentusidinium explanatum*) as the palynomorph subject, it was compared with vitrinite reflectance.

This development of a robust biostratigraphical model for the EGoM basin will greatly facilitate upcoming exploration and development activities in this basin and ensure future energy security.

Contents

Chapter 1 – Introduction

Palynology is the study of organic walled microfossils (palynomorphs) that are typically obtained from rocks following acid digestion. There are several groups of palynomorphs, in particular spores, pollen, achritarchs and dinoflagellate cysts. The main focus of this study is centred around dinoflagellate cysts. Organic walled dinoflagellate cysts are extremely resistant to most forms of decay, and so leave behind a fossil cyst in the geological record, ranging from, 20–200 microns (μm) in size. The cyst, composed of organic dinosporin, at the end of its motile life detaches from the outer theca which breaks apart leaving the cyst behind. After a period of dormancy, the protoplast inside the cyst is excysted through an archaeopyle. The remaining cyst then has the potential to be preserved as a microfossil.

Dinoflagellate cysts are extremely informative, as not only do they allow reconstruction of their depositional environment, but also the age of the rock via biostratigraphy. Biostratigraphy is the classification of sediment units, based on the presence or absence of key fossils. This enables the rock record to be divided into biostratigraphical zones, each one characterised by a distinctive fossil assemblage. Dinoflagellate cysts make excellent biostratigraphical markers as they evolve rapidly, have a wide geographical distribution and are strongly controlled by their environment.

There have been extensive studies of the Late Jurassic and Early Cretaceous dinoflagellate cysts of Europe, Asia and Australasia e.g. Harker and Sarjeant, 1975; Rawson and Riley, 1982; Helby *et al.,* 1987; Ogg, 1994; Riding and Ioannides, 1996; Riding *et al.,* 1999; Torricelli, 2000; Oosting *et al.,* 2006. However, extremely little is published on the dinoflagellate cyst biostratigraphy of North America, in particular the Eastern Gulf of Mexico (EGoM), with the closest biostratigraphical sites found to be in the Blake-Bahama Basin (Habib and Drugg, 1983), South-western Gulf of Mexico (Riley and Fenton, 1984) and the Western Interior Basin (Harris and Tocher, 2003). However, most of the publications concerning the North American continent focus on the biostratigraphy of Canada and Alaska (Pocock, 1967; 1976; 1980; Brideaux and Fisher, 1976; Brideaux, 1977; Barss *et al.,* 1979; May, 1979; Davies, 1983; Van Helden, 1986) or basic taxonomy work (Benson *et al.,* 1999). Although dinoflagellate cyst assemblages from Europe, North America and northern and western South America, do allow comparisons of taxa to be made at a generic level, there are clear differences between the floral communities (Ogg, 1994; Oosting *et al.,* 2006; Riding *et al.,* 2011). Limited comparison can be made with Australian taxa. This may have been due to palaeo-ocean currents (Hay, 2008) and the transport patterns of dinoflagellate cysts (Kessler II, 1968; Dale, 1976; 1992; 2001; Wall *et al.,* 1977; McMinn and Wells, 1992; Harland and Pudsey, 1999; Marret and Zonneveld, 2003).

The economic importance of a dinoflagellate cyst biostratigraphy within the oil and gas industry is extremely significant, as it can be used to place age constraints on rocks, which is useful in both exploration and production. Dinoflagellate cysts have also proven themselves to be a useful tool in palaeoecology, palaeogeography, palaeoclimatology, correlation, maturation, provinciality and biodiversity studies (Davies *et al.,* 1982; Okolodkov and Dodge, 1996; Brinkhuis *et al.,* 1998; Piasecki, 2003; Sluijs *et al.,* 2005; Oosting *et al.,* 2006; De Schepper *et al.,* 2011; Riding *et al.,* 2011; Bowman *et al.,* 2012; and many others). The lack of published research on dinoflagellate cysts and dinoflagellate biostratigarphy in the EGoM basin is the result of: (1) the lack of published scientific research and (2) the non-disclosure of classified oil company research.

The main aim of this project is to fill the data gap from the EGoM and produce a working biostratigraphical model based on dinoflagellate cysts. To fulfil this aim, three objectives need to be met: (1) The systematic description of each dinoflagellate species needs recording. As such, standard palynological techniques will be utilised to extract the dinoflagellate cysts from three wells drilled around the EGoM. (2) Quantitative data needs to be logged for each species present within each sample layer. Hence, the dinoflagellate cysts recovered can be used to age constrain the strata. (3) Palynofacies data needs to be documented in order to reconstruct the sedimentary depositional palaeoenvironment. When these three objectives have been completed, the data can then be collated and analysed to produce a working biostratigraphical model between the three wells based on dinoflagellate cysts for the EGoM.

Chapter 2 – Geological Setting

2.1 Introduction

The Late Jurassic to Early Cretaceous timescale, illustrated in Figure 1 covers a time interval of 64Ma (Walker *et al.,* 2012). The Late Jurassic epoch stretches from the beginning of the Oxfordian (164Ma), through the Kimmeridgian, to the end of the Tithonian (145Ma). The end of the Tithonian marks the onset of the Early Cretaceous epoch, extending from the Berriasian (145Ma), through the Valanginian, Hauterivian, Barremian and Aptian, to the end of the Albian at 100Ma (Walker *et al.,* 2012).

This 64Ma (Oxfordian–Albian) time interval was characterised by the ongoing breakup of the supercontinent Pangea (Scotese, 1991; Kiessling, 2002) that produced the distinctive crescent shaped basin of the Gulf of Mexico (GoM) recognised today (Buffler, 1991). This period in Earth history has also been documented to have higher sea levels than at present (Haq *et al.,* 1987) which resulted in larger habitable area on the submerged continental shelf in which dinoflagellates could thrive.

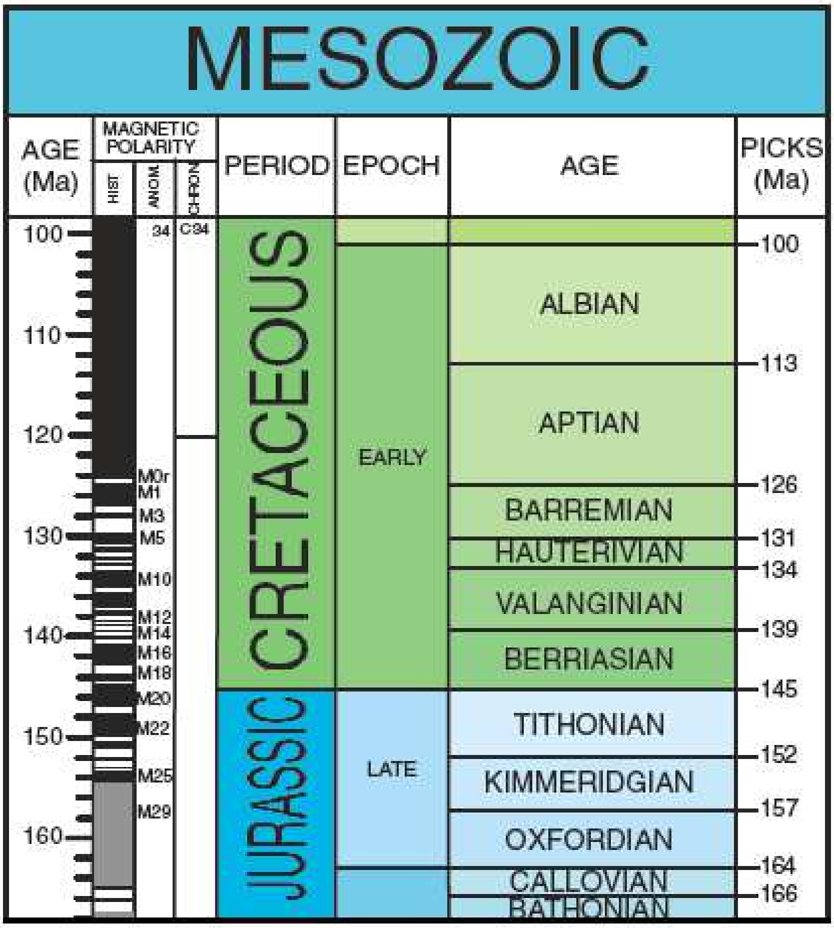


Figure 1. Jurassic/Cretaceous Geological Time Scale. Adapted from Walker *et al.,* 2012.

2.2 Palaeoclimate and Sea Level Change

In recent decades there has been an abundance of palaeoclimate and palaeoceanography studies focused on the Late Jurassic and Early Cretaceous employing numerous and various proxies. The findings of this research suggest a pronounced greenhouse world to an icehouse world during the course of both periods (Kemper, 1987; Frakes and Francis, 1988; Roth, 1989; Weissert and Lini, 1991; Frakes *et al.,* 1992; Weissert and Mohr, 1996; Ditchfield, 1997; Sellwood *et al.,* 2000; Mutterlose and Kessels, 2000; Ford and Golonka, 2003; Gröcke *et al.,* 2003; Sellwood and Valdes, 2008; Kidder and Worsley, 2010; Hay and Floegel, 2012; Huang *et al.,* 2012; Pauly *et al.,* 2012).

2.2.1 Late Jurassic (Oxfordian – Tithonian)

The Jurassic has long been considered a period in which greenhouse climates existed (Roth, 1989; Weissert and Mohr, 1996; Sellwood *et al.,* 2000; Gröcke *et al.,* 2003; Ford and Golonka, 2003; Sellwood and Valdes, 2008). There is an abundance of palaeo biotic and lithological proxy evidence to substantiate this claim (Roth, 1989): (1) Coral carbonate reefs were extended by 10° of latitude towards the poles compared to their present localities (Huber and Watkins, 1992; DeConto *et al.,* 2000; Leinfelder *et al.,* 2002; Sellwood and Valdes, 2008), (2) Evidence of widespread bauxites and other palaeosols (Hallam, 1984; Price *et al.,* 1995; Price *et al.,* 1998), and extensive distributions of evaporites and desert deposits compared to the modern (Parrish *et al.,* 1982; Grocke *et al.,* 2003; Sellwood and Valdes, 2008), (3) Terrestrial plant localities have been discovered from Jurassic (Vakhrameev, 1991) polar regions and from a tropical belt reaching from 30°N to 30°S, (4) There has been largely negative evidence to suggest glacial processes (Hallam, 1984; 1994; Frakes *et al.,* 1992; Ford and Golonka, 2003; Sellwood and Valdes, 2008), (5) There have been records of high atmospheric carbon dioxide (CO_2) levels derived from marine carbonate deposits (Scholle and Arthur, 1980).

As a consequence of the Late Jurassic greenhouse climate there would have been an accelerated water cycle. This enhancement of evaporation and precipitation rates is capable of producing monsoonal rainfall patterns (Parrish *et al.,* 1982; Del Genio *et al.,* 1991; Weissert and Mohr, 1996; Grocke *et al.,* 2003; Sellwood and Valdes, 2008). Consequently, evidence from the rock record and climate models (Weissert and Mohr, 1996; Moore *et al.,* 1992a) suggests that during the break up of Pangea there were palaeogeographic conditions whereby palaeorainfall conditions left a residual trace within the rock record of the accumulation of non-marine silicicalstic sediments (Weissert and Mohr, 1996; Grocke *et al.,* 2003).

Intensified seafloor spreading and volcanic activity also influenced the Jurassic climate (Roth, 1989; Weissert and Mohr, 1996) through the increased flux of CO_2 in the atmosphere. A number of palaeoclimate general circulation models (GCM) (Moore *et al.,* 1992b; Valdes and Sellwood, 1992) suggest that CO_2 concentrations were four times higher than modern values (Roth, 1989; and references therein). This increased CO_2 level would have sustained the Jurassic greenhouse climate due to the strong positive correlation existing between high levels of atmospheric CO_2 and warmer episodes in the geological past. The same correlation holds true between low levels of CO_2 and extensive continental glaciations (Berner and Kothavala, 2001; Royer *et al.,* 2004). The greenhouse climates experienced during the Jurassic are also attribuable to the intensification of the biological carbon pump (Weissert and Mohr, 1996).

Global sea level reached its peak during the Tithonian (Figure 2) (Haq *et al.,* 1987; Ford and Golonka, 2003), which is reflected in the EGoM basin, as the ocean went through a period of transgression (Mancini *et al.,* 2001; Mancini and Puckett, 2005). This is commonly considered to have occurred due to the varying volume of ocean basins, caused by tectonic movement (Hallam, 1992; 2001). However, the disparity in total ocean volume is inconclusive due to the lack of glacioeustatic evidence from the Jurassic (Hallam, 1984; 1993; Frakes *et al.,* 1992; Ford and Golonka, 2003; Sellwood and Valdes, 2008). Moreover, GCMs (Sellwood *et al.,* 2000) show that any glacial influences on sea level change are negligible and are insufficient to leave any evidence in the rock record (Hallam, 2001).

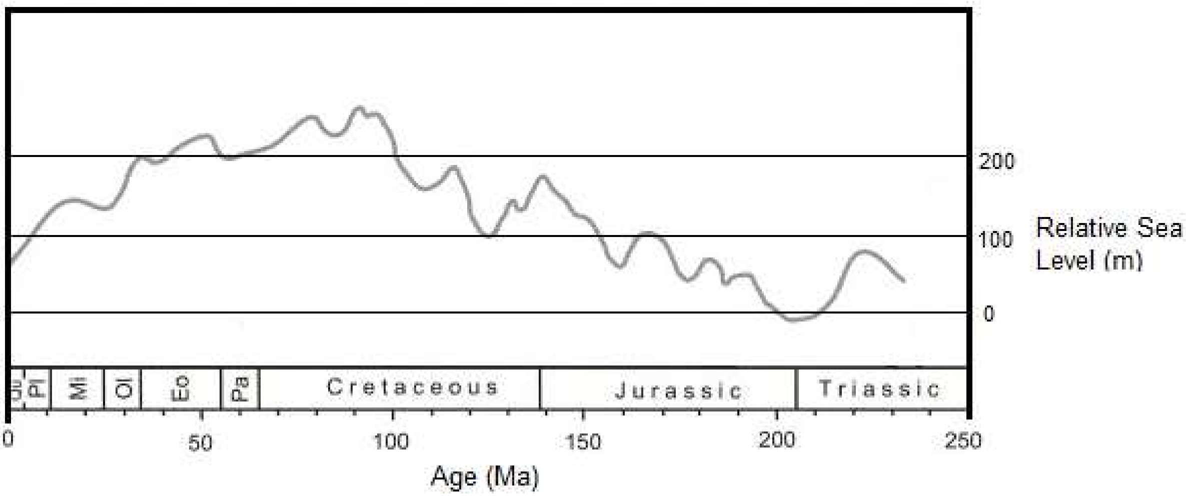


Figure 2. Palaeo Sea Level Curve. Adapted from Haq *et al.,* 1987.

Taking a holistic overview, the Late Jurassic climate was most likely greenhouse, punctuated with pronounced monsoonal rainfall activity, associated with a pronounced sea level rise due to tectonic movement.

2.2.2 Early Cretaceous (Berriasian – Albian)

The palaeoclimate of the Early Cretaceous is still very much a contentious issue amongst palaeoclimatologists. Contradictory research varies between interpretations of a pronounced greenhouse world (Frakes, 1979; Douglas and Woodruff, 1981; Hallam, 1981; Hallam, 1985; Frakes *et* *al.,* 1992; Kuypers *et al.,* 1999; Skelton *et al.,* 2003; Littler *et al.,* 2011; Jenkyns *et al.,* 2011), during which it was considered to have elevated CO_2 levels, (Barron and Washington, 1985; Barron *et al.,* 1993) and an icehouse world (Pauly *et al.,* 2012; Pucéat *et al.,* 2003; Price and Mutterlose, 2004; Price and Nunn, 2010). Some studies choose to divide the greenhouse world into warm and cool modes (Kidder and Worsley, 2010; Hay and Floegel, 2012).

One of the many arguments demonstrating a greenhouse climate during the Early Cretaceous is the continued reversal in climate between periods of aridity and humidity (Hallam, 1985; Price, 1999). The change was induced by turbulence in the global energy balance, which is controlled by the fluxes of CO_2, methane (CH_4) and water vapour (H_2O) in the atmosphere. These fluxes are controlled by biogeochemical weathering, vegetation cover, volcanic activity and the biological pump (Föllmi, 2012). This theory fits with the continued breakup of Pangea during the Early Cretaceous, throughout which there were periods of intense volcanic activity (Scotese, 1991). As the eruptive activity continued, it raised the concentration of greenhouse gases in the atmosphere, thus reinforcing the warm greenhouse climate (Larson and Erba, 1999; Keller *et al.,* 2011). The increase in ambient temperature is also responsible for increased evaporation rates, and as such the water retention capacity of the atmosphere, further increasing humidity and allowing greenhouse conditions to prevail. This is substantiated by the delta 18 oxygen isotope ($\delta^{18}O$) record (Föllmi, 2012). However, greenhouse conditions did not last as they were punctuated by intense episodes of precipitation (Douglas and Woodruff, 1981; Suarez *et al.,* 2011). The intense precipitation is considered to be in the form of monsoonal activity due to evidence of laminated, organic rich muds (Herrle *et al.,* 2004; Browning and Watkins, 2008). Under these conditions changes in relative sea level are most likely to be recorded as a result of major rifting, the creation of new oceans, and the formation of large submarine volcanic plateaus (Föllmi, 2012) and not the result of glacioeustacey.

Conversely, the hypothesis of a greenhouse climate (Frakes, 1979; Hallam, 1981; 1985; Herman and Spicer, 1996) has been challenged by other lines of evidence. This evidence suggests that the Early Cretaceous climate may not have sustained a persistent greenhouse climate, but instead it may have experienced periods of colder icehouse conditions. Frakes and Francis (1988), Frakes *et al.,* (1992), Frakes *et al.,* (1995) and Alley and Frakes (2003) presented evidence of polar ice sheets from the earliest Cretaceous (Berriasian–Valanginian) in the form of glacial deposits from high latitude sites in both hemispheres. Controversially, Bennett and Doyle (1996) suggested that the ice rafted debris and sediments from the Berriasian–Valanginian could also be interpreted as tree rafted debris. However, Haq *et al.,* (1987), Sahagian *et al.,* (1996), Stoll and Schrag (1996) and Takashima *et al.,* (2006) all show an overall reduction in relative sea level for the earliest Cretaceous, although the relative sea level was rising at this time (Ford and Golonka, 2003). Other oxygen and carbon isotope data also reveal cooler palaeotemperatures than previously thought for the Early Cretaceous (Podlaha *et al.,* 1998; Veizer *et al.,* 2000; Pucéat *et al.,* 2003; Price and Mutterlose, 2004; Gröcke *et al.,* 2005; Huang *et al.,* 2012). Mineral evidence also supports a cooler, icehouse world during the Valangian (Kemper and Schmitz, 1975; Kemper and Schmitz, 1981; Kemper, 1983; Kemper, 1987; Price, 1999; Rogov and Zakharov, 2010).

However, here it is considered that the literature shows a growing trend towards the idea of a varied climate during the Early Cretaceous (Weissert and Lini, 1991; Mutterlose and Kessels, 2000; Kidder and Worsley, 2010; Hay and Floegel, 2012; Huang *et al.,* 2012), not only with periods of warmth throughout the Early Cretaceous, but also times where periodic formation of ice caps during the Valangian, Aptian and Albian were possible. These cooler intervals are thought to have had a duration of a few thousand to two million years (Kemper, 1987; Frakes and Francis, 1988; Frakes *et al.,* 1992; Ditchfield, 1997).

2.3 The Geodynamic Evolution of the Gulf of Mexico Basin

The GoM basin, shown in Figure 3, became established during the Late Triassic through to the Early Cretaceous (Figure 4) (MacRae and Watkins, 1996). At this time, it is widely regarded that the supercontinent Pangea was experiencing extensional rifting, faulting and isostatic adjustment of its crust along a triple junction (Pilger, 1981; Van Siclen, 1984; Pindell, 1985; Salvador, 1987; Winker and Buffler, 1988; Buffler, 1991; Mancini *et al.,* 2001; Rueda-Gaxiola, 2004). At the triple junction, North America tore away from Africa and South America to produce the largely iconic crescent shaped basin situated along the southeast margin of the North American continent (Buffler, 1991). The history of the GoM at this time is recorded in the structural and stratigraphical framework of the basin (Rainwater, 1967; Salvador, 1987), in which four well defined periods can be documented (Buffler, 1991): (1) Late Triassic to Early Jurassic rifting; (2) Middle Jurassic attenuation; (3) Late Jurassic oceanic crust; and (4) Early Cretaceous subsidence.

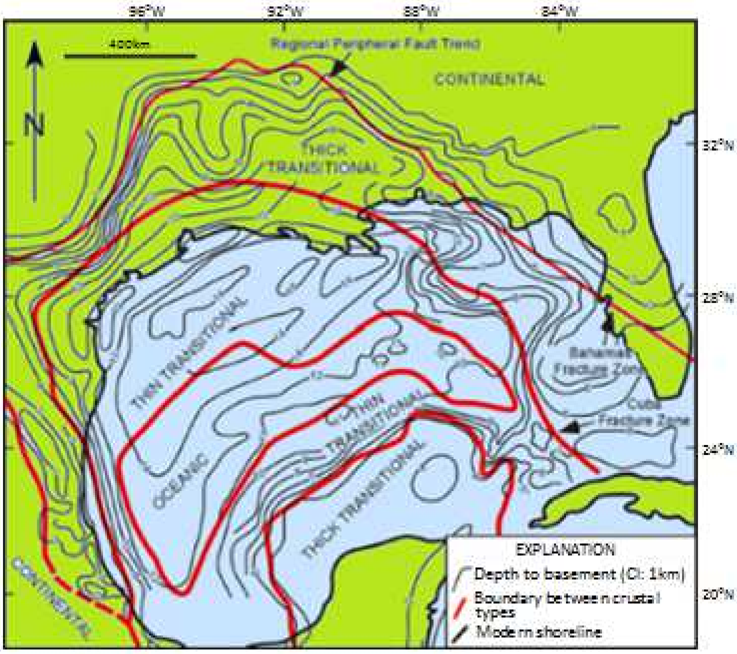


Figure 3. Map of the Gulf of Mexico, displaying the distribution of crustal types and depth to the basement. Adapted from Sawyer *et al.,* 1991

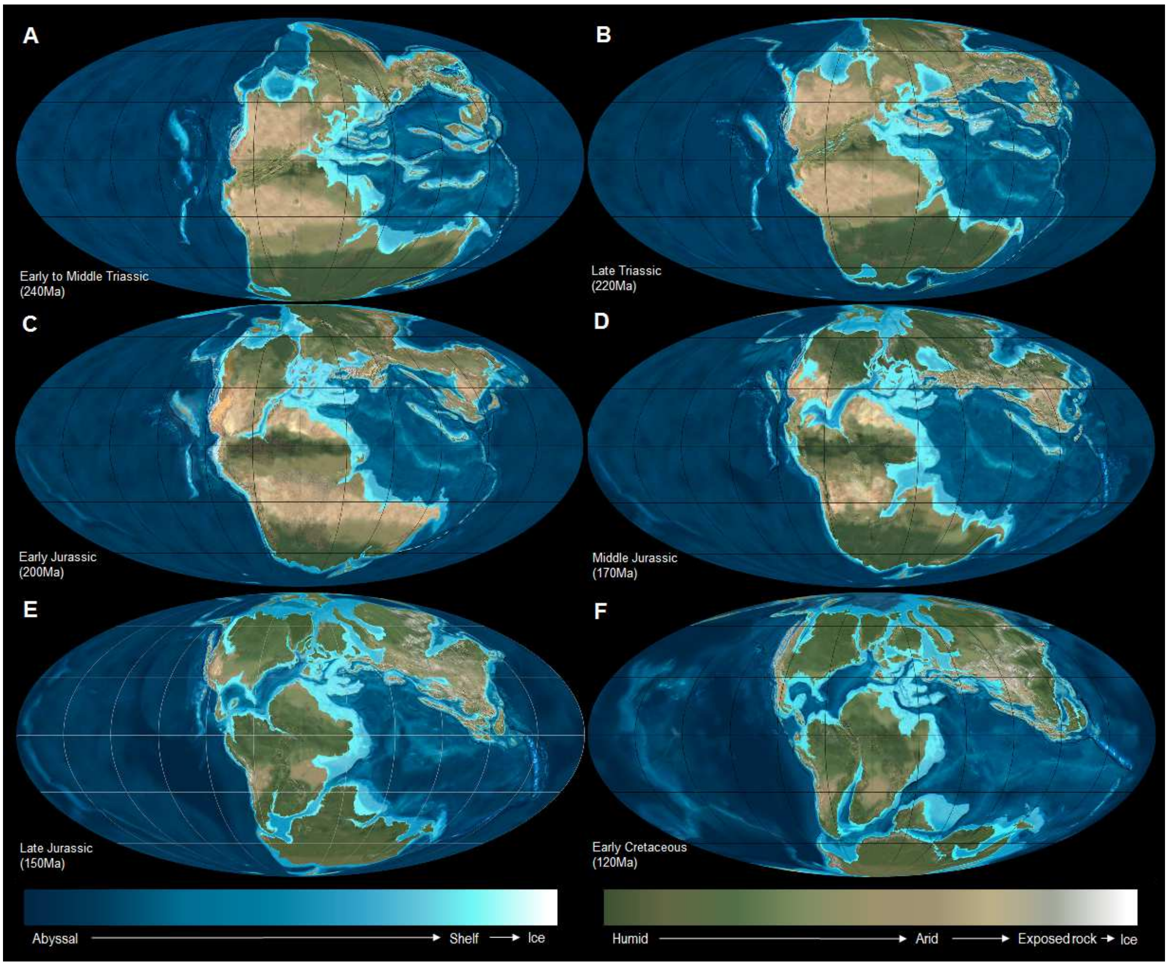


Figure 4. Palaeocontinental reconstructions. Adapted from ©Colorado Plateau Geosystems, Blakey 2016, used with permission.

2.3.1 Late Triassic to Early Jurassic Rifting

Throughout the Triassic to Early Jurassic (Figure 4 A–C) Pangea's crust rifted producing faults, allowing North America to tear away from the rest of the supercontinent. This large scale faulting produced large horsts and grabens deemed to be termed ranges and basins (Winker and Buffler, 1988) in the GoM basin region, which are bound by listric normal faults. During the course of the Late Triassic through to the Early Jurassic, the GoM basin was in-filled with non-marine siliclastic sediments (red-beds), shown in Figure 5 labelled as the Eagle Mills Formation, as well as volcanic rocks (Buffler and Sawyer, 1985; Winker and Buffler, 1988; Sawyer *et al.,* 1991; Buffler, 1991; Mancini *et al.,* 2001).

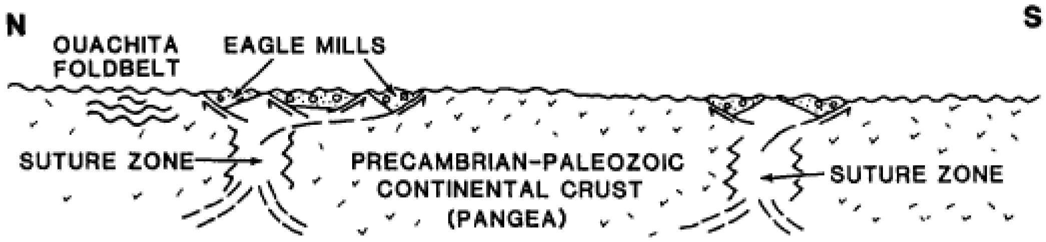


Figure 5. Schematic diagram showing the early evolution of the Gulf of Mexico basin throughout the Late Triassic to Early Jurassic. (From Buffler, 1991, figure 4)

2.3.2 Middle Jurassic Attenuation

During the Middle Jurassic (Figure 4 D) the GoM basin suffered further rifting and attenuation (Alzaga-Ruiz *et al.,* 2009). This resulted in the formation of both thick and thin transitional crust (Buffler and Sawyer, 1985; Buffler, 1991; Mancini *et al.,* 2001). Contained within the thick transitional crust are alternating basement highs and lows which have 100–500km wavelengths and can be seen to flank the basin around its northern, eastern (Figure 6) and western margins (Buffler and Sawyer, 1985; Mancini *et al.,* 2001). These relic basement features represent areas of greater or lesser attenuation caused by a broad area of mantle upwelling shown in Figure 7 (Winker and Buffler, 1988; MacRae and Watkins, 1996; Buffler, 1991; Mancini *et al.,* 2001).

The transition from thick to thin transitional crust marks a major tectonic hinge zone in the GoM basement (Buffler and Sawyer, 1985; Sawyer *et al.,* 1991; Mancini *et al.,* 2001). The hinge zone is defined by the Cuba Fracture Zone and the Pearl River Transform Fault and approximates the position of the Early Cretaceous carbonate shelf margin (Mancini *et al.,* 2001). Throughout the Middle Jurassic period, thick bodies of salt were deposited centrally on the thinner transitional crust, as well as in smaller adjacent basins in the thick crust (Winker and Buffler, 1988; Buffler and Sawyer, 1985; Buffler, 1991). These evaporitic deposits were formed due to episodic marine spillages into the basin across sills from the southern margins of the GoM basin (Buffler, 1991).

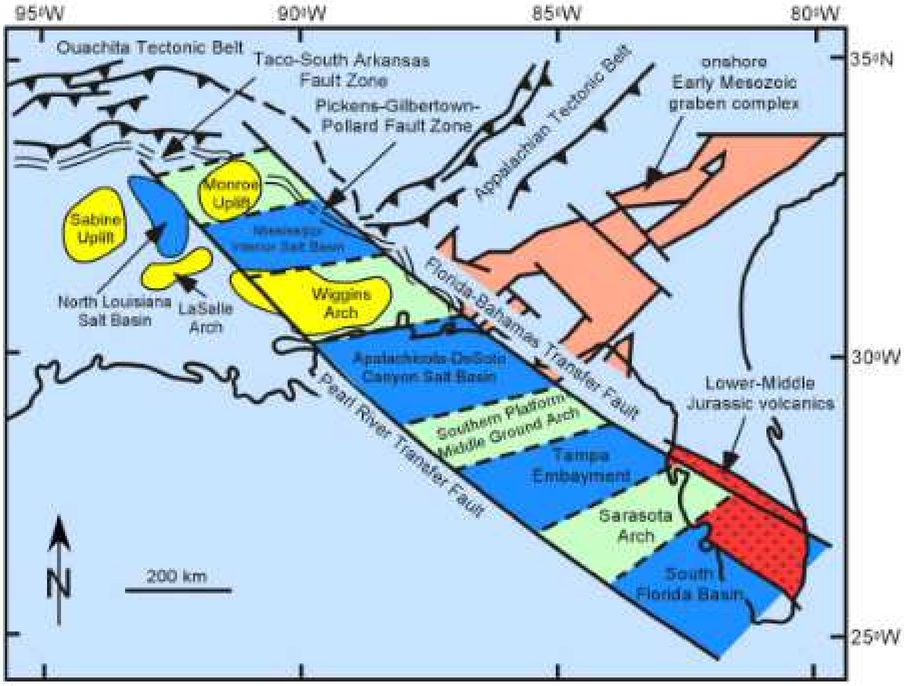


Figure 6. Tectonic framework of the North-eastern Gulf of Mexico. (from Mancini *et al.,* 2001, figure 2)

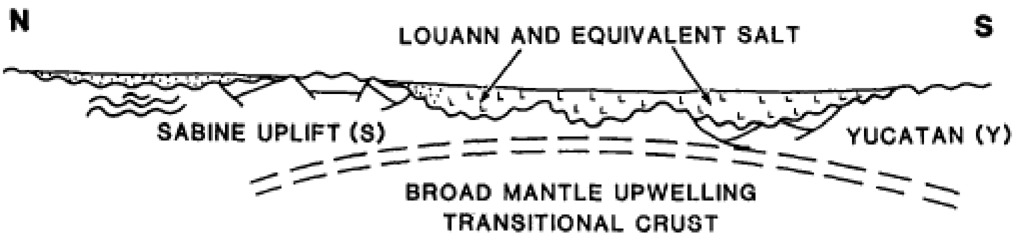


Figure 7. Schematic diagram showing the early evolution of the Gulf of Mexico basin throughout the Middle Jurassic. (From Buffler, 1991, figure 4)

2.3.3 Late Jurassic Oceanic Crust

During the Late Jurassic (Figure 4 E) the upwelling mantle narrowed (Figure 8) in the GoM basin along an east to western striking weakness in the thin transitional crust (Buffler and Sawyer, 1985; Buffler, 1991) and the emplacement of oceanic crust (Buffler, 1991; Mancini *et al.,* 2001; Alzaga-Ruiz *et al.,* 2009). The production of oceanic crust was then complemented by a marine transgression. This occurred as the basin crust cooled and thermally subsided whilst the relative sea level rose (Hallam, 1969; Nunn, 1984; Haq *et al.,* 1987; Winker and Buffler, 1988; Buffler, 1991; Moore *et al.,* 1992a; Mancini *et al.,* 2001; Hallam, 2001). The Late Jurassic was also the time when the Yucatan Peninsula relocated to its now familiar position. Numerous kinematic settings have been presented, however, it is widely regarded amongst the geological community that the Yucatan Block rotated anticlockwise to the southeast of the basin (Humphris, 1979; Shepherd, 1983; Pindell, 1985; Winker and Buffler, 1988). This divided the previously formed Middle Jurassic salt basins in two; now the North Gulf Salt Basin and its southern counterpart, the Sigsbee Salt Basin, shown in Figure 8 (Buffler, 1991).

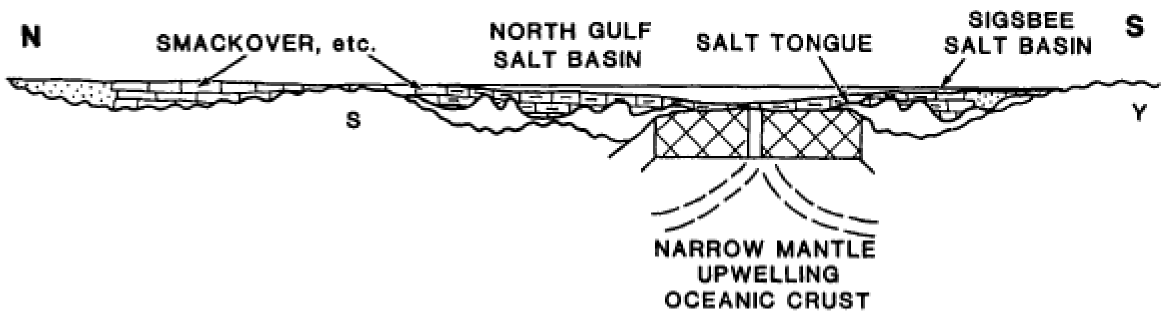


Figure 8. Schematic diagram showing the early evolution of the Gulf of Mexico basin throughout the Late Jurassic. (From Buffler, 1991, figure 4)

2.3.4 Early Cretaceous Subsidence

Thermal subsidence continued into the Early Cretaceous (Figure 4 F) and a carbonate shelf margin platform prograded into the basin along the tectonic hinge zone (Dobson, 1990; Buffler, 1991; Feng and Buffler, 1991; 1996; Mancini *et al.,* 2001; Alzaga-Ruiz *et al.,* 2009). It was this thermal subsidence of the lithosphere which controlled the sedimentation rates and architecture of the GoM basin (Pindell, 1985; Ross and Scotese, 1988; Alzaga-Ruiz *et al.,* 2009).

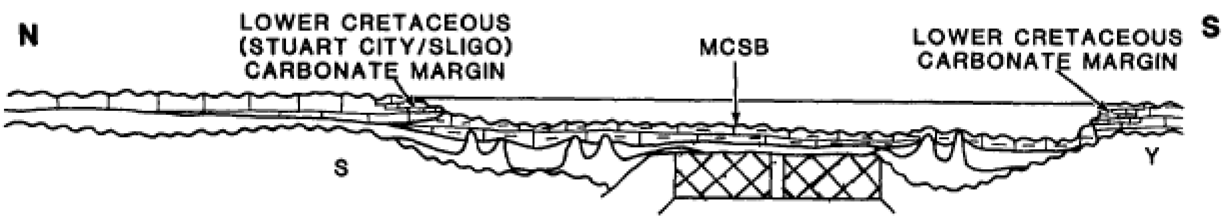


Figure 9. Schematic diagram showing the early evolution of the Gulf of Mexico basin throughout the Early Cretaceous. (From Buffler, 1991, figure 4)

The geodynamic evolution of the GoM basin allowed the progressive infilling of accommodation space via sedimentation throughout the Late Jurassic and Early Cretaceous.

2.4 The Stratigraphical Succession of the Eastern Gulf of Mexico Basin

This section summarises the basic stratigraphy of both offshore deposits and accessible onshore deposits around the EGoM, and considers the sequence and conditions under which the sediments were deposited during the Late Jurassic through to the Early Cretaceous.

Work began on the EGoM strata in the, 1930s (Bingham, 1937; Weeks, 1938; Shearer, 1938), and continues to the present day by the United States Geological Survey (USGS). Building on the work of Dallmus (1957) and Rainwater (1967), Mancini *et al.,* (2001) explain that there are several interlinking factors which affected the orientation of the infilling strata in the North-Eastern GoM: (1) Basement features associated with plate kinematics. (2) Features resulting from Jurassic salt halokinesis. (3) Basement faults such as horsts and grabens, resultant from rifting and plate separation (shown in Figure 6). (4) The placement of two major basement faults (Florida-Bahamas Transfer Fault and the Pearl River Transfer Fault) which trend in a northwest trajectory. (5) The ridge complexes associated with the Palaeozoic Appalachian orogeny.

Much of the same is true for the depositional settings down the Western Floridian peninsular. However, it is the Peninsular Arch which is the dominant subsurface structure trending South-Southeast. This affected the sedimentation during the Cretaceous (Puri and Banks, 1959; Atwater, 1959) as it was a topographical high and so sediment deposited was around it. Also affecting the sedimentation accumulation in Florida were the Ocala uplift and the Chattahoochee Arch (Pressler, 1947; Puri and Banks, 1959; Figure 10).

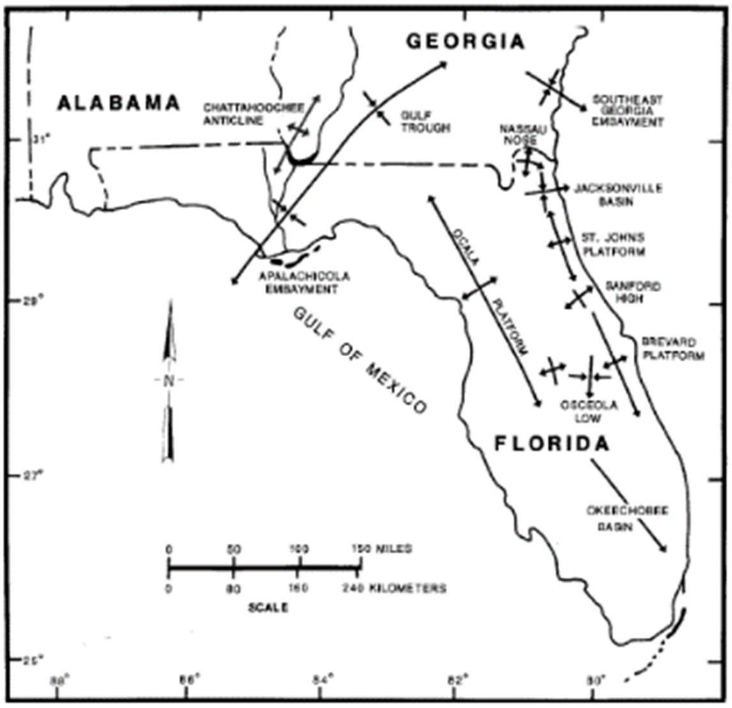


Figure 10. Principal Geological Structures in Florida. Modified from Scott (1988, figure 4)

As with any sedimentary basin, climate played a significant part in the Late Jurassic and Early Cretaceous stratigraphy. Leeder *et al.,* (1998) explain that the rate of sediment supply from an erosional catchment to a depositional basin depends primarily upon climate, relief, catchment slope and lithology, which vary both in time and space. As such, the erosional sediments from the newly formed North American plate, washed down into the GoM and were deposited as sandstone or red beds. The sandstone formations within the GoM are also interbedded with carbonate sediments (Palacas, 1978). The carbonate is formed from lithified remains of marine organisms. In the GoM the carbonate sediment is preserved as both limestone and dolostone.

2.4.1 Offshore Deposits

This overview will look at the offshore stratigraphy from two viewpoints. First, from the Northeast province, which takes into consideration offshore Louisiana, Mississippi, Alabama and the panhandle of Florida. Followed by the offshore stratigraphy from the Western Floridian Peninsula. Included within the description of the GoM strata, where possible, are descriptions of their depositional palaeoenvironments, and their correlation to other neighbouring stratigraphical sequences (Figure 11).

2.4.1.1 Northeast Province – in stratigraphical order:

Eagle Mills Formation

The basement rocks are Palaeozoic in age. On top of this lies the oldest Mesozoic unit, which is dated as Latest Triassic to Earliest Jurassic (Guthrie and Raymond, 1992; Mancini *et al.,* 2001). This is known as the Eagle Mills Formation, which represents a graben filled of red shale or mudstone, with occasional green and grey mudstones, which can be micaceous, calcareous or dolomitic. These were deposited at the time when the GoM began to open (Weeks, 1938; Tolson *et al.,* 1983; Guthrie and Raymond, 1992; Mancini *et al.,* 2001).

Werner Formation

The Werner Formation named by Hazzarrd *et al.,* (1947) is primarily an evaporitic anhydrite. However, its lower member is a conglomeratic redbed, including shale and sandstone (Hazzarrd *et al.,* 1947; Mancini *et al.,* 1990; Wade and Moore, 1993). It is located above the Eagle Mills Formation (Mancini *et al.,* 1990; Wade and Moore, 1993; Mancini *et al.,* 2001) and its age is Middle Jurassic (Bajocian). It represents the initial transgression of marine water into the GoM basin (Hazzarrd *et al.,*1947; Swain, 1949; McKee *et al.,* 1956; Mancini *et al.,* 1990; Wade and Moore, 1993; Mancini *et al.,* 2001).

Louann Salt

The Louann salt is also an evaporitic layer, formed due to the continued transgression of the sea. It is predominantly a silty, sandy, massive halite with intercalated anhydrite (Mancini *et al.,* 1990). The thickness varies due to the influence of the underlying Palaeozoic basement structures. The salt is unsurprisingly thickest in the interior of the Mississippi salt basin, and the Apalachicola–Desoto Canyon salt basin. However, it is absent from the Wiggins Arch and the Southern Platform–Middle Ground arch (Figure 6) (Mancini *et al.,* 1990; Mancini *et al.,* 2001).

Norphlet Formation

The Norphlet Formation has been greatly influenced by the basement topography due to rifting (Mancini *et al.,* 2001). As such, it overlies the Louann Salt, Werner Formation, Eagle Mills Formation or basement rock, and extends a vast distance from Eastern Texas to the panhandle of Florida (Schenk, 1990; Scott, 1991; Rupert, 1991). The Norphlet Formation consists of four main facies. The lowest facies represented by black shales is indicative of a restricted bay or lagoonal environment (Schenk, 1990; Mancini *et al.,* 2001). Above this lies a conglomerate facies (Mancini *et al.,* 1990; Schenk, 1990; Scott, 1991; Rupert, 1991) consisting of grey to red, poorly sorted, fine to very coarse grained sediments, contains pebble to cobble-size clasts of chert, shale, quartzite, rhyolite and metamorphic rocks. It is thought to represent a proximal fluvial fan and wadi deposit (Schenk, 1990; Mancini *et al.,* 2001). Situated above the conglomerate lies a red bed facies of red sandstone, siltstone and mudstone

(Mancini *et al.,* 1990; Schenk, 1990; Scott, 1991; Rupert, 1991); which Schenk (1990) interprets as a distal alluvial fan and fluvial wadi deposit. The final facies consists of quartz sandstone which is fine to very fine grained, moderately well to well sorted and grey to buff, feldspathic sandstone of the Denkman Sandstone Member at the top of Norphlet (Schenk, 1990). The Norphlet Formation is considered to be Late Jurassic (Callovian–Oxfordian) in age (Salvador, 1987; Mancini *et al.,* 1990; Schenk, 1990; Scott, 1991; Rupert, 1991; Mancini *et al.,* 2001).

Smackover Formation

The Smackover Limestone was first mentioned by Bingham (1937) and further described a year later by Weeks (1938). However, it was not until research conducted by Imlay (1940) that it was termed the Smackover Formation. It progressively overlaps the Norphlet Formation following the topography of the underlying basement features, and underlies the Haynesville Formation or Buckner Anhydrite (Dickinson, 1968; Forgotson and Forgotson, 1976). Its sedimentary architecture is consistent with the Late Jurassic marine transgression as the GoM basin thermally subsided due to crustal cooling (Mancini *et al.,* 1990; Tew *et al.,* 1993; Mancini *et al.,* 2001; Mancini and Puckett, 2002).

The sediment, which filled the ever growing accommodation space, can be divided into three members. The lower member consists of intertidal to sub tidal laminated and microbial carbonate mudstones, subtidal peloidal wakestones and packstones. The middle member contains subtidal microbial boundstones capped by an upper member of subtidal to inter tidal peloidal, ooid, oncoidal packstones and grainstones, which are interbedded with fenstal carbonate mudstones (Weeks, 1938; Dickinson, 1968; Mancini *et al.,* 1990; Tew *et al.,* 1993; Mancini *et al.,* 2001; Mancini and Puckett, 2002). Dickinson (1968) suggests that the upper member is probably the same as the Reynolds oolite zone. It is considered that the Smackover Formation is of Late Oxfordian age, based on ammonite zonation in Salvador (1987) and Mancini *et al.,* (1990).

Haynesville Formation

The Haynesville Formation was deposited during the Kimmeridgian (Mancini *et al.,* 2001) and it too followed the basement topography, progressively onlapping the Smackover Formation; extending from Texas to the Floridian panhandle (Forgotson and Forgotson, 1976; Wade and Moore, 1993). The Haynesville Formation had its first published description by Weeks (1938). However, it was not recognised as a formation until Dickinson (1968).

The Haynesville Formation consists of two units. The Lower Buckner Anhydrite, which as the name suggests contains predominately subaqueous to subaerial anhydrites, but also some shelf to shore line, red shale and dolomite. The upper member, however, is predominately made up of aeolian, fluvial and alluvial deposited red mudstone and sandstones (Weeks, 1938; Shearer, 1938; Dickinson, 1968; Wade and Moore, 1993; Mancini *et al.,* 2001).

The Cotton Valley Group

The Cotton Valley Group originally described by Weeks (1938) was laid down during the Tithonian (Latest Jurassic) to the Berriasian (Earliest Cretaceous). It too is affected by the underlying basement topography (Mancini *et al.,* 2001). It consists predominantly of marine beds, composed of various types of shale, sand and limestone (Shearer, 1938).

The group contains three main units. The basal unit is known as the Bossier Shale (Swain, 1944; Mann and Thomas, 1964; Dickinson, 1968; Forgotson and Forgotson, 1976; Mancini *et al.,* 2001) deposited during a fluvial deltaic phase (Mancini *et al.,* 2001). The middle unit, the Schuler Formation, contains sandstone red beds indicative of a near shore facies (Shearer, 1938; Mann and Thomas, 1964; Dickinson, 1968; Forgotson and Forgotson, 1976; Mancini *et al.,* 2001). The final unit of the Cotton Valley Group is termed the Knowles Limestone, which is thought to be the precursor to the development of the Early Cretaceous carbonate shelf margin (Mancini *et al.,* 2001).

~Hiatus~

Between the top of the Cotton Valley Group (Knowles Limestone) and the base of the Hosston Formation there is a hiatus recognised throughout the GoM and Europe (Mancini and Puckett, 2005), it is thought to represent most of the Valanginian stage.

Hosston Formation

The Hosston Formation was deposited during the latest Valanginian stage (Mancini *et al.,* 2001, Mancini and Puckett, 2002) to the earliest Aptian. It overlies the Cotton Valley Group (Imlay, 1940; Swain, 1944; Mancini *et al.,* 2001; Mancini and Puckett, 2002). It is composed of a series of three sandstone beds (Jackson, 1990). The uppermost sandstone has been informally named the Booth Sandstone consisting of fluvial deltaic coarse grained sandstone (Jackson, 1990; Mancini and Puckett, 2002), while the two lower sandstones (ascending) are referred to as Hosston C and Hosston B Sandstones, identified by fine grained sandstone and marine shale (Jackson, 1990; Mancini and Puckett, 2002).

Sligo Formation

The upper most section of the Hosston Formation is intercalated with the dolomitised and oolitic peritidal complexes of the Late Barremian to earliest Aptian Sligo Formation. It is these numerous oolitic packages contained within grainstones and packstones which suggest the lower part of the Sligo Formation was deposited during high energy shelfal conditions relative to other formations

(Phelps *et al.,* 2010) during a marine transgression (Mancini and Puckett, 2002). The upper section of the Sligo Formation consists of interbedded sands, siltstone, shales and mudstones (Warner and Moody, 1992).

Pearsall Formation - Pine Island Shale, James Limestone (Donovan Sands), Bexar Shale Member

The Aptian Pearsall Formation of Texas, Arkansas and Louisiana, in its simplest description is a limestone and shale package. The Pearsall Formation is made up of three units, which in ascending stratigraphic order are: The Pine Island Shale (or Hammett Shale Member), James Limestone, and the Bexar Shale Member (Imlay, 1944; Hackley *et al.,* 2009). These three members are known as individual formations further around the northeastern margins of the basin. The Pearsall Formation was deposited at a time which represents a major rise in basal sea level and marine flooding.

The Pine Island Shale was originally described by Imlay (1940; 1944) but it wasn't until later that Mancini and Puckett (2002; 2005) learnt it represents a regional transgression and transgressive peak. As its name suggests, the Pine Island Shale consists primarily of marine shelf, dark grey to black, calcareous, fossiliferous shale (Imlay, 1940; 1944; Applegate and Lloyd; 1985, Warner and Moody, 1992; Mancini and Puckett, 2002).

The James Limestone includes low-energy, marine shelf limestone and shallow water, high-energy grainstone and reefal boundstone lithofacies (Weeks, 1938; Loucks *et al.,* 1996; Mancini and Puckett, 2002). The Texas equivalent to the James Limestone is known as the Cow Creek Limestone Member.

Throughout the GoM basin, the term Donovan Sands is used informally to designate the predominantly sandstone interval between the top of the Pine Island Shale and the base of the shaley interval below the Ferry Lake Anhydrite (Mancini and Puckett, 2002). The Donovan Sands are the product of a reduction in accommodation space on the shelf together with an increase in siliclastic sediment supply and fluvial sandstones (Mancini and Puckett, 2005). Traditionally the Donovan Sands have been included in the Rodessa Formation, which is primarily made up of carbonate beds. This Late Aptian interval is interpreted to be the onshore equivalent to the offshore James Limestone based on lithostratigraphic correlation (Mancini and Puckett, 2002).

The Bexar Shale is situated directly below the basal surface of the Rodessa Formation, or as it is known in Texas and Louisiana the Glen Rose Formation, and directly above the James Limestone (Forgotson, 1957; Loucks *et al.,* 1996; Mancini and Puckett, 2002). The Bexar unit consists of marine shelf, black, calcareous shale and thin, dense, finely crystalline limestone beds (Forgotson, 1957; Mancini and Puckett, 2002).

Rodessa Formation

The Rodessa Formation (Weeks, 1938) is dated to be between latest Aptian to earliest Albian in age (Mancini and Puckett, 2002; Mancini *et al.,* 2005), and can be recognised by its carbonate composition. It is composed of reefal and marine shelf organics (Imlay, 1940; Mancini and Puckett, 2002), spanning from Western Louisiana (Imlay, 1944) to the panhandle of Florida (Applegate and Lloyd, 1985). It occupies the stratigraphy spanning from the top of the Bexar Shale Member to the base of the Ferry Lake Anhydrite (Raymond *et al.,* 1988; Warner and Moody, 1992).

Ferry Lake Anhydrite

Mancini and Puckett (2002) explain that as the Rodessa (Louisaina, Mississippi, Alabama, Florida panhandle) and Glen Rose (Texas) carbonate reefs were constructed, the shelfal water behind the reefs became restricted and as such gypsum was deposited. It was this deposition of the subaqueous lagoonal gypsum, which later transformed to anhydrite (Lock *et al.,* 1983; Loucks and Longman, 1985; Mancini and Puckett, 2002), which is interbedded with grey shales and reddish-brown dense limestones (Warner and Moody, 1992; Raymond, 1995) and has become known as the Ferry Lake Anhydrite. The Ferry Lake Anhydrite is assigned to an Early Albian age (Mancini and Puckett, 2002; Warner and Moody, 1992; Raymond, 1995).

Mooringsport Formation

The Mooringsport Formation (Imlay, 1940) is recognised as the shaley interval, locked between the Donovan Sands or the Ferry Lake Anhydrite bed and the sandstone which makes up the Paluxy Formation (Warner and Moody, 1992; Raymond, 1995; Mancini *et al.,* 2001; Mancini and Puckett, 2002). The Mooringsport Formation primarily consists of a sequence of shales and mudstones with some subordinate limestones, sands, and siltstones. The shales are maroon, dark-red to grey, firm, and finely micaceous with interlayered greenish-grey mudstones (Raymond *et al.,* 1988; Warner and Moody, 1992; Raymond, 1995). Shallow marine sandstone beds become more prominent updip, and marine shelf and reef limestone beds occur downdip, owing to the development of a shelf margin reef (Dinkins, 1966; Baria, 1981; Mancini *et al.,* 2005). In more southern areas, the Mooringsport Formation includes carbonate and calcareous shale beds (Davis and Lambert, 1963). It correlates with the Western Floridian panhandle Sunniland Formation and is Early Albian in age (Raymond, 1995).

Paluxy Formation

Around the northeastern rim of the GoM basin the Paluxy Formation (Middle Albian) takes on different meanings: (1) In Arkansas, it is deemed a siliciclastic unit that overlies the Mooringsport Formation. (2) In Texas, it is overlain by the Walnut Formation and is considered to be the basal unit of the Fredericksburg Group and overlies the Glen Rose Limestone (Barnes, 1967; 1972; Mancini and

Puckett, 2005). (3) In Louisiana, it overlies the Glen Rose beds and is overlain by the Fredericksburg Group. (4) In Mississippi, it occupies the stratigraphic interval between the top of the Mooringsport Formation and either the base of the carbonate rocks of the Andrew Formation or the thickly bedded sandstone and shale interval of the Dantzler Formation (Warner and Moody, 1992; Mancini and Puckett, 2002; and references therein).

Regardless of the stratigraphic position, the Paluxy Formation chiefly consists of fluvial, coastal, and shallow marine fine to coarse-grained micaceous sandstone beds interbedded with carbonaceous shale (Nunnally and Fowler, 1954; Barnes, 1967; 1972; Warner and Moody, 1992; Mancini and Puckett, 2002; Mancini *et al.,* 2005). Although the middle section of the Paluxy Formation is predominately sandstones, it is bound by its upper and lower units, which have a greater tendency of shale dominance (Mancini and Puckett, 2002).

Andrew Formation

The Andrew Formation is situated in the stratigraphic column for the northeastern GoM region, above the Paluxy Formation and below the Dantzler Formation. It is said to be a transgressive formation (Mancini and Puckett, 2002; Mancini *et al.,* 2005), with the upper part consisting of dull to dark-red, grey, and olive-grey shale containing beds of brownish-grey finely sandy limestone, some shell fragments, and some beds of olive-grey dolomite and light-cream limestone (Eargle, 1964; Mancini and Puckett, 2002; Mancini *et al.,* 2005). The lower units grade downwards into grey and greenish-grey to dull-red micaceous shale alternating with limestone with some minor beds of fine-grained sandstone containing some carbonaceous matter, and greyish-green siltstone (Eargle, 1964; Mancini and Puckett, 2002; Mancini *et al.,* 2005).

It is not well understood how the Andrew Formation links in with the other stratigraphic units of the more central and northern GoM states. In Texas, there are possible links to the Fredericksburg Group, which includes the Walnut Formation and the Edwards Limestone. In Louisiana, it is possibly linked to the upper parts of the Fredericksburg Group and lower limit of the Paluxy Formation. It is not present in Arkansas (Mancini and Puckett, 2002; and references therein). It is thought that the Andrew Formation was deposited during the Middle through to Early/Late Albian (Eargle, 1964; Mancini and Puckett, 2002; Mancini *et al.,* 2005).

Dantzler Formation

The Dantzler Formation (Hazzard *et al.,* 1947) occurs directly above the Paluxy Formation, and directly below the Late Cretaceous Tuscaloosa Group (Hazzard *et al.,* 1947; Eargle, 1964; Eaves, 1976). Thus, the Dantzler Formation is said to be Late Albian in age (Hazzard *et al.,* 1947). Mancini and Puckett (2002; and references therein) describe how the Dantzler Formation includes fluvial, thick bedded, lignitic, fine to medium grained sandstone and carbonaceous shale that are interpreted as a stacked series of braided stream deposits. However, the lower Dantzler is represented by coastal and marine shelf, calcareous sandstone that contains limestone nodules.

2.4.1.2 Western Floridian Peninsula – in ascending order (oldest first):

Wood River Formation

The Late Jurassic and Early Cretaceous Wood River Formation is composed of layered limestone and evaporates overlying a basal clastic section (Pollastro *et al.,* 2001) and is the lowest sedimentary unit in the South Florida Basin. On the few occasions when the clastic unit has been penetrated, it has been found to be composed of dark red shale and fine to coarse grained arkosic sandstone and calcareous sandstone (Applin and Applin, 1965; Applegate *et al.,* 1981). Applin and Applin (1965) interpret the clastic unit as representing fan, fan delta, and fluvial lacustrine and marine deposits, which in their review is termed the Fort Pierce Formation. The overlapping limestone and evaporites, comprised a thick sequence of anhydrite, microcrystalline dolomite, some limestone, and occasional interbedded salt stringers, indicating marine transgression (Applegate *et al.,* 1981; Montgomery, 1987; Pollastro *et al.,* 2001).

Bone Island Formation

The Bone Island Formation was originally named and described by Applegate *et al.,* (1981). It consists of anhydrite and buff to cream, oolitic limestone with occasional micritic limestone or dolomite (Applegate *et al.,* 1981). The Bone Island Formation overlies the Wood River Formation and underlies the Pumpkin Bay Formation, and is Early Cretaceous in age (Applegate *et al.,* 1981; Faulkner and Applegate, 1986).

Pumpkin Bay Formation

The Pumpkin Bay Formation overlies the Early Cretaceous Bone Island Formation and underlies the West Felda Shale Member of the Lehigh Acres Formation of the Glades Group (Applegate *et al.,* 1981; Faulkner and Applegate, 1986). The Pumpkin Bay Formation consists of anhydrite and dolomite in the lower part and a light coloured to brown micritic limestone, occasionally oolitic, in the upper part (Applegate *et al.,* 1981).

Glades Group - Lehigh Acres Formation and Punta Gorda Anhydrite

The Glades Group (Early Cretaceous) consists of interbedded brown limestone, dolostone, and anhydrite and includes the Punta Gorda Anhydrite (Winston, 1971a). The Glades Group overlies the

Pumpkin Bay Formation and underlies the Ocean Reef Group and contains the Lehigh Acres Formation and the Punta Gorda Anhydrite (Winston, 1971a; Applegate *et al.,* 1981).

Lehigh Acres Formation – West Felda Shale Member, Twelve Mile Member, Able Member

The West Felda Shale Member is the lowest member in both the Lehigh Acres Formation and the Glades Group. It is Early Cretaceous in age and consists of dark-grey, micaceous, calcareous shale and shaley limestone (Applegate *et al.,* 1981).

The Twelve Mile Member represents the middle member of the Lehigh Acres Formation (Applegate *et al.,* 1981). It consists of light to dark, micritic, or oolitic limestone beds overlain by a "brown dolomite" zone which consist of a fine-grained, porous, brown dolomite in the lower part, while the upper part is grey argillaceous limestone (Applegate *et al.,* 1981; Faulkner and Applegate, 1986). The Twelve Mile Member overlies the West Felda Shale Member and underlies the Able Member, both from the Lehigh Acres Formation, and is Early Cretaceous in age (Applegate *et al.,* 1981; Faulkner and Applegate, 1986).

The Able Member caps the Lehigh Acres Formation (Applegate *et al.,* 1981). It contains white to grey anhydrite interbedded with brown micritic, pure limestone and grey argillaceous limestone, with occasional dolomite beds (Applegate *et al.,* 1981). It underlies the Punta Gorda Anhydrite of the Glades Group and is considered to be Early Cretaceous in age (Applegate *et al.,* 1981; Faulkner and Applegate, 1986).

Punta Gorda Anhydrite

The Punta Gorda Anhydrite is also Early Cretaceous in age and caps the Glades Group and underlies the Sunniland Formation of the Ocean Reef Group (Puri and Vernon, 1964; Applin and Applin, 1965; Winston, 1971a; Meyerhoff and Hatten, 1974; Applegate *et al.,* 1981; Richards, 1988). It is composed chiefly of anhydrite as its name suggests, but also lesser amounts of irregularly interbedded limestone, dolomite, and dark shale (Applin and Applin, 1965; Meyerhoff and Hatten, 1974). Applegate *et al.,* (1981) suggest that the Punt Gorda Anhydrite is correlated with the Ferry Lake Anhydrite, from the northeastern province. Similarly, Richards (1988) recommended that the Punt Gorda Anhydrite correlates with the Glen Rose and Stuart City Formations of Texas.

Ocean Reef Group – Sunniland Formation, Lake Trafford Formation, Rattlesnake Hammock Formation

Sunniland Formation

The name Sunniland was first used by Pressler (1947), although it was not officially designated nor defined until the later work of Paul Applin (1960) and his wife Ester Applin (1965) respectively. It was later assigned to the Ocean Reef Group by Winston (1971a). Subsequent work by Richards (1988) and

Pollastro and Viger (1998), provided an overview of the Sunniland Formation. Applin (1960) and Winston (1971a) explain that the Sunniland Formation is composed primarily of limestone, dolomite and shale which are sandwiched between two anhydrite layers. The Sunniland Formation underlies the Lake Trafford Formation of the Ocean Reef Group and overlies the Punta Gorda Anhydrite of the Glades Group (Winston, 1971a, Richards, 1988). Its age is defined as Early Cretaceous (Winston, 1971a; Faulkner and Applegate, 1986; Richards, 1988; Lloyd, 1991; Reinhardt, 1992; Pollastro and Viger, 1998).

Lake Trafford Formation

The Lake Trafford Formation of the Ocean Reef Group consists of buff to brown limestone with minor anhydrite (Oglesby, 1965). It overlies the Sunniland Formation (Oglesby, 1965; Winston, 1976; Faulkner and Applegate, 1986; Richards, 1988; Lloyd, 1991; Pollastro and Viger, 1998) and underlies the Rattlesnake Hammock Formation (Winston, 1976; Faulkner and Applegate, 1986; Lloyd, 1991; Pollastro and Viger, 1998). It is considered to be Early Cretaceous in age (Oglesby, 1965; Winston, 1971a; Richards, 1988; Pollastro and Viger, 1998). Richards (1988) correlates the Lake Trafford Formation with the Glen Rose and Stuart City formations of Texas.

Rattlesnake Hammock Formation

The Rattlesnake Hammock Formation is located at the top of the Ocean Reef Group, above the Lake Trafford Formation, and once again is considered to be Early Cretaceous in age (Winston, 1971a; Faulkner and Applegate, 1986; Lloyd, 1991; Pollastro and Viger, 1998). Winston (1971a) reports that it consists of thick, dense limestone at its base and thick, regionally persistent anhydrite at its top, as well as containing dolomite. The Rattlesnake Hammock Formation is capped by the presence of the Marco Junction Formation at the base of the Big Cypress Group (Winston, 1971a; Faulkner and Applegate, 1986; Lloyd, 1991).

Big Cypress Group – Marco Junction Formation, Gordon Pass Formation, Dollar Bay Formation

The Big Cypress Group, formerly called the Fredericksburg Group, consists of limestone, dolomite and anhydrite (Winston, 1971b). It includes the: Marco Junction, Gordon Pass and Dollar Bay formations (Faulkner and Applegate, 1986; Pollastro and Viger, 1998; Lloyd, 1991) and is Middle to Late Albian in age (Winston, 1971b; Reinhardt, 1992).

Marco Junction Formation

The Marco Junction Formation overlies the Rattlesnake Hammock Formation of the Ocean Reef Group and underlies the Gordon Pass Formation (Winston, 1976; Faulkner and Applegate, 1986; Lloyd, 1991; Pollastro and Viger, 1998). It is Early Cretaceous in age (Winston, 1976; Faulkner and Applegate, 1986; Pollastro and Viger, 1998). Winston (1976) described the Marco Junction Formation as consisting predominantly of chalky limestone with dolomite and anhydrite beds. Winston (1976) also described how dense limestone occurs at the base and thick, persistent anhydrite at top of the unit. Conversely, Faulkner and Applegate (1986) report the opposite.

Gordon Pass Formation

Located in the centre of the Early Cretaceous Big Cypress Group, it occurs between the underlying Marco Junction Formation and the overlying Dollar Bay Formation (Winston, 1976; Faulkner and Applegate, 1986; Pollastro and Viger, 1998; Lloyd, 1991). The Gordon Pass Formation consists of anhydrite interbedded with micritic limestone and dolomite (Winston, 1976; Pollastro *et al.,* 2001).

Dollar Bay Formation

The Dollar Bay Formation was first assigned to the Big Cypress Group by Winston (1971b). It underlies the Panther Camp Formation of the Naples Bay Group and overlies the Gordon Pass Formation. It is Early Cretaceous in age (Winston, 1976; Faulkner and Applegate, 1986; Lloyd, 1991; Pollastro and Viger, 1998; Pollastro *et al.,* 2001). The Dollar Bay Formation is composed of limestone, dolomite, and anhydrite (Winston, 1971b).

Naples Bay Group – Panther Camp Formation, Rookery Bay Formation, Corkscrew Swamp Formation

The Early Cretaceous Naples Bay Group was first described by Winston (1971a) and later named by Reinhardt (1992). The group is overlain by Late Cretaceous chalk of the Pine Key Formation (Faulkner and Applegate, 1986) and underlain by a regionally mappable anhydrite bed of the Big Cypress Group (Winston, 1971a; Faulkner and Applegate, 1986). The Naples Bay Group includes the: Panther Camp, Rookery Bay and Corkscrew Swamp formations (Faulkner and Applegate, 1986; Lloyd, 1991; Pollastro and Viger, 1998; Pollastro *et al.,* 2001).

Panther Camp Formation

The Panther Camp Formation makes up the basal unit of the Naples Bay Group, overlying the Dollar Bay Formation of the Big Cypress Group (Winston, 1976; Faulkner and Applegate, 1986; Lloyd, 1991; Pollastro and Viger, 1998; Pollastro *et al.,* 2001). It consists of porous pelletal limestone, dolomite and a regionally persistent anhydrite bed (Winston, 1976).

Rookery Bay Formation

Winston (1976) assigned the name Rookery Bay Formation to the middle unit of the Naples Bay Group. The formation is predominately made up of anhydrite with interbedded chalky limestone and dolomite. However, a thin pelletal micritic limestone occurs at its base and a thick, regionally persistent anhydrite bed is found at its top (Winston, 1976). The Early Cretaceous Rookery Bay overlies the Panther Camp Formation and provides the foundations to the overlying Corkscrew Swamp

Formation (Winston, 1976; Faulkner and Applegate, 1986; Lloyd, 1991; Pollastro and Viger, 1998; Pollastro *et al.,* 2001).

Corkscrew Swamp Formation

The Corkscrew Swamp Formation occupies the top of the Naples Group (Winston, 1976). It is composed of limestone with thin anhydrite and microcrystalline dolomite beds, with a dense micritic limestone occurring at the base, capped by a thin anhydrite bed (Winston, 1976). The Corkscrew Swamp Formation is of latest Early Cretaceous, and is overlain by the Late Cretaceous chalk of the Pine Key Formation (Winston, 1976; Faulkner and Applegate, 1986; Lloyd, 1991; Pollastro and Viger, 1998; Pollastro *et al.,* 2001).

2.4.2 Onshore Deposits

Exposed onshore deposits of Late Jurassic to Early Cretaceous strata are known mainly to exist in Texas. Although there are Cretaceous exposures in other southern states of America (clockwise direction): Oklahoma, Arkansas, Mississippi, Alabama and Georgia. However, the deposits become younger in Cretaceous age the further clockwise around the GoM basin, until there are no exposed onshore deposits in the entirety of Florida – they are all offshore or subsurface.

This onshore deposit section will aim to include: (1) a description of the onshore strata; (2) descriptions of their depositional palaeoenvironments where possible; (3) their correlation to other neighbouring stratigraphic sequences (Figure 11) and; (4) an exposed outcrop where a sample could be taken for future comparisons with the offshore samples from this study.

2.4.2.1 Northeast Province (Onshore Late Jurassic)

At present, only one potential outcrop of Late Jurassic strata has been identified in the literature.

Malone (Texas)

The Malone bed (Taff 1891) or Formation (Richardson, 1904) consists of (in ascending order): 25ft. pale-yellow flaggy limestone; 45ft. white, fissile, granular gypsum; 170ft. massive blue granular limestone; and 110ft. of almost pure, crumbly, granular gypsum, which is lithologically the same as first gypsum horizon, and contains comparatively little organic matter (Taff 1891). However, Taff (1891) continues to explain that metamorphism is to such an extent that organic remains, if any, may have been destroyed, as the rock is now a marble. Conversley, Richardson (1904) briefly gives an overview of a small outcrop of Malone, which is about 1.5miles long and 0.25miles wide immediately northeast of Malone Station, Hudspeth Co, TX in a Permian basin. The outcrop is an outlier of the Malone Mountains just south of the railway line.

2.4.2.2 Northeast Province (Onshore Early Cretaceous)

There are known outcrops of Early Cretaceous sedimentary units throughout the Gulf Coast States. However, further in-depth research and geological mapping will be required to locate more relevant Early Cretaceous outcrops in the Gulf States. There is much less detail in the literature on the Eastern Gulf States, with the focus generally being on Texas.

Segovia (Texas)

The Segovia Member (Barnes, 1976a; Barnes, 1977) consists chiefly of limestone and dolomite. In the upper part there is cherty, light-grey, miliolid, shell fragment, rudistid limestone. In the middle, dolomite, medium brownish-grey, porous, massive to thin-bedded, cherty, collapse breccia. In the lower part, light yellowish-grey miliolid limestone and marl and marly limestone (Rose, 1972; Barnes, 1977). It overlies the Fort Terrett Formation of the Edwards Group and underlies the Del Rio Clay (Rose, 1972; Barnes, 1976a; Barnes, 1977), and includes the Burt Ranch Member, Allen Ranch Breccia Member, Orr Ranch Bed and Black Bed (Rose, 1972). The Segovia member is exposed at Joy Creek, off U.S. Highway I-10, 8 to 16km southeast of Segovia, Kimble County, Texas.

Fort Terrett (Texas)

The Fort Terrett Formation/Member is from the Lower Edwards Group/Limestone (Rose, 1972; Barnes, 1976a; 1976b; 1977). It was named after a, 19th century army post, 13 km to the west (Rose, 1972). The limestone constituent of the Fort Terrett Formation/Member is mostly fine grained, argillaceous, thin to thick bedded and massive, in part nodular, greyish yellow to light grey. The limestone can either be interbebbed with shale (North shore of Cedar Lake and West shore of McKenzie Lake in Eastern Gaines Co, TX (Barnes, 1976b)) or dolomite (drainage of East Nueces River in northeastern Edwards Co, TX (Barnes, 1977)). At the type locality, where U.S. Highway 290 rises out of valley of North Llano River, onto Edwards Plateau, 0.8 km South of Roosevelt, Kimble County, central Texas, it is interbedded with dolomite.

Finlay Mountains (Texas)

The Finlay Mountains are, as the name suggests, a range of mountains and not a stratigraphic unit. They are situated five miles North of Finlay in South central Hudspeth County (Texas) and extend seven miles to the East (centre is at 31°21' N, 105°35' W), and are thought to contain a number of Early Cretaceous deposits: Campagrande, Cox, Finlay, Kiamichi. They are all thought to correlate to the Fredricksburg Group (Richardson, 1904; Barnes, 1979; Taff 1892; Winton, 1925; Alexander, 1929; Adkins, 1932; Thompson, 1935; Gillerman, 1953; Lozo *et al.,* 1959).

Delight (Arkansas)

The Delight Sand (Imlay, 1940) is a member of the Cossatot Formation, in the Trinity group. As its name suggests it is primarily sand, which is grey, generally fine-grained and cross-bedded, thick-bedded, and interbedded with some clay and locally impregnated with asphalt. The Delight Sand Member is exposed at the surface of an asphalt quarry, West of Wolf Creek and approximately 3.75 miles northwest of Delight, Pike County, southwestern Arkansas (Imlay, 1944).

De Queen (Arkansas)

Strata equivalent in age to the Mooringsport and Sunniland Formations, the De Queen Formation outcrops in Arkansas (Weeks, 1938; Mancini and Puckett, 2002). In this area, the De Queen Formation consists of interbedded siliciclastic sediments, limestone and evaporite (gypsum and halite) (Lock *et al.,* 1983; Pittman, 1984).

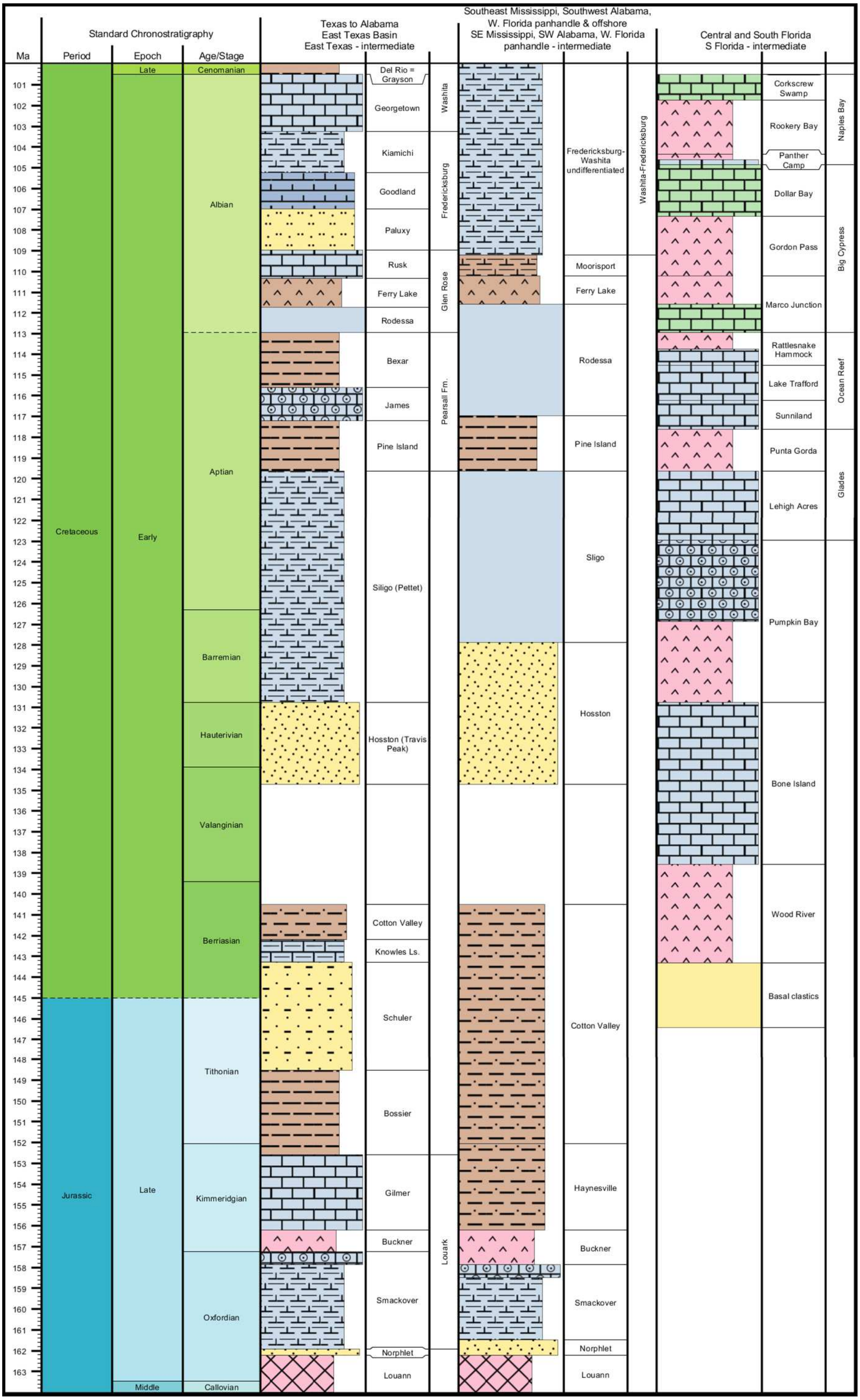
Little Bear (Mississippi)

Mellen (1937) describes how the Little Bear Formation deposits vary depending on locality, due to the formation originating in situ from decomposition of older Palaeozoic strata. Originally it was thought to extend from Kentucky to West-central Alabama, and perhaps extend to central and eastern Alabama and western Georgia. Current thinking now suggests that it could reach through Missouri and up into Illinois, and be Early Cretaceous in age (Harrison and Litwin, 1997; Harrison, 1999). The type locality for the Little Bear Formation is one mile northeast of Iuka, Tishomingo County northeastern Mississippi (Mellen, 1937).

2.4.3 Correlation of Stratigraphic Sequences

Figure 11 illustrates how the offshore formations and members of the stratigraphical sequence correlate with one another.

Figure 11 (page opposite). Idealised Lithology of the Texas to Alabama East Texas Basin, Onshore and Offshore Southeast Mississippi, Southwest Alabama, Western Florida panhandle and Central and South Florida. Made in Time Scale Creator with Gulf of Mexico data pack.



Standard Chronostratigraphy
Ma
Period
Epoch
Age/Stage
Texas to Alabama
East Texas Basin
East Texas - intermediate
Southeast Mississippi, Southwest Alabama,
W. Florida panhandle & offshore
SE Mississippi, SW Alabama, W. Florida
panhandle - intermediate
Central and South Florida
S Florida - intermediate
Cretaceous
Jurassic
Early
Late
Middle
Cenomanian
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
Tithonian
Kimmeridgian
Oxfordian
Callovian
Del Rio = Grayson
Georgetown
Kiamichi
Goodland
Paluxy
Rusk
Ferry Lake
Rodessa
Bexar
James
Pine Island
Siligo (Pettet)
Hosston (Travis Peak)
Cotton Valley
Knowles Ls.
Schuler
Bossier
Gilmer
Buckner
Smackover
Norphlet
Louann
Washita
Fredericksburg
Glen Rose
Pearsall Fm.
Louark
Fredericksburg-Washita undifferentiated
Moorisport
Ferry Lake
Rodessa
Pine Island
Sligo
Hosston
Cotton Valley
Haynesville
Buckner
Smackover
Norphlet
Louann
Washita-Fredericksburg
Corkscrew Swamp
Rookery Bay
Panther Camp
Dollar Bay
Gordon Pass
Marco Junction
Rattlesnake Hammock
Lake Trafford
Sunniland
Punta Gorda
Lehigh Acres
Pumpkin Bay
Bone Island
Wood River
Basal clastics
Naples Bay
Big Cypress
Ocean Reef
Glades

Chapter 3 – Materials and Methods

3.1 Introduction

The material used in this research comes from three offshore wells located in the EGoM (Figure 12) the co-ordinates of which are recorded in Table 1. Each well has a longer title used in industry, Well V is VK117 Apache OCS-G6872 1, Well D is DC 353 Shell OCS-G 2852 1 and Well C is CH 265 Shell OCS-G 3912 1. However, for conciseness in the write up they will be referred to as wells VK117, DC353 and CH265.

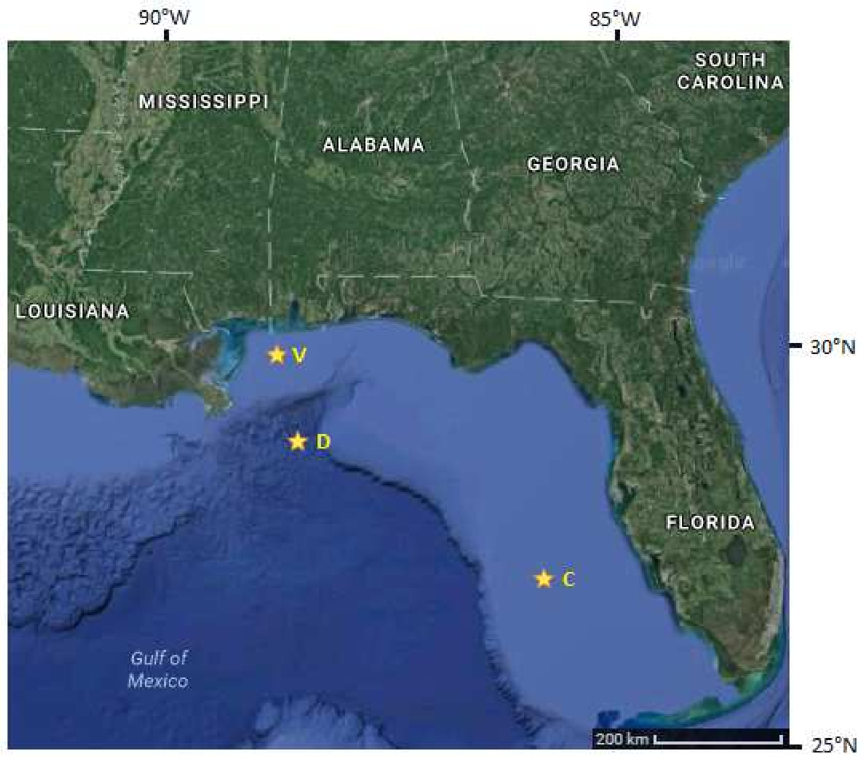


Figure 12. Localities of 3 Offshore wells on the Eastern Gulf of Mexico (Image adapted from Google Earth)

Well	Title	Spud Year	Surface Longitude	Surface Latitude	Bottom Longitude	Bottom Latitude
VK117	VK117 Apache OCS-G 6872 1	1985	-88.269025	29.854199	-88.269025	29.854199
DC353	DC 353 Shell OCS-G 2852 1	2007	-87.900888	28.606947	-87.900717	28.607293
CH265	CH 265 Shell OCS-G 3912 1	1981	-83.937842	36.643097	-83.938222	36.64324

Table 1. Co-ordinates of Well localities

3.2 Sampling Material

The rock samples used in this research were collected by Shell USA, either during drilling (cuttings) or from core samples. The samples are fresh and unweathered due to the conditions in that they were collected from deep offshore wells. Thus, it is likely that any palynomorphs within the samples will be well preserved. From the three wells 175 samples have been taken, all of which are cuttings unless otherwise stated (Figure 13). In each well the resistivity has been measured, however each well has been measured differently, which is likely due to the spud date and operator of each well.

3.2.1 VK117

The 79 samples from Well VK117 tried to be taken at regular intervals to ensure an even coverage throughout the well. However, not all the samples had enough material to be processed and so the closest sample was taken instead. Well VK117 sits in the vicinity of Viosca Knoll a basement horst feature (range). The samples range in depth from 12600ft. to 24960ft. (Figure 13).

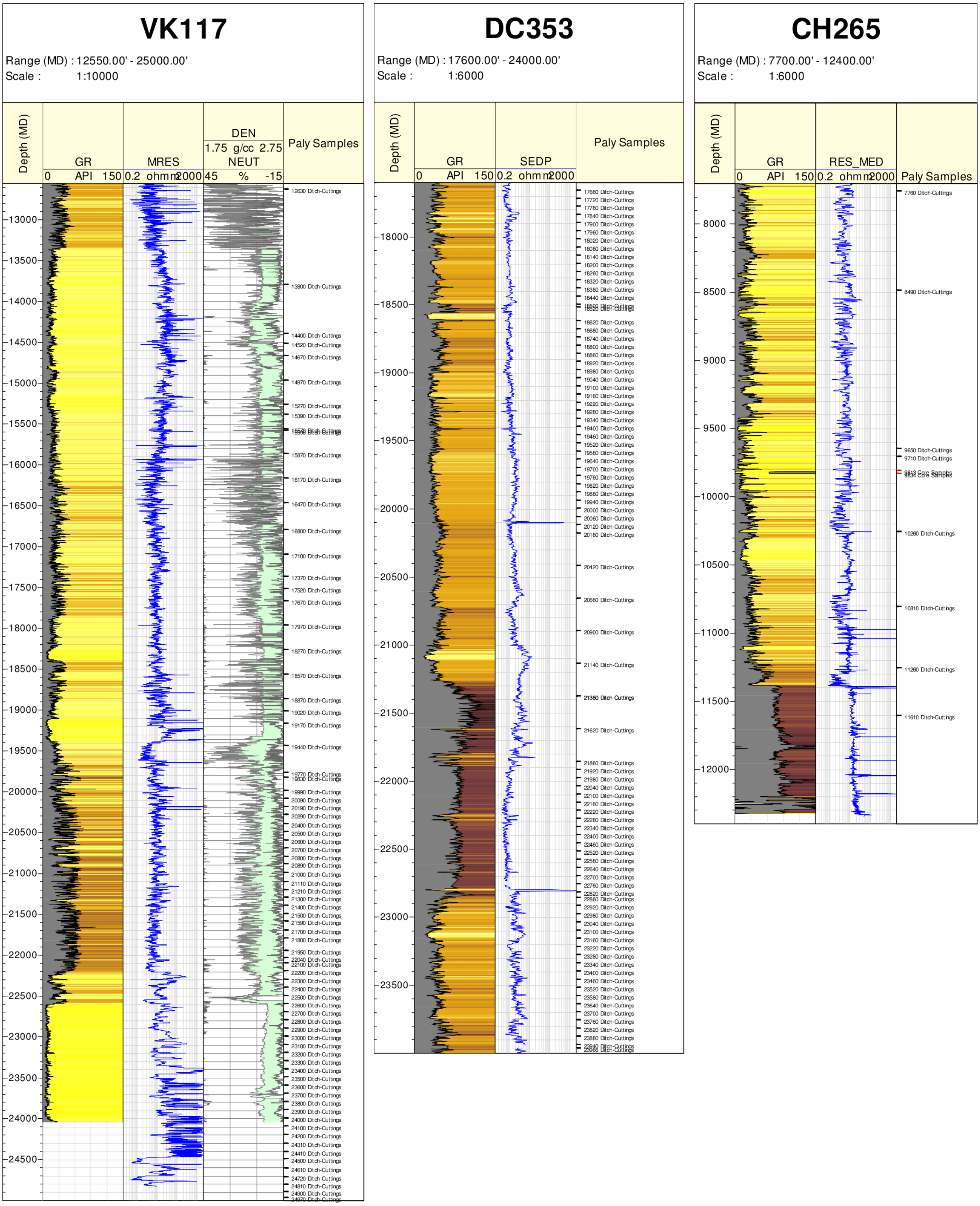
3.2.2 DC353

The 86 samples from Well DC353 were pre-prepared in-house by Shell USA. This well is a deep sea well and is situated in a basement graben feature (basin) more commonly known as DeSoto Canyon. The samples range in depth from 17600ft. to 23966ft. (Figure 13).

3.2.3 CH265

Well CH265 had 10 samples taken in total. Two of which were core samples taken from a depth of 9812.5ft. and 9834.1ft. Well CH265 is again situated on a basement horst feature (range) in the area of Charlotte Harbour. The samples range in depth from 7750ft. to 11600ft. (Figure 13).

Figure 13 (opposite page). Sample Depths in VK117, DC353 and CH265. Created in Oilfield Data Manager. Resistivity is measured in ohm per meter (ohm m), Density is measured in grams by cubic centimetres (g/cc), Neutron Log is measured in percentage (%).


VK117
Range (MD) : 12550.00' - 25000.00'
Scale : 1:10000
Depth (MD)
GR
0 API 150
MRES
0.2 ohmm 2000
DEN
1.75 g/cc 2.75
NEUT
45 % -15
Paly Samples
DC353
Range (MD) : 17600.00' - 24000.00'
Scale : 1:6000
Depth (MD)
GR
0 API 150
SEDP
0.2 ohmm 2000
Paly Samples
CH265
Range (MD) : 7700.00' - 12400.00'
Scale : 1:6000
Depth (MD)
GR
0 API 150
RES_MED
0.2 ohmm 2000
Paly Samples

3.3 Methods

There are two methods employed for studying palynomorphs. (1) Sample preparation, whereby the palynomorphs are extracted from the samples and mounted onto slides. (2) Microscope analysis, where the newly created slides are analysed using a light microscope.

3.3.1 Sample Preparation

Standard palynological preparation techniques (Traverse, 2007a) where used for all the samples; both the Shell in-house samples and those prepared at the University of Sheffield. This is to ensure accuracy and maintain a consistency throughout the samples. Figure 14 shows a flow diagram representing each step of the sample preparation.

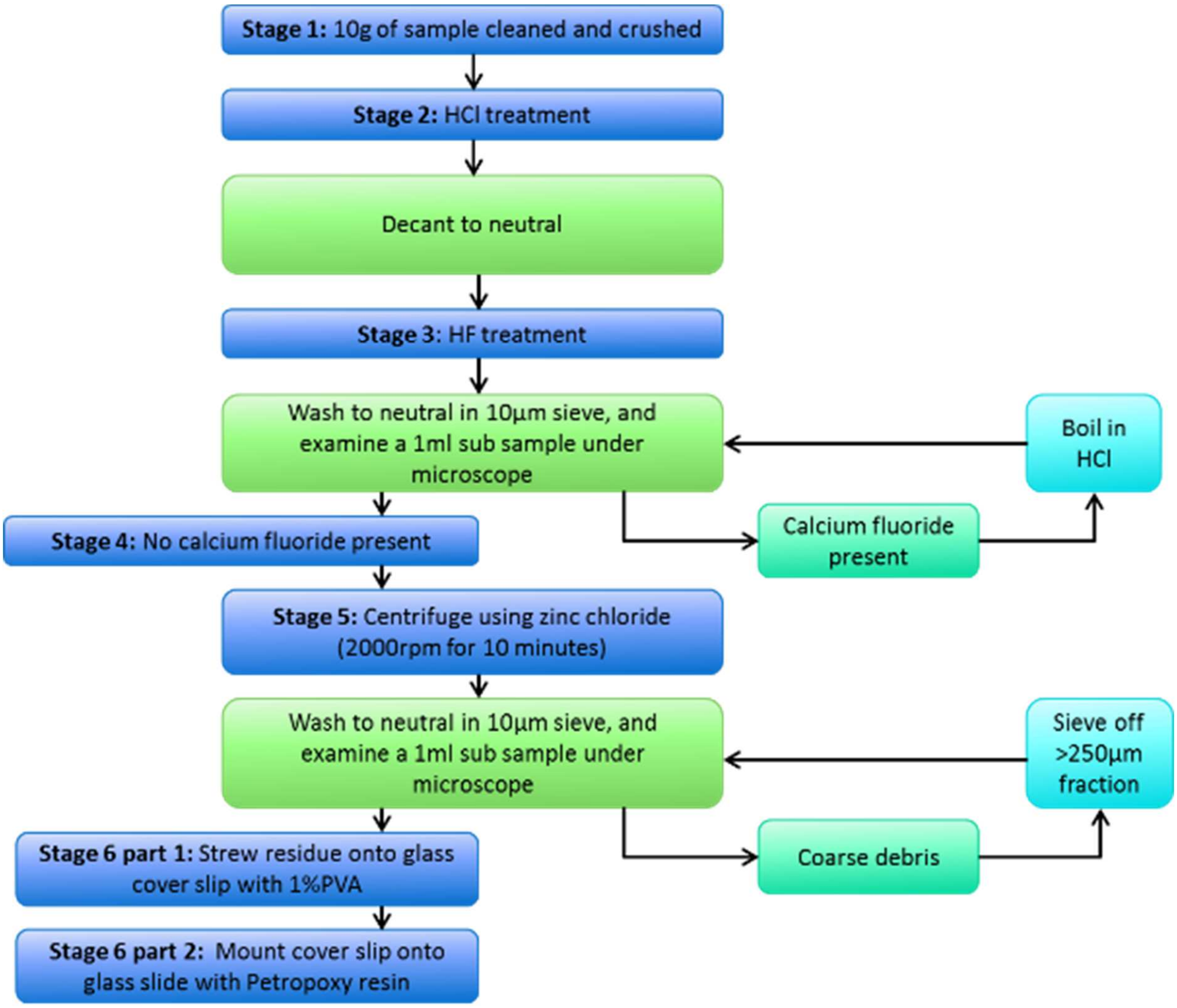


Figure 14. Flow diagram showing the standard palynology preparation technique. Dark blue, essential stage; Green, neutralisation step; Turquoise, removal of extrainious material step; Light Blue, remediation step.

Stage 1: Sample Preparation

In all cases approximately 10g of each sample where thoroughly cleaned with a mild detergent to remove contaminants from the well line, as well as any modern palynomorphs which may have settled on the samples.

Core

Core samples were then crushed into pea-sized fragments (approx. 0.5cm^3) to yield a large surface area for acid digestion.

Cuttings

Cutting samples were a similar size range to sand grain particles and were not crushed any further.

Stage 2: Extraction of Carbonate

Each sample was placed into a clean and sterile polythene bottle with a few drop of distilled water added to moisten the sample and prevent any dust mobilisation. Each sample was then tested for carbonate minerals by adding a few drops of 10% hydrochloric acid (HCl). In all samples an effervescence occurred (some more violently than others) which is attributed to the reaction of the high carbonate content of the EGoM rocks. The addition of a further 20ml of 36% HCl was undertaken with care, by trickling it slowly down the side of the bottle, to avoid causing a spillage of the contents over the sides. This process continued until the carbonate fraction had been dissolved. The residue (the remaining fraction) was allowed to settle for 24 hours. The acidic fluid was then carefully decanted off, to avoid disturbing any of the settled fraction. Once the acidic constituent had been removed the remaining fraction and residue was topped up with water. The decanting process and topping up with water continued until the final liquid reached a neutral pH.

It was crucial that all of the carbonate minerals are digested by the HCl in order to remove the positively charged calcium ions (shown in red) via the decantation process. If this process is incomplete the addition of hydrofluoric acid (HF) in the next stage of the process will produce insoluble calcium fluoride precipitate.

$$CaCO_{3(s)} + 2\ HCl_{(aq)} \rightarrow CaCl_{2(aq)} + CO_{2(g)} + H_2O_{(l)}$$

$$CaCO_3 + 2\ HCl \rightarrow Ca^{2+} + Cl_2{}^{2-} + CO_2 + H^+ + O^-$$

$$Ca^{2+} + 2HF \rightarrow 2H^+ + CaF_2$$

Not only is it possible for the calcium fluoride to obstruct sieving, by causing the residue to clump together, but there is also the potential to lose palynomorphs during heavy liquid separation.

Stage 3: Extraction of Silicates

Upon completion of Stage two, 20ml of 39% HF was added to the residue by slowly trickling it down the side of the bottle, to avoid splash back. The HF was then left to fully digest the silicate minerals present within the rock matrix at room temperature over a period of several days. Each sample was agitated every 24 hours, to ensure maximum digestion. This calming and agitation process was repeated until there was no further reaction, even upon the addition of supplementary HF. This took between 3 days for cuttings and 2 weeks for core samples. Once there was no further reaction, each sample was left to settle and was decanted to neutrality as in the previous stage (approximately 10 decants).

Stage 4: Extraction of fluoride crystals

Stage four focuses on improving the clarity of the palynomorph assemblages by reducing the inorganic material remaining in the samples as much as possible (fluoride crystals which formed during the addition of the HF and HCl/HF resistant clay minerals).

To check the sample for fluoride crystals a clean pipette was used to agitate the sample and collect a small 1ml sub sample which was pipetted on to a clean slide and examined for the fluoride crystals.

No Calcium Fluoride Present

If no large calcium fluoride crystals were observed, then normal heavy liquid separation was employed to remove the small amounts of calcium fluoride remaining and any clay minerals.

Calcium Fluoride Present

If the sample was found to contain large fluoride crystals, they were removed by dissolution in boiling 36% HCl for one minute. Once cooled, each sample was then decanted to neutrality as in the previous stage and rechecked. If no crystals were present, the residue was able to be centrifuged as in stage five.

Removal of the calcium fluoride is vitally important. If calcium fluoride is seen to entrap and obscure palynomorphs, the likelihood is it would cause the palynomorphs to sink during heavy liquid separation. This would cause an unknown loss of palynomorphs and a bias in the samples.

Stage 5: Extraction of mineral grains (heavy liquid separation)

By stage five the samples contained the palynomorphs but also acid-resistant mineral grains. In order to separate the lighter kerogen fraction including the palynomorphs (less dense) from the heavier mineral fraction (more dense) each sample was placed in a centrifuge tube with the addition of 30ml of zinc bromide, which has a specific gravity of 1.95. The samples were spun in the centrifuge at, 2000rpm for 10 minutes. This separated the fractions into two distinct layers; the lighter organic and palynomorphs rich layer at the top, was poured off into a clean 10μm sieve, leaving the concentrated mineral fraction behind at the bottom of the centrifuge tube, which was disposed of. The contents of the sieve were then washed using warm water to remove any residual zinc bromide, before being poured into a clean 7ml tube with screw on lid to await slide mounting and residue storage. It should also be noted that the samples where not oxidised by the addition of nitric acid, so as to allow for palynofacies analysis.

Stage 6: Mounting to slide

The excess water was pipetted off the top of the residue after a 24 hour settling period. The residue was then mixed and shaken gently with 1% polyvinyl alcohol (PVA) to emulsify the organic matter and to ensure a homogenous spread of palynomorphs. This new mixture was then pipetted onto a 22x22mm cover slip in an even layer, ensuring it goes right to the edges and corners. The coated cover slips were then left on a warm-plate for approximately 1 hour to allow the PVA to evaporate and the organic residue to adhere to the cover slip. The coated cover slips were then mounted by inversion on to a glass slide, ensuring minimal air bubble entrapment, using a small amount of Petropoxy 154 Epoxy resin. The slides were then left on a hot-plate to cure at 120˚C for approximately 30 minutes. The Petropoxy 154 Epoxy resin deteriorates very little with age and as its name suggests has a refractive index of 1.54, which is similar to that of glass.

If possible two slides were made up for each sample. In some cases, only one slide was made due to the scarcity of organic material within the samples. All of the slides were clearly labelled with the Well identification and depth. Any residue mixed with PVA remaining after slide mounting were acidified using two of drops of 10% HCl. This acidification allows for long storage periods as it hinders bacterial and mould growth within the residues.

3.3.2 Microscope Analysis

All light microscope logging and taxonomic analysis was carried out using an Olympus CH-2 transmitted light microscope, using x20, x40 and x60 eyepieces and x100 oil immersion objective. An England Finder has been used to record and reference the position of palynomorphs of interest to allow the same palynomorph to be re-located at a later date. All slides prepared for this research are lodged in the Palynology laboratory within the the Department of Animal and Plant Sciences at the University of Sheffield.

Photographs of dinoflagellate cysts were taken using a Lumenera Infinity five megapixel camera attached to a Meiji MT500 series transmitted light microscope. Two software packages were used to acquire the final images. Firstly, Lumenera Infinity Analyze was used to capture the dinoflagellate cyst images, this software is also capable of layering different images from several focal depth images in order to create one single, in focus multi composite image. This multi composite image is then able to be adjusted using Adobe Photoshop C5 for final use.

Dinoflagellate cyst Identification and Counts

Identification of dinoflagellate cysts was conducted by reading the descriptions of previously published work of dinoflagellates of a similar age. When a description and published plate matched the defining features on the slide being examined, a name would be assigned to genus and/or species level. As a result of this, two rough working catalogues have been produced one containing a selection of plates and descriptions of Late Jurassic dinoflagellate cysts and the other of Early Cretaceous.

Within each sample, the first, 200 dinoflagellate cysts were counted. After the 200 counts, the remainder of the slide would be scanned in case anything had been missed. In the very few cases when another genus or species would appear after the first, 200 count, a note was made and they were included with the final assemblage.

Palynofacies Counts

In order for the palynodebris to be interpreted in a useful way, they were first grouped into twelve categories based on their morphological affinities. These grouping can be seen in Table 2. In each of the 175 samples, the first 300 palynological particles where counted aided by a tally chart (Table 2). Further details on the groupings can be found in Chapter 7.

Palynofacies	300 Count
Phytoclasts - Opaque - Equidemensional	
Phytoclasts - Opaque – Needle Shaped	
Phytoclasts - Translucent - Equidemensional	
Phytoclasts - Translucent - Needle Shaped	
Phytoclasts - Plant cuticle	
Pollen	
Spores	
AOM	
Dinoflagellate Cysts	
Acritarchs	
Foram Linings	
Algae	

Table 2. Palynofacies tally chart displaying 12 groupings.

Chapter 4 – Biology

4.1 Introduction

Over the recent decades dinoflagellate cysts have proved to be an outstanding palynological asset. They expanded the understanding of palaeoecological environments in a number of ways and also demonstrate high preservation rates. This is advantageous compared to other microfossil groups such as calcareous nanofossils and forams, as these tend to succumb to diagenesis at the carbonate compensation depth (Versteegh and Zonneveld, 2002; Reichart and Brinkhuis, 2003). As dinoflagellates are part of the larger microfossil community, they are one of the marine world's primary producers and are abundant in neritic settings (Brasier, 1985; Dale and Fjellså, 1994). These shallow water settings happen to be the areas of highest interest in terms of future climate change, and in terms of this research have the greatest economic importance to the hydrocarbon industry.

All of the preserved strata from the EGoM during the Late Jurassic to the Early Cretaceous was deposited in a shallow marine environment. It was this shallow neritic environment that played host to the largest communities of now extinct dinoflagellates. If the dinoflagellate cyst became fossilised, it is then possible to use the palynological techniques described in Chapter 3 to isolate them and use them to interpret sedimentary sections (Rainwater, 1967; Gutjahr, 1960).

4.2 Dinoflagellates Biology

Dinoflagellates are unicellular algae in the division Dinoflagellata that are widespread in modern marine sediments, and are known to have a long geological fossil record from the Late Triassic (Fensome *et al.,* 1993; MacRae *et al.,* 1996). They are predominantly marine, eukaryotic plankton that typically occur as motile cells in surface waters (Goodman, 1987; Fensome *et al.,* 1996a; 1996b). They have two dissimilar flagella (Fensome *et al.,* 1996b) (Figures 15 and 16) that propel them through the water in a corkscrew action (Williams *et al.,* 2012). Together, both the dinoflagellate's dissimilar flagella and their unique forward corkscrew motion encouraged Otto Bütschli in 1885 to suggest the name "Dinoflagellata", coming from the Greek "dino" meaning a whirling rotation and the Latin word "flagellum" meaning small whip.

The current preference is to refer to dinoflagellates as protists, whereas previously they have been classed as protozoans or algae (Traverse, 2007b; Williams *et al.,* 2012). In order for an organism to be accepted as a dinoflagellate it must have either or both: (1) A motile cell in its life cycle which possesses two dissimilar flagella and/or (2) a dinokaryon. A dinokaryon (Figure 15) is a special eukaryotic nucleus lacking histones in which the fibrillar chromosomes remain condensed between episodes of mitotic cell division (Evitt, 1961; Fensome *et al.,* 1996c).

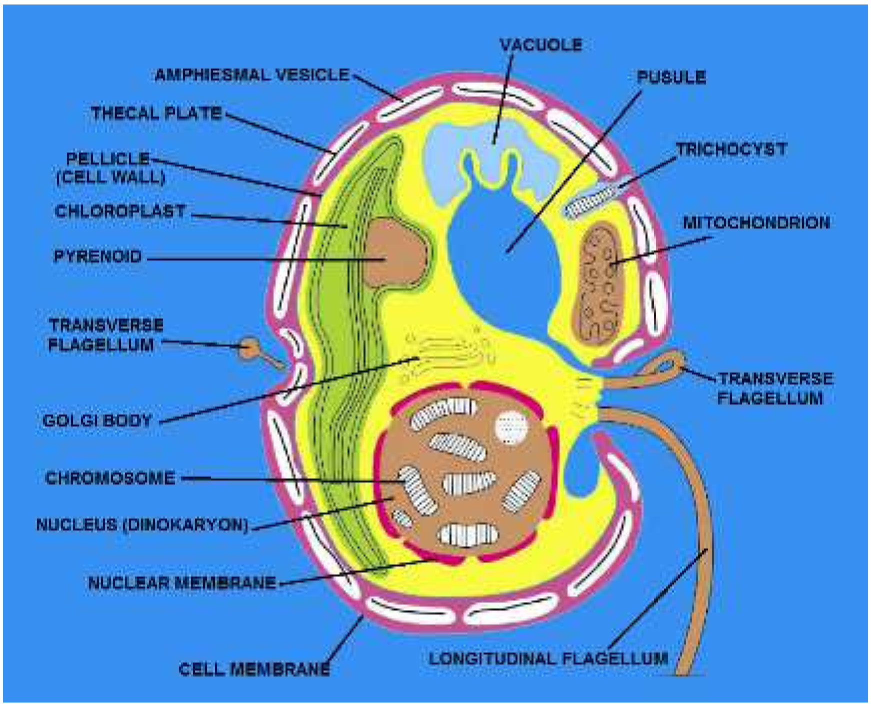


Figure 15. Cross section through a generalised thecate motile Dinoflagellate. Adapted from Taylor, 1980, text-fig 1

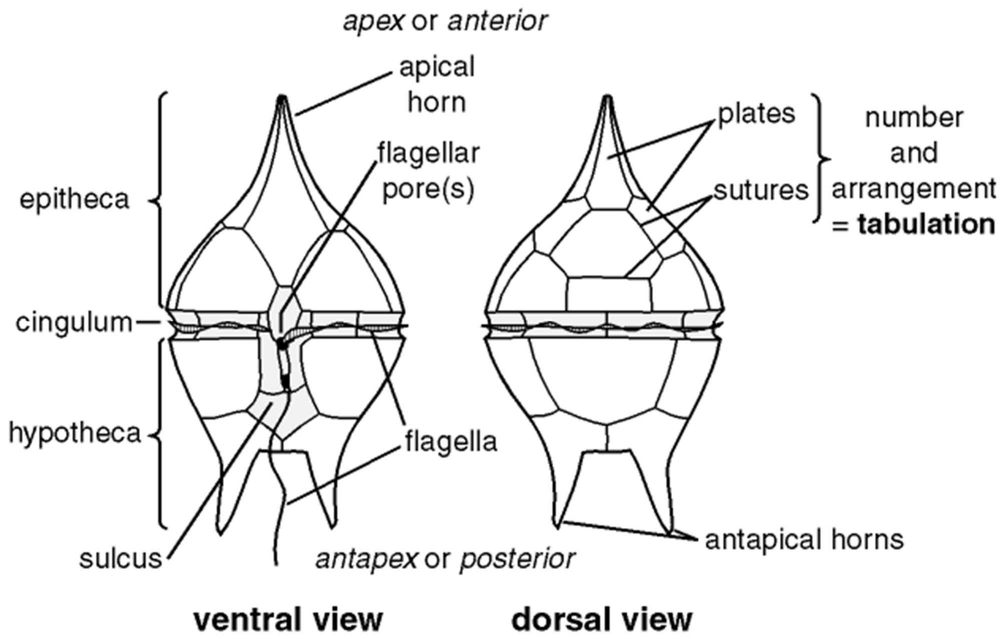


Figure 16. General thecal morphology of a motile Peridinialean Dinoflagellate. Adapted from Evitt, 1985.

The motile cell moves in the direction of the apex (Figure 16), which typically has a single protruding horn, commonly referred to as the apical horn (Taylor, 1987; Fensome *et al.,* 1996b). The forward pointing part of the cell, anterior to the cingulum, is termed the episome, epicyst in cysts, epitheca in motile thecate cells and epicone in anthecate cells. At the posterior end, the antapex, trails behind, propelled by the flagella which, species dependent, may either have a rounded base or more often than not, two unequal antapical horns (Taylor, 1987; Fensome *et al.,* 1996b). The trailing posterior part of the cell is termed the hypocyst. The name of a thecate motile cell is the hypotheca, while the antheca cell if referred to as the hypocone. Figure 15 displays both flagella originating from a single equatorial pore in the motile cell on the ventral side. This area is termed the sulcus (Taylor, 1987).

4.2.1 Life Cycle and Cyst Production

Taylor (1987), Edwards *et al.,* (1991) and Sluijs *et al.,* (2005) all agreed that dinoflagellates have complex life cycles which, when idealised as by Evitt (1985), can be divided into six sections based on the cell ploidy and the cells mobility (Figure 17). In section one the dinoflagellates experience the onset of rapid growth and a population explosion due to mitosis. Then as they enter the second stage the haploid schizonts pair up and fuse to form diploid planozygotes. Throughout the third phase of their life, the zygotes construct new theca and resume their motility. The fourth phase sees a reduction in activity before both flagella are lost and the cell becomes a hypnozygote. The inner protoplast along with one or two membrane layers then shrinks away from the outer theca. The plates which make up the theca are then able to break apart or be destroyed by bacterial action. This leaves the dinoflagellate cyst (made of the membranes) exposed. The resting cyst is then able to behave as a sedimentary particle, and so can either be transported downslope or by ocean currents (Dale, 1976; Wall *et al.,* 1977) before settling out through the water column and coming to rest on a depositional interface (Evitt, 1985). At this point the dinoflagellate cyst has the potential to be preserved as a microfossil. Following an unspecified period of dormancy, while waiting for favourable conditions (temperature, salinity, nutrient availability), the protoplast is excysted through an operculate archaeopyle. This completes the life cycle as the protoplast undergoes mitosis once more (Matsuoka, 1985; Evitt, 1985; Matsuoka, 1988; Armstrong and Brasier, 2005).

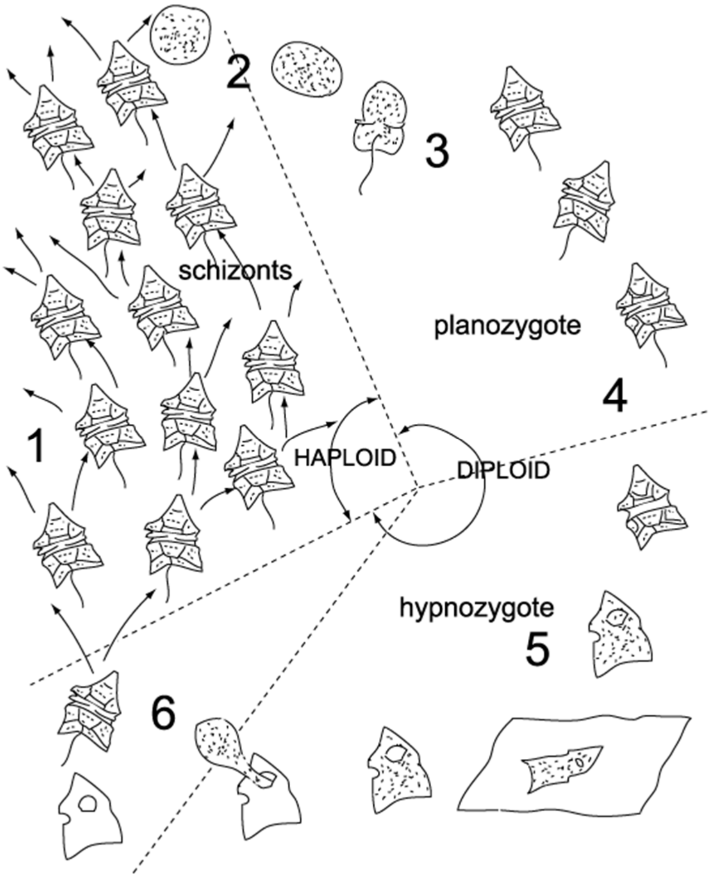


Figure 17. The idealised life cycle of a cyst producing Dinoflagellate. Adapted from Evitt, 1985, Figure 1.3.

4.2.2 Dinoflagellate Morphology to Aid Identification

The identification of dinoflagellates species in the fossil record is relied upon by the hydrocarbon industry (Evitt, 1962). Therefore, it is of the upmost importance to be able to reliably distinguish species from one another. This is done by observing: (1) The overall shape of the dinoflagellate cyst; (2) The number and arrangement of plates or processes; (3) The type of cyst and; (4) The positioning or character of the archaeopyle.

Tabulation and The Kofoid System

Each dinoflagellate species has its own unique tabulation pattern and ornamentation. The cross section in Figure 15 shows the amphiesmal vesicles confined within the boundaries of the cell membrane (Taylor, 1987). Contained within these amphiesmal vesicles are cellulosic thecal plates. These plates can either be psilate or ornamented. It is the arrangement and number of thecal plates that makes up the tabulation pattern (Figure 18); this together with ornamentation, is essential in being able to classify both living cells and fossil dinoflagellate cysts in palynological analysis (Fensome *et al.,* 1993).

Tabulation arrangements in both modern and fossil dinoflagellates occur in six very distinct patterns (Figure 18 and references therein). However, within this study the dinoflagellates with gonyaulacoid or peridinioid tabulation (Figure 18 C) are of particular interest. They have well developed thecal plates within the amphiesmal vesicles, and are arranged in five or six latitudinal series, with a well-defined ventral longitudinal sulcal series. The system of plate nomenclature used for this tabulation type is based on the work of Kofoid (1907; 1909), and as such is known as the Kofoid system.

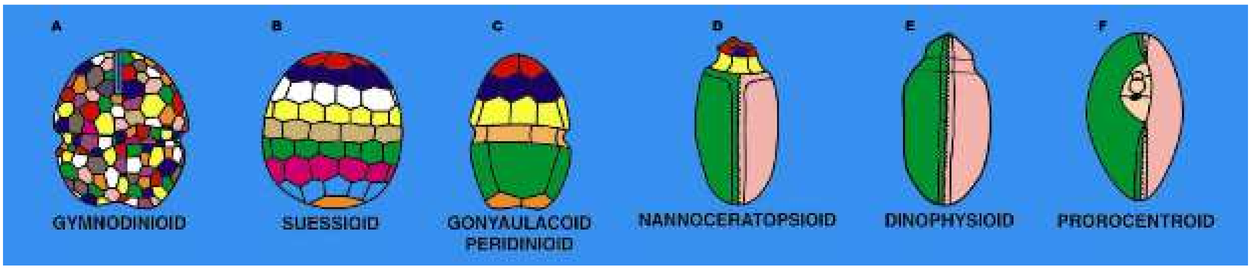


Figure 18. Tabulation arrangements. A is in ventral view, B-E are in dorsal view, F is in oblique apical view. A, F are adapted from Taylor (1990, text-figs. 14, 10); B is adapted from Evitt (1985, text-fig. 5.3E); C is adapted from Loeblich III (1968, text-fig.3)

The Kofoid system shown in Figure 19 works by numbering the plates from left to right in each latitudinal series, starting with the plate adjoining to the midventral position. Each latitudinal series also uses its own designated series of primes to denote the locality of the plate, such as apical ('), precingular (''), postcingular ('''), and antapical ('''') plates; whereas, the cingular (c), sulcal (s), anterior intercalary (a), and posterior intercalary (p) plates are categorised by letters. These denotations are useful when labelling plates and producing plate formulae.

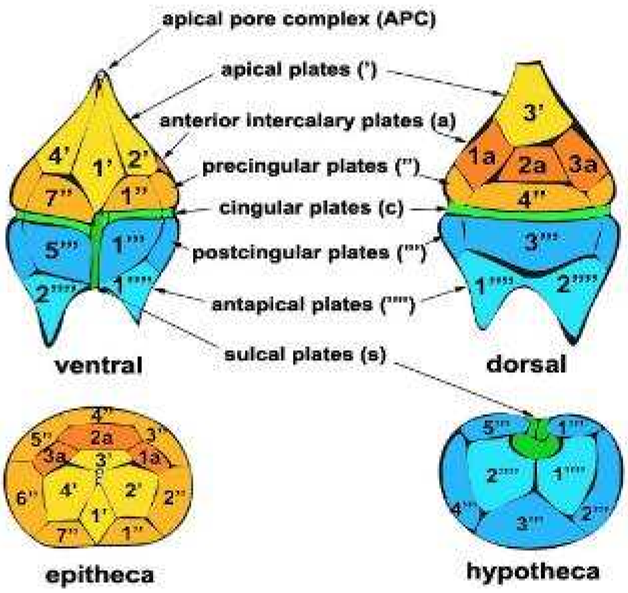


Figure 19. Kofoid system of Tabulation (Hoppenrath, 2008).

Ornamentation and Processes

Dinoflagellate cysts can occur in many different shapes, with the presence or absence of ornamentation or processes (Sarjeant, 1982a). When processes are absent, the cyst is deemed to be proximate (Figure 20) and usually has a form of ornamentation, as illustrated in Figure 21, covering the autophragm. However, if the cyst does have processes, it is said to be proximochorate to chorate, depending upon the height of the extension relative to the central body (Sarjeant, 1982a; Fensome *et al.,* 1996b; Williams *et al.,* 2012; Figure, 20). Figure 22, shows how the ornamentation on the dinoflagellate cysts usually reflects the position of the once outer thecal plates (Fensome *et al.,* 1996b; Williams *et al.,* 2012).

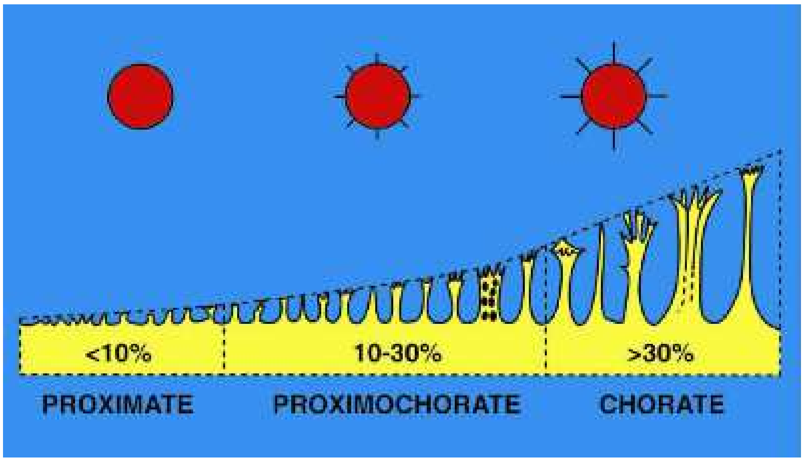


Figure 20. Process length terminology, based on the process length as a percentage to the shortest diameter of the central body. Adapted from Sarjeant (1982a, text-fig.2).

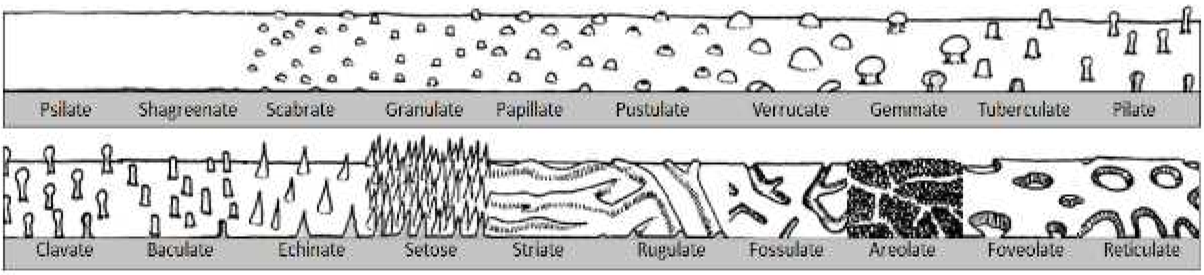


Figure 21. Illustration of surface ornamentation used in descriptions of fossilised dinoflagellate cysts. (Taken from Wood *et al.,* 2016, which has been modified from Williams *et al.,* 1978)

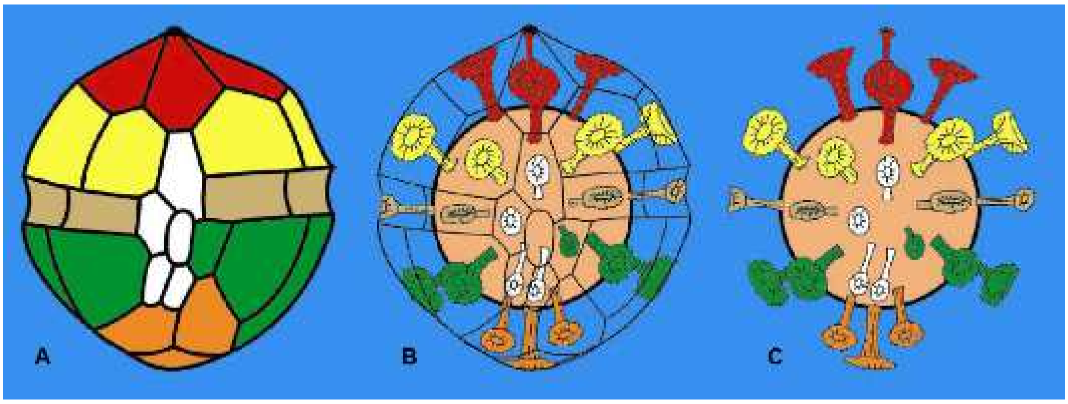


Figure 22. Interpretation of a chorate cyst. (A) thecate cell, (B) relationship between a thecate cell and a chorate cyst, (C) chorate cyst. The central body of the cyst is shaded. Adapted from Fensome *et al.,* (1996b, text-fig. 26).

Evitt (1985) and Fensome *et al.,* (1996b) explain that the processes that protrude from the dinoflagellate cyst take on many different shapes and forms, giving rise to both process shape and tip terminology. This can be seen in Figure 23, whereas Figure 24 explains the terminology used to describe the locality of the ornamentation or processes on the cyst. Process/ornamentation distribution can either be plate centred – intratabular (Figure 24 A, E, J–N); at the edge of each plate – penitabular (Figure 24 A, D, H, I–K) or arranged randomly – nontabular (Figure 24 B). Furthermore, if a process is along a suture where two plates are adjoining, the process is said to be gonal (Figure 23 kk). However, if the process extends from a triple junction, it is said to be intergonal (Figure 23 jj). Figure 24 G shows both gonal and intergonal processes with bifurcation and trifurcation respectively at the process tips. However, when the processes link up with one another (Figure 25 E and F), they are termed trabeculate processes, coming from the Latin ‘trabeculae’ meaning small beam.

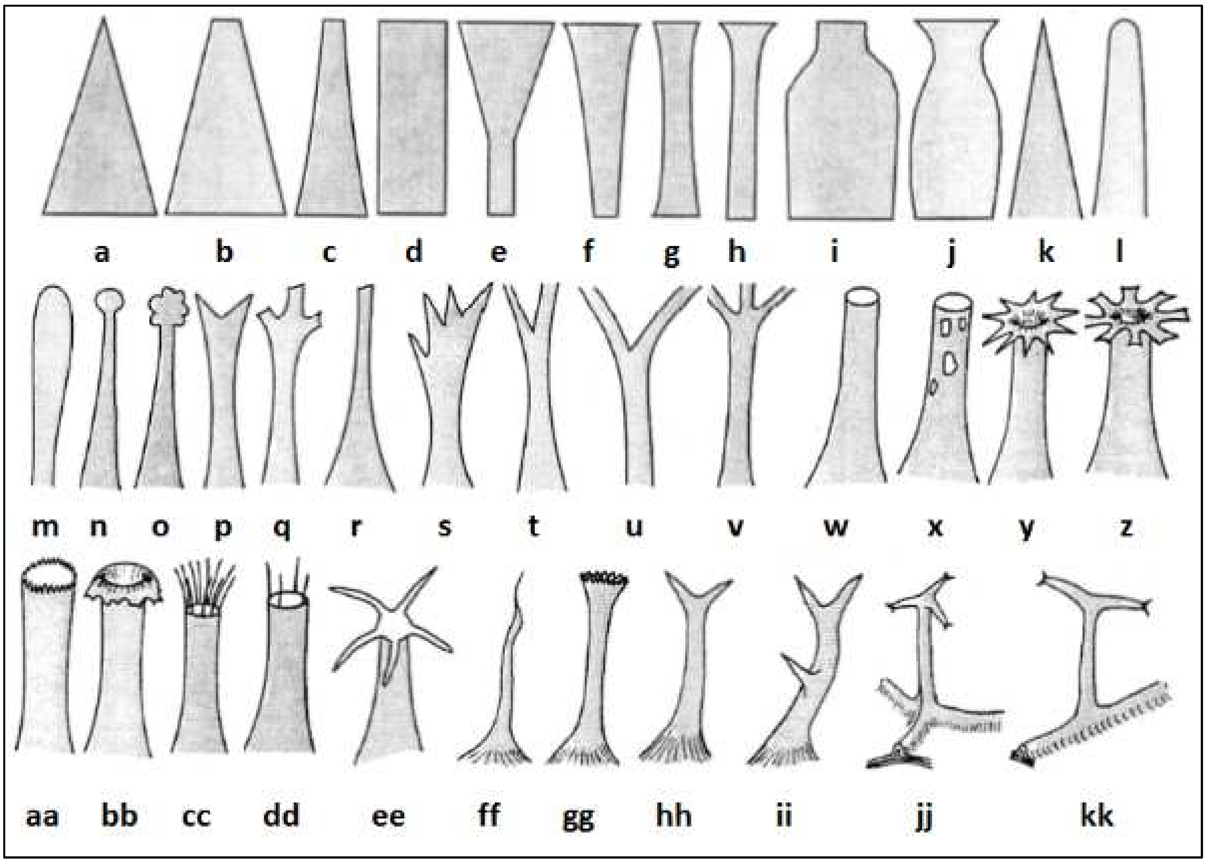


Figure 23. Illustrations of process shape (a-j), process tips (k-ee) and process types (ff-kk). (Modified from Williams *et al.,* 1978) a. conical; b. subconical; c. tapering; d. cylindrical; e. infundibular; f. flared; j. tubiform; k. buccinate; l. evexate; m. bulbose; n. capitate; o. cauliflorate; p. bifid; q. foliate; r. foliate; s. digitate; t. branched; u. bifurcate; v. trifurcate; w. entire; x. fenestrate; y. aculeate; z. secate; aa. denticulate; bb. recurved; cc. patulate; dd. dirigate; ee. orthogonal; ff. acicular; gg. tubiform; hh. bifid; ii. branched bifid, jj. trifurcate; jj. trifurcate gonal; kk. bifurcate intergonal or sutural.

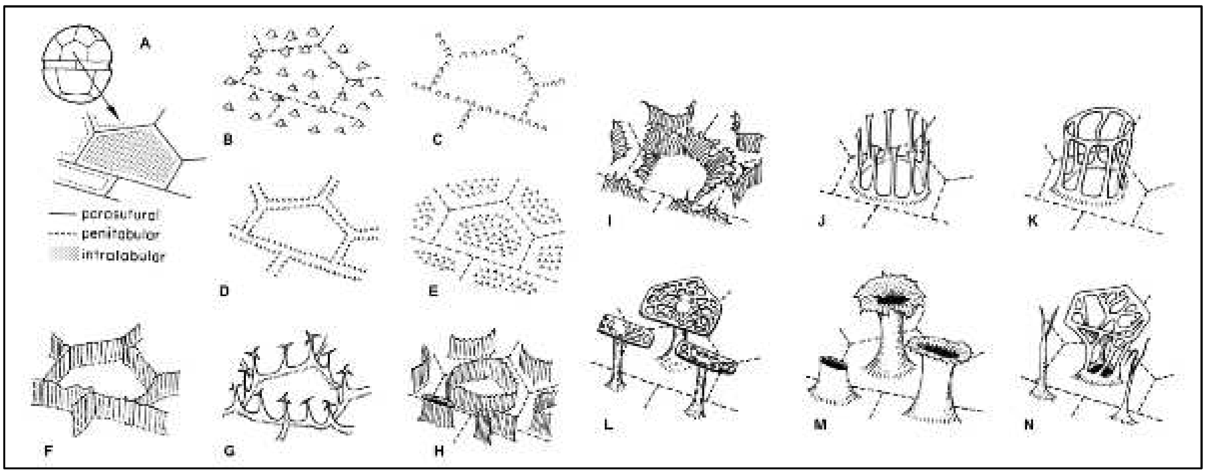


Figure 24. Process complexes. (Adapted from Evitt, 1985, figure 4.4).

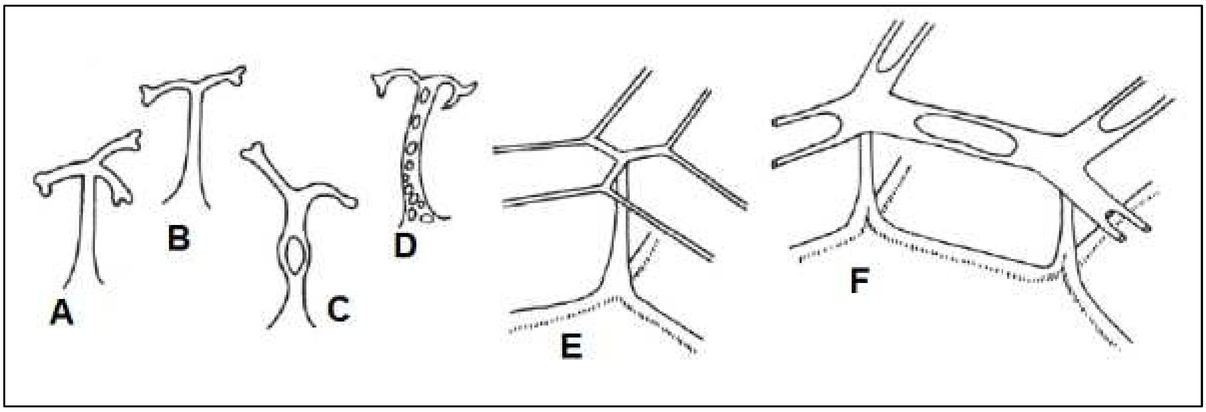


Figure 25. Process nomenclature. (Adapted from Evitt, 1985, figure 10.7).

Wall Layers

Dinoflagellate cysts may have anything from one up to four layered walls depending on the species, although, in general, most cysts, have one or two walls. If the dinoflagellate cyst only has a single layer, the wall is termed an autophragm (Figure 26 A). However, if the cyst has two walls which are unconnected by pillars or other supportive constructions, the inner and outer layers are termed the endophragm and periphragm respectively (Figure 26 B).

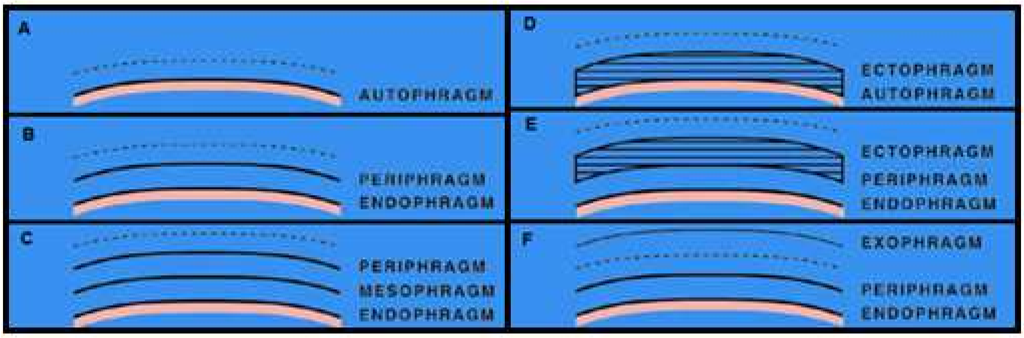


Figure 26. Terminology for the wall layers in dinoflagellate cysts. (Adapted from Fensome *et al.,* 1996b, text-fig.23).

Cavation

If a cyst has a cavity between one or more of the wall layers they are termed cavate (Figure 27). Acavate is the name used to describe a cyst which has only an autophragm, and thus no cavities. However, if a cavity is said to be circumcavate, it means that the cavity is uninterrupted all the way around the cyst. Bicavate cysts have cavities at both poles, but are attached equatorially to the theca. Cysts that only have cavities in the horns are termed cornucavate, while suturocavate cysts only have cavities along the lines of sutures. A holocavate cyst requires an ectophragm braced by processes, extending outwards from either an autophragm or a periphragm. Other cavities also exist, such as epicavate, whereby the cavity is only present at the anterior end. The opposite is true for hypocavate cysts, where the cavity is present at the posterior end of the cyst. Cavities described as camocavate are present down one side of the cyst only and cysts which have cavities restricted to the base of spines or processes are described as apiculocavate. Figure 27 also displays a cyst surrounded by a calyptra, although not considered part of the wall or a cavity; it is a gelatinous mass of enveloping material which is irregular in thickness. Calyptras are not often found surrounding cysts, however, they are most commonly found surrounding dinoflagellate cysts of Late Jurassic to Early Cretaceous age, such as *Sentusidinium agglutinatum.*

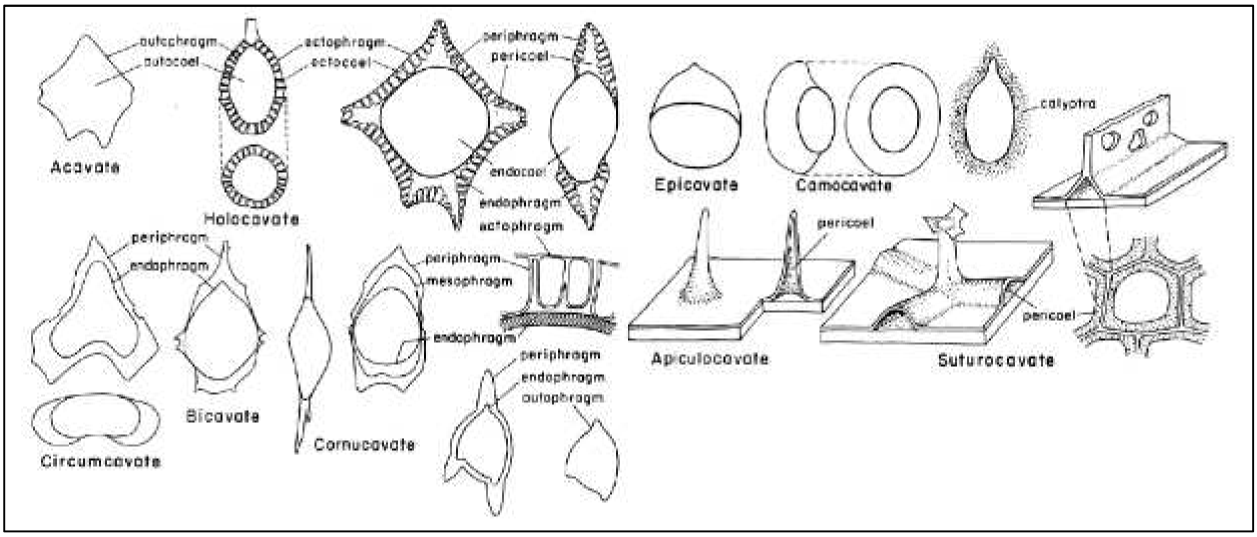


Figure 27. Cavation variation. (Adapted from Evitt, 1985, figure 4.1)

Archaeopyle

The archaeopyle, in its most basic terminology, is a rupture in the cyst wall through which the protoplast emerges during excystment (Evitt, 1985). However, the archaeopyle location and style is very much species dependent. If one or more of the paraplates (plates that make up the cyst wall) are removed in one piece it is termed the operculum. However, if removed in several pieces, they create opercular pieces. The rupture may occur along or parallel to a specific set of parasutures. The rupture can occur in several ways. Matsuoka (1985) first described a chasmic archaeopyle, a slit like opening which occurs on the cyst without the need to create an operculum (Figure 28 D and E). In the same paper a tremic archaeopyle was also described, where an almost circular opening is created in the apical region, this time creating an operculum (Figure 28 A–C).

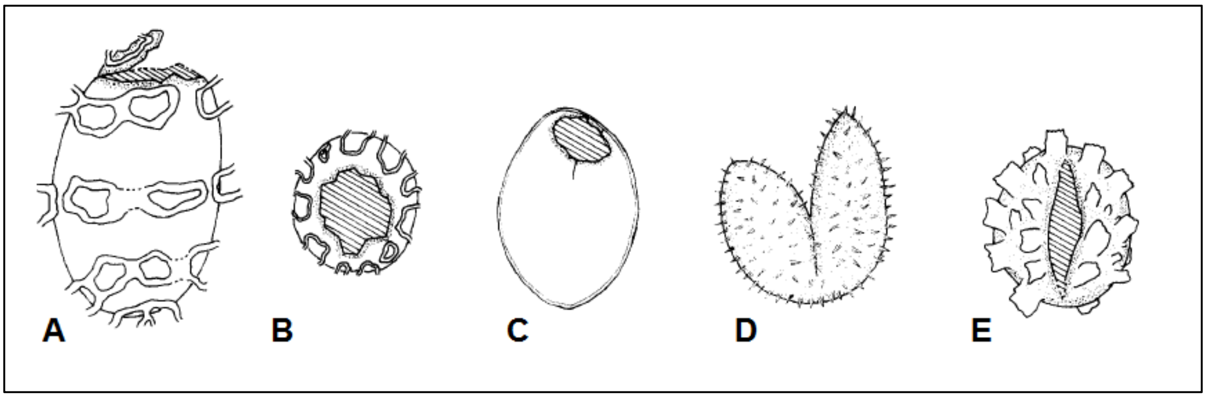


Figure 28. Chasmic and Tremic archaeopyles. (Adapted from Matsuoka, 1985, figure 1).

Alternatively, the dinoflagellate cyst may have an archaeopyle which is described as having a saphropylic (distinct gate) operculum (Matsuoka, 1988) (Figure 29 B, E and F), whereby the operculum is completely released. However, when the operculum is not fully released, it is said to be adnate, and thus described as theropylic (hinged gate) (Matsuoka, 1988) (Figure 29 C).

Usually the archaeopyle is lost from the cyst's dorsal plates. Together with Matsuoka's (1985; 1988) terminology, archaeopyles are also named with reference to the series of plates from which the operculum is comprised. For this reason, archaeopyles can be described as being apical (Figure 29 B and C), intercalary (Figure 29 F) or precingular (Figure 29 E). When amalgamations of paraplates are lost, they are termed combination archaeopyles (Figure 29 D). However, when the combination comprises the entirety of the epicyst, it is then termed an epicystal archaeopyle (Figure 29 A) (Williams *et al.,* 2012).

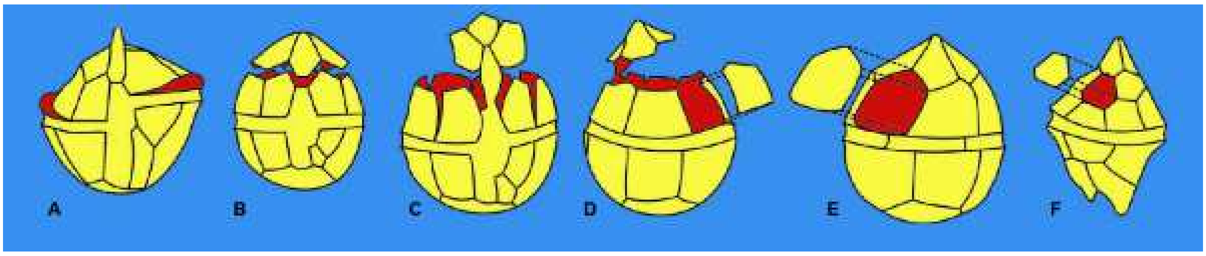


Figure 29. Types of archaeopyles. Adapted from Fensome *et al.,* (1996b Text- Figure 28)

A claustrum is another term introduced by Norris (1978a), for an opening within the outer wall of the dinoflagellate cyst other than the archaeopyle. They are, however, not limited to process tips, but may also occur in paraplates. Examples of claustras can be observed in Figure 24 K, L, M, N and Figure 25 C, D and F.

4.3 Dinoflagellate Palaeoecology

The relationship a fossilised dinoflagellate cyst once had with its surroundings when motile is described as its palaeoecology. It is this relationship which controlled the distribution of dinoflagellate cysts, with each taxon being restricted to a particular environmental niche. Thus their presence or absence can be exploited as a palaeoenvironmental proxy (Wall *et al.,* 1977). Recent research has been using dinoflagellate cysts as a proxy to provide a highly sensitive surface water reconstruction of distinct geographic patterns, which confirms that dinoflagellate distribution is limited by sea surface conditions (Dale, 1996; Verleye and Louwye, 2010) such as temperature, (de Vernal *et al.,* 2001; Esper and Zonneveld, 2007) salinity, (Mudie *et al.,* 2002; Marret *et al.,* 2009; Verleye *et al.,* 2009) sea ice cover (Harland *et al.,* 1999) and nutrient concentrations (Marret and Zonneveld, 2003). Although our knowledge of modern and Quaternary dinoflagellate assemblages, based on actuopalaeontological techniques is more comprehensive than deep time (Neogene and older), it should be noted that pre-Quaternary palaeoenvironmental reconstructions are becoming more sophisticated (Williams *et al.,* 2012).

As previously mentioned, dinoflagellates are known from the Late to Middle Triassic onwards (MacRae *et al.,* 1996; Moldowan and Talyzina, 1998). However, Evitt (1981) suggests that the fossil record for dinoflagellates is incomplete, which is in agreement with Head's (1996) later research. It is now thought that recent evidence from biogeochemical markers dinosteranes (Summons *et al.,* 1992; Moldowan *et al.,* 1996) supports the theory that dinoflagellates existed well before the Triassic, in the Early Cambrian (Moldowan and Talyzina, 1998). Evidence for this is preserved in a few Proterozoic rocks (Summons and Walter, 1990; Pratt *et al.,* 1991). These dinosteranes are now thought to derive from the ancestors of modern dinoflagellates.

During the Early Triassic, there was a large area of submerged continental shelf, which is the preffered habitat of dinoflagellates. Therefore, current thinking suggests that this preferred palaeoenvironment allowed dinoflagellates to diversify, and from then on have the ability to produce fossilisable cysts (Fensome *et al.,* 1996c). The diversification from the Late Triassic can be seen in Figure 30 and Figure 31.

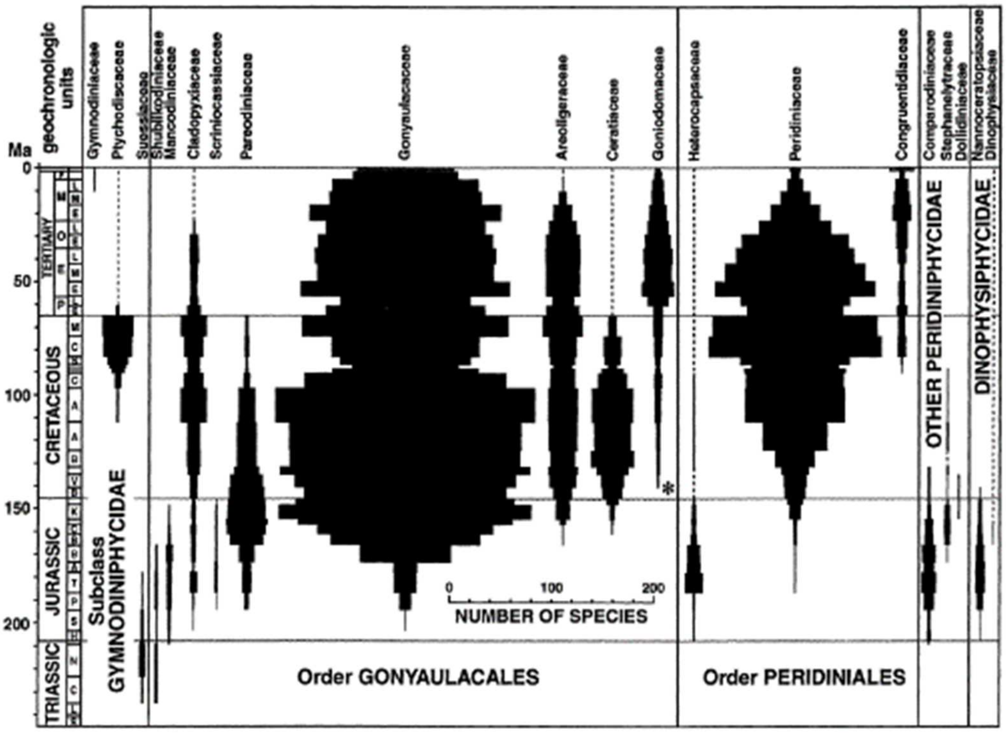


Figure 30. Spindle diagram, displaying the number of species per family in each geological stage. Adapted from Fensome *et al.,* (1996c Figure 1)

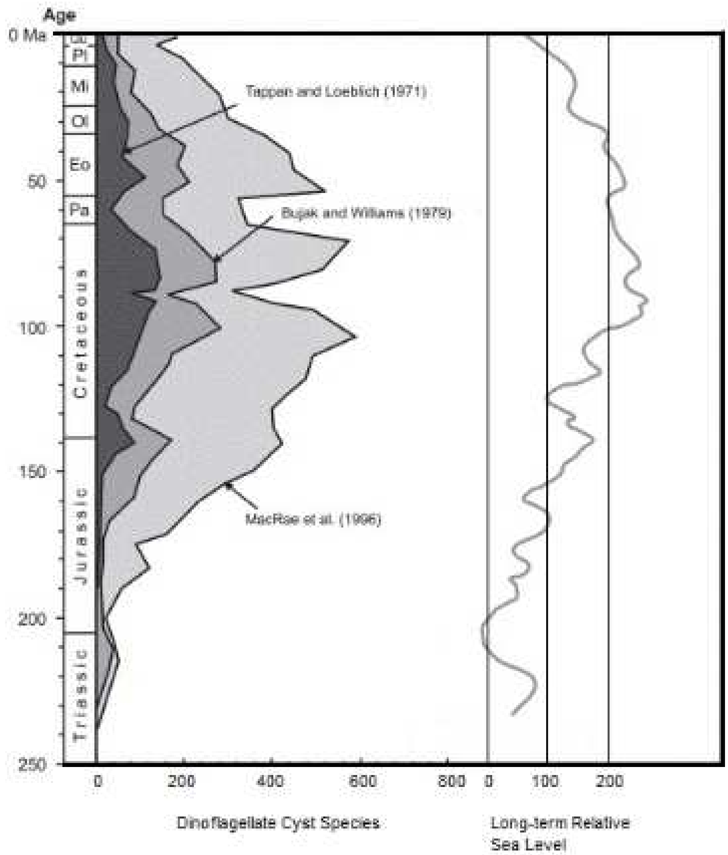


Figure 31. Dinoflagellate species diversity compared with Mesozoic - Cenozoic sea-level curve. (Dinoflagellate cyst species, adapted from MacRae *et al.,* 1996), (Long term relative sea level adapted from Haq *et al.,* 1987)

A great proportion of dinoflagellate species are known to inhabit shallow marine (neritic) settings on the continental shelf (Figure 32). This is largely due to dinoflagellate cysts dependence on returning to the restricted photic zone prior to excystment. This therefore limits the number of cyst forming species in the open ocean, as they would struggle to return to the photic zone (Vink *et al.,* 2000; Williams *et al.,* 2012). The provincialism of dinoflagellate cyst assemblages was first recorded by scientists working within the constraints of the Mesozoic (Norris, 1965a; Lentin and Williams, 1980; Goodman, 1987). It was found that the spatial differentiation of dinoflagellate cyst assemblages is largely reliant on both the physical and chemical characteristics of the water mass and on surface water circulation patterns which transport the thecal stage, which can be seen annotated in Figure 32.

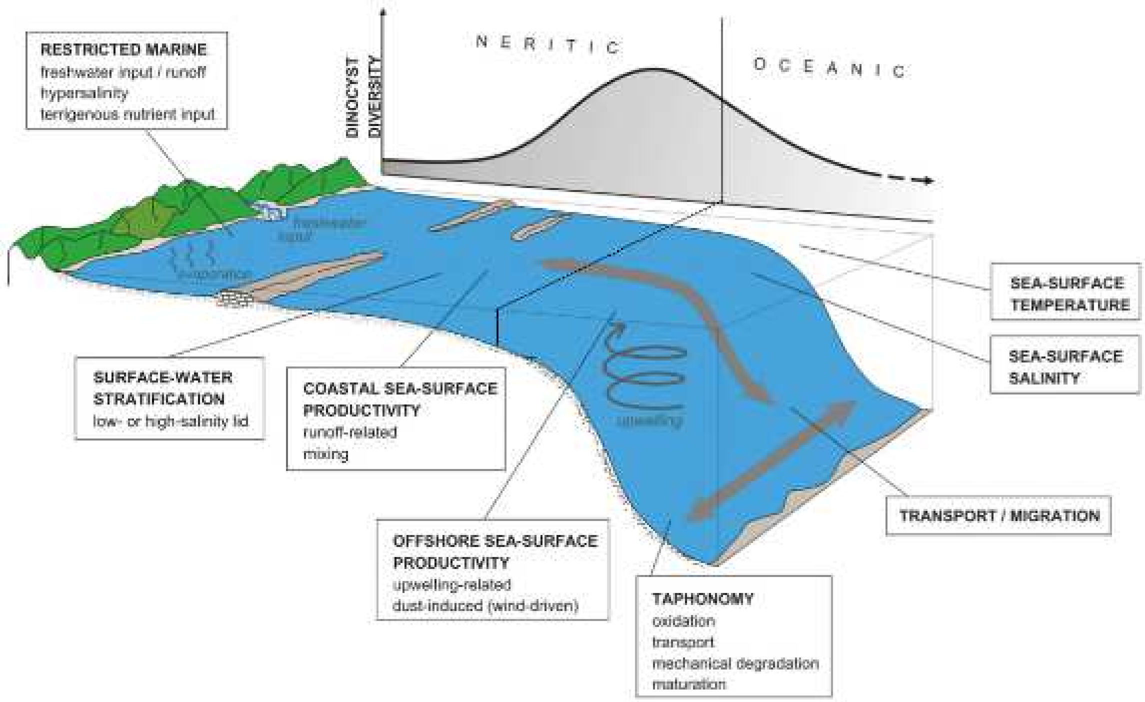


Figure 32. Schematic representation of a continental shelf displaying different environmental niches, complete with a schematic dinoflagellate cyst diversity profile along the shelf and hypothetical shelf areas. Adapted from Sluijs *et al.,* (2005, Figure 9).

Due to the high dependence of their surrounding water mass, it is of no surprise, that dinoflagellate cyst diversity has an astonishing correlation with that of the sea level fluctuation throughout geological time. This correlation, seen in Figure 31, reflects a larger preferred habitat for dinoflagellates, whereby, the higher the relative sea level, the more area of neritic habitat was created. This allowed higher ecological variability and promoted diversity amongst the dinoflagellate community (Williams *et al.,* 2012).

It should also be noted that, when working with fossilised dinoflagellate cyst assemblages, the dinoflagellate cysts present do not equate to the overall diversity of assemblage. This is because fossilised cysts only represent a part of the dinoflagellate life cycle (Fensome *et al.,* 1996b). From contemporaneous thinking, at least, 2000 species of dinoflagellates are known to exist today (Williams *et al.,* 2012). However, of this large number, only a small fraction of 10–15% (Head, 1996) form a preservable cyst. This therefore has to be taken into account when working in the geological past.

Chapter 5 – Systematics

5.1 Introduction

This section outlines the detailed systematics of all Jurassic and Cretaceous dinoflagellate cysts recovered from the three wells in the EGoM and their occurences in each well. The taxonomic classification follows that introduced by Bütschli (1885) and includes latter amendments by Fensome *et al.,* (1993). The terminology used to describe the dinoflagellate cysts in this section, primarily comes from those established in Williams *et al.,* (1978), Evitt (1985), Fensome *et al.,* (1996b) and Williams *et al.,* (2000).

All but two of the samples recovered from the wells are cuttings. In general, well cuttings are considered poor as they are often contaminated with drilling mud containing rock fragments from up-well (Traverse, 2007a). Therefore, within this study instances of caving and reworking have been highlighted under the occurrence section in each systematic entry.

In general, the overall diameter of a dinoflagellate cyst can range in size, anywhere from, 20 to 200µm. Throughout this systematics chapter there are three categories of size outlined by Stover and Evitt (1978, p. 5) which are employed: small (<50 µm), intermediate (50–100 µm), and large (>100 µm).

5.2 Taxonomy

Division DINOFLAGELLATA (Bütschli, 1885) Fensome *et al.,* 1993

Subdivision DINOKARYOTA Fensome *et al.,* 1993

Class DINOPHYCEAE Pascher, 1914

Subclass PERIDINIPHYCIDAE Fensome *et al.,* 1993

Order GONYAULACALES Taylor, 1980

Suborder CERATIINEAE Fensome *et al.,* 1993

Family CERATIACEAE Willey and Hickson, 1909

Genus *MUDERONGIA* Cookson and Eisenack, 1958

1958 *Muderongia* Cookson and Eisenack, p. 40–41.

TYPE: Cookson and Eisenack, 1958, p. 41, pl. 6, figs. 1–5, as *Muderongia mcwhaei.*

SYNOPSIS: The genus *Muderongia* contains intermediate to large ceratioid cysts that are dorso-ventrally compressed, with a wide-based apical horn, two lateral horns and one antapical horn. The horns are distally closed, and have ornamentation or perforations along their length. The cyst is cornucavate. The endophragm is psilate and the periphragm is psilate or with ornament of low relief. The paratabulation is not always expressed, but when it is, it is ceratioid. The archaeopyle is apical, type (4A). The paracingulum is indicated by a concavity on the lateral horns. The parasulcus is not discernible, except when paratabulation is well developed and indicates a distinctly left-offset parasulcal notch.

Muderongia endovata Riding *et al.,* 2001

Plate I, Fig. a

2001 *Muderongia endovata* Riding *et al.,* p. 24–26, 28, pl. 1, figs. 1–2; text-fig. 3.

Description: *Muderongia endovata* are intermediate to large, proximate, cornucavate cysts. The thin, shagreenate to scabrate periphragm forms one apical horn, two lateral horns and one offset antapical horn, producing a rhomboid to rounded subpentagonal outline. The shagreenate endophragm is rounded rhomboid to elongate ovoid in shape. The paratabulation is generally not visible, but is occasionally reflected by low, smooth, discontinuous ridges on the periphragm. The archeopyle is apical (4A). The paracingulum can be evident through a medial concavity on the lateral horns.

Remarks: This species was first described from the Valanginian of Germany.

Size: Intermediate to large.

Occurrence: DC353, 19760–19820ft. to 21080–21140ft. (Hauterivian–Valanginian); VK117, 17490–17520ft. to 19800–19830ft. (Hauterivian–Berriasian); CH265, 11250–11260ft. to 11600–11610ft. (Hauterivian–Valanginian).

Muderongia pariata Duxbury, 1983

Plate I, Fig. b

1983 *Muderongia pariata* Duxbury, p. 36–37, pl. 2, figs. 5, 8; text-fig. 16.

Description: *Muderongia pariata* are intermediate to large, proximate, cornucavate cysts. The thin, shagreenate to scabrate periphragm forms one apical horn, two lateral horns and one centrally located antapical horn, producing a rhomboid to rounded subpentagonal outline. The shagreenate endophragm is rounded-rhomboid to elongate-ovoid in shape. The wall of all four horns has perforations, and so the distal ends may appear open on the apical and antapical horns. The paratabulation is not discernible. The archeopyle is apical, type (4A). The paracingulum is reflected by a slight medial concavity on the lateral horns or by smooth, low, parallel ridges that partially encircle the cyst. Thus indicating a distinctly left-offset parasulcal notch.

Remarks: This species was originally recovered from the Early Aptian–Early Albian sediments of southern England.

Size: Intermediate to large.

Occurrence: DC353, 17780–17840ft. to 20060–20120ft. (Aptian–Valanginian); VK117, 13770–13800ft. to 15540–15570ft. (Aptian–Barremian); CH265, 7750–7760ft. to 11250–11260ft. (Aptian–Hauterivian).

Muderongia perforata Alberti, 1961

Plate I, Fig. c

1961 *Muderongia perforata* Alberti, p. 13, pl. 2, figs. 8–9.

2001 *Muderongia perforata* Riding *et al.,* 2001, p. 28, pl. 1, fig. 3.

Description: *Muderongia perforata* are intermediate to large, proximate, cornucavate cysts. The thin shagreenate periphragm forms one apical horn, two lateral horns and two unequal antapical horns (left side longer), producing a rhomboid to rounded subpentagonal outline. The horns vary from being open distally to closed due to perforations or scalloped margins. The shagreenate endophragm is rounded-rhomboid to elongate-ovoid in shape. The paratabulation is not discernible. The archeopyle is apical (4A). The paracingulum is marked by a medial concavity on the lateral horns.

Remarks: The holotype (Alberti, 1961, pl. 2, fig. 8) is lost according to Riding *et al.,* (2001, p. 28). A lectotype (Alberti, 1961, pl. 2, fig. 9, refigured by Riding *et al.,* 2001, pl. 1, fig. 3) was designated (as a "neotype") by Riding *et al.,* (2001). This species was first described from the Turonian sediments of northern and central Germany.

Size: Intermediate to large.

Occurrence: DC353, 17840–17900ft. to 18080–18140ft. (Aptian); VK117, 16560–16590ft. to 19140–19170ft. (Barremian–Valanginian) with reworking at 12600–12630ft. (Albian); CH265, not present.

Muderongia simplex Alberti, 1961

Plate I, Fig. d

1961 *Muderongia simplex* Alberti, p. 12, pl. 2, figs. 1–2, 4–6; pl. 12, figs. 1–2.

1987 *Senoniasphaera tabulata* Backhouse and Helby, p. 317–319, figs. 21A–G, 22A–C, 23.

Description: *Muderongia simplex* are intermediate to large, proximate, cornucavate cysts. The thin psilate to finely scabrate periphragm forms one apical horn, two lateral horns and two unequal antapical horns (left side longer), producing a rhomboid to rounded subpentagonal outline. The horns are conical with closed, rounded distal ends. However, the lateral horns may have a concavity at the distal end, approximating the position of the paracingulum. The endophragm is rounded-subpentagonal in outline. The endophragm has a slight prominence corresponding to the left antapical horn. The paratabulation is not discernible. The archeopyle is apical (4A).

Remarks: The holotype (Alberti, 1961, pl. 2, fig. 4) is lost according to Riding *et al.,* (2001, p.30). A lectotype (as a neotype) was designated by Riding *et al.,* (2001, p. 30) and figured by Davey (1979c, pl. 2, fig. 5, as *Muderongia* sp. A), by Monteil (1991a, pl. 1, figs. 3a–c as *Senoniasphaera tabulata*), and by Riding *et al.,* (2001, pl. 1, figs. 4–5). *Muderongia simplex* was originally recorded from the Valanginian to Early Barremian of northern and central Germany.

Size: Intermediate to large.

Occurrence: DC353, 19940–20000 to 20360–20420 (Hauterivian) with caving at 22640–22700 (Kimmeridgian); VK117, 16440–16470 to 18240–18270 (Barremian–Hauterivian); CH265, not present.

Muderongia staurota Sarjeant, 1966a

Plate I, Fig. e

1966a *Muderongia staurota* Sarjeant, p. 203–204, pl. 21, figs. 6–7; pl. 23, fig. 4; text-fig. 53.

Description: *Muderongia staurota* are intermediate to large, proximate, cornucavate cysts. The thin, psilate to finely scabrate periphragm forms one apical horn, two lateral horns (left horn more reduced than the right) and one antapical horn (which protrudes out to the left side), producing a rhomboid to rounded subpentagonal outline. The horns are conical in shape, with closed, pointed distal ends; the antapical horn is particularly wide. The periphragm comprising the apical horn may be perforated in its distal two-thirds. The psilate to granulate endophragm produces an endocyst that is rhombic in outline. No paratabulation is discernible. The archaeopyle is apical (4A).

Remarks: *Muderongia staurota* was first described from the Early Barremian of the Speeton Clay, Yorkshire, England.

Size: Intermediate to large.

Occurrence: DC353, 18260–18320 to 20840– 20900 (Barremian–Valanginian) with caving at 22760–22820 (Kimmeridgian); VK117, 14490–14520 to 17640–17670 (Aptian–Hauterivian); CH265, 10250–10260 (Aptian).

Muderongia tomaszowensis Alberti, 1961

Plate I, Fig. f

1961 *Muderongia tomaszowensis* Alberti, p. 12–13, pl. 2, figs. 12–13.

Description: *Muderongia tomaszowensis* are large, proximate, cornucavate cysts. The thin, psilate to scabrate periphragm forms one apical horn, two lateral horns and one left antapical horn, producing a pericyst with rhomboid to rounded subpentagonal outline. The horns are conical, with closed, rounded distal terminations. The lateral horns may have a concavity distally, reflecting the position of the paracingulum. The psilate to granulate endophragm forms an endocyst that is rhombic in outline. The paratabulation is not discernible. The archeopyle is apical (4A).

Remarks: The holotype (Alberti, 1961, pl. 2, fig. 12) is lost according to Riding *et al.,* (2001, p.31). Riding *et al.,* (2001) designated the lectotype (as a neotype) as Alberti (1961, pl. 2, fig. 13), refigured as Riding *et al.,* (2001, p. 31, pl. 1, fig. 7). *Muderongia tomaszowensis* was originally recorded from the Valanginian of northern and central Germany.

Size: Large.

Occurrence: DC353, 19820–19880 (Hauterivian); VK117, 16140–16170 to 18990–19020 (Barremian–Valanginian) with caving into Jurassic strata between 20990–21000 to 22890–22900 (Tithonian–Kimmeridgian); CH265, not present.

Genus *NYKTERICYSTA* Bint, 1986

1986 *Nyktericysta* Bint, p. 148–149.

1986 *Balmula* Bint, p. 158.

TYPE: Bint, 1986, p.149–150, 152–153, pl.4, figs.1–12; pl.8, figs.1–6; text-figs. 3A–C, 4A–B, 10A–B, as *Nyktericysta davisii.*

SYNOPSIS: The genus *Nyktericysta* comprises intermediate to large, dorso-ventrally compressed ceratioid cysts. The outline includes a wide-based apical horn, two asymmetrical antapical horns (left horn longer) and two wide lateral horns, that may have pre- and postcingular extensions. The lateral horns may have anteriorly and posteriorly pointing projections. The distal terminations of the horns are closed and vary from pointed to rounded. The wall is cavate to holocavate, with a narrow pericoel. The autophragm is psilate to reticulate and connected to the ectophragm. The development of large ectophragmal perforations near horn tips can lead to detachment of ectophragm there, and so appear cornucavate. The paratabulation is not expressed. The archaeopyle is apical, the operculum generally attached. The paracingulum may be indicated by a distal concavity on the lateral horns. The parasulcus is not discernible, except when paratabulation is well developed and indicates a distinctly left-offset parasulcal notch.

Nyktericysta arachnion Bint, 1986

Plate I, Fig. g

1986 *Nyktericysta arachnion* Bint, p. 153–154, pl. 4, figs. 13–16; pl. 5, figs. 1–5; pl. 8, figs. 7–8.

Description: *Nyktericysta arachnion* are intermediate to large, proximate, cornucavate cysts. The periphragm is reticulate and produces a star-shaped outline, with five pointed horns: one apical horn, two lateral horns, and two antapical horns (left horn longer). The endophragm is psilate and does not reach to the end the horns; thus the endocyst is much more rounded than the pericyst. The paratabulation is undiscernible, however, the paracingulum is indicated by indentations on the lateral horns and by transverse lines. The archaeopyle is apical; the operculum usually remains attached ventrally, but may be torn off.

Remarks: This species was first described from the Early Late Albian of Kansas, U.S.A.

Size: Intermediate to large.

Occurrence: DC353, not present; VK117, 18990–19020ft. (Valanginian); CH265, 9640–9650ft. (Aptian).

Genus *ODONTOCHITINA* Deflandre, 1937

1937 *Odontochitina* Deflandre, p. 94.

TYPE: Wetzel, 1933, p. 170, pl. 2, figs. 21–22; text-fig. 3, as *Odontochitina operculata.*

SYNOPSIS: The genus *Odontochitina* comprises large ceratioid cysts that are dorso-ventrally compressed. The shape is dominated by the horns: one long, wide-based apical horn, one left sided lateral horn, which curves towards the hypocyst, and one long antapical horn. The distal terminations of the horns are either open or closed. The cyst is cornucavate, the endophragm being appressed to the periphragm except at the horns. The endophragm is psilate, the periphragm is psilate or bears ornament of low relief, and may be perforate along the horns. The paratabulation is not always expressed, but when it is, it is ceratioid. The archaeopyle is apical. The paracingulum is indicated by a medial concavity on the lateral horns. The parasulcus is indicated by a sulcal notch in the archaeopyle margin, but otherwise not discernible except where paratabulation is well developed.

Odontochitina ancala Bint, 1986

Plate I, Fig. h

1986 *Odontochitina ancala* Bint, p. 139–140, pl. 1, figs. 2–8; pl. 7, figs. 1–2; text-fig. 2A.

Description: *Odontochitina ancala* is a large, cornucavate cyst, with ceratioid outline. The right lateral horn projects away from the endophragm at a right angle, before curving around to point towards the hypocyst. The paracingulum may be reflected by a medial concavity on the curved lateral horn and by two parallel lines that traverse the cyst equatorially. The psilate to finely scabrate periphragm detaches from the psilate endophragm at the horns. However, in the case of the antapical horn the pericoel extends up to the level of cingulum on the left ventral side. Along each of the horns there is an area of concentrated perforations. The paratabulation is undiscernible. The archaeopyle is apical, with a detached operculum.

Remarks: This species was first recorded from the Middle–Late Albian of Kansas, U.S.A.

Size: Large.

Occurrence: DC353, 17720–17780ft. to 20060–20120ft. (Aptian–Valanginian); VK117, 12600–12630ft. (Albian); CH265, 9700–9710ft. (Aptian).

Odontochitina imparalis (Duxbury, 1980) Jain and Khowaja-Ateequzzaman, 1984

Plate I, Fig. i

1980 *Muderongia imparilis* Duxbury, p. 127–129, pl. 5, figs. 2, 4–5; text-figs. 11A–B.

1984 *Odontochitina imparilis* (Duxbury, 1980) Jain and Khowaja-Ateequzzaman, p. 38.

Description: *Odontochitina imparilis* is a large, cornucavate cyst. It has a ceratioid outline, with three entire horns (i.e., no perforations); one very long apical horn, one right lateral horn and one antapical horn. The right lateral horn projects away from the endophragm at a right angle, before curving around to point towards the hypocyst. The psilate to shagreenate periphragm detaches from the psilate endocyst at the horns. The paratabulation is undiscernible. The archaeopyle is apical, with a detached operculum. The paracingulum may be reflected by two parallel lines that traverse the cyst.

Remarks: This species was originally recorded from the Middle–Late Barremian of Yorkshire, England.

Size: Large.

Occurrence: DC353, 19700–19760ft. (Hauterivian); VK117, 13770–13800ft. to 15540–15570ft. (Aptian–Barremian); CH265, not present.

Odontochitina operculata (Wetzel, 1933) Deflandre and Cookson, 1955

Plate I, Fig. j

1933 *Ceratium (Euceratium) operculata* Wetzel, p. 170, pl. 2, figs. 21–22.

1937 *Odontochitina silicorum* Deflandre, p. 95, pl. 18 (al. pl. 15), figs. 8–13.

1955 *Odontochitina operculata* Deflandre and Cookson, p. 291–292.

Description: *Odontochitina operculata* is a large, cornucavate cyst. It has a ceratioid outline, with three long straight pointed horns; one apical horn, one right lateral horn and one antapical horn. The psilate endophragm is subspherical in outline. The psilate periphragm separates from the endophragm at the horns. In some specimens the periphragm perforates halfway along the horn. The paratabulation is undiscernible. The archaeopyle is apical, with a detached operculum. The paracingulum is infrequently reflected by two parallel lines that traverse the cyst equatorially.

Remarks: This species was first recorded from the Coniacian–Danian strata of Germany.

Size: Large.

Occurrence: DC353, 19400–19460ft. to 19520–19580ft. (Barremian–Hauterivian); VK117, 13770–13800ft. to 17640–17670ft. (Albian–Hauterivian); CH265, not present.

Odontochitina porifera Cookson, 1956

Plate I, Fig. k

1956 *Odontochitina porifera* Cookson, p. 188, pl. 1, fig. 17.

Description: *Odontochitina porifera* is a large, cornucavate cyst. It has a ceratioid outline, with three perforated horns; one apical horn, one right lateral horn and one antapical horn. The right lateral horn points towards the hypocyst. The psilate to finely scabrate periphragm detaches from the psilate subspherical endocyst at the horns. Each of the horns are perforated in their middle sections, by regularly arranged holes and are pointed at their distal extremity. However, along the apical horn the perforations are much larger and oval in shape, and arranged in rows that encircle the horn. The paratabulation is undiscernible. The archaeopyle is apical, usually with a detached operculum.

Remarks: This species was originally described from the Coniacian–Danian sediments of Australia.

Size: Large.

Occurrence: DC353, not present; VK117, 15840–15870ft. to 16440–16470ft. (Barremian); CH265, not present.

Genus *PHOBEROCYSTA* Millioud, 1969

1969 *Phoberocysta* Millioud, p. 431–432.

TYPE: Gocht, 1957, p. 172–178, pl. 19, figs. 1–5; pl. 20, figs. 1–7; text-figs. 7–16, as *Wetzeliella neocomica.*

SYNOPSIS: The genus *Phoberocysta* comprises large ceratioid cysts that are dorso-ventrally compressed. The shape is controlled by horn development, with one apical horn, one or two lateral horns and one antapical horn, occasionally with a second small antapical horn. The wall is cornucavate, the endophragm being appressed to the periphragm except at the horn tips. The endophragm is psilate and the periphragm is psilate or with ornament of low relief. The paratabulation, when expressed, is ceratioid. The archaeopyle is apical. The paracingulum is indicated by means of a medial concavity on the lateral horns. The parasulcus is not discernible, except when paratabulation is well developed and indicates a distinctly left-offset parasulcal notch.

Phoberocysta neocomica (Gocht, 1957) Millioud, 1969

Plate I, Fig. l

1957 *Wetzeliella*? *neocomica* Gocht, p. 172–178, pl. 19, figs. 1–5; pl. 20, figs. 1–7; text-figs. 7–16.

1969 *Phoberocysta neocomica* (Gocht, 1957) Millioud, p. 432.

1993 *Muderongia neocomica* (Gocht, 1957) Lentin and Williams, p. 438.

Description: *Phoberocysta neocomica* is a large, proximochorate, cornucavate cyst with a rhomboidal outline. The psilate to finely granulate periphragm forms one apical horn, two lateral horns and one antapical horn on the left with antapical bulge to the right. The two lateral horns curve toward the hypocyst. The periphragm is sporadically covered with solid capitate spines. The shagreenate endophragm is closely appressed to the periphragm, thus replicating its shape, except in the horn areas where a pericoel is present. The paratabulation is ceratioid. The archeopyle is apical. The paracingulum may be reflected by a medial concavity on the lateral horns

Remarks: Poulson (1996, p. 59) retained this genus as he did no subscribe to Monteil's (1991a, p. 56) emendation to include species with processes and circumcavation into the genus *Muderongia*. This species was originally recorded from the Hauterivian sediments of northwestern Germany.

Size: Large.

Occurrence: DC353, 20840–20900ft. (Valanginian); VK117, 15240–15270ft. (Aptian); CH265, not present.

Genus *PSEUDOCERATIUM* Gocht, 1957

1957 *Pseudoceratium* Gocht, p. 166.

TYPE: Gocht, p. 166–168, pl. 18, figs. 1–2; text-figs. 1–3, as *Pseudoceratium pelliferum.*

SYNOPSIS: The genus *Pseudoceratium* comprises intermediate to large, acavate cysts that are dorso-ventrally compressed. The shape is controlled by a wide-based long apical horn, an offset (to the left) antapical horn, and one lateral horn. The distal terminations of the horns are closed, with low-relief ornamentation along the horns. The autophragm is either psilate or bears low-relief ornamentation, the ornament may appear reduced in the mid-dorso-ventral areas of some cysts. There is no discernible paratabulation. The archaeopyle is apical.

Pseudoceratium brevicornutum Herngreen *et al.,* 2000

Plate I, Fig. m

2000 *Pseudoceratium brevicornutum* Herngreen *et al.,* p. 50, pl. 9, figs. 6–7.

Description: *Pseudoceratium brevicornutum* is a large, proximate, acavate cyst with an elongated subpentagonal outline. The outline is formed by the presence of a wide based blunt apical horn, a blunt left antapical horn and a right antapical bulge, with the widest part of the cyst around the level of the paracingulum and lateral bulges. The autophragm is densely granular with short tubercles. There is no discernible paratabulation. The archaeopyle is apical.

Remarks: This species was first recorded from the Late Ryazanian–Early Hauterivian of the Central North Sea Graben and the Vlieland Basin.

Size: Large.

Occurrence: DC353, 20060–20120ft. to 20840–20900ft. (Hauterivian–Valanginian); VK117, 21390–21400ft. (Tithonian); CH265, not present.

Pseudoceratium pelliferum Gocht, 1957

Plate I, Fig. n

1957 *Pseudoceratium pelliferum* Gocht, p. 166–168, pl. 18, figs. 1–2; text-figs. 1–3.

Description: *Pseudoceratium pelliferum* is a large, proximate, acavate cyst with an elongated asymmetrical triangular outline. The shape is controlled by a wide-based long apical horn, an offset (to the left) antapical horn, and one lateral horn. The autophragm is finely granular, covered with nontabular short processes that have variable distal terminations. There is no discernible paratabulation. The archaeopyle is apical.

Remarks: This species was initially recorded from the Valanginian–Late Hauterivian of northwestern Germany.

Size: Large.

Occurrence: DC353, 18440–18500ft. to 19940–20000ft. (Barremian–Hauterivian); VK117, concentrated between 15540–15570ft. to19800–19830ft. (Barremian–Berriasian), with reworking at 13770–13800ft. (Aptian) and caved to 22290–22300ft. (Tithonian); CH265, not present.

Pseudoceratium retusum Brideaux, 1977

Plate I, Fig. o

1977 *Pseudoceratium retusum* Brideaux, p. 14–15, pl. 4, figs. 10–12; pl. 5, figs. 1–2, 5–10.

Description: *Pseudoceratium retusum* is a large, proximate, acavate cyst with an elongated asymmetrically triangular outline. The outline is formed by the presence of a wide-based blunt apical horn, a blunt left antapical horn and a right antapical bulge. The autophragm is psilate to scabrate, covered in nontabular short spines. The spines vary in width and have a various types of distal ends. Ornament is reduced in the central dorsal and ventral regions. There is no discernible paratabulation. The archaeopyle is apical, and is normally detached.

Remarks: This species was first recorded from the Barremian-Aptian of Mackenzie, Canada.

Size: Large.

Occurrence: DC353, 18260–118320ft. to 18440–18500ft. (Barremian); VK117, 15240–15270 ft. to 16770–16800ft. (Aptian–Barremian) with caving at 20690–20700ft. (Tithonian); CH265, not present.

Pseudoceratium securigerum (Davey and Verdier, 1974) Bint, 1986

Plate I, Fig. p

1974 *Aptea securigera* Davey and Verdier, p. 642–643, pl. 91, figs. 2–3; text-fig. 5(vii).

1986 *Pseudoceratium securigerum* (Davey and Verdier, 1974) Bint, p. 145.

Description: *Pseudoceratium securigerum* is a large, proximochorate, acavate cyst with an elongated asymmetrically triangular outline. The outline is formed by the presence of a wide-based blunt apical horn, a rounded left antapical horn and a right antapical. The autophragm is psilate or with ornament of low relief, covered in nontabular short spines. The spines vary in shape and length but typically the distal end is flat-topped. There is a reduction in spines in the central dorsal and ventral regions. There is no discernible paratabulation. The archaeopyle is apical, and is normally detached.

Remarks: This species was originally described from the Early Aptian of southeastern France.

Size: Large.

Occurrence: DC353, 18320–18380ft. (Barremian); VK117, 13770–13800ft. to 14490–14520ft. (Aptian); CH265, 10250–10260ft. (Aptian).

Genus *XENASCUS* Cookson and Eisenack, 1969

1969 *Xenascus* Cookson and Eisenack, p. 7.

TYPE: Cookson and Eisenack, 1969, p.7, figs.1I–K, as *Xenascus australensis.*

SYNOPSIS: The genus *Xenascus* comprises large ceratioid cysts that are dorso-ventrally compressed. The shape is controlled by the horns: one wide-based apical horn, one left lateral horn that curves towards the hypocyst, and one antapical horn. The distal terminations of the horns are either open or closed, with ornamentation or perforations along the horns. The wall is cornucavate, with the endophragm appressed to the periphragm except at the horn tips. The endophragm is psilate and the periphragm is psilate or bears ornament of low relief, and may also be locally perforate. The paratabulation, when expressed, is ceratioid. The archaeopyle is apical. The paracingulum is reflected by a medial concavity on the lateral horns. The parasulcus is not discernible, except when paratabulation is well developed and indicates a distinctly left-offset parasulcal notch.

Xenascus ceratioides (Deflandre1937) Lentin and Williams, 1973

Plate I, Fig. q

1937 *Hystrichosphaera ceratioides* Deflandre, p.66–67, pl. 12 (al. pl. 9), figs. 7–8.

1967 *Pseudoceratium ceratioides* (Deflandre, 1937) Clarke and Verdier, p. 60.

1970 *Spiniferites ceratioides* (Deflandre, 1937) Sarjeant, p. 76.

1971 *Phoberocysta ceratioides* (Deflandre, 1937) Davey and Verdier, p. 26.

1973 *Xenascus ceratioides* (Deflandre1937) Lentin and Williams, p. 144.

Description: *Xenascus ceratioides* is a large, proximochorate, cavate cyst. The endophragm has a spherical outline, while the thin shagreenate periphragm forms pericoels in the horns — one long pointed apical horn, one right lateral horn and one rounded antapical horn. The right-lateral horn projects away from the endophragm at a right angle, before curving around to point towards the hypocyst. All of the horns are adorned by short intratabular spines, which are simple or bifurcate distally. The paratabulation is not discernible. The archeopyle is apical.

Remarks: This species was first described from the Coniacian–Danian of France.

Size: Large.

Occurrence: DC353, 19040–19100ft. (Barremian); VK117, not present; CH265, not present.

Xenascus perforatus (Vozzhennikova, 1967) Yun Hyesu, 1981

Plate I, Fig. r

1967 *Endoceratium perforatum* Vozzhennikova, p. 188–189, pl. 112, figs. 1a–b, 3; pl. 113, fig. 1.

1981 *Xenascus perforatus* (Vozzhennikova, 1967) Yun Hyesu, p. 62.

Description: *Xenascus perforates* is a large, proximochorate, cavate cyst. The endophragm has an ovoidal outline, while the thin shagreenate periphragm forms pericoels in the horns — one blunted apical horn, one right lateral horn and one rounded antapical horn. The right lateral horn projects away from the endophragm at a right angle, before curving around to point towards the hypocyst. The horns are all perforated and the antapical horn is distally open. The paratabulation is not discernible. The archeopyle is apical.

Remarks: This species was originally described from the Late Cretaceous of Russia.

Size: Large.

Occurrence: DC353, 19040–19100ft. (Barremian); VK117, not present; CH265, not present.

Xenascus plotei Below, 1981

Plate I, Fig. s

1981 *Xenascus plotei* Below, p. 21–22, pl. 2, figs. 8–9; pl. 8, figs. 20a–b, 21; pl. 14, fig. 15; text-fig. 10.

Description: *Xenascus plotei* is a large, proximochorate, cavate cyst. The endophragm has an ovoidal outline, while the thin shagreenate periphragm forms pericoels in the horns — one blunted apical horn, one right lateral horn and one rounded antapical horn. The lateral and antapical horns are both distally open with minor fenestrations near the distal margins. The paratabulation is not discernible. The archeopyle is apical.

Remarks: This species was initially recorded from the Late Aptian–Early Cenomanian of southwestern Morocco.

Size: Large.

Occurrence: DC353, 19040–19100ft. (Barremian); VK117, not present; CH265, not present.

Suborder CLADOPYXIINEAE Fensome *et al.,* 1993

Family PAREODINIACEAE Gocht, 1957

Subfamily BROOMEOIDEAE (Eisenack, 1969) Fensome *et al.,* 1993

Genus *APROBOLOCYSTA* Duxbury, 1977

1977 *Aprobolocysta* Duxbury, p. 52.

TYPE: Duxbury 1977, p. 52–53, pl. 14, figs. 4–5, 8; text-figs. 19A–B, as *Aprobolocysta eilema.*

SYNOPSIS: The genus *Aprobolocysta* comprises intermediate, proximate cysts with an elongate ovoidal outline. The epicyst is longer and tapers more than the hypocyst. The apex lacks any prominence, while the antapex occasionally displays two weakly developed projections. There is no discernible paratabulation other than folds in the periphragm reflecting the paracingulum and the shape of the archaeopyle margin. The periphragm is psilate or bears ornament of low relief. The archaeopyle is apical.

Aprobolocysta eilema Duxbury, 1977

Plate I, Fig. t

1977 *Aprobolocysta eilema* Duxbury, p. 52–53, pl. 14, figs. 4–5, 8, text-figs. 19A–B. Retained by Lentin and Williams (1993, p. 31).

1990 *Necrobroomea eilema* (Duxbury, 1977) Below, p. 53.

Description: *Aprobolocysta eilema* are elongated to ovoidal, proximate dinoflagellate cysts, with a longer epicyst than hypocyst. The cyst wall has an unusual relationship in that the endophragm is thicker than the periphragm, the latter being delicate and loosely enclosing the endocyst. The loose periphragm is most evident around the level of the cingulum and around the antapex. Other than along outline of the apical archeopyle, tabulation is not discernible.

Remarks: This species was first recorded from the Late Hauterivian of North Yorkshire, UK.

Size: Intermediate.

Occurrence: DC353, not present; VK117, 15540–15570ft. (Barremian); CH265, not present.

Genus *BATIOLADINIUM* Brideaux, 1975

1975 *Batioladinium* Brideaux, p.1241.

TYPE: Alberti, 1961, p. 26, pl. 5, figs. 1–7, as *Broomea jaegeri.*

SYNOPSIS: The genus *Batioladinium* comprises intermediate, dorso-ventrally compressed, proximate cysts, with an elongate ovoidal outline. The epicyst is longer than, and tapers more than, the hypocyst. There is one apical horn, which varies in length, and two antapical horns of equal or unequal length. The autophragm is psilate to finely ornamented. There is no discernible paratabulation. The archaeopyle is apical.

Batioladinium jaegeri (Alberti, 1961) Brideaux, 1975

Plate II, Fig. a

1961 *Broomea jaegeri* Alberti, p. 26, pl. 5, figs. 1–7.

1975 *Batioladinium jaegeri* (Alberti, 1961) Brideaux, p. 1240.

1975 *Necrobroomea jaegeri* (Alberti, 1961) Wiggins, p. 111.

1980 *Imbatodinium jaegeri* (Alberti, 1961) Dörhöfer and Davies, p. 37.

Description: *Batioladinium jaegeri* is a proximate dinoflagellate cyst, with the epicyst longer than the hypocyst. The autophragm is granulate. There is one distinct apical horn and two shorter antapical horns. No tabulation is discernible except along the archeopyle margin.

Remarks: *Batioladinium jaegeri* was originally described from the Late Barremian of Germany.

Size: Intermediate.

Occurrence: DC353, not present; VK117, 17340–17370ft. to 18540–18570ft. (Barremian–Hauterivian); CH265, not present.

Genus *PARAEVANSIA* Below, 1990

1990 *Paraevansia* Below, p. 58.

TYPE: Fensome, 1979, p. 29–31, pl. 4, figs. 3, 5–7; text-figs. 11A–E, as *Pareodinia brachythelis.*

SYNOPSIS: The genus *Paraevansia* comprises intermediate, proximate to proximochorate acavate cysts. The outline is subspherical to ovoidal, with an apical protuberance, which is dorso-ventrally compressed. The autophragm is either psilate or ornamented, and may or may not have a kalyptra. There is no discernible paratabulation, other than the outline of the intercalary archaeopyle.

Paraevansia brachythelis (Fensome, 1979) Below, 1990

Plate II, Fig. b

1979 *Pareodinia brachythelis* Fensome, p. 29–31, pl. 4, figs. 3, 5–7; text-figs. 11A–E.

1990 *Paraevansia brachythelis* (Fensome, 1979) Below, p. 58.

Description: *Paraevansia brachythelis* are intermediate, proximate, acavate cysts with an ovoid to ellipsoid outline, surmounted by a short rounded apical horn. The apical horn occasionally has a short antenna like spine attached, which occasionally can be mimicked at the antapex. The autophragm is densely granulate to verrucate There is no discernible paratabulation. The archaeopyle is intercalary, with the loss of three anterior intercalary plates. The paracingulum is not reflected.

Remarks: This species was first recorded from the Bajocian–Callovian of East Greenland.

Size: Intermediate.

Occurrence: DC353, 22800–22860ft. to 23160–23220ft. (Oxfordian); VK117, not present; CH265, not present.

Subfamily PAREODINIOIDEAE Autonym

Genus *GOCHTEODINIA* Norris, 1978b

1978b *Gochteodinia* Norris, p. 7.

TYPE: Vozzhennikova, 1967, p. 56, pl. 12, figs. 1a–b, 2a–b, 3a–b; pl. 13, figs. 1a–e, 2, 3a–d; pl. 14, figs. 1a–e, 2a–i; pl. 15, figs. 1–2, as *Imbatodinium villosum.*

SYNOPSIS: The genus *Gochteodinia* consists of intermediate to large, proximate to proximochorate, acavate cysts, with an elongate ovoidal outline and a well-developed apical horn. The autophragm is ornamented with non-tabular, acuminate or evexate terminated projections. There is no discernible paratabulation. The archaeopyle is formed from the loss of two or three anterior intercalary plates.

Gochteodinia villosa (Vozzhennikova, 1967) Norris, 1978b

Plate II, Fig. c

1967 *Imbatodinium villosum* Vozzhennikova, p. 56, pl. 12, figs. 1a–b, 2a–b, 3a–b; pl. 13, figs. 1a–e, 2, 3a–d; pl. 14, figs. 1a–e, 2a–i; pl. 15, figs. 1–2.

1975 *Pareodinia dasyforma* (Vozzhennikova, 1967) Wiggins, p. 107.

1978b *Gochteodinia villosa* (Vozzhennikova, 1967) Norris, p. 7.

Description: *Gochteodinia villosa* are intermediate to large, proximate, acavate dinoflagellate cysts. It is elongate, with the apex drawn out into a long 'antenna like' apical horn. The autophragm is densely granular surmounted with short projections. The projections vary in length, but are predominately short, solid, and distally capitate, cauliflorate or evexate. There is no discernible paratabulation. The archaeopyle is formed from the loss of two or three anterior intercalary plates.

Remarks: This species was initially described from the Late Jurassic of Russia.

Size: Intermediate to large.

Occurrence: DC353, not present; VK117, 22890–22900ft. (Kimmeridgian); CH265, not present.

Genus *PAREODINIA* Deflandre, 1947b

1947b *Pareodinia* Deflandre, p.4.

TYPE: Deflandre, 1947b, p. 4, text-figs. 1–3, as *Pareodinia ceratophora.*

SYNOPSIS: The genus *Pareodinia* comprises small to large, proximate to proximochorate cysts. They have an ellipsoidal outline and an apical horn. The autophragm is either psilate or variously ornamented. Paratabulation is usually indiscernible, but may be reflected by discontinuous parasutural features. The archaeopyle is formed by the loss of intercalary plates.

Pareodinia ceratophora Deflandre, 1947b

Plate II, Fig. d

1947b *Pareodinia ceratophora* Deflandre, p. 4, text-figs. 1–3.

1962 *Cryptomeriapollenites coralliensis* (Deflandre, 1947b) Sarjeant, p. 263).

1975 *Kalyptea monoceras* (Deflandre, 1947b) Wiggins, p. 103.

1975 *Paranetrelytron strongylum* (Deflandre, 1947b) Wiggins, p. 103.

1975 *Pareodinia nuda* (Deflandre, 1947b) Wiggins, p. 103.

1990 *Kalyptea monoceras* (Deflandre, 1947b) Below, p. 65.

1990 *Pareodinia nuda* (Deflandre, 1947b) Kunz, p. 13.

Description: *Pareodinia ceratophora* are intermediate, proximate, acavate cysts. It is ellipsoidal, with an apical horn. The autophragm is granulate with short solid projections that distally branch or bifurcate. There is no discernible paratabulation. The archaeopyle is formed from the loss of two anterior intercalary plates.

Remarks: This species was first described from the Late Callovian sediments of Monaco.

Size: Intermediate.

Occurrence: DC353, 22040–22100ft. to 22640–22700ft. (Tithonian) with reworking at 17600–17660ft. (Albian); VK117, 17640–17670ft. to 18990–19020ft. (Hauterivian–Valanginian), with reworking at 12600–12630ft. (Albian); CH265, 11250–11260ft. to 11600–11610ft. (Hauterivian).

Suborder GONIODOMINEAE Fensome *et al.,* 1993

Family GONIODOMACEAE Lindemann, 1928

Subfamily PYRODINIOIDEAE Fensome *et al.,* 1993

Genus *HYSTRICHOSPHAERIDIUM* Deflandre, 1937

1937 *Hystrichosphaeridium* Deflandre, p. 68.

TYPE: Ehrenberg, 1838, pl. 1, fig. 16, as *Xanthidium tubiferum.*

SYNOPSIS: The genus *Hystrichosphaeridium* comprises intermediate, chorate, acavate cysts, with a subspheroidal cerntral body. The psilate to finely granulate central body bears numerous solid or hollow processes. The intratabular processes are proximally flared and distally closed or open and with varying tips. There is no discernible paratabulation. The archaeopyle is apical.

Hystrichosphaeridium arborispinum Davey and Williams, 1966a

Plate II, Fig. e

1966a *Hystrichosphaeridium arborispinum* Davey and Williams, p. 61, pl. 9, figs. 5, 10.

Description: *Hystrichosphaeridium arborispinum* are intermediate chorate cysts with a subspherical central body, which is shagreenate to finely granulate. The wall produces hollow, cylindrical to tubiform processes, which have expanded and open distal ends that have secate to denticulate margins. The archaeopyle is apical.

Remarks: This species was first described from the Early to Middle Barremian of Yorkshire, England.

Size: Intermediate.

Occurrence: DC353, not present; VK117, not present; CH265, 9640–9650ft. (Aptian).

Hystrichosphaeridium recurvatum (White, 1842) Lejeune-Carpentier, 1940

Plate II, Fig. f

1842 *Xanthidium tubiferum* var. *recurvatum* White, p. 39, pl. 4, fig. 12.

1842 *Xanthidium tubiferum* var. *palmatum* White, p.39–40, pl. 4, fig. 12.

1842 *Xanthidium tubiferum* var. *palmaforme* White, p. 39, pl. 4, fig. 12.

1848 *Xanthidium palmatum* (White, 1842) Bronn, p. 1375.

1940 *Hystrichosphaeridium recurvatum* subsp. *recurvatum* (White, 1842) Lejeune-Carpentier, p. B221–B222.

1989 *Hystrichosphaeridium duplum* Lentin and Williams, p. 181.

Description: *Hystrichosphaeridium recurvatum* are intermediate chorate cysts with a subspherical central body. The endophragm is finely granulate. The shagreenate periphragm pulls away to produce long, slender processes, which are buccinate and open, with a secate to patulate margin. There is no discernible paratabulation. The archaeopyle is apical, with no evidence of a paracingulum or parasulcus.

Remarks: This taxon has a complex nomenclatural history, but Fensome and Williams (2004) concluded that the correct name, as long as the species remains in this genus, is *Hystrichosphaeridium recurvatum*. This species was first recorded from Coniacian–Danian strata, but has also been found much earlier in sections from southern France (Barremian–Aptian; Oosting *et al.,* 2015).

Size: Intermediate.

Occurrence: DC353, 19280–19340ft. (Barremian); VK117, not present; CH265, not present.

Genus *TALEISPHAERA* Duxbury, 1979a

1979a *Taleisphaera* Duxbury, p. 201.

TYPE: Duxbury, 1979a, p. 201, pl. 2, figs. 1, 4, 6–7, as *Taleisphaera hydra.*

SYNOPSIS: The genus *Taleisphaera* comprises intermediate, chorate, acavate cysts, with central bodies ranging in shape from, subpolygonal, ovoidal to ellipsoidal. The central body has a finely perforated autophragm, and bears numerous solid processes. The processes are proximally flared and distally flared and furcate. A gonyaulacoid tabulation is reflected by low pentabular crests connecting the process bases. The processes may be striate. The archaeopyle is precingular, formed by the detachment of two dorsal plates.

Taleisphaera hydra Duxbury, 1979a

Plate II, Fig. g

1979a *Taleisphaera hydra* Duxbury, 1979a, p. 201, pl. 2, figs. 1, 4, 6–7. Retained by Lentin and Williams (1985, p. 348).

1982a *Kiokansium hydra* (Duxbury, 1979a) Below, p. 16.

Description: *Taleisphaera hydra* are intermediate, chorate, acavate cysts. The psilate to finely perforated central body has a subspherical central body. Arising from the autophragm are solid penitabular processes. The processes are connected proximally by a ridge, which conforms to a parasuture. Each process is long and slender, and branches distally. The archaeopyle is precingular.

Remarks: This species was first described from the Middle Barremian of Yorkshire, England.

Size: Intermediate.

Occurrence: DC353, 17960–18020ft. to 20000–20060ft. (Aptian–Hauterivian); VK117, 15540–15570ft. to 18240–18270ft. (Barremian–Hauterivian); CH265, 9700–9710ft. to 11600–11610ft. (Aptian–Valanginian).

Suborder GONYAULACINEAE (Autonym)

Family GONYAULACACEAE Lindemann, 1928

Subfamily CRIBROPERIDINIOIDEAE Fensome *et al.,* 1993

Genus *APTEODINIUM* Eisenack, 1958

1958 *Apteodinium* Eisenack, p. 385.

TYPE: Eisenack, 1958, p. 386–387, pl. 23, fig. 9, as *Apteodinium granulatum***.**

SYNOPSIS: The genus *Apteodinium* comprises intermediate, proximate, acavate cysts. They have a globular to ovoidal outline, with a short, generally broad-based apical horn. The autophragm is thick and ornamented. Occasionally there is a small antapical horn. The epi- and hypocyst are divided by a narrow (often not visible or difficult to see) paracingulum. There is no discernible paratabulation. The archaeopyle is precingular.

Apteodinium granulatum Eisenack, 1958

Plate II, Fig. h

1958 *Apteodinium granulatum* Eisenack, p. 386–387, pl. 23, figs. 8–14.

Description: *Apteodinium granulatum* is acavate and roughly spherical in shape with a protruding apical horn. The autophragm is thick and has a scabrate to papillate ornament. The cingulum can be observed by means of parallel ridges partially circling the cyst, with a slight depression in between them. Other than the archaeopyle and the cingulum, paratabulation is not discernible.

Remarks: *Apteodinium granulatum* was originally described from the Aptian of Germany. Jan du Chêne *et al.,* (1986a, p. 46) considered *Apteodinium thelium* to be a taxonomic junior synonym of *Apteodinium granulatum*. However, Lentin and Williams (1989, p.21) retained *Apteodinium thelium* as a separate species.

Size: Intermediate.

Occurrence: DC353, not present; VK117, 16140–16170ft. to, 18240–18270ft. (Barremian–Hauterivian); CH265, not present.

Apteodinium maculatum Eisenack and Cookson, 1960

PLATE II, Fig. i

1960 *Apteodinium maculatum* Eisenack and Cookson, p. 4–5 pl. 2, figs. 1–3.

1988 *Cribroperidinium conjunctum* (Eisenack and Cookson, 1960) Backhouse, p. 74.

Description: *Apteodinium maculatum* is acavate and rounded to slightly elongate in outline. It has a thick autophragm with a granular to spongy appearance, with a short apical horn. The only evidence of paratabulation is from the precingular archeopyle.

Remarks: This species was originally described from the Aptian–Albian of Australia. Backhouse (1988, p. 74) considered *Cribroperidinium conjunctum* to be a taxonomic junior synonym.

Size: Intermediate.

DC353, not present; VK117, 15240–15270ft. to 17070–17100ft. (Aptian–Barremian) with caving at 18990–19020ft. (Valanginian); CH265, not present.

Genus *CRIBPROPERIDINIUM* Neale and Sarjeant, 1962

Plate II, Fig. p

1962 *Cribroperidinium* Neale and Sarjeant, p. 443.

TYPE: Neale and Sarjeant, 1962, p. 443–444, pl. 19, fig. 4; text-fig. 3a–b, as *Cribroperidinium sepimentum*.

SYNOPSIS: The genus *Cribroperidinium* consists of intermediate to large, proximate, acavate cysts with a subcircular to ovoidal outline and a wide-based apical horn. The autophragm is variably ornamented. The paratabulation is indicated by parasutural crests. The archaeopyle is precingular.

Specimens which cannot be assigned to a species, but belong to *Cribroperidinium* synopsis are classified as *Cribroperidinium spp.*

Cribroperidinium boreas (Davey, 1974) Helenes, 1984

Plate II, Fig. j

1974 *Gonyaulacysta boreas* Davey, p. 52–53, pl. 4, figs. 1–4; pl. 7, fig. 5.

1978 *Millioudodinium*? *boreas* (Davey, 1974) Stover and Evitt, p. 174.

1984 *Cribroperidinium boreas* (Davey, 1974) Helenes, p. 121.

Description: *Cribroperidinium boreas* is a proximate, acavate, ovoidal cyst, with an apical horn. Its autophragm has fibrous intratabular ornament surrounded by striate parasutural ridges. The sutural ridges are well developed, and even more pronounced around the cingulum. These ridges reflect a gonyaulacoid (cribroperidinioid) tabulation. *Cribroperidinium boreas* has a precingular archaeopyle formed by the detachment of the 3’’ plate.

Remarks: This species was initially described from the Late Barremian of East Yorkshire.

Size: Intermediate.

Occurrence: DC353, 17720–17780ft. to 20120–20180ft. (Aptian–Hauterivian); VK117, 13770–13800ft. to 19800–19830ft. (Aptain–Berriasian) with caving at 22890–22900ft. (Kimmeridgian); CH265, 10250–10260ft. (Aptian).

Cribroperidinium confossum (Duxbury, 1977) Helenes, 1984

Plate II, Fig. k

1977 *Gonyaulacysta confossa* Duxbury, p. 33, pl. 2, figs. 2–4.

1982b *Millioudodinium confossum* (Duxbury, 1977) Sarjeant, p.39

1984 *Cribroperidinium confossum* (Duxbury, 1977) Helenes, p. 128.

Description: *Cribroperidinium confossum* are ovoidal, acavate, proximate cysts. Its apical horn is approximately equal in length to that of the epicyst. The autophragm is densely granular, and the paratabulation is indicated by parasutural ridges. The archaeopyle is precingular, formed through the loss of the 3'' plate.

Remarks: *Cribroperidinium confossum* was originally described from the Late Hauterivian from East Yorkshire. Helenes (1984, p. 128) questioned this species assignment due to its similarity to *Gonyaulacysta*. However, Jan du Chêne *et al.,* (1986a, p. 77) included it in *Cribroperidinium* without question.

Size: Intermediate to large.

Occurrence: DC353, 20840–20900ft. (Valanginian); VK117, 14370–14400ft. to 19410–19440ft.(Aptian–Berriasian); CH265, not present.

Cribroperidinium exilicristatum (Davey, 1969a) Stover and Evitt, 1978

Plate II, Fig. l

1969a *Gonyaulacysta exilicristata* Davey, p. 121, pl. 1, figs. 1–2; text-figs. 9A–B.

1978 *Cribroperidinium exilicristatum* (Davey, 1969a) Stover and Evitt, p. 150.

Description: *Cribroperidinium exilicristatum* is a proximate, acavate, subspherical cyst with an apical horn. Its autophragm is thick and densely granular. The gonyaulacoid tabulation is poorly defined by weak ridges, which occasionally form small spines at plate junctions. The cingulum is weakly developed but visible. The archaeopyle is precingular, formed through loss of the 3’’ plate.

Remarks: *Cribroperidinium exilicristatum* was originally described from the Cenomanian.

Size: Intermediate.

Occurrence: DC353, 18440–18500ft. (Barremian); VK117, 13770–13800ft. to 17940–17970ft. (Aptian–Hauterivian); CH265, 10250–10260ft. (Aptian).

Cribroperidinium orthoceras (Eisenack, 1958) Davey, 1969a

Plate II, Fig. m

1958 *Gonyaulax orthoceras* Eisenack, p. 388, pl. 21, figs. 3–11; pl. 24, fig. 1.

1966b *Gonyaulacysta orthoceras* (Eisenack, 1958) Sarjeant, p. 121.

1969a *Cribroperidinium orthoceras* (Eisenack, 1958) Davey, p.128–129.

Description: *Cribroperidinium orthoceras* is a proximate, acavate subspherical to ovoidal cyst. It has a thick granular autophragm and a long apical horn that is approximately one quarter of the cyst-length. The gonyaulacoid tabulation, including the cingulum, is marked by spiny interlocking crests. The archaeopyle is precingular, formed through detachment of the 3’’ plate.

Remarks: *Cribroperidinium orthoceras* was initially described from the Aptian of Germany. Jan du Chêne *et al.,* (1986a, p. 80) questioned the assignment of this species to *Cribroperidinium*, but Sarjeant (1985a, p. 49) retained it in the genus without question. Davey and Verdier (1971, p. 17) considered *Gonyaulax* (as *Cribroperidinium*) *edwardsii* to be a taxonomic senior synonym. However, Below (1981, p. 39–40) and Lentin and Williams (1985, p.79) retained the two species separately.

Size: Intermediate.

Occurrence: DC353, not present; VK117, not present; CH265, 10250–10260ft. (Aptian).

Cribroperidinium? _gigas_ (Raynaud, 1978) Helenes, 1984

Plate II, Fig. n

1978 *Gonyaulacysta gigas* Raynaud, p. 392–393, pl. 2, fig. 16.

1981 *Millioudodinium gigas* (Raynaud, 1978) Lentin and Williams, p. 190.

1984 *Cribroperidinium*? *gigas* (Raynaud, 1978) Helenes, p. 128.

Description: *Cribroperidinium*? *gigas* is a large subspherical to ovoidal, proximate, acavate cyst. It has a thick granular autophragm, with a very long 'antenna-like' apical horn. Although Bailey (1993) suggested that the tabulation should be marked by thick crests, they are poorly defined on specimens recovered from the EGoM. The archaeopyle is precingular, with the removal of the 3'' plate.

Remarks: This species was initially described from the Late Kimmeridgian–Portlandian of northern Europe. Helenes (1984, p. 128) questioned this species assignment due to the similarity in shape to *Cribroperidinium intricatum*.

Size: Large.

Occurrence: DC353, 21980–22040ft. to 22860–22920ft. (Tithonian–Kimmeridgian); VK117, not present; CH265, not present.

Cribroperidinium? _tenuiceras_ (Eisenack, 1958) Poulsen, 1996

Plate II, Fig. o

1958 *Gonyaulax tenuiceras* Eisenack, p. 389–391, pl. 21, figs. 14–15; pl. 22, figs. 1–3; pl. 24, fig. 2; text-figs. 4a–c, 5.

1969 *Gonyaulacysta tenuiceras* (Eisenack1958) Sarjeant, p. 11.

1978 *Diacanthum tenuiceras* (Eisenack, 1958) Stover and Evitt, p. 152.

1981 *Occisucysta tenuiceras* (Eisenack, 1958) Below, p.63.

1985a *Acanthaulax tenuiceras* (Eisenack, 1958) Sarjeant, p. 63.

1986b *Tehamadinium tenuiceras* (Eisenack, 1958) Jan du Chêne *et al.,* p. 32.

1996 *Cribroperidinium*? *tenuiceras* (Eisenack, 1958) Poulsen, p. 78.

Description: *Cribroperidinium*? *tenuiceras* is a proximate, acavate cyst with an ovoidal outline. It has a short apical horn, and its autophragm is echinate. The gonyaulacoid tabulation is outlined by crests, which have slightly larger spines. The archaeopyle is precingular, formed through detachment of the 3'' plate.

Remarks: *Cribroperidinium*? *tenuiceras* was first described form the Late Barremian–Aptian of Germany. Poulsen (1996, p. 78) questioned the assignment of this species. Pöthe de Baldis and Ramos (1988, p. 33) considered *Occisucysta victorii* to be a taxonomic junior synonym of *Cribroperidinium*? *tenuiceras*.

Size: Intermediate.

Occurrence: DC353, 18560–18620ft.to 19400–19460ft. (Barremian); VK117, 17340–17370ft. (Barremian); CH265, not present.

Genus *FLORENTINIA* Davey and Verdier, 1973

1973 *Florentinia* Davey and Verdier, p. 185–186.

TYPE: Davey and Verdier, 1973, p. 186–187, pl. 2, figs. 1, 3–4, 6–7, 9, as *Florentinia laciniata*.

SYNOPSIS: The genus *Florentinia* is comprised of intermediate to large, chorate cysts. They are subspherical to subovoidal, with one intratabular process per plate. The processes are hollow and open at the distal end. The pre- and postcingular processes are large (proximally wide and distally an open funnel of number of tubules), the apical processes are slightly smaller. The antapical process is the largest. The paracingular and parasulcal processes are much narrower. The archaeopyle is precingular.

Florentinia buspina (Davey and Verdier, 1976) Duxbury, 1980

Plate II, Fig. q

1976 *Silicisphaera buspina* Davey and Verdier, p. 321–322, pl. 2, figs. 1–6; text-fig. 3

1980 *Florentinia buspina* (Davey and Verdier, 1976) Duxbury, p. 121.

Description: This species comprises intermediate, chorate, acavate cyst, with a subspherical central body. The endophragm is granular, while the periphragm pulls away from the endophragm to produce processes that vary in width but are approximately equal in length. The processes are weakly striate and wide at their base; distal endings vary greatly, from acuminate, bifurcate to trifurcating tips, to more complex large processes. These large complex processes represent the postcingular plates. The archaeopyle is precingular, formed through the loss of the 3'' plate.

Remarks: *Florentinia buspina* was originally described from the Santonian of France

Size: Intermediate.

Occurrence: DC353, 17780–17840ft. to 17840–17900ft. (Aptian); VK117, 15360–15390ft. (Aptian); CH265, 10250–10260ft. (Aptian).

Florentinia deanei (Davey and Williams, 1966a) Davey and Verdier, 1973

Plate II, Fig. r

1966a *Hystrichosphaeridium deanei* Davey and Williams, p. 58–59, pl. 6, figs. 4,8.

1973 *Florentinia deanei* (Davey and Williams, 1966a) Davey and Verdier, p. 187.

Description: *Florentinia deanei* is a intermediate, chorate, acavate cyst, with a subspherical central body. The endophragm is granular, while the periphragm pulls away from the endophragm to produce one tapering process per plate. Each process is weakly striate along its length, and may have either an entire or denticulate distal margin. The precingular processes are similar to the apical processes, but slightly shorter, while the processes in the cingular region are more slender. The largest processes are in the hypocyst and are more subconical in appearance. The archaeopyle is precingular, by the loss of the 3'' plate.

Remarks: This species was originally described from the Cenomanian of southern England. Davey and Verdier (1976, p. 316) considered that *Florentinia deanei* could be a taxonomic synonym of the Eocene species *Hystrichokolpoma unispinum*, with the type material of the latter species being possibly reworked from the Cretaceous.

Size: Intermediate.

Occurrence: DC353, 17660–17720ft. to 17960–18020ft. (Albian–Aptain) with caving at 19520–19580ft. (Hauterivian); VK117, 14940–14970ft. (Aptian); CH265, not present.

Subfamily GONYAULACOIDEAE (Autonym)

Genus *ACHOMOSPHAERA* Evitt, 1963

1963 *Achomosphaera* Evitt, p. 163.

TYPE: Deflandre, 1937, p. 74, pl. 14 (al. pl. 11), figs. 5–6; pl. 17 (al. pl. 14), fig. 10, as *Hystrichosphaeridium ramuliferum.*

SYNOPSIS: The genus *Achomosphaera* comprises intermediate, chorate cysts. They have a subspherical to ovoidal central body. The walls are closely appressed to one another, except when the periphragm rises up to form parasutural processes, which bifurcate and trifurcate distally. The processes are not connected proximally or distally. The archaeopyle is precingular.

Achomosphaera neptuni (Eisenack, 1958) Davey and Williams, 1966b

Plate II, Fig. s

1958 *Baltisphaeridium neptuni* Eisenack, p. 399, pl. 26, figs. 7–8.

1983 *Spiniferites neptuni* (Eisenack, 1958) Duxbury, p. 55.

1985a *Florentinia*? *neptuni* (Eisenack, 1958) Sarjeant, p. 89–90, 92.

1966b *Achomosphaera neptuni* (Eisenack, 1958) Davey and Williams, p. 51–52.

Description: *Achomosphaera neptuni* are intermediate, chorate cysts, with a spheroidal to ovoidal central body. The psilate to microgranulate cyst wall is comprised of two layers that are in very close proximity to one another, except when the periphragm pulls away from the endophragm to form the processes and pericoels. The processes are parasutural and have have bifurcating and trifurcating distal terminations; they do not interconnect. *Achomosphaera neptuni* has a precingular archeopyle.

Size: Intermediate.

Occurrence: DC353, 17720–17780ft. to 21800–21860ft. (Aptian–Berriasian); VK117, 13770–13800ft. to 18540–18570ft. (Aptian–Hauterivian); CH265, 9700–9710ft. to 10800–10810ft. (Aptian – Barremian).

Genus *EXIGUISPHAERA* Duxbury, 1979a

1979a *Exiguisphaera* Duxbury, p. 198–199

TYPE: Duxbury, 1979a, p. 199, pl. 2, figs. 2–3, 5; text-figs. 1A–B, 2, as *Exiguisphaera phragma*

SYNOPSIS: The genus *Exiguisphaera* consists of small to intermediate, proximochorate, acavate cysts. They have a subspherical central body. The autophragm is finely perforated. The paratabulation is outlined by rows of short simple spines distally connected by trabeculae, which gives each crest a 'fence-like appearance'. Intratabular projections may also be present. The archaeopyle is precingular, formed by the detachment of the 3'' and 4'' plates.

Exiguisphaera plectilis Duxbury, 1980

Plate II, Fig. t

1980 *Exiguisphaera plectilis* Duxbury, p. 118–119, pl. 3, figs. 5, 8, 11.

Description: *Exiguisphaera plectilis* is a proximochorate, acavate, subspherical cyst. Its autophragm is shagreenate to granular, and is surmounted by intratabular projections. The projections are thin, with various distal terminations that may connect to form crests. The tabulation is undiscernible. The archaeopyle is precingular (2P).

Remarks: *Exiguisphaera plectilis* was initially described from the Middle Barremian of East Yorkshire.

Size: Intermediate.

Occurrence: DC353, not present; VK117, 16770–16800ft. (Barremian); CH265, not present.

Genus *IMPAGIDINIUM* Stover and Evitt, 1978

1978 *Impagidinium* Stover and Evitt, p. 165–166.

TYPE: Cookson and Eisenack, 1965a, p. 122–123, pl. 12, figs. 5–7, as *Leptodinium dispertitum*.

SYNOPSIS: The genus *Impagidinium* comprises small to intermediate, proximochorate, acavate cysts. The cyst is subspherical to ovoidal, typically with no apical prominence. The autophragm is finely ornamented. The gonyaulacacean 'S-type' paratabulation is outlined by parasutural septa. The archaeopyle is precingular.

Impagidinium alectrolophum (Sarjeant, 1966b) Stover and Evitt, 1978

Plate III, Fig. a

1966b *Leptodinium alectrolophum* Sarjeant, p. 134–135, pl. 15, figs. 3–6; text-fig. 34.

1978 *Impagidinium alectrolophum* (Sarjeant, 1966b) Stover and Evitt, p. 165. Retained in *Impagidinium* by Lentin and Williams (1985, p. 194).

1982b *Pterodinium alectrolophum* (Sarjeant, 1966b) Below, p. 352–353.

Description: *Impagidinium alectrolophum* is a small to intermediate, acavate cyst. It has a rounded subpolygonal to elongate outline, without an apical horn. The autophragm is psilate to shagreenate in intratabular regions. However, the parasutures are marked by crests with entire margins. The crests make the gonyaulacoid 'S-type' paratabulation easy to observe. The archaeopyle is precingular, with a detached operculum.

Remarks: This species was first recorded from the Middle Barremian of Yorkshire, England.

Size: Small to intermediate.

Occurrence: DC353, 17760–17720ft. to 22100–22160ft. (Albian–Tithonian); VK117, 13770–13800ft. to 19800–19830ft. (Aptian–Berriasian); CH265, 7750–7760ft. to 11600–11610ft. (Aptian–Valanginian).

Genus *SPINIFERITES* Mantell, 1850

1850 *Spiniferites* Mantell, p. 191.

TYPE: Ehrenberg, 1838, pl. 1, figs. 1–2, 5, as *Xanthidium ramosum,* designated by Davey and Williams (1966b, p. 32) as a lectotype of *Hystrichosphaera ramosa*.

SYNOPSIS: The genus *Spiniferites* comprises small to intermediate, proximochorate to chorate cysts with a subspherical to subovoidal central body. The finely ornamented endophragm and periphragm are appressed except where gonal and sutural processes arise; the processes are joined proximally by parasutural ridges. The sutural processes usually bifurcate and the gonal processes trifurcate distally. The archaeopyle is precingular.

Spiniferites dentatus (Gocht, 1959) Lentin and Williams, 1973

Plate III, Fig. b

1959 *Hystrichosphaera*? *dentata* Gocht, p. 75–76, pl. 4, fig. 11; pl. 7, fig. 19.

1973 *Spiniferites*? *dentatus* (Gocht, 1959) Lentin and Williams, p. 128.

1977 *Spiniferites dentatus* (Gocht, 1959) Duxbury, p. 49.

Description: *Spiniferites dentatus* are intermediate, proximate, suturocavate cyst, with a spherical to subhexagonal outline. The psilate to finely granulate endophragm and periphragm are appressed except under parasutural ridges. The parasutural features form a continuous acanthate margin, from which trifurcating gonal spines arise. The archaeopyle is precingular.

Remarks: This species was first described from the Late Hauterivian of Germany.

Size: Intermediate.

Occurrence: DC353, 18260–18320ft. to 20600–20600ft. (Barremian–Valanginian); VK117, 15360–15390ft. to 18540–18570ft. (Barremian–Hauterivian); CH265, 7750–7760ft. to 11600–11610ft. (Aptian–Hauterivian).

Spiniferites fenestratus Duxbury 2001

Plate III, Fig. c

2001 *Spiniferites fenestratus* Duxbury, p. 114–115, fig. 14, nos. 1–6.

Description: *Spiniferites fenestratus* are intermediate, proximochorate, suturocavate cyst, with an oval to subhexagonal outline to the central body. The dense verrucate endophragm and periphragm are appressed except under the generally high parasutural crests, which have entire and fenestrate margins. Short, gonal trifurcating and intergonal bifurcating processes extend beyond the crests. The archaeopyle is precingular.

Remarks: This species was first recorded form the Late Hauterivian–Middle Barremian of the Central North Sea.

Size: Intermediate.

Occurrence: DC353, not present; VK117, 13770–13800ft. (Aptian); CH265, 10250–10260ft. (Aptian).

Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854

Plate III, Fig. d

1838 *Xanthidium ramosum* Ehrenberg, pl. 1, figs. 1–2, 5.

1838 *Xanthidium furcatum* Ehrenberg, pl. 1, figs. 12, 14.

1854 *Spiniferites ramosus* (Ehrenberg, 1838) Mantell, p.239. Retained by Sarjeant (1970, p. 75).

1895 *Geodia*? *tripunctata* Merrill, p. 16; text-fig. 15.

1937 *Hystrichosphaera ramose* (Ehrenberg, 1838) Deflandre, p. 64.

1938 *Bion ramosum* (Ehrenberg, 1838) Eisenack, p. 243 (caption to pl.16, fig.5).

1959 *Areoligera birama* Maier, p. 304, pl. 29, fig. 2.

1959 *Galea korykos* Maier, p. 310–311, pl. 30, figs .7–8.

1959 *Hystrichosphaeridium echinoides* Maier, p. 318–319, pl. 32, figs. 5–6.

1981 *Homotryblium distinctum* Salujha and Kindra, p. 51, pl. 2, fig. 45–46.

Description: *Spiniferites ramosus* are intermediate, chorate, suturocavate cyst, with a spherical to subhexagonal outline. The psilate to finely granulate endophragm and periphragm are appressed except under the parasutural ridges. The parasutural boundaries have entire margins, with gonal trifurcating and intergonal bifurcating processes. The archaeopyle is precingular.

Remarks: Ehrenberg (1838) did not designate a holotype, so a lectotype (Ehrenberg, 1838, pl.1, fig.5) was selected by Davey and Williams (1966b, p.32). *Spiniferites ramosus* was originally described from the Late Cretaceous of Hungary.

Size: Intermediate.

Occurrence: DC353, abundant between 17600–17660ft. to 20000–20060ft. (Aptian–Hauterivian) but also present in smaple 20840–20900ft. (Valanginian); VK117, 12600–12630ft. to 18540–18570ft. (Aptian–Hauterivian); CH265, abundant between 7750–7760ft. to 11250–11260ft. (Aptian–Hauterivian) but also present in sample 11600–11610ft. (Valanginian).

Genus *TUBOTUBERELLA* Vozzhennikova, 1967

1967 *Tubotuberella* Vozzhennikova, p. 179–180

TYPE: Vozzhennikova, 1967, pl. 101, figs. 2a–b; pl. 104, fig. 2, as *Tubotuberella rhombiformis*.

SYNOPSIS: The genus *Tubotuberella* comprises intermediate to large, proximate, bicavate cysts. They have an elongate ovoidal outline, with or without an apical horn. The hypocyst has a prominent pericoel, which is quadrate in outline and is open distally. The finely ornamented endophragm and periphragm are appressed except at the poles. The gonyaulacacean paratabulation is outlined by parasutural ridges or septa that have variable margins. The archaeopyle is precingular.

Tubotuberella apatela (Cookson and Eisenack, 1960) Ioannides *et al.,* 1977

Plate III, Fig. e

1960 *Scriniodinium apatelum* Cookson and Eisenack, p. 249, pl. 37, figs. 12–13.

1969 *Psaligonyaulax apatela* (Cookson and Eisenack, 1960) Sarjeant, p. 15.

1977 *Tubotuberella apatela* (Cookson and Eisenack, 1960) Ioannides *et al.,* p. 464. Retained by Sarjeant (1982b, p. 41).

1977 *Glabridinium apatelum* (Cookson and Eisenack, 1960) Brideaux, p. 35.

Description: *Tubotuberella apatela* are intermediate to large, proximate, bicavate cysts, with an elongated subpentagonal outline. The shagreenate periphragm detaches from the psilate endophragm in the apical and antapical regions, to form a blunt apical horn and a truncated open ended antapical horn. Faint parasutural ridges are developed on the periphragm. The archaeopyle is precingular.

Remarks: This species was first described from the Late Jurassic of Western Australia.

Size: Intermediate to large.

Occurrence: DC353, 21980–22040ft. to 23760–23820ft. (Tithonian–Oxfordian); VK117, not present; CH265, not present.

Subfamily LEPTODINIOIDEAE Fensome *et al.,* 1993

Genus *CTENIDODINIUM* Deflandre, 1939

1939 *Ctenidodinium* Deflandre, p. 181.

TYPE: Eisenack, 1935, pl. 4, fig. 9, as *Lithodinia jurassica* var. *ornata*.

SYNOPSIS: The genus *Ctenidodinium* consists of intermediate, proximochorate cysts that are ellipsoidal to subspherical, with no apical horn. The finely ornamented endophragm and periphragm are appressed except where the gonyaulacacean paratabulation is outlined by parasutural rows of isolated or proximally linked spines or by parasutural ridges with denticulate to spinate margins. This paratabulation reveals the presenece of anterior intercalary paraplates, as well as one or two preapical paraplates located at the apex, thus separating the 2’ and 4’ apical paraplates. The archaeopyle is epicystal.

Ctenidodinium elegantulum Millioud, 1969

Plate III, Fig. f

1969 *Ctenidodinum elegantum* Millioud, p. 427, pl. 2, figs. 1–3.

Description: *Ctenidodinum elegantum* are acavate, proximochorate cysts, which have a rounded pentagonal outline. The thin and shagreenate endophragm and periphragm are appressed except where the paratabulation is outlined by parasutural ridges of thin solid acicular spines (2–3µm in length). The archaeopyle is epicystal.

Remarks: This species was first described from the Late Hauterivian–Barremian from Western Europe.

Size: Intermediate.

Occurrence: DC353, 19700–19760ft. (Hauterivian); VK117, 15540–15570ft. to 18540–18570ft. (Barremian–Hauterivian) with caving at 19800–19830ft. (Berriasian); CH265, not present.

Genus *DICHADOGONYAULAX* Sarjeant, 1966b

1966b *Dichadogonyaulax* Sarjeant, p. 153.

TYPE: Norris, 1965b, figs.8–9, as *Gonyaulax culmula*.

SYNOPSIS: The genus *Dichadogonyaulax* consists of intermediate, proximochorate cysts. They are subspherical, with no apical horn. The autophragm is finely ornamented, and the gonyaulacacean paratabulation is indicated by parasutural crests, ridges or rows of isolated or proximally linked spines. This paratabulation reveals the absence of anterior intercalary paraplates, as well as the preapical paraplates being displaced posteroventrally, thus allowing contact between the 2’ and 4’ apical paraplates. The archaeopyle is epicystal.

Dichadogonyaulax irregularis Benson, 1985

Plate III, Fig. g

1985 *Dichadogonyaulax irregularis* Benson, p. 154, pl. 2, figs. 5–12.

Description: *Dichadogonyaulax irregularis* are acavate, proximate cysts, subspherical in shape and lacking an apical horn. The autophragm is thin and shagreenate. The tabulation is revealed by low parasutural crests that are ornamented with acuminate spines. The archaeopyle is epicystal.

Remarks: This species was first described from the Berriasian–Hauterivian (Neocomian) of the USA.

Size: Intermediate.

Occurrence: DC353, 17780–17840ft. to 22800–22860ft. (Aptian–Tithonian); VK117, 15840–15870ft. to 22890–22900ft. (Barremian–Kimmeridgian); CH265, 11250–11260ft. (Hauterivian).

Dichadogonyaulax*? *pannea (Norris, 1965b) Sarjeant, 1969

Plate III, Fig. h

1965b *Leptodinium panneum* Norris, p. 796–798, figs. 3, 10–13.

1969 *Dichadogonyaulax pannea* (Norris, 1965b) Sarjeant, p. 14. Retained by Benson (1985, p. 152).

1973 *Ctenidodinium panneum* (Norris, 1965b) Lentin and Williams, p. 36.

1987a *Dichadogonyaulax*? *pannea* (Norris, 1965b, Sarjeant, 1969, Benson, 1985) Questionable assignment by Riding, p. 260.

Description: *Dichadogonyaulax pannea* are acavate, proximate cysts, subspherical in shape and lacking an apical horn. The autophragm is thin and shagreenate to granular. The tabulation is revealed by low parasutural crests that are ornamented with thin spines, which may be simple, but more commonly branched or bifurcate. The archaeopyle is epicystal.

Remarks: *Dichadogonyaulax pannea* was retained by Benson (1985, p. 152) and has since been questionably assigned to *Dichadogonyaulax*? by Riding (1987, p. 260). Although Riding (1987) agreed with Benson over the assignment to *Dichadogonyaulax*, Riding (1987) clarified that Benson (1985) failed to demonstrate that *Dichadogonyaulax pannea* has a single preapical paraplate, which when displaced posteroventrally results in contact between the 2' and 4' plates, as well as lacking anterior intercalary plates. As such this species has been given a questionable assignment.

Size: Intermediate.

Occurrence: DC353, 22160–22220ft. (Tithonian); VK117, 19800–19830ft. to 22790–22800ft. (Berriasian–Tithonian); CH265, not present.

Genus *DUROTRIGIA* Bailey, 1987

1987 *Durotrigia* Bailey, p. 89, 91, 94.

TYPE: Bailey, 1987, pl. 2, figs. 1, 4, 9, as *Durotrigia daveyi*.

SYNOPSIS: The genus *Durotrigia* consists of intermediate, proximochorate cysts. They are subspherical in shape. The autophragm is finely ornamented, and the gonyaulacacean paratabulation is indicated by parasutural ridges or crests surmounted by isolated spines. The archaeopyle is formed by the loss of one to five precingular plates.

Durotrigia aspera Bailey and Partington, 1991

Plate III, Fig. i

1991 *Durotrigia aspera* Bailey and Partington, p. 246, 248, pl. 2, figs. 1–6, 9.

Description: *Durotrigia aspera* are intermediate, proximate, acavate cysts with a rounded to subhexagonal outline. The autophragm is densely granulate to semi-reticulate. The gonyaulacoid paratabulation is reflected by irregular ridges. The archaeopyle is composed of a variable number of precingular paraplates.

Remarks: This species was first described from the Bathonian of the northern North Sea.

Size: Intermediate.

Occurrence: DC353, 22800–22860ft. to 23700–23760ft. (Kimmeridgian); VK117, not present; CH265, not present.

Genus *EGMONTODINIUM* Gitmez and Sarjeant, 1972

1972 *Egmontodinium* Gitmez and Sarjeant, p. 228–229.

TYPE: Gitmez and Sarjeant, 1972, p. 229–231, pl. 8, figs. 1–4; pl. 9, fig. 3; pl. 11, figs. 5–6, 8; text-figs. 24A–D, as *Egmontodinium polyplacophorum.*

SYNOPSIS: The genus *Egmontodinium* consists of intermediate, proximochorate cysts. They have an elongate oval outline. The autophragm is finely ornamented, with nontabular projections that may line up in vertical rows. The paratabulation is indicated by parasutural ridges. The archaeopyle is apical.

Egmontodinium toryna Cookson and Eisenack, 1960

Plate III, Fig. j

1960 *Hystrichosphaeridium toryna* Cookson and Eisenack, p. 252, pl. 38, figs. 6, 15.

1972 *Prolixosphaeridium*? *toryna* (Cookson and Eisenack, 1960) Eisenack and Kjellström, p. 951.

1978 *Tanyosphaeridium toryna* (Cookson and Eisenack, 1960) Stover and Evitt, p.85.

1979c *Egmontodinium toryna* (Cookson and Eisenack, 1960) Davey, p.60.

Description: *Egmontodinium toryna* is a proximochorate, acavate, rounded elongate cyst. It has a shagreenate autophragm surmounted by intratabular projections. The projections are short and variable in shape and size; They are either thin and distally capitate or wider and terminally branched. There is no discernible paratabulation, and the archaeopyle is apical.

Remarks: This species was initially described from the Tithonian–Hauterivian (Neocomian) of Australia and New Guinea.

Size: Intermediate .

Occurrence: DC353, 17720–17780ft. to 20600–20600ft. (Aptian–Valanginian); VK117, 12600–12630ft. (Albian); CH265, not present.

Genus *GONYAULACYSTA* Deflandre, 1964

1964 *Gonyaulacysta* Deflandre, p. 5030.

TYPE: Deflandre, 1939, pl. 6, figs. 2–3; text-figs. 1–2, as *Gonyaulax jurassica*.

SYNOPSIS: The genus *Gonyaulacysta* comprises intermediate to large, ovoidal to subspherical, proximate cysts with an apical horn. The finely ornamented endophragm is surrounded by an elongated subpolygonal periphragm. Parasutural ridges indicate a gonyaulacacean paratabulation; the ridges have denticulate to spinulate margins. The archaeopyle is precingular.

Gonyaulacysta jurassica (Deflandre, 1939) Norris and Sarjeant, 1965

Plate III, Fig. k

1939 *Gonyaulacysta jurassica* Deflandre, p. 168, pl. 6, figs. 2–5; text-figs. 1–2.

1965 *Gonyaulacysta jurassica* (Deflandre, 1939) Norris and Sarjeant, p. 65.

Description: *Gonyaulacysta jurassica* are intermediate to large, proximate, epicavate dinoflagellate cysts. It has a rounded subpolygonal to elongate outline, with an apical horn. In the central region the psilate to shagrenate endophragm and periphragm are in close contact with one another. However, in the apical region the periphragm pulls away from the endophragm to produce the apical horn. The gonyaulacoid paratabulation can be observed by smooth undulating to denticulate parasutural crests, revealing the paracingulum and the S-type ventral organisation. The archaeopyle is precingular (type P), involving the 3’’ plate; the operculum is detached.

Remarks: This species was first described from the Oxfordian of southern France. Sarjeant (1982b, p. 29) considered *Psaligonyaulax* (as and now *Gonyaulacysta*) *dualis* to be a taxonomic junior synonym. However, Jan du Chêne *et al.,* (1986a, p. 131) and Górka (1965, p. 298) retained *Gonyaulacysta dualis*.

Size: Intermediate to large.

Occurrence: DC353, to 22800–22860ft. to 23340–23400ft. (Oxfordian) with reworking between 20840–20900ft. to 22760–22820ft. (Valanginian–Kimmeridgian); VK117, 22590–22600ft. (Tithonian) considered reworked; CH265, not present.

Gonyaulacysta*? *kleithria Duxbury, 1983

Plate III, Fig. l

1983 *Gonyaulacysta*? *kleithria* Duxbury, p. 47–48, pl. 5, figs. 1–2; text-fig. 22.

Description: This species contains intermediate, proximate, epicavate dinoflagellate cysts. It has a rounded subpolygonal to elongate outline, with an apical horn. Over most of the cyst, the psilate to shagrenate endophragm and periphragm are in close contact. However, in the apical region the periphragm pulls away from the endophragm to produce an apical horn. The gonyaulacoid paratabulation can be observed by smooth loricate to denticulate parasutural crests, revealing the paracingulum and the S-type ventral organisation. The archaeopyle is precingular (type P), involving the 3’’ plate; with a operculum.

Remarks: *Gonyaulacysta*? *kleithria* was initially described from the Early Aptian of southern England.

Size: Intermediate.

Occurrence: DC353, not present; VK117, 13770–13800ft. to 20080–20090ft. (Aptian–Berriasian); CH265, 9640–9650ft. to 11600–11610ft. (Aptian–Hauterivian).

Genus *KLEITHRIASPHAERIDIUM* Davey, 1974

1974 *Kleithriasphaeridium* Davey, p. 55–56.

TYPE: Davey, 1974, p. 56–57, pl. 5, figs. 1–5; text-fig. 3, as *Kleithriasphaeridium corrugatum.*

SYNOPSIS: The genus *Kleithriasphaeridium* is composed of intermediate to large, proximate cysts, with a subspherical outline. The endophragm is surrounded by the periphragm, from which hollow, intratabular processes arise. The paratabulation is indicated by the position of the processes. The archaeopyle is precingular.

Kleithriasphaeridium corrugatum Davey, 1974

Plate III, Fig. m

1974 *Kleithriasphaeridium corrugatum* Davey, p. 56–57, pl. 5, figs. 1–5; text-fig. 3.

Description: This intermediate, chorate cyst has a spherical central body. The endophragm is densely granular, while the periphragm is rugulate. The rugulation is more apparent on the processes, making them appear corrugated. The processes vary in both length and width, distally expanding toward a secate or denticulate margin. Paratabulation can be inferred by the position of the processes. The archaeopyle is precingular.

Remarks: *Kleithriasphaeridium corrugatum* was first described from the Early Barremian of Yorkshire, United Kingdom.

Size: Intermediate.

Occurrence: DC353, 19520–19580ft. to 19760–19820ft. (Hauterivian); VK117, 14490–14520ft. to 18540–18570ft. (Aptian–Hauterivian) with caving at 20880–20890ft. (Tithonian); CH265, not present.

Kleithriasphaeridium eoinodes (Eisenack, 1958) Davey, 1974

Plate III, Fig. n

1958 *Hystrichosphaeridium eoinodes* Eisenack, p. 402, pl. 27, figs. 3–4.

1963 *Cordosphaeridium eoinodes* (Eisenack, 1958) Sarjeant, p. 74–75.

1974 *Kleithriasphaeridium eoinodes* (Eisenack, 1958) Davey, p. 58.

Description: *Kleithriasphaeridium eoinodes* are intermediate, chorate cysts. The main body has a spherical outline. The endophragm is shagreenate, as is the adjoining periphragm. The periphragm pulls away from the endophragm to produce intrabular processes. The processes vary in both length and width, being particularly narrow around the sulcal region. They expand distally, terminating in a denticulate margin. Paratabulation can be inferred by the position of the processes. The archaeopyle is precingular.

Remarks: *Kleithriasphaeridium simplicispinum* is considered to be a taxonomic junior synonym: according to Below (1982a, p. 17). *Kleithriasphaeridium eoinodes* was originally recorded from the Late Aptian of Germany.

Size: Intermediate.

Occurrence: DC353, 17720–17780ft. to 19580–19640ft. (Aptian–Hauterivian); VK117, 13770–13800ft. to 19410–19440ft. (Aptian–Barremian) with caving at 23990–24000ft. (Undifferentiated strata); CH265, 9640–9650ft. to 10800–10810ft. (Aptian–Barremian).

Kleithriasphaeridium loffrense Davey and Verdier, 1976

Plate III, Fig. o

1976 *Kleithriasphaeridium loffrense* Davey and Verdier, p. 310–312, pl. 1, figs. 1–6.

Description: *Kleithriasphaeridium loffrense* are intermediate, chorate cysts. The main body has a spherical outline. The endophragm is psilate to shagreenate. The periphragm pulls away from the endophragm to produce intrabular tubiform processes. The processes are similar in length but vary in width, being particularly narrow around the sulcal region and wide in the postcingular region. They expand distally, terminating in a secate margin. Paratabulation can be inferred by the position of the processes. The archaeopyle is precingular.

Remarks: This species was first described from the Coniacian–Danian of Northern France.

Size: Intermediate.

Occurrence: DC353, 17720–17780ft. (Aptian); VK117, 15540–15570ft. (Barremian); CH265, not present.

Kleithriasphaeridium porosispinum Davey, 1982

Plate III, Fig. p

1982 *Kleithriasphaeridium porosispinum* Davey, p. 29–30, pl. 10, figs. 8–12. Retained by Lentin and Williams (1985, p. 209).

1984 *Tityrosphaeridium porosispinum* (Davey, 1982) Norris and Jux, p. 160.

Description: *Kleithriasphaeridium porosispinum* are intermediate, chorate cysts. The main body has a spherical to ovoidal outline. The endophragm is densely granular, while the periphragm appears to have some reticulation. The periphragm pulls away from the endophragm to produce intratabular tubiform processes. The processes vary in both length and width, being particularly narrow around the parasulcal region and large in the hypocystal region. They expand distally and terminate with a denticulate margin. Paratabulation can be inferred by the position of the processes. The archaeopyle is precingular.

Remarks: This species was originally recorded from the Late Kimmeridgian–Late Ryazanian of Denmark

Size: Intermediate.

Occurrence: DC353, not present; VK117, 23990–24000ft. (Kimmeridgian); CH265, not present.

Genus *LEPTODINIUM* Klement, 1960

1960 *Leptodinium* Klement, p. 45–46.

TYPE: Klement, 1960, p. 46–47, pl. 6, figs. 1–4; text-figs. 23–24, as *Leptodinium subtile.*

SYNOPSIS: The genus *Leptodinium* is composed of intermediate, proximochorate cysts. They have a subpolygonal to ellipsoidal outline, with or without an apical prominence. The finely ornamented endophragm and periphragm are closely appressed. The gonyaulacacean paratabulation is expressed by means of parasutral ridges. The archaeopyle is precingular.

Leptodinium subtile Klement, 1960

Plate III, Fig. q

1960 *Leptodinium subtile* Klement, p. 46–47, pl. 6, figs. 1–4; text-figs. 23–24.

1963 *Gonyaulax freakei* Sarjeant, p. 85–86, pl .1, figs. 1–3.

1969 *Leptodinium freakei* (Sarjeant, 1963) Sarjeant in Davey *et al.,* p. 12.

Description: *Leptodinium subtile* are intermediate, proximate cysts. It has a rounded subpolygonal to elongate outline. Both the endophragm and periphragm are psilate to shagreenate and are closely adjoined. This paratabulation is clearly visible were the parasutral ridges form crests with an entire margin. The archaeopyle is precingular, with the loss of the 3’’ plate.

Remarks: *Leptodinium subtile* was first described from the Early Kimmeridgian of southwestern Germany.

Size: Intermediate.

Occurrence: DC353, 22760–22820ft. (Oxfordian); VK117, not present; CH265, not present.

Genus *LITOSPHAERIDIUM* Davey and Williams, 1966a

1966a *Litosphaeridium* Davey and Williams, p. 79–80.

TYPE: Cookson and Eisenack, 1958, p. 44, pl. 11, fig. 8, as *Hystrichosphaeridium siphoniphorum*.

SYNOPSIS: The genus *Litosphaeridium* is composed of intermediate, chorate cysts, with a subspherical outline. The finely ornamented endophragm and periphragm are closely appressed, except where the periphragm pulls away to produce intratabular, hollow, subconical to cylindrical processes. The processes are intratabular, reflecting a gonyaulacacean paratabulation. The archaeopyle is apical.

Litosphaeridium conispinum Davey and Verdier, 1973

Plate III, Fig. r

1973 *Litosphaeridium conispinum* Davey and Verdier, p. 193–194, pl. 4, figs. 4, 6, 8–9. Retained by Lucas-Clark (1984, p. 187).

1978 *Polysphaeridium*? *conispinum* (Davey and Verdier, 1973) Stover and Evitt, p. 76.

1981 *Dapsilidinium? conispinum* (Davey and Verdier, 1973) Lentin and Williams, p. 69.

Description: *Litosphaeridium conispinum* are intermediate, proximochorate, apiculocavate cyst. The main cyst outline is spherical. The endophragm is finely granulate, while the periphragm is shagreenate. The periphragm detaches from the endophragm to form intratabular processes. The processes are hollow and vary from bulbous, conical to tapering. The distal ends of the processes are truncated. Processes around the paracingulum are generally smaller than those elsewhere. The archaeopyle is apical.

Remarks: This species was originally recorded from the Late Albian of Spain.

Size: Intermediate.

Occurrence: DC353, 17600–17660ft. to 20360–20420ft. (Albian–Hauterivian); VK117, not present; CH265, 8480–8490ft. to 10800–10810ft. (Aptian–Barremian).

Genus *MEIOUROGONYAULAX* Sarjeant, 1966b

1966b *Meiourogonyaulax* Sarjeant, p. 144

TYPE: Valensi, 1953, pl.12, figs. 12–13, as *Gonyaulax sp.*

SYNOPSIS: The genus *Meiourogonyaulax* is composed of composed of intermediate, proximochorate, suturocavate cysts. They have a subspherical to subpolygonal outline. The finely ornamented endophragm and periphragm are closely appressed, except where the periphragm pulls away to produce parasutural ridges, expressing the gonyaulacacean paratabulation. The archaeopyle is apical.

Meiourogonyaulax caytonensis (Sarjeant, 1959) Sarjeant, 1969

Plate III, Fig. s

1959 *Gonyaulax caytonensis* Sarjeant, p. 330–332, pl. 13, fig. 1; text-fig. 1.

1969 *Meiourogonyaulax caytonensis* (Sarjeant, 1959) Sarjeant, p. 14. Retained by Riding and Helby (2001, p. 81, 83).

1976 *Lithodinia caytonensis* (Sarjeant, 1959) Gocht, p. 334.

Description: *Meiourogonyaulax caytonensis* are intermediate, proximate, suturocavate cysts, with a subspolygonal outline. The endophragm and periphragm are psilate to finely granulate and are compressed together in intratabular regions. However, the periphragm rises up at the parasutural boundaries to produce crests, which are either entire or perforated, with an occasional denticle along the margin. The crests make the gonyaulacoid paratabulation easy to observe and the paracingulum and parasulcus distinct. The archaeopyle is apical, with a detached operculum.

Remarks: This species was initially recorded from the Early Callovian of Yorkshire, England.

Size: Intermediate.

Occurrence: DC353, 22760–22820ft. to 23640–23700ft. (Oxfordian–Kimmeridgian); VK117, 22890–22900ft. (Undifferentiated strata); CH265, not present.

Meiourgonyaulax pertusa (Duxbury, 1977) Below, 1981

Plate III, Fig. t

1977 *Lithodinia pertusa* Duxbury, p. 41–43, pl. 8, fig. 5; text-fig. 15.

1981 *Meiourogonyaulax pertusa* (Duxbury, 1977) Below, p. 57.

Description: *Meiourogonyaulax pertusa* are intermediate, proximate, suturocavate cysts, with a subhexagonal outline. The endophragm and periphragm are microperforate and are appressed in intraplate areas. However, the periphragm rises up at the parasutural boundaries to produce crests, which are also perforated. The crests make the gonyaulacoid paratabulation easy to observe and the paracingulum and parasulcus distinct. The archaeopyle is apical, with a detached operculum.

Remarks: This species was first described from Late Berriasian–Early Hauterivian of Yorkshire, England.

Size: Intermediate.

Occurrence: DC353, 18260–18320ft. to 20600–20600ft. (Barremian–Valanginian); VK117, 15360–15390ft. to 18540–18570ft. (Barremian–Hauterivian); CH265, 7750–7760ft. to 11600–11610ft. (Aptian–Valanginian).

Genus *OLIGOSPHAERIDIUM* Davey and Williams, 1966a

Plate IV, Fig. h

1966a *Oligosphaeridium* Davey and Williams, p. 70–71

TYPE: White, 1842, p. 39, pl. 4, fig. 11, as *Xanthidium tubiferum* var. *complex*.

SYNOPSIS: The genus *Oligosphaeridium* is composed of intermediate to large, chorate cysts, with a subspherical outline. The finely ornamented endophragm and periphragm are closely appressed, except where the periphragm pulls away to produce intratabular, hollow processes, which are cylindrical to tubiform and open and generally expanded distally. The gonyaulacacean paratabulation is expressed by means of intratabular processes, except around the paracingulum where processes are absent. The archaeopyle is apical.

Specimens which fit the synopsis, but are unable to be identified to species level are described here as *Oligosphaeridium spp*.; these occur in well DC353 between 18620–18680ft. to 19940–20000ft. (Barremian–Hauterivian).

Oligosphaeridium albertense (Pocock, 1962) Davey and Williams, 1969

Plate IV, Fig. a

1962 *Hystrichosphaeridium albertense* Pocock, p. 82, pl. 15, figs. 226–227.

1962 *Hystrichosphaeridium irregulare* Pocock, p. 82, pl. 15, figs. 228–229

1964 *Hystrichosphaeridium coelenteratum* Tasch in Tasch *et al.,* p. 195, pl. 2, fig. 11.

1964 *Hystrichosphaeridium dispare* Tasch in Tasch *et al.,* p. 195, pl. 2, fig. 8.

1964 *Hystrichosphaeridium reniforme* Tasch in Tasch *et al.,* p. 193, pl. 2, fig. 6.

1969 *Oligosphaeridium albertense* (Pocock, 1962) Davey and Williams, p. 5.

1969 *Oligosphaeridium*? *coelenteratum* (Tasch in Tasch *et al.,* 1964) Davey and Williams, p. 5.

1969 *Oligosphaeridium*? *dispare* (Tasch in Tasch *et al.,* 1964) Davey and Williams, p .5.

1969a *Oligosphaeridium reniforme* (Tasch in Tasch *et al.,* 1964) Davey, p.148.

1969 *Oligosphaeridium irregulare* (Pocock, 1962) Davey and Williams, p. 5.

1978 *Oligosphaeridium irregulare* (Pocock, 1962) Stover and Evitt, p. 68–69.

Description: *Oligosphaeridium albertense* are intermediate to large, chorate cysts, with the main body having a subspherical outline. The endophragm is shagreenate to finely scabrate. The shagreenate periphragm detached from the endophragm to produce 13 processes. Each process is hollow and tubiform in morphology, the distal end flares out to an aculeate, secate or denticulate margin. There is no discernible paratabulation. The archaeopyle is apical, with no evidence of a paracingulum or parasulcus in the specimens preserved.

Remarks: This species was first described from the Barremian of western Canada.

Size: Intermediate to large.

Occurrence: DC353, 17600–17660ft. to 21080–21140ft. (Albian–Valanginian); VK117, 12600–12630ft. to 18990–19020ft. (Albian–Valanginian) with caving at 23990–24000ft. (Undifferentiated strata); CH265, 8480–8490ft. to 11600–11610ft. (Barremian–Valanginian).

Oligosphaeridium complex (White, 1842) Davey and Williams, 1966a

Plate IV, Fig. b

1842 *Xanthidium tubiferum* var. *complex* White, p. 39, pl. 4, fig. 11.

1848 *Xanthidium complex* (White, 1842) Bronn, p. 1375.

1895 *Geodia*? *irregularis* Merrill, p. 16; text-fig. 4.

1940 *Hystrichosphaeridium elegantulum* Lejeune-Carpentier, p. B222; text-figs. 11–12.

1946 *Hystrichosphaeridium complex* (White, 1842) Deflandre, p. 111.

1966a *Oligosphaeridium complex* (White, 1842) Davey and Williams, p. 71–74.

1970 *Oligosphaeridium cephalum* Sah *et al.,* p. 147, pl. 2, figs. 22–23.

1981 *Hystrichosphaeridium himalayense* Mehrotra and Sinha, p. 152, pl. 1, figs. 7–9.

1981 *Hystrichosphaeridium speciale* (Merrill, 1895) Lentin and Williams, p. 147.

Description: *Oligosphaeridium complex* are intermediate to large, chorate cysts, with the central body having a subspherical outline. The endophragm is psilate to shagreenate, with a psilate periphragm that detaches from the endophragm to produce intratabular processes. Each process is hollow and tubiform, which occasionally distally branch, the distal end is open and flared with an aculeate or secate margin. The paratabulation is inferred by the location of the processes. The archaeopyle is apical, with a detached operculum.

Remarks: *Oligosphaeridium complex* was first described from the Coniacian–Danian of England.

Size: Intermediate to large.

Occurrence: DC353, 17600–17660ft. to 20840–20900ft. (Albian–Valanginian); VK117, 13770–13800ft. to 20180–20190ft. (Aptian–Valanginian) with caving at 23990–24000ft. (Undifferentiated strata); CH265, 10250–10260ft. to 11600–11610ft. (Aptian–Valanginian).

Oligosphaeridium fenestratum Duxbury, 1980

Plate IV, Fig. c

1980 ***Oligosphaeridium fenestratum*** Duxbury, p. 130–131, pl. 9, figs. 8–9.

Description: *Oligosphaeridium fenestratum* are intermediate to large, chorate cysts, with the main cyst having a subspherical outline. The endophragm is psilate to shagreenate with a psilate periphragm detached from the endophragm to produce processes. Each process is hollow and tubiform in morphology; about halfway along its length, each process begins to flare outwards, with walls bearing fenestrations. The distal end is open and flared with a serrated margin. There is no discernible paratabulation. The archaeopyle is apical.

Remarks: This species was originally recorded from the Barremian of Yorkshire, England.

Size: Intermediate to large.

Occurrence: DC353, 17600–17660ft. to 20360–20420ft. (Albian–Hauterivian); VK117, 14370–14400ft. to 17340–17370ft. (Aptian–Barremian) with caving at 22890–22900ft. (Kimmeridgian); CH265, 9700–9710ft. (Aptian).

Oligosphaeridium perforatum (Gocht, 1959) Davey and Williams, 1969

Plate IV, Fig. d

1959 *Hystrichosphaeridium perforatum* Gocht, p. 68–69, pl. 3, fig. 7; pl. 7, figs. 13–16.

1969 *Oligosphaeridium perforatum* (Gocht, 1959) Davey and Williams, p. 5.

Description: *Oligosphaeridium perforatum* are intermediate to large, chorate cysts, with a subspherical to ovoidal outline. The endophragm is psilate with a psilate periphragm which rises up from the endophragm to produce intratabular processes. Each process is hollow and tubiform in morphology, the distal end of each process flaring out to an entire or slightly serrated margin. Along the length of each process are subspherical perforations. The archaeopyle is apical, with no evidence of a paracingulum or parasulcus in the specimens preserved.

Remarks: This species was first described from the Hauterivian–Barremian sediments of northwestern Germany.

Size: Intermediate to large.

Occurrence: DC353, 17600–17660ft. to 20600–20600ft. (Albian–Valanginian); VK117, 13770–13800ft. to840–18870ft. (Aptian–Valanginian) with caving at 23990–24000ft. (Undifferentiated strata); CH265, 7750–7760ft. to 11600–11610ft. (Aptian–Valanginian).

Oligosphaeridium poculum Jain, 1977

Plate IV, Fig. e

1977 *Oligosphaeridium poculum* Jain, p. 181, pl. 1, figs. 1–3.

Description: *Oligosphaeridium poculum* are intermediate to large, chorate cysts, with a subspherical outline. The endophragm is shagreenate, with a shagreenate periphragm detaching from the endophragm to produce wide processes. Each process is hollow and tubiform in morphology, the distal end flares out to a denticulate or recurved margin. There is no discernible paratabulation. The archaeopyle is apical.

Remarks: This species was originally recorded form the Early Albian sediments of southern India.

Size: Intermediate.

Occurrence: DC353, 17600–17660ft. to 20840–20900ft. (Albian–Valanginian) with caving at 21980–22040ft. (Tithonian); VK117, 13770–13800ft. to 17640–17670ft. (Aptian–Hauterivian) with caving at 23990–24000 (Undifferentiated strata); CH265, 7750–7760ft. to 11600–11610ft. (Aptian–Valanginian).

Oligosphaeridium pulcherrimum (Deflandre and Cookson, 1955) Davey and Williams, 1966a

Plate IV, Fig. f

1955 *Hystrichosphaeridium pulcherrimum* Deflandre and Cookson, p. 270–271, pl. 1, fig. 8; text-figs. 21–22.

1966a *Oligosphaeridium pulcherrimum* (Deflandre and Cookson, 1955) Davey and Williams, p. 75–76.

Description: *Oligosphaeridium pulcherrimum* are intermediate to large, chorate cysts, with a subspherical to ovoidal outline. The endophragm is psilate to shagreenate, with a psilate periphragm which detaches from the endophragm to produce intratabular processes. Each process is hollow and tubiform in morphology, half way or further along, the processes widen into deep, strongly perforated funnels, with an aculeate margin. The rims of the processes may have thin spins which connect up. The archaeopyle is apical.

Remarks: This species was first described from the Albian sediments of Australia.

Size: Intermediate to large.

Occurrence: DC353, 17600–17660ft. to 20000–20060ft. (Aptain–Hauterivian); VK117, 13770–13800ft. to 15240–15270ft. (Aptain); CH265, 10250–10260ft. to 11600–11610ft. (Aptian–Valanginian).

Oligosphaeridium umbraculum Duxbury, 2001

Plate IV, Fig. g

2001 *Oligosphaeridium umbraculum* Duxbury, p. 109–111, fig. 10:1–2

Description: *Oligosphaeridium umbraculum* are chorate cysts, with a subspherical outline. The endophragm is psilate, with a psilate to shagreenate periphragm detaching from the endophragm to produce long intratabular processes. Each process is hollow and tubiform in morphology, the distal end flares out to produce a polygonal to pentagonal, mostly entire margin, although with sparse denticles. Perforations may occasionally occur within the distal part of the process. The paratabulation is reflected by the distribution of the processes. The archaeopyle is apical.

Remarks: This species was originally recorded from the Early Hauterivian of the Central North Sea.

Size: Intermediate to large.

Occurrence: DC353, 18260–18320ft. to 20360–20420ft. (Barremian–Hauterivian); VK117, 12600–12630ft. to 14940–14970ft. (Albian–Aptian) one specimen caved to 17640–17670ft. (Hauterivian); CH265, 9640–9650ft. to 9812.5ft. (Aptian).

Genus *RHYNCHODINIOPSIS* Deflandre, 1935

1935 *Rhynchodiniopsis* Deflandre, p. 231.

TYPE: Deflandre, 1935, p. 231, pl. 5, fig. 10; pl. 8, figs.7–9, as *Rhynchodiniopsis aptiana*.

SYNOPSIS: The genus *Rhynchodiniopsis* is composed of intermediate, proximate, acavate cysts. They have a subspherical to subpolyhedral outline, with an apical prominence. The autophragm is scabrate to finely reticulate. The gonyaulacacean paratabulation is reflected by parasutural ridges, surmounted by fine, closely spaced spinules, with more prominent spines in gonal positions. The archaeopyle is precingular.

Rhynchodiniopsis cladophora (Deflandre, 1939) Below, 1981

PLATE IV, Fig. i

1939 *Gonyaulax cladophora* Deflandre, 1939, p. 173–176, pl. 7, figs. 1–5; text-figs. 5–6.

1967 *Gonyaulacysta cladophora* (Deflandre, 1939) Dodekova, p. 17–18.

1968 *Gonyaulacysta gottisii* Dupin, p. 4, pl. 1, figs. 7–12.

1972 *Gonyaulacysta downiei* Pocock, p. 87, pl. 22, figs. 1–2; text-fig. 2.

1972 *Gonyaulacysta canadensis* Pocock, p. 89, pl. 24, figs. 1–2; text-fig. 4.

1978 *Hystrichogonyaulax cladophora* (Deflandre, 1939) Stover and Evitt, p.162.

1978 *Millioudodinium*? *gottisii* (Dupin, 1968) Stover and Evitt, p. 174.

1978 *Hystrichosphaeropsis downiei* (Pocock, 1972) Stover and Evitt, p. 164.

1978 *Hystrichogonyaulax canadensis* (Pocock, 1972) Stover and Evitt, p. 162.

1981 *Rhynchodiniopsis cladophora* (Deflandre, 1939) Below, p. 118.

1982b *Rhynchodiniopsis*? *downiei* (Pocock, 1972) Sarjeant, p.36.

1984 *Apteodinium gottisii* (Dupin, 1968) Helenes, p. 134.

1986 *Rhynchodiniopsis canadensis* (Pocock, 1972) Jansonius, p. 214.

Description: *Rhynchodiniopsis cladophora* are intermediate, proximate, suturocavate cysts, with a globular to polyhedral outline. The endophragm and periphragm are closely appressed to one another, except from where the periphragm rises up at the parasutural boundaries to produce crests with a hystricate margin. A prominent apical pericoel is present. The archaeopyle is precingular, with a detached operculum.

Remarks: This species was first described from the Early Oxfordian of Calvados, France.

Size: Intermediate.

Occurrence: DC353, 23160–23220ft. (Kimmeridgian); VK117, not present; CH265, not present.

Genus *STANFORDELLA* Helenes and Lucas-Clark, 1997

1997 *Stanfordella* Helenes and Lucas-Clark, p. 180, 182.

TYPE: Helenes and Lucas-Clark, 1997, pl. 2, figs. 1–2, as *Stanfordella granulosa.*

SYNOPSIS: The genus *Stanfordella* is composed of intermediate, proximate, cavate cysts. They have a subspherical to subpolyhedral outline, with a small apical prominence. The epicyst is cornucavate and the hypocyst is suturocavate. The gonyaulacacean paratabulation is indicated by parasutural ridges. The archaeopyle is precingular.

Stanfordella fastigiata (Duxbury, 1977) Helenes and Lucas-Clark, 1997

Plate IV, Fig. j

1977 *Gonyaulacysta fastigiata* Duxbury, p. 36–37, pl. 1, figs. 8–9, 12; text-fig. 11.

1997 *Stanfordella fastigiata* (Duxbury, 1977) Helenes and Lucas-Clark, p. 183.

Description: *Stanfordella fastigiata* are intermediate, proximate, cornucavate and suturocavate cysts. They have a subhexagonal outline with an apical horn. The psilate to finely granulate endophragm and periphragm are appressed except under the apical horn and the parasutural ridges. The parasutural features form a continuous hystricate margin, that define the paratabulation. The archaeopyle is precingular.

Remarks: This species was initially recorded from the Early Hauterivian–Early Barremian of Yorkshire, England.

Size: Intermediate.

Occurrence: DC353, 19460–19520ft. to 20840–20900ft. (Barremian–Valanginian) with caving at 21980–22040ft. (Tithonian); VK117, 17490–17520ft. to 19800–19830ft. (Hauterivian–Berriasian); CH265, not present.

Genus *SYSTEMATOPHORA* Klement, 1960

1960 *Systematophora* Klement, p. 61–62.

TYPE: Klement, 1960, p. 62–65, pl. 9, figs. 1–3, as *Systematophora areolata.*

SYNOPSIS: The genus *Systematophora* is composed of intermediate to large, chorate cysts, with a subspherical outline. The finely ornamented autophragm is beset by complex penitabular annular process complexes, which indicate the gonyaulacoid paratabulation. The proximal ends of the processes within each complex are interconnected by a basal ridge, and on occasion but not always the distal ends of the processes are connected. The archaeopyle is apical.

Systematophora areolata Klement, 1960

Plate IV, Fig. k

1960 *Systematophora areolata* Klement, p. 62–65, pl. 9, figs. 1–8; text-figs. 32–35.

Description: *Systematophora areolata* is a large, chorate cyst, with a subspherical main body outline. The autophragm is smooth to finely granulate, with the paratabulation indicated by penitabular annular process complexes, each consisting of several long slender processes (usually four or less), which are either simple or bifurcate distally. At the base of each complex is a ridge. The archaeopyle is apical.

Remarks: This species was first recorded from the Early Kimmeridgian of southwest Germany.

Size: Intermediate to large.

Occurrence: DC353, 22100–22160ft. to 22760–22820ft. (Tithonian–Oxfordian); VK117, 19740–197700 to 22890–22900ft. (Berriasian–Undifferentiated strata); CH265, not present.

Systematophora complicata Neale and Sarjeant, 1962

Plate IV, Fig. l

1962 *Systematophora complicata* Neale and Sarjeant, p.455–456, pl.19, figs.6–7.

Description: *Systematophora complicata* is a large, chorate cyst, with a subspherical main body outline. The autophragm is smooth to granulate, with the paratabulation indicated by penitabular annular process complexes comprising several long slender processes, the distal terminations of which vary from simple and bifurcate to branched with further bifurcations. At the base of each complex there is a ridge. The archaeopyle is apical.

Remarks: This species was initially described from the Late Hauterivian–Middle Barremian of Yorkshire, England.

Size: Large.

Occurrence: DC353, 18560–18620ft.to 21860–21920ft. (Barremian–Berriasian); VK117, 17490–17520ft. to 20180–20190ft. (Hauterivian–Berriasian); CH265, 10250–10260ft. (Aptian).

Systematophora palmula Davey, 1982

Plate IV, Fig. m

1982 *Systematophora palmula* Davey, p. 11–12, pl. 1, figs. 1–4.

Description: *Systematophora palmula* is a large, chorate cyst, with a subspherical main body outline. The psilate to scabrate endo- and periphragm are closely appressed except where the periphragm pulls away to form the processes. The penitabular processes are arranged in annular complexes, each complex dividing medially into two or more branches that then bifurcate at the distal termination. The archaeopyle is apical.

Remarks: This species was first described from the Ryazanian–Valanginian of Denmark.

Size: Large.

Occurrence: DC353, 18260–18320ft. to 20600–20600ft. (Barremian–Valanginian); VK117, 15360–15390ft. to 18540–18570ft. (Barremian–Hauterivian); CH265, 7750–7760ft. to 11600–11610ft. (Aptian–Valanginian).

Systematophora silybum Davey, 1979a

Plate IV, Fig. n

1979a *Systematophora silybum* Davey, p. 433–434, 436, pl. 48, figs. 7–8; pl. 50, figs. 2–3, 5–6, 7–9.

Description: *Systematophora silybum* is a large, chorate cyst, with a subspherical main body outline. The autophragm is smooth to granulate, with the paratabulation indicated by penitabular annular process complexes. At the base of each complex there is a ridge which pinches up to form several long slender processes (usually four or less), which are either simple or are medially branched with buccinate terminations. The archaeopyle is apical.

Remarks: This species was initially recorded from the Barremian of the northern North Sea.

Size: Large.

Occurrence: DC353, 18500–18560ft. to 18800–18860ft. (Barremian); VK117, 14490–14520ft. to 18540–18570ft. (Aptian–Hauterivian); CH265, 9640–9650ft. (Aptian).

Systematophora*? *daveyi Riding and Thomas, 1988

Plate IV, Fig. o

1988 *Systematophora daveyi* Riding and Thomas, p. 82, 84, 86, pl. 3, figs. 8–10; text-figs. 10a–b.

1990 *Systematophora*? *daveyi* Stancliffe and Sarjeant, p. 208.

Description: *Systematophora*? *daveyi* is a large, chorate cyst, with a subspherical main body outline. The autophragm is smooth to finely granulate, with the paratabulation indicated by penitabular annular process complexes. The complexes are comprised of several slender, solid processes which branch two or more times medially or distally. The branched complexes then typically adjoin each other by trabeculae. The trabeculae may also bear short spines. The archeopyle is apical.

Remarks: This species was initially recorded from the Early Kimmeridgian–Early Portlandian of Dorset, England.

Size: Large.

Occurrence: DC353, 20600–20660ft. to 22520–22580ft. (Valanginian–Oxfordian); VK117, 16770–16800ft. to 22890–22900ft. (Barremian–Undifferentiated strata); CH265, not present.

Subfamily UNCERTAIN

Genus *CALLAIOSPHAERIDIUM* Davey and Williams, 1966a

1966a *Callaiosphaeridium* Davey and Williams, p. 103.

TYPE: Deflandre and Courteville, 1939, pl. 4, fig. 1, as *Hystrichosphaeridium asymmetricum*.

SYNOPSIS: The genus *Callaiosphaeridium* is composed of intermediate to large, chorate cysts. They have a subspherical outline. The endophragm and periphragm are finely ornamented and appressed, except wherethe periphragm pulls away to produce parasutural ridges between gonal processes and by means of intratabular paracingular hollow processes. The archaeopyle is apical.

Callaiosphaeridium asymmetricum (Deflandre and Courteville, 1939) Davey and Williams, 1966b

Plate V, Fig. a

1939 *Hystrichosphaeridium asymmetricum* Deflandre and Courteville, p. 100–101, pl. 4, fig. 1.

1966a *Callaiosphaeridium asymmetricum* (Deflandre and Courteville, 1939) Davey and Williams, p. 104.

1967 *Hexasphaera asymmetricum* (Deflandre and Courteville, 1939) Clarke and Verdier, p. 43.

Description: *Callaiosphaeridium asymmetricum* are intermediate, chorate cysts, with a subspherical outline. The endophragm and periphragm are psilate to shagreenate and closely appressed, except where the periphragm pulls away from the endophragm to form the processes. Corresponding to the cingulum are six large hollow processes; the distal ends of which flare outwards with the addition of tendril extensions. The apical and antapical plates have solid parasutural processes which bifurcate at the plate boundaries. The archeopyle is epicystal.

Remarks: This species was originally described from the Coniacian–Danian of Northern France.

Size: Intermediate.

Occurrence: DC353, 17780–17840ft. to 20600–20660ft. (Aptian–Valanginian); VK117, 16140–16170ft. (Barremian); CH265, not present.

Callaiosphaeridium trycherium (Duxbury, 1980)

Plate V, Fig. b

1980 *Callaiosphaeridium trycherium* Duxbury, p. 114, pl. 11, figs. 6, 9.

Description: The central body of the cyst is psilate to shagreenate and almost spherical. The cyst wall is comprised of two layers. When the periphragm pulls away from the endophragm, it forms six tubular spines which are irregularly recurved at their termination. The processes are connected at their base by high parasutural crests which are distally irregular too. The archeopyle is epicystal.

Remarks: *Callaiosphaeridium trycherium* was originally described from the Barremian of East Yorkshire.

Size: Intermediate.

Occurrence: DC353, 18020–18080ft. to 18980–19040ft. (Aptian–Barremian); VK117, not present; CH265, not present.

Genus *COMETODINIUM* Deflandre and Courteville, 1939

1939 *Cometodinium* Deflandre and Courteville, p. 98.

TYPE: Deflandre and Courteville, 1939, pl. 2, fig. 1, as *Cometodinium obscurum*.

SYNOPSIS: The genus *Cometodinium* is composed of intermediate, chorate cysts. They have a subspherical central body. The finely ornamented endophragm and periphragm are in very close proximity to one another, except when the periphragm pulls away to produce numerous nontabular processes. There is no discernible paratabulation and the paracingulum and parasulcus are not apparent. The archaeopyle is apical.

Cometodinium obscurum Deflandre and Courteville, 1939

Plate IV, Fig. p

1939 *Cometodinium obscurum* Deflandre and Courteville, p. 99, pl. 2, fig. 1.

Description: *Cometodinium obscurum* is a chorate cyst, with a subspherical endocyst. The periphragm forms multiple acicular processes which are numerous and have an even occurrence over the entire cyst. There is no discernible paratabulation and the paracingulum and parasulcus are not apparent. Archaeopyle is apical.

Remarks: *Cometodinium obscurum* was initially described from the Turonian of northern France. The original description was emended by Monteil (1991b p. 443–444), who thought *Cometodinium* obscurum had an autophragm. The holotype from Deflandre and Courteville (1939, pl. 2, fig. 1) was lost according to Monteil (1991b, p. 439), as such a lectotype was designated by Monteil (1991b, pl. 1, figs. 1a–b).

Size: Intermediate.

Occurrence: DC353, 18080–18140ft. to 18920–18980ft. (Aptian–Barremian); VK117, 13770–13800ft. (Aptian); CH265, 10250–10260ft. (Aptian).

Cometodinium whitei (Deflandre and Courteville, 1939) Stover and Evitt, 1978

Plate IV, Fig. q

1939 *Hystrichosphaeridium whitei* Deflandre and Courteville, p. 103, pl. 3, figs. 5–6.

1965 *Baltisphaeridium whitei* (Deflandre and Courteville, 1939) Downie and Sarjeant, p.98.

1966 *Impletosphaeridium whitei* (Deflandre and Courteville, 1939) Morgenroth, p. 37.

1969 *Comasphaeridium whitei* (Deflandre and Courteville, 1939) de Coninck, p. 59.

1978 *Cometodinium whitei* (Deflandre and Courteville, 1939) Stover and Evitt, p. 227.

Description: *Cometodinium whitei* is a chorate cyst, with a subspherical shagreenate endocyst. The periphragm forms groups of processes that congregate together like tufts. The processes are varied in thickness and distal termination; however, the process height remains constant. There is no discernible paratabulation and the paracingulum and parasulcus are not apparent. Archaeopyle is apical.

Remarks: This species was initially described from the Coniacian–Danian of northern France. The holotype was lost according to Monteil (1991b, p.439), who designated a neotype (Monteil, 1991b, pl. 2, figs. 1a–c; pl. 3, fig. 9).

Size: Intermediate.

Occurrence: DC353, 17840–17900ft. to 19640–19700ft. (Aptian–Hauterivian); VK117, not present; CH265, not present.

Cometodinium*? *comatum Srivastava, 1984

Plate IV, Fig. r

1984 *Cometodinium*? *comatum* Srivastava, p. 29, pl. 7, figs. 4–8.

Description: *Cometodinium*? *comatum* is a proximochorate cyst, with a subspherical shagreenate endocyst. The periphragm forms a tangled mass of acicular processes, which gives the impression of a kalyptra. There is no discernible paratabulation and the paracingulum and parasulcus are not apparent. This remains a questionable species due to the uncertainty of an apical archaeopyle.

Remarks: This species was originally described from the Late Barremian of Southeastern France. It was given a questionable assignment by Monteil (1991b, p. 440) due to type materials undetermined archaeopyle.

Size: Intermediate.

Occurrence: DC353, 186020–18080ft. to 18200–18260ft. (Aptian) with caving at 22760–22820ft. (Kimmeridgian); VK117, 15360–15390ft. to 18540–18570ft. (Barremian–Hauterivian); CH265, 7750–7760ft. to 11600–11610ft. (Aptian–Valanginian).

Genus *CORONIFERA* Cookson and Eisenack, 1958

1958 *Coronifera* Cookson and Eisenack, p. 45.

TYPE: Cookson and Eisenack, 1958, pl. 12, fig. 6, as *Coronifera oceanica.*

SYSNOPSIS: The genus *Coronifera* is composed of intermediate, chorate cysts. They have a subspherical to ellipsoidal outline. The finely ornamented endophragm and periphragm are in very close proximity to one another, except when the periphragm pulls away to produce numerous nontabular processes, with one wider antapical process There is no discernible paratabulation. The archaeopyle is precingular.

Coronifera oceanica Cookson and Eisenack, 1958

Plate IV, Fig. s

1958 *Coronifera oceanica* Cookson and Eisenack, p. 45, pl. 12, fig. 5–6.

Description: *Coronifera oceanica* is a subspherical chorate cyst. The cyst wall is composed of two layers, the psilate endophragm and the periphragm, which pulls away from the endocyst to form nontabular largely acicular (sometimes bi- or trifurcate) processes over the entire cyst. It has one large distinctive antapical process, which is smooth and tubular with a denticulate tip. There is no discernible paratabulation, including a lack of a parasulcus and paracingulum. It has a precingular archaeopyle.

Remarks: *Coronifera oceanica* was initially described from the Albian of Australia and New Guinea. Sarjeant (1985b, p. 145–147) considered *Hystrichosphaera*? (as *Coronifera*) *pedata* a taxonomic senior synonym. However, Kirsch (1991, p. 71) retained this species. Whereas, Below (1982a, p. 5) considered *Hystrichosphaeridium* (as *Coronifera*) *monstruosum* a taxonomic junior synonym. However, Fauconnier in Fauconnier and Masure (2004, p. 176) retained *Hystrichosphaeridium* (as *Diphyes*?) *monstruosum*.

Size: Intermediate.

Occurrence: DC353, 17600–17660ft. to 19640–19700ft. (Albian– Hauterivian) with caving at 22800–22860ft. (Oxfordian); VK117, 14490–14520ft. to 15840–15870ft. (Aptian–Barremian) with caving at 21290–21300ft. (Tithonian); CH265, 9640–9650ft. to 9700–9710ft. (Aptian).

Coronifera striolata (Deflandre, 1937) Stover and Evitt, 1978

Plate IV, Fig. t

1937 *Hystrichosphaeridium striolatum* Deflandre, p. 72–73, pl. 15 [al. pl. 12], figs. 1–2.

1965 *Baltisphaeridium striolatum* (Deflandre, 1937) Downie and Sarjeant, p. 97.

1969a *Exochosphaeridium striolatum* (Deflandre, 1937) Davey, p. 164.

1978 *Coronifera striolata* (Deflandre, 1937) Stover and Evitt, p. 148.

Description: *Coronifera striolata* is a chorate cyst with a subspherical to ovoidal outline. The endocyst is shagreenate to micro granulate, while the fibrous periphragm forms nontabular slender acicular processes (some can be bifurcated) over the entire cyst. There is no discernible paratabulation, including a lack of a parasulcus and paracingulum. It has a precingular archeopyle.

Remarks: This species was initially described from the Late Cretaceous of France.

Size: Intermediate.

Occurrence: DC353, not present; VK117, 16770–16800ft. to 17490–17520ft. (Barremian–Hauterivian); CH265, not present.

Genus *DISSILODINIUM* Drugg, 1978

1978 *Dissilodinium* Drugg, p. 67–68.

TYPE: Drugg, 1978, pl. 4, fig. 5, as *Dissiliodinium globulus*.

SYNOPSIS: The genus *Dissilodinium* is composed of small to large, proximate, acavate cysts. They have a subspherical to ellipsoidal outline. The psilate to coarsely ornamented autophragm displays variable expressions of paratabulation (well-developed to undeveloped). The archaeopyle is formed by the removal of several precingular plates.

Dissiliodinium baileyi Feist-Burkhardt and Monteil 2001

PLATE V, Fig. d

2001 *Dissiliodinium baileyi* Feist-Burkhardt and Monteil, p.68, 71, fig. 10, nos. 1–5; fig. 20, no. 1; table 2.

Description: *Dissiliodinium baileyi* are acavate, proximate, subspherical cysts. They have a thin psilate to scabrate autophragm, ornamented with small to large verrucae. The paratabulation is indicated by the archeopyle. The archaeopyle is precingular, formed by the loss of 5 paraplates (1′′–5′′) with the apical plate remaining attached to the hypocyst via a narrow isthmus consisting of paraplate 6′′ and the parasulcus

Remarks: This species was originally recorded from the Bajocian–Bathonian of Oxfordshire, UK.

Size: Intermediate.

Occurrence: DC353, 22800–22860ft. (Kimmeridgian); VK117, not present; CH265, not present.

Dissilodinium curiosum Burger and Sarjeant, 1995

Plate V, Fig. c

1995 *Dissiliodinium curiosum* Burger and Sarjeant, p. 120–122, 124, figs. 3, 4a–c, 5a–b, 6a–b, 7a–b, 8a–b, 9a–b, 10a–b, 11a–c, 12a–b, 13a–b, 14a–b.

Description: *Dissiliodinium curiosum* are acavate, proximate, subspherical cysts. They have a thin autophragm with a shagrenate to densely granular ornament. The paratabulation is occasionally indicated on the epicyst due to the lack of ornamentation. The archeopyle is precingular, formed by the loss of 5 paraplates (1''–5'') with the apical plate remaining attached to the hypocyst via a narrow isthmus consisting of paraplate 6''.

Remarks: *Dissiliodinium curiosum* was first described from the latest Jurassic–Early Cretaceous of Australia. Leereveld (1997, p. 413) considered *Dissiliodinium globulus* to be a taxonomic senior synonym, however, Feist-Burkhardt and Monteil (2001, p. 64, 72) retained this species.

Size: Intermediate.

Occurrence: DC353, 22100–22160ft. to 22760–22820ft. (Tithonian–Kimmeridgian) one specimen reworked to 21320–21380ft. (Valanginian); VK117, 22890–22900ft. (Kimmeridgian); CH265, not present.

Genus *FIBROCYSTA* Stover and Evitt, 1978

1978 *Fibrocysta* Stover and Evitt, p. 155.

TYPE: Cookson and Eisenack, 1965b, pl. 16, fig. 8, as *Cordosphaeridium bipolare*.

SYNOPSIS: The genus *Fibrocysta* is composed of small to intermediate, proximochorate to chorate, acavate cysts. They have an ellipsoidal outline, with small to long apical and antapical hornlike protrusions. The ornamented autophragm, is also covered in numerous solid or hollow, nontabular processes. The paratabulation is usually indicated by the paracingulum. The archaeopyle is precingular.

Fibrocysta? deflandrei (Lejeune-Carpentier, 1941) Lejeune-Carpentier and Sarjeant, 1981

Plate V, Fig. e

1941 *Hystrichosphaeridium spinosum* var. *deflandrei* Lejeune-Carpentier, p. B84, fig. 6.

1965 *Baltisphaeridium spinosum* var. *deflandrei* (Lejeune-Carpentier, 1941) Downie and Sarjeant, p. 96.

1969a *Exochosphaeridium spinosum* var. *deflandrei* (Lejeune-Carpentier, 1941) Davey, p. 166.

1973 *Exochosphaeridium spinosum* subsp. *deflandrei* (Lejeune-Carpentier, 1941) Lentin and Williams, p.56.

1973 *Exochosphaeridium*? *spinosum* subsp. *deflandrei* (Lejeune-Carpentier, 1941) Lentin and Williams, p.56.

1981 *Fibrocysta? deflandrei* (Lejeune-Carpentier, 1941) Lejeune-Carpentier and Sarjeant, p. 14.

Description: *Fibrocysta? deflandrei* is a intermediate, proximochorate, acavate cyst; which has an elongate to ellipsoidal outline with a short prominent apical horn. The autophragm is densely granular, surmounted by acicular projections, which are nontabular and vary in length. The archaeopyle is precingular (type P) and there is no discernible evidence of a paracingulum and parasulcus.

Remarks: This species was originally described from the Late Cretaceous of Belgium.

Size: Intermediate.

Occurrence: DC353, 17960–18020ft. to 19700–19760ft. (Aptian–Hauterivian); VK117, 14370–14400ft. to 15360–15390ft. (Aptian–Barremian); CH265, 10800–10810ft. (Barremian).

Genus *HYSTRICHODINIUM* Deflandre, 1935

1935 *Hystrichodinium* Deflandre, p. 229–230.

TYPE: Deflandre, 1935, pl. 5, fig. 1; text-figs. 9–11, as *Hystrichodinium pulchrum*.

SYNOPSIS: The genus *Hystrichodinium* is composed of intermediate to large, chorate cysts, with a subspherical to polyhedral outline. The finely ornamented autophragm also bears numerous parasutural spines. The paratabulation is not always clear, but can be indicated by the precingular archaeopyle.

Hystrichodinium ramoides Alberti, 1961

PLATE V, Fig. f

1961 *Hystrichodinium ramoides* Alberti, p. 15–16, pl. 8, figs. 11–13.

Description: *Hystrichodinium ramoides* are intermediate, proximochorate cysts. They have a rounded egg shaped cyst outline. The autophragm is granulate and covered in long, slender, hollow processes, all of equal length, but varying width. The processes are open distally and vary from having aculeate to recurved margins. There is no discernible paratabulation, with the exception of the precingular archaeopyle. The paracingulum and parasulcus are not observed.

Remarks: This species was first described from the Late Barremian of northern and central Germany.

Size: Intermediate.

Occurrence: DC353, 18380–18440ft. (Barremian); VK117, 13770–13800ft. to 15540–15570ft. (Aptian–Barremian); CH265, not present.

Hystrichodinium voigtii Alberti, 1961 (Davey, 1974)

Plate V, Fig. g

1961 *Heliodinium voigtii* Alberti, p. 33, pl. 8, figs. 1–5.

1974 *Hystrichodinium voigtii* (Alberti, 1961) Davey, p.54.

Description: *Hystrichodinium voigtii* are intermediate, proximochorate cysts. They have an ovoidal cyst outline. The autophragm is granulate and covered in long, slender, hollow acuminate to evexate processes. The processes are closed distally There is no discernible paratabulation from specimens recovered from these three wells, with the exception of the precingular archaeopyle observed on a few specimens along with the paracingulum. However, the parasulcus has not been observed.

Remarks: According to the emended description by Sarjeant (1966b) the parasutures should be marked with a low ridge, while the cingulum and antapex are boarded by low crests. These features are not visible on the specimens recovered from the EGoM. It should also be noted that the processes have a tendency to locate at the poles of the cyst, but not always. *Hystrichodinium voigtii* was first recorded from the Barremian–Early Aptian of Northern and Central Germany.

Size: Intermediate.

Occurrence: DC353, not present; VK117, 13770–13800ft. to 20790–20800ft. (Aptian–Tithonian); CH265, not present.

Genus *KIOKANSIUM* Stover and Evitt, 1978

1978 *Kiokansium* Stover and Evitt, p. 167.

TYPE: Tasch *et al.,* 1964, pl. 3, fig. 8, as *Hystrichosphaeridium unituberculatum*.

SYNOPSIS: The genus *Kiokansium* is composed of intermediate, chorate cysts, with an ellipsoidal to elongated subspherical outline. The finely ornamented autophragm also bears numerous nontabular solid processes, with variable tips. There is no discernible paratabulation. The archaeopyle is precingular (2P).

Kiokansium prolatum Duxbury, 1983

Plate V, Fig. h

1983 *Kiokansium prolatum* Duxbury, p. 49–50, pl. 6, figs. 4, 8.

Description: *Kiokansium prolatum* are intermediate, chorate, acavate cysts. The psilate central body has an elongate outline. Arising from the autophragm are intratabular solid processes. Each process has a distally recurved patulate margin. There is no discernible paratabulation. The archaeopyle is precingular.

Remarks: This species was originally described from the Late Aptian–Early Albian of the Isle of White, United Kingdom.

Size: Intermediate.

Occurrence: DC353, 17600–17660ft. (Albian); VK117, not present; CH265, not present.

Kiokansium unituberculatum (Tasch in Tasch *et al.,* 1964) Stover and Evitt, 1978

Plate V, Fig. i

1964 *Hystrichosphaeridium unituberculatum* Tasch in Tasch *et al.,* p., 194, pl. 3, fig. 8.

1978 *Kiokansium unituberculatum* (Tasch in Tasch *et al.,* 1964) Stover and Evitt, p. 167, 267.

Description: *Kiokansium unituberculatum* is an intermediate, chorate, acavate cyst. The psilate central body has a subspherical outline. Arising from the autophragm are nontabular solid processes. Each process distally flares and furcates into several spines. There is no discernible paratabulation. The archaeopyle is precingular.

Remarks: This species has a total of 15 taxonomic junior synonyms. It was first described from the Albian of Kansas, U.S.A.

Size: Intermediate.

Occurrence: DC353, 17720–17780ft. to 19880–19940ft. (Aptian–Hauterivian); VK117, 13770–13800ft. to 18240–18270ft. (Aptian–Hauterivian) with caving at 23990–24000 (Undifferentiated strata); CH265, 9640–9650ft. to 11600–11610ft. (Aptian–Valanginian).

Kiokansium williamsii Singh, 1983

Plate V, Fig. j

1983 *Kiokansium williamsii* Singh, p. 150, pl. 54, figs. 3–6.

Description: *Kiokansium williamsii* is an intermediate, chorate, acavate cyst. The psilate central body has an ellipsoidal outline. Arising from the autophragm are nontabular solid processes. Each process is distally different. Some flare while others furcate or recurve. There is no discernible paratabulation. The archaeopyle is precingular.

Remarks: This species was first recorder form the Albian–Cenomanian of Alberta, Canada.

Size: Intermediate.

Occurrence: DC353, 17600–17660ft. to 19340–19400ft. (Albian–Barremian); VK117, 12600–12630ft. to 17340–17370ft. (Albian–Barremian); CH265, 9640–9650ft. to 11250–11260ft. (Aptian–Hauterivian).

Genus *LAGENORHYTIS* Duxbury, 1979b

1979b *Lagenorhytis* Duxbury, p. 587.

TYPE: Duxbury, 1977, pl. 12, fig. 4, as *Speetonia delicatula*.

SYNOPSIS: The genus *Lagenorhytis* is composed of intermediate to large, proximate cysts. They have a subspherical outline, with an apical horn. The autophragm is ornamented and may bear tubercules. There is no evidence of paratabulation, except for the release of the operculum. The archaeopyle is precingular (2P).

Lagenorhytis delicatula (Duxbury, 1977) Duxbury, 1979b

Plate V, Fig. k

1977 *Lagenorhytis delicatula* Duxbury, p. 49, pl. 12, figs. 1–2, 4–5; text-fig. 18.

1979b *Lagenorhytis delicatula* (Duxbury, 1977) Duxbury, p. 587.

Description: *Lagenorhytis delicatula* are intermediate to large, proximate, acavate cysts. They have a spherical to ovoidal outline, with a strong apical horn. The autophragm is densely granular, sporadically interspersed with tubercles. There are localised tubercules on the apex of the apical horn. There is no evidence of paratabulation, except for the release of the operculum. The archaeopyle is precingular (type 2P) with the detachment of the 3’’ plate and sometimes the 4’’ plate too.

Remarks: This species was first recorded from the Early Valanginian of Yorkshire, United Kingdom.

Size: Intermediate to large.

Occurrence: DC353, not present; VK117, 16140–16170ft. to 18990–19020ft. (Barremian–Valanginian); CH265, not present.

Genus *NEXOSISPINUM* Davey, 1979b

1979b *Nexosispinum* Davey, p. 557–558.

TYPE: Davey, 1979b, pl. 6, fig. 5, as *Nexosispinum hesperus*.

SYNOPSIS: The genus *Nexosispinum* is composed of small to intermediate, proximochorate to chorate cysts, with a subspherical outline. The finely ornamented autophragm also bears numerous nontabular solid processes, with variable tips and sometimes linking up. There is no discernible paratabulation. The archaeopyle is precingular.

Nexosispinium hesperus Davey, 1979b

Plate V, Fig. l

1979b *Nexosispinum hesperus* Davey, p. 558, pl. 6, figs. 1–5. Retained by Prössl (1990, p.104).

1987 *Kiokansium hesperus* (Davey, 1979b) Stover and Williams, p. 163.

Description: *Nexosispinum hesperus* is a small to intermediate, chorate cyst. The main cyst body is spherical in outline. The autophragm is shagreenate to finely granular with numerous processes. The processes are clumped together and are connect by trabeculae part of the way up. At their distal ends, they generally capitate or briefly bifurcate. There is no discernible paratabulation. The archaeopyle is precingular.

Remarks: This species was first recorded from the Albian sediments in the northern Bay of Biscay, France

Size: Small to intermediate.

Occurrence: DC353, not present; VK117, 13770–13800ft. to 14490–14520ft. (Aptian); CH265, 10250–10260ft. (Aptian).

Nexosispinium vetusculum (Davey, 1974) Davey, 1979b

Plate V, Fig. m

1974 *Adnatosphaeridium vetusculum* Davey, p. 45, pl. 1, figs. 1–2.

1977 *Systematophora vetuscula* (Davey, 1974) Duxbury, p. 51.

1979b *Nexosispinum vetusculum* (Davey, 1974) Davey, p.558. Retained by Prössl (1990, p. 104).

1987 *Kiokansium vetusculum* (Davey, 1974) Stover and Williams, p. 163.

Description: *Nexosispinum vetusculum* is a small to intermediate, chorate cyst. The main cyst body is spherical in outline. The autophragm is finely granular with numerous processes. The processes are clumped together in groups, to produce process complexes, thereby making the process look hollow and larger than they actually are. The individual processes are connected by trabeculae at their distal extremities. There is no discernible paratabulation. The archaeopyle is precingular.

Remarks: This species was first described from the Early Barremian of the Speeton Clay, Yorkshire, England.

Size: Small to intermediate.

Occurrence: DC353, 17960–18020ft. to 20600–20660ft. (Aptian–Valanginian); VK117, 15840–15870ft. to 16140–16170ft. (Barremian) with caving between 19740–19770ft. to 22890–22900ft. (Berriasian–Kimmeridgian); CH265, not present.

Genus *PERVOSPHAERIDIUM* Yun Hyesu, 1981

1981 *Pervosphaeridium* Yun Hyesu, p. 26–27.

TYPE: Deflandre, 1937, pl. 15 (al. pl. 12), fig. 3, as *Hystrichosphaeridium pseudhystrichodinium*.

SYNOPSIS: The genus *Pervosphaeridium* is composed of small to intermediate, proximochorate to chorate cysts, with a subspherical to ovoidal outline. The finely ornamented endophragm is in close proximity to the periphragm, however, the periphragm detaches from the endophragm to form simple and acuminate nontabular processes. There is no discernible paratabulation. The archaeopyle is precingular (2P).

Pervosphaeridium cenomaniense (Norvick, 1976) Below, 1982a

Plate V, Fig. n

1976 *Exochosphaeridium cenomaniense* Norvick, p. 52–53, pl. 4, figs. 4, 8.

1978 *Exochosphaeridium*? *cenomaniense* (Norvick, 1976) Stover and Evitt, p. 154

1982a *Pervosphaeridium cenomaniense* (Norvick, 1976) Below, p. 27.

Description: *Pervosphaeridium cenomaniense* is a small to intermediate, proximochorate cyst with a prolate to spherical outline. The granulate endophragm is in close proximity to the reticulate periphragm. However, the periphragm detaches from the endophragm to form nontabular processes (≈5µm in length). The processes are striate, and are distally pointed or capitate. There is no discernible paratabulation. The archaeopyle is precingular (2P) with the detachment of two precingular plates.

Remarks: This species was first described from the Cenomanian strata of Australia.

Size: Small to intermediate.

Occurrence: DC353, 17760–17720ft. to 19760–19820ft. (Albian–Hauterivian); VK117, 15360–15390ft. to 17340–17370ft. (Barremian); CH265, 11600–11610ft. (Valanginian).

Pervosphaeridium granaciculare Fensome *et al.,* 2009

Plate V, Fig. o

2009 *Pervosphaeridium granaciculare* Fensome *et al.,* p. 54–55, pl. 9, figs. p–s.

Description: *Pervosphaeridium granaciculare* is a small to intermediate, chorate cyst with a spherical outline. The finely granulate endophragm and periphragm are in close proximity to one another, apart from when the periphragm detaches to form nontabular processes (≈10µm in length). The processes are also finely granular and acicular in morphology. There is no discernible paratabulation. The archaeopyle is precingular.

Remarks: This species was first described from the Early Campanian from the Scotian margin, Canada.

Size: Small to intermediate.

Occurrence: DC353, 17720–17780ft. to 20060–20120ft. (Aptian–Hauterivian) with caving at 22400–22460ft. (Kimmeridgian); VK117, 12600–12630ft. to 16140–16170ft. (Albian–Barremian); CH265, 7750–7760ft. to 11250–11260ft. (Aptian–Hauterivian).

Pervosphaeridium pseudhystrichodinium (Deflandre, 1937) Yun Hyesu, 1981

Plate V, Fig. p

1937 *Hystrichosphaeridium pseudhystrichodinium* Deflandre, p. 73, pl. 15 (al. pl. 12), figs. 3–4.

1965 *Baltisphaeridium pseudhystrichodinium* (Deflandre, 1937) Downie and Sarjeant, p. 95.

1969 *Exochosphaeridium*? *pseudhystrichodinium* (Deflandre, 1937) Davey *et al.,* p. 16–17.

1981 *Pervosphaeridium pseudhystrichodinium* (Deflandre, 1937) Yun Hyesu, p. 29.

Description: *Pervosphaeridium pseudhystrichodinium* are intermediate, chorate cysts with a spherical outline. The granulate endophragm is in close proximity to the reticulate periphragm. However, the periphragm detaches from the endophragm to form long nontabular processes (≈20µm in length). The hollow processes are acicular, and occasionally branch medially. There is no discernible paratabulation. The archaeopyle is precingular with the detachment of one or two precingular plates.

Remarks: Yun Hyesu (1981, p. 29) and Ziaja (1989, p. 214) considered *Hystrichosphaeridium* (as *Exochosphaeridium*) *palmatum* and *Exochosphaeridium muelleri*, respectively to taxonomic junior synonyms of *Pervosphaeridium pseudhystrichodinium*. This species was first described from the Late Cretaceous of France.

Size: Intermediate.

Occurrence: DC353, 17900–17960ft. (Aptian); VK117, not present; CH265, not present.

Genus *PROTOELLIPSODINIUM* Davey and Verdier, 1971

1971 *Protoellipsodinium* Davey and Verdier, p. 28.

TYPE: Davey and Verdier, 1971, pl. 5, fig. 2, as *Protoellipsodinium spinocristatum*.

SYNOPSIS: The genus *Protoellipsodinium* is composed of intermediate to large, proximochorate to chorate cysts, with an elongate outline. The finely ornamented autophragm is covered in nontabular processes, which are closed distally. There is no discernible paratabulation. The archaeopyle is precingular.

Protoellipsodinium spinosum Davey and Verdier, 1971

Plate V, Fig. q

1971 *Protoellipsodinium spinosum* Davey and Verdier, p. 29–30, pl. 5, fig. 10.

Description: *Protoellipsodinium spinosum* are intermediate to large, proximochorate, apiculocavate cyst, with an elongated ovoidal outline. The finely granulate autophragm produces hollow nontabular, acuminate processes. The paratabulation is not discernible. The archaeopyle is precingular.

Remarks: This species was initially described from the Early–Late Albian of the Paris Basin, France.

Size: Intermediate to large.

Occurrence: DC353, 17780–17840ft. to 18740–18800ft. (Aptian–Barremian); VK117, not present; CH265, not present.

Genus *SCRINIODINIUM* Klement, 1957

1957 *Scriniodinium* Klement, p. 409–410.

TYPE: Deflandre, 1939, p. 165, pl. 5, figs. 1–3, as *Gymnodinium crystallinum*.

SYNOPSIS: The genus *Scriniodinium* is composed of intermediate to large, proximate, generally circumcavate cysts. They have a subspherical to elongate ovoidal outline; with or without an apical and/or antapical horn. They are slightly dorso-ventrally flattened, with a more spherical endophragm. A transverse furrow may be visible to outline the paracingulum on the periphragm. Paratabulation is not always clear. The archaeopyle is precingular.

Scriniodinium barremianum Duxbury 2001

Plate V, Fig. r

2001 *Scriniodinium barremianum* Duxbury, p. 112–113, fig. 12, nos. 1–2.

Description: *Scriniodinium barremianum* are intermediate to large, proximate, cavate cysts, with an elongated ovoidal outline. The psilate periphragm separates from the finely granulate endophragm, to produce cavation around the apical, ventral and cingular areas. The apical horn, formed by the periphragm is long, hollow and open and perforated at the distal end. The archeopyle is precingular. The paracingulum can be observed as two parallel ridges which traverse the circumference of the cyst.

Remarks: The holotype for this species is believed to be caved into the Middle Barremian. However, it is thought that the actual age of the holotype specimen is Late Barremian, recovered from the Central North Sea.

Size: Intermediate to large.

Occurrence: DC353, not present; VK117, 14490–14520ft. (Aptian); CH265, not present.

Scriniodinium campanula Gocht, 1959

Plate V, Fig. s

1959 *Scriniodinium campanula* Gocht, p. 61–62, pl. 4, fig. 6; pl. 5, figs. 1a–b.

1967 *Endoscrinium campanula* (Gocht, 1959) Vozzhennikova, p. 175.

1978 *Scriniodinium*? *campanula* (Gocht, 1959) Stover and Evitt, p. 187.

2003 *Scriniodinium campanula* (Gocht, 1959) Riding and Fensome, p. 13–14.

Description: *Scriniodinium* campanula are intermediate to large, proximate, circumcavate cysts, with a spherical outline. The shagreenate periphragm separates from the finely granulate endophragm, to produce cavation around the apical, antapical and cingular areas. The apical horn is short and truncated, while the antapical horn is more rounded but also truncated. The archeopyle is precingular. The paracingulum can be observed as two parallel ridges which traverse the circumference of the cyst.

Remarks: *Gonyaulacysta fragosa* is considered a taxonomic junior synonym according to Harker and Sarjeant (1975, p. 224) and Brideaux and McIntyre (1975, p. 33). *Scriniodinium campanula* was initially described from Hauterivian sediments from northwest Germany.

Size: Intermediate to large.

Occurrence: DC353, not present; VK117, 14490–14520ft. (Aptian); CH265, not present.

Genus *SENTUSIDINIUM* Sarjeant and Stover, 1978 emend. nov.

1978 *Sentusidinium* Sarjeant and Stover, p. 49–50.

1980 *Escharisphaeridia* Erkmen and Sarjeant, p. 62–63.

1989 *Sentusidinium* Sarjeant and Stover, 1978, emend. Courtinat, p. 192.

1989 *Barbatacysta* Courtinat, p. 185.

1989 *Pilosidinium* Courtinat, p. 190.

TYPE: *Sentusidinium rioultii* (Sarjeant, 1968) Sarjeant and Stover, 1978.

ORIGINAL DIAGNOSIS: Proximate to proximo-chorate cysts, subspherical to ellipsoidal; wall single-layered or apparently so, and bearing short, usually evenly distributed nontabular projections such as coarse granulae, tuberculae, verrucae, baculae, or spines with blunt, acuminate, capitate or branched tips. These surface features are generally isolate, but some adjacent projections may have confluent bases and/or interconnected tips. The length of the projections is consistently less than one-half, and typically less than one-third, of the shortest diameter of the cyst. Paratabulation is indicated mainly by the type A apical archaeopyle, whose principal suture is generally zigzag (although the angulation may not be readily apparent on uncompressed specimens). Short, longitudinally directed accessory archaeopyle sutures are frequently present, their positions denoting the anterior boundaries between precingular paraplates. The operculum is free, its constituent paraplates not differentiated. An equatorial alignment of some projections, delimiting a lightly ornamented or unornamented paracingulum, may sometimes be observed; but this is usually inconspicuous and may not be developed. Other indications of paratabulation are lacking. Overall size is generally less than 100 µm (Sarjeant and Stover, 1978, p. 49–50).

EMENDED DIAGNOSIS: Proximate to proximochorate, acavate gonyaulacacean dinoflagellate cysts with a subspheroidal to ovoidal central body. The autophragm may be psilate or bear densely, generally evenly distributed, nontabular sculptural elements that are usually of low to moderate relief and isolated. Archaeopyle apical, type (tA), normally with a detached operculum; deep accessory archaeopyle sutures between the six precingular plates are typically present.

EMENDED DESCRIPTION: Small to intermediate gonyaulacacean dinoflagellate cysts which may be proximate or proximochorate. The outline in dorso-ventral view is subspherical, oval or elongate oval and the cyst organisation is acavate. The autophragm is variable in thickness and is devoid of ornament or covered by numerous mostly isolated nontabular sculptural elements of low to medium relief. The ornamentation is highly variable between species: for example, the autophragm may be psilate, shagreenate, scabrate, granulate, papillate, postulate, verrucate, gemmate, tuberculate, pilate, clavate, baculate, echinate or setose (Williams *et al.,* 2000, pl. 24). Smooth (psilate and shagreenate) forms are less common than ornamented forms. The ornamentational elements are typically evenly distributed, nontabular and short. Rarely, the ornamentation may be concentrated locally. Occasionally the individual elements of the ornamentation may be proximally confluent; distal connections or trabeculae are extremely rare. Occasionally a kalyptra may be developed. The archaeopyle is apical, type (tA), with a free operculum, although in some cases the operculum does not always fully detach; accessory archaeopyle sutures between the precingular plates are typically well developed, particularly those of Late Jurassic age. The shapes of the archaeopyle and operculum and the angular principal archaeopyle suture are strongly indicative of the standard sexiform gonyaulacacean tabulation. Very rarely, the ornamentation may partially reflect and indicate the cingulum, but other indications of the tabulation are rarely if ever developed.

REMARKS: Sarjeant and Stover (1978, p. 49–50) derived the generic name *Sentusidinium* from the Latin sentus, meaning thorny. The genus was emended by Courtinat (1989, p., 192), who gave a more concise diagnosis than the original description of Sarjeant and Stover (1978) and presented a tabulation formula. Courtinat (1989) also stated that the ornamentation (he used the term processes) is both intratabular and sutural. However, sutural ornamentation in *Sentiusidinium* is extremely rare; only a few species exhibit alignment of the ornamentation to indicate the cingulum (e.g. *Sentusidinium fibrillosum*). The overwhelming majority of the low-to-medium-relief elements on *Sentusidinium* are nontabular

The genera *Barbatacysta*, *Escharisphaeridia* and *Pilosidinium* are considered to be taxonomic junior synonyms of *Sentusidinium*. The genus *Escharisphaeridia* was described by Erkmen and Sarjeant (1980) for psilate forms previously included in *Chytroeisphaeridia* that clearly have an apical archaeopyle. *Barbatocysta* was erected by Courtinat (1989, p.185) for 'bearded cysts' with a granular or verrucate autophragm, which have conical, subconical, buccinate, tubular or evexate intratabular processes that are distally acuminate, capitate, bifurcate or foliate. Courtinat (1989, p., 190) also described *Pilosidinium*, distinguishing it on the presence of capitate or bifurcate conical granules or spines, which may be interconnected and/or sutural. However, a review of the species in this genus indicates that the processes are consistently isolated and nontabular. Consequently, the generic concepts of both *Barbatocysta* and *Pilosidinium* fall within the circumscription of *Sentusidinium*.

The synonymy of *Barbatacysta*, *Escharisphaeridia* and *Pilosidinium* with *Sentusidinium* has clearly necessitated the transfer of their constituent species into *Sentusidinium*. A full taxonomic review can be found in Wood *et al., In press* (which is included as Appenix 1 in accordance with the personal use copyrights of Elsevier).

Sentusidinium agglutinatum (McIntyre and Brideaux, 1980) comb. nov.

Plate VI, Fig. a

1980 *Batiacasphaera agglutinata* McIntyre and Brideaux, p. 25, pl. 12, figs. 5–12.

Description: *Sentusidinium agglutinatum* is an intermediate, proximate, acavate cyst, which is subspherical in outline. The autophragm is densely granulate to sporadically rugulate, surrounded by a kalyptra. There is no discernible tabulation including no evidence of a cingulum and sulcus. Archaeopyle is apical.

Remarks: The species *Batiacasphaera agglutinata* was originally described from Valanginian strata of the Northwest Territories in Canada by McIntyre and Brideaux (1980). It is unusual in having a prominent kalyptra.

Size: Intermediate.

Occurrence: DC353, not present; VK117, 16140–16170ft. to 22890–22900ft. (Barremian–Kimmeridgian); CH265, not present.

Sentusidinium aptiense (Burger, 1980a) Burger, 1980b

Plate VI, Fig. b

1980a *Tenua aptiense* Burger, p. 76, pl. 23, figs. 1, 5; pl. 24, fig. 1.

1980 *Sentusidinium erythrocomum* Erkmen and Sarjeant, p. 56, 58, pl. 2, fig. 11; pl. 3, figs. 1–6, 8–11; pl. 4, fig. 5.

1980b *Sentusidinium aptiense* (Burger, 1980a) Burger, p. 277.

1986a *Batiacasphaera aptiensis* (Burger, 1980a) Kumar, p. 32.

1998 *Sentusidinium fungosum* Harding, 1990 ex Harding in Williams *et al.,* p. 557.

2000 *Kallosphaedridium dolomiticum* Torricelli, p. 261–262, pl. 4, figs. 9, 12.

2004 *Pilosidinium aptiense* (Burger, 1980a) Courtinat in Fauconnier and Masure, p. 447.

Description: *Sentusidinium aptiense* is an intermediate, proximochorate, acavate cyst, which is subspherical to elongate in outline. The autophragm is finely granulate and is characterised by its cover of distinctive nontabular hollow spines. The distal ends of the spines are acuminate or bifid. There is no discernible tabulation including no evidence of a cingulum and sulcus. Archaeopyle is apical.

Remarks: *Sentusidinium aptiense* was first described from the Early Cretaceous (Aptian) of the Surat Basin, Australia, by Burger (1980a) and is characterised by its cover of distinctive hollow spines. It is considered that *Kallosphaedridium dolomiticum*, *Sentusidinium erythrocomum* and *Sentusidinium fungosum* are taxonomic jurnior synonyms of *Sentusidinium aptiense* as they also exhibit hollow nontabular spines and are similar in all other aspects. *Tenua aptiense* and *Sentusidinium erythrocomum* were both published during February 1980, but the former was published first on February 15th (Burger, 1980a) and hence has priority over Erkmen and Sarjeant, 1980, which was published on February 29th (Geobios, 13:1). The stratigraphical range of *Sentusidinium aptiense* as now constituted is Middle Jurassic (Callovian) to Early Cretaceous (Aptian) and has a global Occurrence.

Size: Intermediate.

Occurrence: DC353, 17900–17960ft. to 23280–23340ft. (Aptian–Oxfordian); VK117, 13770–13800ft. to 22890–22900ft. (Aptian–Kimmeridgian); CH265, 9700–9710ft. to 11250–11260ft. (Aptian–Hauterivian).

Sentusidinium asymmetrum (Fenton *et al.,* 1980) Lentin and Williams, 1981

Plate VI, Fig. c

Basionym: *Tenua asymmetra* Fenton *et al.,* 1980, p. 160, 162, pl. 16, figs. 1, 3, 5.

1980 *Tenua asymmetra* Fenton *et al.,* p. 160, 162, pl. 16, figs. 1, 3, 5.

1981 *Sentusidinium asymmetrum* (Fenton *et al.,* 1980) Lentin and Williams, p. 253.

2004 *Pilosidinium asymmetrum* (Fenton *et al.,* 1980) Courtinat in Fauconnier and Masure, p. 447.

Description: *Sentusidinium asymmetricum* is an intermediate, proximate, acavate cyst, which is subspherical in outline. The autophragm is adorned with granulate to baculate ornamentation which is reduced towards the apex. There is no discernible tabulation including no evidence of a cingulum and sulcus. Archaeopyle is apical.

Remarks: The type material is from the latest Bajocian of Dorset, England, and the species is a reliable marker for the Bajocian–Bathonian transition (Fenton *et al.,* 1980; Feist-Burkhardt and Monteil, 1997). Prauss (1989) also reported *Sentusidinium* cf. *asymmetricum* from the Bajocian of northwest Germany. However, it is found much high in the stratigraphy in the EGoM, which suggests possible reworking in the Tithonian and Hauterivian in DC353.

Size: Intermediate.

Occurrence: DC353, reworked to 19700–19760ft. to 22160–22220ft. (Hauterivian–Tithonian); VK117, not present; CH265, not present.

Sentusidinium baculatum (Dodekova, 1975) Sarjeant and Stover, 1978

Plate VI, Fig. d

Basionym: *Tenua baculata* Dodekova, 1975, p. 28–29, pl. 6, figs. 1–3; text-fig. 7.

1975 *Tenua baculata* Dodekova, p. 28–29, pl. 6, figs. 1–3; text-fig. 7.

1978 *Sentusidinium baculatum* (Dodekova, 1975) Sarjeant and Stover, p. 50.

1978 *Tenua biornata* Jiabo, p. 52, pl. 22, figs. 21–29; pl. 23, figs. 1–4.

1981 *Kallosphaeridium biparatum* Lentin and Williams, p. 160.

1985 *Batiacasphaera biornata* (Jiabo, 1978) Jan du Chêne *et al.,* p. 15.

1988 *Batiacasphaera hystricosa* Mao Shaozhi and Norris, p .40, pl. 8, figs. 17–20.

1989 *Barbatacysta baculata* (Dodekova, 1975) Courtinat, p. 185.

1989 *Sentusidinium biornatum* (Jiabo, 1978) He Chengquan *et al.,* p. 67.

1989 *Batiacasphaera oligacantha* He Chengquan *et al.,* p. 39, pl. 7, fig. 13.

1992 *Sentusidinium biornatum* subsp. *conispicula* Liu Zhili and Zheng Yuefang in Liu Zhili *et al.,* p. 84–85, pl. 9, figs. 10–11.

2004 *Batiacasphaera biornata* subsp. *conispicula* (Liu Zhili and Zheng Yuefang in Liu Zhili *et al.,* 1992) Fensome and Williams, p 74.

Description: *Sentusidinium baculatum* is an intermediate, proximate, acavate cyst, which is subspherical in outline. The autophragm is covered with variable ornamentation, including irregular gemmae to baculae with sparse short spines either distally joined or closed. There is no discernible tabulation including no evidence of a cingulum and sulcus. Archaeopyle is apical.

Remarks: Dodekova (1975, p. 29) described the ornamentation of *Sentusidinium baculatum* (as *Tenua baculata*) from the Middle Jurassic of Bulgaria, as follows: The processes are rare, short, and of varying types (also see Dodekova, 1975, text-fig 7). Subsequently Sarjeant and Stover (1978) transferred it to *Sentusidinium*, and as such is retained in this genus. Courtinat (1989) transferred the species to *Barbatacysta*. However, *Barbatacysta* is now considered a taxonomic junior synonym of *Sentusidinium*. Henceforth, *Sentusidinium baculatum* is the senior synonym of *Batiacasphaera biornata, Batiacasphaera biornata* subsp. *conispicula*, *Batiacasphaera hystricosa* and *Batiacasphaera oligacantha*. The stratigraphical range of *Sentusidinium baculatum* is Middle Jurassic (Bathonian) to Late Eocene.

Size: Intermediate.

Occurrence: DC353, 17600–17660ft. to 23760–23820ft. (Albian–Oxfordian); VK117, 12600–12630ft. to 23990–24000ft. (Albian–Undifferentiated strata); CH265, 7750–7760ft. to 11600–11610ft. (Aptian–Valanginian).

Sentusidinium capillatum (Davey, 1975) Lentin and Williams, 1981

PLATE VI, Fig. e

1975 *Tenua capillata* Davey, p. 155–156, pl. 2, figs. 4, 7.

1977 *Canningia spumosa* Brideaux, p. 12, pl. 3, figs. 9–14.

1980a *Membranosphaera romaensis* Burger, p. 74, pl. 27, figs. 1–3.

1980b *Kallosphaeridium*? *romaense* (Burger, 1980a) Burger, p. 277.

1981 *Sentusidinium capillatum* (Davey, 1975) Lentin and Williams, p. 253.

1981 *Batiacasphaera spumosa* (Brideaux, 1977) Below, p. 26.

1983 *Sentusidinium filiatum* Davies, p. 29–30, pl. 10, figs. 5–6, 8–9; text–fig. 27.

1989 *Pilosidinium filiatum* (Davies, 1983) Courtinat, p. 191.

1992 *Pilosidinium cactosum* Quattrocchio and Sarjeant, p. 91–92.

2004 *Pilosidinium capillatum* Courtinat in Fauconnier and Masure 2004, p. 448.

Description: *Sentusidinium capillatum* is an intermediate, proximate, acavate cyst, which is subspherical to subovoidal in outline. The thin autophragm is setose, being very densely covered by short (c. 2 μm) slender spines, with varying tips. There is no discernible tabulation including no evidence of a cingulum and sulcus. Archaeopyle is apical.

Remarks: *Sentusidinium capillatum* is considered to be a taxonomic senior synonym of *Batiacasphaera spumosa*, *Kallosphaeridium*? *romaense*, *Pilosidinium cactosum* and *Pilosidinium filatum*. The overall stratigraphical range of *Sentusidinium capillatum* is Late Jurassic to Late Cretaceous.

Size: Intermediate.

Occurrence: DC353, 17600–17660ft. to 22860–22920ft. (Albian–Oxfordian); VK117, 12600–12630ft. to 22890–22900ft. (Albian–Kimmeridgian); CH265, 7750–7760ft. to 11250–11260ft. (Aptian–Hauterivian).

Sentusidinium explanatum Bujak in Bujak *et al.,* 1980, comb. nov.

Plate VI, Fig. f

Basionym: *Chytroeisphaeridia explanata* Bujak in Bujak *et al.,* 1980, p. 44, pl. 13, figs. 13–14.

1980a *Canningia minor* Cookson and Hughes, 1964 var. psilata Burger, p. 71, pl. 25, figs. 5–11.

1980 *Chytroeisphaeridia explanata* Bujak in Bujak *et al.,* p. 44, pl. 13, figs. 13–14.

1983 *Batiacasphaera explanata* (Bujak in Bujak *et al.,* 1980) Islam, p. 235.

1985 *Chytroeisphaeridia minor* (Cookson and Hughes, 1964) Morgan, 1980 subsp. psilata (Burger, 1980a) Lentin and Williams, p. 58.

1986b *Escharispharidia psilata* Kumar, p. 383, 385, pl. 2, fig. 2; text-fig. 3.

1988 *Escharisphaeridia laevigata* Smelror, p. 152–153, figs. 10G–H.

1989 *Kallosphaeridium*? *helbyi* Lentin and Williams, 1989 subsp. *psilatum* (Burger, 1980a) Lentin and Williams, p. 206.

1989 *Kallosphaeridium inornatum* Prauss, p. 41–42, pl. 5, figs. 4–6; pl. 6, fig. 18; text-fig. 17 (an illegitimate name; see below)

1993 *Kallosphaeridium praussii* Lentin and Williams, p. 365.

1997 *Batiacasphaera laevigata* (Smelror, 1988) Feist-Burkhardt and Monteil, p. 40.

Description: *Sentusidinium explanatum* is an intermediate, proximate, acavate cyst, which is subspherical to elongate in outline. The thin psilate autophragm is devoid of any ornamentation. There is no discernible tabulation including no evidence of a cingulum and sulcus. Archaeopyle is apical.

Remarks: This taxon was first described from the Lower Cretaceous of the Surat Basin, eastern Australia by Burger (1980a) as a variety of *Canningia minor*. It was elevated to subspecies status by Lentin and Williams (1985). It was raised to species rank by Kumar (1986b), but not before other species had been proposed that it is considered synonymous with. Among these synonyms, the earliest at specific rank is *Chytroeisphaeridia explanata* Bujak in Bujak *et al.,* 1980, which is therefore transfered to *Sentusidinium* as the correct name for this taxon at specific rank. (*Canningia minor* var. *psilatum* and *Batiacasphaera explanata* were both published in 1980; the former in a paper issued February 15th and the latter in December; but the latter name has priority at species rank.)

Sentusidinium explanatum is considered to the taxonomic senior synonym of *Batiacasphaera laevigata* (as first proposed by Poulsen, 1996, p. 80) and *Kallosphaeridium praussii*, (a substitute name for *Kallosphaeridium inornatum* Prauss) as well as *Canningia minor* var. *psiliata* (= *Escharisphaeridia psilata*); all of these taxa lack ornamentation.

The stratigraphical range of *Sentusidinium explanatum* is Middle Jurassic (Aalenian) to Late Eocene and the species has a global Occurrence.

Size: Intermediate.

Occurrence: DC353, 17600–17660ft. to 23760–23820ft. (Albian–Oxfordian); VK117, 12600–12630ft. to 22890–22900ft. (Albian–Kimmeridgian); CH265, 7750–7760ft. to 11600–11610ft. (Aptian–Valanginian).

Sentusidinium ringnesiorum (Manum and Cookson, 1964) comb. nov.

Plate VI, Fig. g

Basionym: Canningia ringnesii Manum and Cookson, 1964, p. 15, pl. 2, fig. 10.

1964 *Canningia ringnesii* Manum and Cookson, p. 15, pl. 2, fig. 10.

1968 *Chytroeisphaeridia pocockii* Sarjeant, p. 230, pl. 3, fig. 9.

1972 *Chytroeisphaeridia mantelli* Gitmez and Sarjeant, p. 186, pl. 1, figs. 3–4; pl. 12, fig. 3.

1972 *Meiourogonyaulax dicryptos* Gitmez and Sarjeant, p. 225–226, pl. 7, fig. 6; text fig. 22.

1975 *Batiacasphaera macrogranulata* Morgan, p. 162, pl. 2, figs. 3a–d.

1976 *Lithodinia dicrypta* (Gitmez and Sarjeant, 1972) Gocht, p. 334.

1976 *Membranosphaera granulata* Norvick, p.79–80, pl. 11, fig. 9; pl. 12, fig. 3.

1978 *Kallosphaeridium*? *granulatum* (Norvick, 1976) Stover and Evitt, p.59.

1979d *Lithodinia pocockii* (Sarjeant, 1968) Davey, p. 217.

1980 *Escharisphaeridia pocockii* (Sarjeant, 1968) Erkmen and Sarjeant, p. 62.

1980 *Batiacasphaera ringnesiorum* (Manum and Cookson, 1964) Dörhöfer and Davies, p. 40.

1980 *Chytroeisphaeridia ringnesiorum* (Manum and Cookson, 1964) Morgan, p. 19.

1980a *Membranosphaera norvickii* Burger, p. 73–74, pl. 26, figs. 7–8.

1980 *Chytroeisphaeridia rugosa* Courtinat in Courtinat and Gaillard, p. 15–16, pl. 1, fig. 12; pl. 2, fig. 1; text fig. 2d.

1980 *Chytroeisphaeridia granulata* Courtinat in Courtinat and Gaillard, p. 13–14, pl. 1, figs. 4, 6; text fig. 2b.

1981 *Kallosphaeridium norvickii* (Burger, 1980a) Lentin and Williams, p. 161.

1981 *Canningia dicrypta* (Gitmez and Sarjeant, 1972) Below, p. 31.

1983 *Escharisphaeridia rudis* Davies, p. 28, pl. 10, figs. 7, 10–18; text fig. 25.

1987 *Escharisphaeridia granulata* (Courtinat in Courtinat and Gaillard, 1980) Stover and Williams, p. 89.

1987 *Kallosphaeridium*? *ringnesiorum* (Manum and Cookson, 1964) Helby, p. 324–325.

1988 *Escharisphaeridia senegalensis* Jan du Chêne, p. 155, pl. 15, figs. 1–8.

1989 *Escharisphaeridia mantelli* (Gitmez and Sarjeant, 1972) Courtinat, p. 180.

1989 *Batiacasphaera norvickii* (Burger, 1980a) Lentin and Williams, p. 35.

1989 *Escharisphaeridia rugosa* (Courtinat in Courtinat and Gaillard, 1980) Courtinat, p. 181.

1989 *Escharisphaeridia gaillardii* Courtinat, p. 178–179, pl. 17, fig. 7; pl. 20, figs. 5, 8; pl. 21, fig. 10; pl. 22, fig. 13; pl. 23, figs. 2, 7–8; text fig. 78A.

1989 *Batiacasphaera henanensis* He Chengquan *et al.,* p. 38, pl. 7, fig. 10.

1990 *Batiacasphaera mica* Harding, p. 48, pl. 25, figs. 10–19 ex Harding in Williams *et al.,* 1998, p 67.

1991 *Batiacasphaera sparsa* He Chengquan, p. 53–54, pl. 6, fig. 4.

1991 *Batiacasphaera tuberculata* He Chengquan, p. 54, pl. 6, fig. 2.

1993 *Batiacasphaera xinjiangensis* Lentin and Williams, p. 57.

1993 *Escharisphaeridia dicrypta* (Gitmez and Sarjeant, 1972) Williams *et al.,* p. 57.

1994 *Sentusidinium spatiosum* Dodekova, p. 33, pl. 5, figs. 6–8, 11.

1997 *Batiacasphaera granofoveolata* Pan Zhaoren in Xu Jinli *et al.,* p. 43, pl. 39, fig. 1; name not validly published, as there was no English or Latin description.

2009 *Batiacasphaera granofoveolata* Pan Zhaoren in Xu Jinli *et al.,* 1997, ex He Chengquan *et al.,* p. 649.

2009 *Batiacasphaera macropyla* He Chengquan *et al.,* p. 644, pl. 56, fig. 6.

Description: *Sentusidinium ringnesiorum* is an intermediate, proximate, acavate cyst, which is subspherical in outline. The autophragm is relatively thick and robust, covered in a highly irregular granular ornamentation (Davies, 1983, fig. 25). There is no discernible tabulation including no evidence of a cingulum and sulcus. Archaeopyle is apical.

Remarks: *Sentusidinium ringnesiorum* was first described, as *Canningia ringnesii*, from the Late Cretaceous of Arctic Canada by Manum and Cookson (1964). (The epithet is correctly rendered as "ringnesiorum", rather than "ringnesii", because the species was named avowedly for the Ringnes brothers, not for an individual). The species, and its synonyms, have been attributed to a total of nine genera, and as such has 19 taxonomic junior synonyms. After reviewing the published descriptions and illustrations of the taxonomic junior synonyms, it is considered that they cannot be consistently separated. *Sentusidinium ringnesiorum* has a long stratigraphical range, from the Jurassic through to the Eocene, reflecting its simple morphology.

Size: Intermediate.

Occurrence: DC353, 17720–17780ft. to 23760–23820ft. (Albian–Oxfordian); VK117, 12600–12630ft. to 23990–24000 (Albian–Undifferentiated strata); CH265, 9640–9650ft. to 11600–11610ft. (Aptian–Valanginian).

Genus *TRICHODINIUM* Eisenack and Cookson, 1960

1960 *Trichodinium* Eisenack and Cookson, p. 5.

TYPE: Eisenack and Cookson, 1960, pl. 2, fig. 4, as *Trichodinium pellitum*.

SYNOPSIS: The genus *Trichodinium* is composed of large, proximochorate, acavate cysts. They have a subspherical to ellipsoidal outline, with a short apical protrusion. The autophragm is densely ornamented, with spines or tubercules. Paratabulation is indicated by the traverse furrow of the paracingulum and the precingular archaeopyle.

Trichodinium ciliatum (Gocht, 1959) Eisenack and Klement, 1964

Plate VII, Fig. c

1959 *Apteodinium ciliatum* Gocht, p. 65, pl. 8, figs. 5–6.

1964 *Trichodinium ciliatum* (Gocht, 1959) Eisenack and Klement, p. 811.

Description: *Trichodinium ciliatum* is a large, proximate, acavate cyst, with a subspherical outline. The shagreenate autophragm is adorned with tubercules. There is a slight apical protuberance where the tubercules are slightly longer. There is no discernible paratabulation. The archaeopyle is precingular and the paracingulum can be evidenced by two parallel rows of tubercules that circumvent the cyst.

Remarks: This species was first recorded from the Late Hauterivian of northwest Germany.

Size: Large.

Occurrence: DC353, 18920–18980ft. to 20120–20180ft. (Barremian–Hauterivian); VK117, 17490–17520ft. (Hauterivian) with reworking at 12600–12630ft. (Albian); CH265, not present.

Trichodinium scarburghense (Sarjeant, 1964) Williams *et al.,* 1993

Plate VII, Fig. d

1964 *Gonyaulacysta scarburghensis* Sarjeant, p. 472–473.

1985 *Acanthaulax scarburghensis* (Sarjeant, 1964) Lentin and Williams, p. 2.

1986 *Liesbergia scarburghensis* (Sarjeant, 1964) Berger, p. 343.

1993 *Trichodinium scarburghense* (Sarjeant, 1964) Williams *et al.,* p. 57.

Description: *Trichodinium scarburghense* is a large, proximate, acavate cyst, with a subspherical to elongate outline. The reticulate autophragm is adorned with short nontabular spines, which linked by trabeculae at their distal tips. The apical horn is short, narrow and covered in short spines. There is no discernible paratabulation, and the paracingulum was not seen on specimens recovered in this study. The archaeopyle is precingular

Remarks: *Acanthaulax senta* is a taxonomic junior synonym according to Berger (1986, p. 343). *Trichodinium scarburghense* was initially described from the Late Callovian–Early Oxfordian of Yorkshire, England.

Size: Large.

Occurrence: DC353, not present; VK117, 20080–20090 to 20590–20600 (Berriasian–Tithonian); CH265, not present.

Trichodinium speetonense Davey, 1974

Plate VII, Fig. e

1974 *Trichodinium speetonense* Davey, p. 63, pl. 7, figs. 2–3. Retained by Lentin and Williams (1981, p. 281).

1981 *Occisucysta*? *speetonensis* (Davey, 1974) Below, p. 60.

Description: *Trichodinium speetonense* is a large, proximate, acavate cyst, with a subspherical outline. The shagreenate to finely granulate autophragm is adorned with short nontabular acicular spines. The apical horn is short and narrow, almost antenna-like. There is no discernible paratabulation. The archaeopyle is precingular and the paracingulum can be evidenced by two parallel rows of spines that encircle the cyst.

Remarks: This species was first described from the Barremian of Yorkshire, England.

Size: Intermediate.

Occurrence: DC353, not present; VK117, 13770–13800ft. to 18240–18270ft. (Aptian–Hauterivian); CH265, not present.

Family AREOLIGERACEAE Evitt, 1963

Genus *ADNATOSPHAERIDIUM* Williams and Downie, 1966

1966 *Adnatosphaeridium* Williams and Downie, p. 215.

TYPE: Williams and Downie, 1966, pl. 24, fig. 7; text-fig. 56, as *Adnatosphaeridium vittatum*.

SYNOPSIS: The genus *Adnatosphaeridium* is composed of intermediate to large, chorate cysts, with a subspherical outline. The finely ornamented autophragm is punctuated by solid or hollow, tubular to flared intratabular processes. Adjacent processes may be distally connected by solid or perforated trabeculae. Dorso-ventral areas lack any ornamentation and processes. There is no discernible paratabulation. The archaeopyle is apical.

Adnatosphaeridium caulleryi (Deflandre, 1939) Williams and Downie, 1969

Plate V, Fig. t

1939 *Hystrichosphaeridium caulleryi* Deflandre, p. 189, pl. 11, figs. 2–3.

1961 *Cannosphaeropsis caulleryi* (Deflandre, 1939) Sarjeant, p. 103.

1969 *Adnatosphaeridium caulleryi* (Deflandre, 1939) Williams and Downie, p. 17. Retained by Stancliffe and Sarjeant (1990, p. 200)

1989 *Polystephanephorus caulleryi* (Deflandre, 1939) Courtinat, 1989, p. 171.

Description: *Adnatosphaeridium caulleryi* is a chorate cyst. The shagreenate autophragm is spherical, while the processes pull away forming radial processes which vary greatly at their distal ends, some of which are connecting. The dorsal and ventral sides of the cyst are devoid from processes. Tabulation is indiscernible. The archaeopyle is apical.

Remarks: This species was first described form the Early Oxfordian of France.

Size: Intermediate to large.

Occurrence: DC353, 22040–22100ft. to 23760–23820ft. (Tithonian–Oxfordian); VK117, not present; CH265, not present.

Genus *CERBIA* Below, 1981

1981 *Cerbia* Below, p. 8.

TYPE: Davey and Verdier, 1974, pl. 92, figs. 1, 4, as *Cyclonephelium tabulatum*.

SYNOPSIS: The genus *Cerbia* is composed of small to large, proximate to proximochorate, lenticular cysts. They have a subpentagonal outline, formed from a weak apical bulge and two asymmetrical antapical lobes, forming an indentation in the hypocyst. The autophragm is either psilate or sculpted. The paratabulation is indicated by penitabular ornamentation. The archaeopyle is apical.

Cerbia magna Duxbury 2001

Plate VII, Fig. a

2001 *Cerbia magna* Duxbury, p.101–102, fig. 4, nos. 1–4.

Description: *Cerbia magna* is a large, proximate, acavate cyst, with a subcircular outline and low apical, lateral and antapical prominences. The autophragm is finely granulate, adorned with either nontabular or penitabular short spines. The paratabulation is occasionally observable due to the arrangement of the ornament. The archaeopyle is apical.

Remarks: This species was first described from the Late Barremian of the central North Sea.

Size: Large.

Occurrence: DC353, 17660–17720ft. to 19460–19520ft. (Aptian–Barremian); VK117, 16770–16800ft. to 18990–19020ft. (Barremian–Valanginian); CH265, not present.

Cerbia tabulata (Davey and Verdier, 1974) Below, 1981

Plate VII, Fig. b

1974 *Cyclonephelium tabulatum* Davey and Verdier, p. 630, 632, pl. 92, figs. 1–4; pl. 93, fig. 6.

1977 *Canninginopsis tabulata* (Davey and Verdier, 1974) Duxbury, p. 27.

1981 *Cerbia tabulata* (Davey and Verdier, 1974) Below, p. 9.

Description: *Cerbia tabulata* is an intermediate, proximate, acavate cyst, with a subcircular outline. The autophragm is finely granulate, adorned with penitabular short spines. The paratabulation is ocaionally observable due to the arrangement of the ornament. The archaeopyle is apical.

Remarks: This species was initially recorded from the Aptian of south east France.

Size: Intermediate.

Occurrence: DC353, 17900–17960ft. to 18260–18320ft. (Aptian–Barremian); VK117, 17490–17520ft. to 18540–18570ft. (Hauterivian); CH265, 7750–7760ft. to 10250–10260ft. (Aptian).

Genus *CIRCULODINIUM* Alberti, 1961

1961 *Circulodinium* Alberti, p. 28

TYPE: Alberti, 1961, pl. 4, fig. 10, as *Circulodinium hirtellum*.

SYNOPSIS: The genus *Circulodinium* is composed of small to large, proximate to proximochorate, lenticular cysts. They have a subspherical outline, with a small or weakly developed apical prominence and two asymmetrical antapical lobes, forming an indentation in the hypocyst. With the exception of the mid dorsal and ventral areas and the antapical concavity the autophragm is ornamented with short solid spines with variable tips. There is no discernible paratabulation. The archaeopyle is apical.

Circulodinium attadalicum (Cookson and Eisenack, 1962) Helby, 1987

Plate VI, Fig. h

1962 *Cyclonephelium*? *attadalicum* Cookson and Eisenack, p. 495, pl. 5, figs. 12–15.

1974 *Aptea attadalica* (Cookson and Eisenack, 1962) Davey and Verdier, p. 643.

1978 *Canningia attadalica* (Cookson and Eisenack, 1962) Stover and Evitt, p.24–25.

1987 *Circulodinium attadalicum* (Cookson and Eisenack, 1962) Helby, p. 324–325.

Description: *Circulodinium attadalicum* is an intermediate, proximate, acavate cyst. It has a subcircular to slightly polygonal outline with a small asymmetrical antapical prominence. This species has a granular autophragm with capitate nontabular spines, which are quite variable in both length and width. The ornamentation is reduced in both the mid dorso-ventral and antapical concavity areas. The archaeopyle is apical, type 4A, with a detached operculum. There is no discernible paracingulum or parasulcus.

Remarks: This species was originally described from the Aptian–Albian of Australia.

Size: Intermediate.

Occurrence: DC353, 17600–17630ft. to 20120–20180ft. (Albian–Valanginian); VK117, 12600–12630ft. to 18990–19020ft. (Albian–Valanginian) three specimens present at 22890–22900ft.(Tithonian); CH265, 7750–7760ft. to 11600–11610ft. (Aptian–Valanginian).

Circulodinium distinctum (Deflandre and Cookson, 1955) Jansonius, 1986

PLATE VI, Fig. i

1955 *Cyclonephelium distinctum* Deflandre and Cookson, p. 285–286, pl. 2, fig. 14; text-figs. 47–48.

1986 *Circulodinium distinctum* (Deflandre and Cookson, 1955) Jansonius, p. 204

Description: This species is an intermediate, proximate, acavate cyst. It has a subcircular outline with a small asymmetrical antapical prominence. *Circulodinium distinctum* has a granular autophragm surmounted with short projections; which are distally buccinate, capitate, branched or tapering. Occasionally the projections are joined to one another to form short lamellae. The ornamentation is reduced in both the mid dorso-ventral and antapical concavity areas. The archaeopyle is apical, type 4A, with a detached operculum. There is no discernible paracingulum or parasulcus.

Remarks: *Circulodinium distinctum* was initially described from the Coniacian–Danian of Australia. *Circulodinium deflandrei* was considered a taxonomic junior synonym by Millioud (1969, p. 427) and Harker and Sarjeant in Harker *et al.,* (1990, p. 80). However, Fauconnier and Londeix in Fauconnier and Masure (2004, p. 114) retained this species.

Size: Intermediate.

Occurrence: DC353, 17600–17630ft. to 23340–23400ft. (Albian–Oxfordian); VK117, 12600–12630ft. to 23990–24000ft. (Albian–Undifferentiated strata); CH265, 7750–7760ft. to 11600–11610ft. (Aptian–Valanginian).

Circulodinium latoaculeum (Yun Hyesu, 1981) Prince *et al.,* 1999

Plate VI, Fig. j

1981 *Cleistosphaeridium multifurcatum* subsp. latoaculeum Yun Hyesu, p. 42–43, pl. 11, figs. 17–19.

1993 *Heterosphaeridium latoaculeum* (Yun Hyesu, 1981) Islam, p. 84.

1999 *Circulodinium latoaculeum* (Yun Hyesu, 1981) Prince *et al.,* p. 160.

Description: *Circulodinium latoaculeum* is an intermediate, proximochorate, acavate cyst, with a subcircular outline. This species has a granular autophragm surmounted with long projections; which are distally buccinate, flared, denticulate, or digitate. The ornamentation is reduced in the middorsoventral areas. The archaeopyle is apical, type 4A, with a detached operculum. There is no discernible paracingulum or parasulcus.

Remarks: This species was first described from the Early Santonian of Germany.

Size: Intermediate.

Occurrence: DC353, 18020–18080ft. to 18680–18740ft. (Aptian–Barremian); VK117, 15240–15270ft. (Aptian); CH265, not present.

Circulodinium*? *araneosum (Brideaux, 1977) Fauconnier in Fauconnier and Masure 2004

Plate VI, Fig. k

1977 *Cleistosphaeridium araneosum* Brideaux, p. 22–23, pl. 9, figs. 1–3.

1993 *Heterosphaeridium araneosum* (Brideaux, 1977) Islam, p. 84.

2004 *Circulodinium*? *araneosum* (Brideaux, 1977) Fauconnier in Fauconnier and Masure, p. 115.

Description: This species is a small to intermediate, proximate, acavate cyst. It has a subcircular outline, with a small asymmetrical antapical prominence present of a few specimens. *Circulodinium*? *araneosum* has a granular autophragm with echinate nontabular ornamentation, which is reduced in the mid dorso-ventral areas. The archaeopyle is apical, type 4A, with a detached operculum. There is no discernible paracingulum or parasulcus.

Remarks: *Circulodinium*? *araneosum* was first described from the Aptian–Albian of Canada.

Size: Intermediate.

Occurrence: DC353, 17660–17720ft. to 19940–20000ft. (Albian–Hauterivian); VK117, 13770–13800ft. to 18990–19020ft. (Aptian–Valanginian); CH265, 9640–9650ft. to 10800–10810ft. (Aptian–Hauterivian).

Genus *CYCLONEPHELIUM* Deflandre and Cookson, 1955

1955 *Cyclonephelium* Deflandre and Cookson, p. 285.

TYPE: Deflandre and Cookson, 1955, pl. 2, fig. 12, as *Cyclonephelium compactum*.

SYNOPSIS: The genus *Cyclonephelium* is composed of intermediate to large, proximate to proximochorate, lenticular cysts. They have a subspherical outline, with a small or weakly developed apical prominence and one left sided antapical lobe. The antapex is occasionally indented. The autophragm is covered in a variety of ornamentation and numerous spines. The spines viewed from the margin, produce interconnecting crests. There is reduced ornamentation in the mid dorsal and ventral regions of the cyst. There is no discernible paratabulation. The archaeopyle is apical.

Cyclonephelium clathromarginatum Cookson and Eisenack, 1962

Plate VI, Fig. l

1982b *Cyclonephelium clathromarginatum* Cookson and Eisenack, p. 495, pl. 6, figs. 1–4.

Description: *Cyclonephelium clathromarginatum* is an intermediate to large, proximochorate, acavate cyst, which is subspherical in outline. The autophragm is densely granular, and has projections around the circumference of the cyst. The projections are short with adjoined buccinate tips. There is no discernible tabulation including no evidence of a cingulum and sulcus. Archaeopyle is apical.

Remarks: This species was initially described from the Late Albian–Cenomanian of Australia.

Size: Intermediate to large.

Occurrence: DC353, not present; VK117, 16770–16800ft. to 20880–20890ft. (Barremian–Tithonian); CH265, 10250–10260ft. (Aptian).

Cyclonephelium compactum Deflandre and Cookson, 1955

Plate VI, Fig. m

1955 *Cyclonephelium compactum* Deflandre and Cookson, p. 285, pl. 2, figs. 11–13; text-figs. 44–46.

Description: *Cyclonephelium compactum* is a proximate, acavate cyst, with a subspherical outline. The autophragm is granular with marginate linear projections. The projections are short and are taeniate, murate, or distally connected. The dorsal and ventral regions of the cyst are devoid of projections and have reduced ornamentation. Occasionally the left antapical horn is more pronounced, creating an indent in the antapex, which has reduced or no ornament. There is no discernible tabulation including no evidence of a cingulum and sulcus. Archaeopyle is apical.

Remarks: *Cyclonephelium compactum* was first described from the Albian–Santonian of Australia.

Size: Intermediate.

Occurrence: DC353, 18020–18080ft. to 19520–19580ft. (Aptian–Hauterivian); VK117, 16560–16590ft. to 22890–22900ft. (Barremian–Kimmeridgian); CH265, 10800–10810ft. to 11250–11260ft. (Barremian–Hauterivian).

Cyclonephelium formosum Iosifova, 1992

Plate VI, Fig. n

1992 *Circulodinium formosum* Iosifova, p. 61, pl. 9, figs. 3a–c; text-figs. 1c–d.

2004 *Cyclonephelium formosum* (Iosifova, 1992) Fauconnier in Fauconnier and Masure 2004, p. 146.

Description: *Cyclonephelium formosum* is a proximochorate, acavate cyst, with a subspherical outline. The autophragm is densely granular with marginate linear projections. The projections are long and are distally flared or bifid. The dorsal and ventral regions of the cyst have reduced ornamentation and no projections. There is no discernible tabulation including no evidence of a cingulum and sulcus. Archaeopyle is apical.

Remarks: *Cyclonephelium formosum* was originally described from the Valanginian of Russia.

Size: Intermediate.

Occurrence: DC353, not present; VK117, 17340–17370ft. to 19800–19830ft. (Barremian–Berriasian); CH265, not present.

Cyclonephelium hughesii Clarke and Verdier, 1967

Plate VI, Fig. o

1967 *Cyclonephelium hughesii* Clarke and Verdier, 1967, p. 21–22, pl. 2, fig. 6; text-fig. 8.

Description: *Cyclonephelium hughesii* is a proximochorate, acavate cyst, with a subspherical outline. The autophragm is granular with marginate projections. The projections are broad and short, with distally flared and denticulate terminations. The dorsal and ventral regions of the cyst are devoid of projections and have reduced ornamentation. There is no discernible tabulation including no evidence of a cingulum and sulcus. Archaeopyle is apical.

Remarks: *Cyclonephelium hughesii* was initially described from the Cenomanian–Early Turonian of Russia.

Size: Intermediate.

Occurrence: DC353, 17660–17720ft. to 17720–17780ft. (Aptian–Albian boundary); VK117, not present; CH265, not present.

Cyclonephelium inconspicuum Duxbury, 1983

Plate VI, Fig. p

1983 *Cyclonephelium inconspicuum* Duxbury, p. 32–33, pl. 3, fig. 6.

Description: *Cyclonephelium inconspicuum* is a proximate, acavate cyst, with a subspherical outline. The autophragm is reticulate, with the dorsal and ventral regions having reduced ornament. The left antapical horn is more pronounced, creating an indent at the antapex. There is no discernible tabulation including no evidence of a cingulum and sulcus. Archaeopyle is apical.

Remarks: *Cyclonephelium inconspicuum* was first described from the Late Aptian of southern England.

Size: Intermediate.

Occurrence: DC353, 17600–17660ft. to 19520–19580ft. (Albian–Hauterivian); VK117, 15840–15870ft. to 17340–17370ft. (Barremian); CH265, 9640–9650ft. to 11250–11260ft. (Aptian–Hauterivian).

Cyclonephelium longispinatum (Davey, 1978) Fauconnier in Fauconnier and Masure 2004

Plate VI, Fig. q

1978 *Cyclonephelium distinctum* subsp. *longispinatum* Davey, p. 894, pl. 3, figs. 4, 7–8.

1989 *Circulodinium distinctum* subsp. *longispinatum* (Davey, 1978) Lentin and Williams, p. 63.

2004 *Cyclonephelium longispinatum* (Davey, 1978) Fauconnier in Fauconnier and Masure, p. 146.

Description: *Cyclonephelium longispinatum* is a proximochorate, acavate cyst, with a subspherical outline. The autophragm is granular with long projections. The projections vary greatly in size and shape, which are distally flared. The dorsal and ventral regions of the cyst are devoid of projections and have reduced ornamentation. There is a slight indent in the antapex which has reduced or no ornament. There is no discernible tabulation including no evidence of a cingulum and sulcus. Archaeopyle is apical.

Remarks: This species was first described from the Turonian of offshore South Africa, and raised to specific rank by Fauconnier in Fauconnier and Masure 2004.

Size: Intermediate to large.

Occurrence: DC353, not present; VK117, 13770–13800ft. (Aptian); CH265, not present.

Cyclonephelium maugaad Below, 1981

Plate VI, Fig. r

1981 *Cyclonephelium maugaad* Below, p. 15, pl. 11, figs. 2, 3a–b; pl. 15, fig. 20.

Description: *Cyclonephelium maugaad* is a proximate, acavate cyst, with a subspherical outline. The autophragm is granular with marginate projections. The projections are short and have varied distal teminations. The dorsal and ventral regions of the cyst are devoid of projections and have reduced ornamentation. The antapex is rounded. There is no discernible tabulation including no evidence of a cingulum and sulcus. Archaeopyle is apical.

Remarks: This species was originally described from the Hauterivian–Aptian of south-west Morocco.

Size: Intermediate.

Occurrence: DC353, 17660–17720ft. to 18080–18140ft. (Albian–Aptian) with caving at 23340–23400ft. (Oxfordian); VK117, 12600–12630ft. to 22790–22800ft. (Albian–Tithonian); CH265, 11250–11260ft. to 11600–11610ft. (Hauterivian–Valanginian).

Cyclonephelium vannophorum Davey, 1969a

Plate VI, Fig. s

1969a *Cyclonephelium vannophorum* Davey, p. 168, 170, pl. 9, fig. 3; pl. 11, figs. 11–12; text-fig. 16E.

Description: *Cyclonephelium vannophorum* is a proximate, acavate cyst, with a subspherical outline. The autophragm is granular with marginate linear projections. The projections vary greatly in size and shape, ranging from enlarge granules to short narrow projections which are distally flared, and on occasion distally connected. The dorsal and ventral regions of the cyst are devoid of projections and have reduced ornamentation. The left antapical horn is more pronounced, as such creates an indent in the antapex which has reduced or no ornament. However, where the antapical horn is enlarged and similarly where the right antapical horn should be located there are localised projection height increases. There is no discernible tabulation including no evidence of a cingulum and sulcus. Archaeopyle is apical.

Remarks: *Cyclonephelium vannophorum* was initially described from the Cenomanian.

Size: Intermediate.

Occurrence: DC353, 17600–17660ft. to 20840–20900ft. (Albian–Valanginian); VK117, 12600–12630ft. to 20180–20190ft. (Albian–Berriasian); CH265, 7750–7760ft. to 11250–11260ft. (Aptian–Hauterivian).

Suborder UNCERTAIN

Family UNCERTAIN

Subfamily UNCERTAIN

Genus *CASSICULOSPHAERIDIA* Davey, 1969a

1969a *Cassiculosphaeridia* Davey, p. 141.

TYPE: Davey, 1969a, pl. 4, fig. 3, as *Cassiculosphaeridia reticulata*.

SYNOPSIS: The genus *Cassiculosphaeridia* is composed of intermediate, proximate cysts. They have a subspherical outline. The autophragm is covered in low ridges that form a reticulum. There is no discernible paratabulation. The archaeopyle is apical.

Cassiculosphaeridia magna Davey, 1974

Plate VII, Fig. f

1974 *Cassiculosphaeridia magna* Davey, p. 46, pl. 1, figs. 3–7. Retained by Slimani (1994, p. 100).

1989 *Valensiella magna* (Davey, 1974) Courtinat, p. 183.

Description: *Cassiculosphaeridia magna* is an intermediate proximate, acavate cyst, which is subspherical to ovoidal in outline. Its autophragm is ornamented with a tightly packed reticulum. The luminae are small, surrounded by a delicate muri. Paracingulum and parasulcus are absent. There is no discernible paratabulation. Archaeopyle is apical.

Remarks: This species was originally described from the Early–Late Barremian of East Yorkshire.

Size: Intermediate.

Occurrence: DC353, 19520–19580ft. to 20000–20060ft. (Hauterivian) with caving between 21800–21860ft. to 22100–22160ft. (Berriasian–Tithonian); VK117, not present; CH265, not present.

Cassiculosphaeridia*? *tocheri Schiøler, 1993

Plate VII, Fig. g

1993 *Cassiculosphaeridia*? *tocheri* Schiøler, p. 104, pl. 4, figs. 4–12.

Description: *Cassiculosphaeridia*? *tocheri* is an intermediate proximate, acavate cyst, which is subspherical to ovoidal in outline. The autophragm is thick and has a tall reticulate ornament in comparison to other *Cassiculosphaeridia* species, on which large subspherical lumina open out through the muri to create irregular subcircular holes over the entire cyst. Paracingulum and parasulcus are absent. There is no discernible paratabulation. Archaeopyle is approximated to be apical.

Remarks: Due to the uncertainty of the archaeopyle and lack of paratabulation Schiøler (1993, p. 104) questionably assigned this new taxon at a generic level and hesitantly in the Class Dinophyceae. *Cassiculosphaeridia*? t*ocheri* was originally described from the Late Maastrichtian of the Danish North Sea.

Size: Intermediate.

Occurrence: DC353, 19340–19400ft. (Barremian); VK117, not present; CH265, 7750–7760ft. (Aptian).

Genus *DAPSILIDINIUM* Bujak *et al.,* 1980

1980 *Dapsilidinium* Bujak *et al.,* p. 27–28.

TYPE: Davey and Williams, 1966a, pl. 4, fig. 10, as *Polysphaeridium pastielsii*.

SYNOPSIS: The genus *Dapsilidinium* is composed of intermediate, chorate cysts. They have a subspherical to ovoidal central body in which the endo- and periphragm are closely appressed. However, the ornamented periphragm bears numerous intratabular processes; which are generally uniform in length but vary slightly in width. The processes are hollow and distally open, tubiform or tapering in morphology. There is no discernible paratabulation. The archaeopyle is apical.

Dapsilidinium laminaspinosum (Davey and Williams, 1966a) Lentin and Williams, 1981

Plate VII, Fig. h

1966a *Polysphaeridium laminaspinosum* Davey and Williams, p. 94–95, pl. 8, fig. 8.

1981 *Dapsilidinium laminaspinosum* (Davey and Williams, 1966a) Lentin and Williams, p.69.

Description: *Dapsilidinium laminaspinosum* is a chorate cyst with a subspherical outline. Its endophragm is shagreenate, with a periphragm pulling away to produce intratabular processes; The processes are smooth and cylindrical with entire distal margins. There is no discernible paratabulation. The archaeopyle is apical.

Remarks: This species was initially described from the Cenomanian of southern England

Size: Intermediate.

Occurrence: DC353, 20840–20900ft. (Valanginian); VK117, not present; CH265, not present.

Dapsilidinium warrenii (Habib, 1976) Lentin and Williams, 1981

Plate VII, Fig. i

1976 *Polysphaeridium warrenii* Habib, p. 383, pl. 2, figs. 4, 6a–b.

1981 *Dapsilidinium warrenii* (Habib, 1976) Lentin and Williams, p. 70.

Description: *Dapsilidinium warrenii* is a chorate cyst with a subspherical outline. Its endophragm is shagreenate to microgranulate, with a smooth periphragm pulling away to produce numerous intratabular processes. The processes are long (about 15µm) and cylindrical with entire distal margins. There is no discernible paratabulation. The archaeopyle is apical.

Remarks: *Dapsilidinium warrenii* was originally described from the Berriasian–Aptian of the western North Atlantic.

Size: Intermediate.

Occurrence: DC353, 17720–17780ft. to 20840–20900ft. (Aptian–Valanginian); VK117, 15240–15270ft. to 15840–15870ft. (Aptian–Barremian); CH265, not present.

Genus *DINGODINIUM* Cookson and Eisenack, 1958

1958 *Dingodinium* Cookson and Eisenack, p. 39.

TYPE: Cookson and Eisenack, 1958, pl. 1, fig. 10, as *Dingodinium jurassicum*.

SYNOPSIS: The genus *Dingodinium* is composed of intermediate to large, proximate, camocavte cysts. They have a compressed ellipsoidal outline, with or without an apical horn. The epi- and periphragm are appressed dorsally and nowhere else. There is no discernible paratabulation. The archaeopyle is uncertain.

Dingodinium cerviculum Cookson and Eisenack, 1958

Plate VI, Fig. t

1958 *Dingodinium cerviculum* Cookson and Eisenack, p. 40, pl. 1, figs. 12–14.

1984a *Dingodinium cerviculum* (Cookson and Eisenack, 1958) Emended by Mehrotra and Sarjeant, p. 296–300.

1990 *Dingodinium cerviculum* (Cookson and Eisenack, 1958) Emended by Khowaja-Ateequzzaman *et al.,* p. 274.

Description: *Dingodinium cerviculum* is a proximate, camocavate cyst with two distinct layers. The subspherical endophragm is thick and densely granular with tubercles. In contrast the polygonal periphragm is psilate to shagreenate, which exhibits a prominent blunt apical horn and a left lateral horn, with a large cavate area under the apical region of the endophragm. There is no discernible tabulation. The archaeopyle is apical.

Remarks: This species was originally described from the Hauterivian (Late Neocomian)–Aptian of Australia and New Guinea. Haskell (1970, p. 60) and Khowaja-Ateequzzaman *et al.,* (1990, p.274) considered *Dingodinium*? *albertii* to be a taxonomic junior synonym of *Dingodinium cerviculum.*

Size: Intermediate.

Occurrence: DC353, 18320–18380ft. to 20840–20900ft. (Berriasian–Valanginian) with caving between 22160–22220ft. to 22800–22860ft. (Tithonian–Oxfordian); VK117, 12600–12630ft. to 19980–19990ft. (Albian–Berriasian) with caving between 20490–20500ft. to 23990–24000ft. (Tithonian–Undifferentiated strata); CH265, not present.

Genus *EPIPLOSPHAERA* Klement, 1960

1960 *Epiplosphaera* Klement, p. 73.

TYPE: Klement, 1960, pl. 8, figs. 1–2, as *Epiplosphaera bireticulata*.

SYNOPSIS: The genus *Epiplosphaera* is composed of intermediate, proximochorate cysts, with a subspherical to ellipsoidal outline. The autophragm has a reticulate appearance surmounted with spines, the spines have variable tips. There is no discernible paratabulation. The archaeopyle is apical.

Epiplosphaera gochtii (Fensome, 1979) Brenner, 1988

Plate VII, Fig. j

1979 *Ellipsoidictyum gochtii* Fensome, p. 20–22, pl. 2, figs. 8–9, 11–12; text-fig. 8.

1988 *Epiplosphaera gochtii* (Fensome, 1979) Brenner, p. 51.

Description: *Epiplosphaera gochtii* is an acavate, proximochorate, subspherical to elongate ovoidal dinoflagellate cyst. The autophragm is shagreenate to granular, surmounted by short intratabular projections which are interlinked at their bases by septa. Giving the appearance of a reticulum The cingulum is devoid of ornament. The tabulation is undiscernible, except where the cingulum is visible and when the operculum is detached to reveal an apical archaeopyle.

Remarks: This species was first described from the Early Callovian of East Greenland. Poulsen (1992, p. 68) considered *Sentusidinium* (as *Epiplosphaera*) *ornata* to be a taxonomic junior synonym.

Size: Intermediate.

Occurrence: DC353, 22460–22520ft. to 23700–23760ft. (Kimmeridgian–Oxfordian); VK117, not present; CH265, not present.

Genus *EXOCHOSPHAERIDIUM* Davey *et al.,* 1966

1966 *Exochosphaeridium* Davey ***et al.,*** p. 165.

TYPE: Davey *et al.,* 1966, pl. 2, figs. 9–10, as *Exochosphaeridium phragmites*.

SYNOPSIS: The genus *Exochosphaeridium* is composed of intermediate, chorate cysts, with a subspherical outline. The autophragm is covered in numerous nontabular, simple or branched, fibrous usually solid processes. The processes at the apex and antapex are occasionally either wider, longer or more branched than those covering the rest of the cyst. There is no discernible paratabulation. The archaeopyle is precingular.

Exochosphaeridium arnace Davey and Verdier, 1973

Plate VII, Fig. k

1973 *Exochosphaeridium arnace* Davey and Verdier, p. 184–185, pl. 1, figs. 3, 6.

Description: *Exochosphaeridium arnace* is a proximochorate, acavate cyst with a subspherical to ovoidal outline. The surface of the autophragm is densely covered in projections, which gives a fibrous appearance. However, the distal ends of the projections are acicular, and may be joined medially. It has a precingular archaeopyle, though there is no discernible paratabulation, including a lack of a parasulcus and paracingulum.

Remarks: *Exochosphaeridium arnace* was originally described from the Late Albian–Early Cenomanian of France.

Size: Intermediate.

Occurrence: DC353, 17660–17720ft. to 20360–20420ft. (Albian–Hauterivian); VK117, 13770–13800ft. to 19800–19830ft. (Aptian–Berriasian) with caving to 22890–22900ft. (Kimmeridgian); CH265, 7750–7760ft. to 11600–11610ft. (Aptian–Valanginian).

Exochosphaeridium bifidum (Clarke and Verdier, 1967) Clarke *et al.,* 1968

Plate VII, Fig. l

1967 *Baltisphaeridium bifidum* Clarke and Verdier, p. 72–73, pl. 17, figs. 5–6; text-fig. 30.

1968 *Exochosphaeridium bifidum bifidum* (Clarke and Verdier, 1967) Clarke *et al.,* p. 182.

Description: *Exochosphaeridium bifidum* is a proximochorate, acavate cyst with a subspherical to ovoidal cyst body. The autophragm is striate, surmounted by projections. The projections are wide at the base and have bifid distal terminations. It has an apical archaeopyle, though there is no discernible paratabulation, including a lack of a parasulcus and paracingulum.

Remarks: *Exochosphaeridium bifidum* was first described from the Cenomanian–Campanian of southern England. It was latter emended by Davey (1969b, p. 27, 29) to be considered a dinoflagellate cyst rather than an acritarch upon confirmation of a precingular archaeopyle.

Size: Intermediate.

Occurrence: DC353, 17600–17660ft. to 19760–19820ft. (Albian–Hauterivian); VK117, 13770–13800ft. to 15360–15390ft. (Aptian–Barremian); CH265, 10250–10260ft. to 11250–11260ft. (Aptian–Hauterivian).

Exochosphaeridium phragmites Davey *et al.,* 1966

Plate VII, Fig. m

1966 *Exochosphaeridium phragmites* Davey *et al.,* p. 165–166, pl. 2, figs. 8–10.

Description: *Exochosphaeridium phragmites* is a proximochorate, acavate cyst with a subspherical to ovoidal outline. The autophragm is microgranular surmounted by acicular processes. It has a precingular archaeopyle, however, there is no evident paratabulation, including a lack of a parasulcus and paracingulum.

Remarks: This species was initially described from the Cenomanian of southern England.

Size: Intermediate.

Occurrence: DC353, 17600–17660ft. to 21080–21140ft. (Albian–Valanginian); VK117, 13770–13800ft. to 17340–17370ft. (Aptian–Barremian); CH265, 9640–9650ft. to 11250–11260ft. (Aptain–Hauterivian).

Genus *GARDODINIUM* Alberti, 1961

1961 *Gardodinium* Alberti, p. 18.

TYPE: Alberti, 1961, pl. 3, fig. 11, as *Gardodinium eisenackii*.

SYNOPSIS: The genus *Gardodinium* is composed of small to intermediate, proximate, holocavate cysts, with a subspherical outline. The ectophragm forms a prominent apical horn, supported by thin spines arising from the autophragm, which are connected distally. There is no discernible paratabulation. The archaeopyle is apical.

Gardodinium trabeculosum (Gocht, 1959) Alberti, 1961

Plate VII, Fig. n

1959 *Scriniodinium trabeculosum* Gocht, p. 62, pl. 4, fig. 5.

1961 *Gardodinium trabeculosum* (Gocht, 1959) Alberti, p. 18. Retained by Lentin and Williams (1989, p. 143).

1961 *Gardodinium eisenackii* Alberti, p. 18, pl. 3, figs. 8–13.

1962 *Gardodinium albertii* Neale and Sarjeant, p. 445–446, pl. 19, fig. 8; text-figs. 4a–b.

1967 *Gardodinium pyriforme* Vozzhennikova, p. 179, pl. 100, figs. 1, 4.

1971 *Gardodinium elongatum* Singh, p. 381–383, pl. 68, figs. 3–4.

1978 *Chlamydophorella trabeculosa* (Gocht, 1959) Davey, p. 893.

1978 *Chlamydophorella albertii* (Neale and Sarjeant, 1962) Davey, p. 893.

1978 *Chlamydophorella pyriformis* (Vozzhennikova, 1967) Davey, p. 893.

Description: *Gardodinium trabeculosum* is an intermediate, proximate, holocavate dinoflagellate cyst, with an elongate outline. The autophragm is granular which supports thin solid processes which in turn supports a thin ectophragm, giving rise to a parallel sided apical horn. The paracingulum is pronounced in some specimens by means of longer processes. No full paratabulation and as such paracingulum can be evidenced from the specimens recovered from this study. The archaeopyle is apical.

Remarks: Harding (1996) reports the development of full paratabulation on the ectophragm, by means of low parasutural ridges. The specimens recovered for this study do not show this feature. This species was first observed from the Hauterivian of northwest Germany.

Size: Small to intermediate.

Occurrence: DC353, 19100–19160ft. (Barremian); VK117, 16770–16800ft. to 19140–19170ft. (Barremian–Berriasian); CH265, not present.

Genus *HETEROSPHAERIDIUM* Cookson and Eisenack, 1968

1968 *Heterosphaeridium* Cookson and Eisenack, p. 115.

TYPE: Cookson and Eisenack, 1968, text-fig. 4H, as *Heterosphaeridium conjunctum*.

SYNOPSIS: The genus *Heterosphaeridium* is composed of intermediate, proximochorate to chorate cysts, with a subspherical outline. The autophragm is finely ornamented, surmounted by numerous nontabular hollow or solid spines, which are distally simple or branched. Proximally the processes may be adjoined by intratabular ridges. There is no discernible paratabulation. The archaeopyle is apical.

Heterosphaeridium conjunctum Cookson and Eisenack, 1968

Plate VII, Fig. o

1968 *Heterosphaeridium conjunctum* Cookson and Eisenack, p. 115; text-figs. 4G–H.

Description: *Heterosphaeridium conjunctum* is an intermediate, chorate cyst, with a subspherical central body outline. The autophragm finely granulate; while the numerous spines which are all roughly the same length, but vary in width, arise from the autophragm. The distal ends of the spines are either acuminate, branched or digitate; while their bases are occasionally joined by intratabular ridges. There is no discernible evidence of paratabulation, and as such no paracingulum or parasulcus is supported. The archaeopyle is apical.

Remarks: This species was originally described from the Santonian–Early Campanian of Western Australia.

Size: Intermediate.

Occurrence: DC353, 17600–17660ft. to 20840–20900ft. (Albian–Valanginian); VK117, 12600–12630ft. to 18540–18570ft. (Albian–Hauterivian); CH265, 8480–8490ft. to 11600–11610ft. (Aptian–Valanginian).

Heterosphaeridium verdieri Yun Hyesu, 1981

Plate VII, Fig. p

1981 *Heterosphaeridium verdieri* Yun Hyesu, p. 48, pl. 3, figs. 3, 5.

Description: *Heterosphaeridium verdieri* is an intermediate, chorate cyst with a subspherical cyst outline. The autophragm has shagreenate to granulate ornamentation. Processes arise from the autophragm to produce thin, hollow spines that open distally, and on occasion connect via trabeculae.

The open end is recurved. There is no evidence of paratabulation, as such no paracingulum or parasulcus can be evidenced. The archaeopyle is apical.

Remarks: This species was originally described from the Early Santonian of Western Germany.

Size: Intermediate.

Occurrence: DC353, not present; VK117, 16140–16170ft. (Barremian); CH265, not present.

Genus *IMPLETOSPHAERIDIUM* Morgenroth, 1966

1966 *Impletosphaeridium* Morgenroth, p. 32.

TYPE: Morgenroth, 1966, pl. 10, fig. 5, as *Impletosphaeridium transfodum*.

SYNOPSIS: The genus *Impletosphaeridium* is composed of intermediate, proximochorate to chorate cysts, with a subspherical to ellipsoidal outline. The autophragm is psilate to finely ornamented, surmounted by numerous nontabular hollow or solid spines, which are distally morphologically varied. There is no discernible paratabulation. The archaeopyle is apical.

Impletosphaeridium capitatum Fensome *et al.,* 2009

Plate VII, Fig. q

2009 *Impletosphaeridium capitatum* Fensome *et al.,* p. 38, 39, pl. 5, figs. m–p.

Description: *Impletosphaeridium capitatum* is an intermediate, proximochorate, acavate cyst. The central psilate body has a, spheroidal to ovoidal outline. Arising from the autophragm are numerous and nontabular solid spines. The spines are capitate distally. There is no discernible paratabulation, as such no evidence for the paracingulum and parasulcus are present. The archaeopyle is uncertain.

Remarks: This species was first described from the Scotian Margin, offshore eastern Canada to be of Late Cretaceous age. It should be noted that the holotype is from a cuttings sample so it may come from younger strata; also no first appearance datum could be assessed, (Fensome *et al.,* 2009). However, it is present throughout Well DC353 from the Tithonian to the Barremian, even into the earliest Aptain in Well VK117.

Size: Intermediate.

Occurrence: DC353, 18320–18380ft. to 21980–22040ft. (Barremian–Tithonian); VK117, 15240–15270ft. to 15360–15390ft. (Aptian–Barremian); CH265, not present.

Impletosphaeridium ehrenbergii (Deflandre, 1947a) Islam, 1993

Plate VII, Fig. r

1947a *Hystrichosphaeridium ehrenbergii* Deflandre, fig. 1, no. 5.

1961 *Baltisphaeridium ehrenbergii* (Deflandre, 1947a) Sarjeant, p. 103.

1969 *Cleistosphaeridium*? *ehrenbergii* (Deflandre, 1947a) Davey *et al.,* p. 16.

1993 *Impletosphaeridium ehrenbergii* (Deflandre, 1947a) Islam, p. 86.

Description: *Impletosphaeridium ehrenbergii* is an intermediate, chorate, acavate cyst. The main central body is spheroidal in outline. Arising from the shagreenate autophragm are numerous and nontabular long solid acicular spines. There is no discernible paratabulation, as such there is no evidence for the paracingulum and parasulcus. The archaeopyle may be apical.

Remarks: This species was first described from the Oxfordian of Monaco. Here the emended diagnosis by Fauconnier and Masure (2004) is not followed as this species appears to have an autophragm rather than 'two attached membranes'; moreover, there is no evidence for an apical archaeopyle on the holotype.

Size: Intermediate.

Occurrence: DC353, 22400–22460ft. (Kimmeridgian); VK117, not present; CH265, not present.

Impletosphaeridium furcillatum (Prössl, 1992) Williams *et al.,* 1998

Plate VII, Fig. s

1992 *Cleistosphaeridium furcillatum* Prössl (1990) p. 100, pl. 7, figs. 12, 14 ex Prössl, p. 113–114.

1998 *Impletosphaeridium furcillatum* (Prössl, 1992) Williams *et al.,* 1998, p. 332.

Description: *Impletosphaeridium furcillatum* is an intermediate, chorate, acavate cyst. The main central body is spheroidal in outline. Radiating from the shagreenate autophragm are numerous nontabular solid spines. The spines bifurcate distally. There is no discernible paratabulation, as such no evidence for the paracingulum and parasulcus are present. The archaeopyle is uncertain.

Remarks: The name *Cleistosphaeridium furcillatum* was invalid due to the author not specifying the lodgement of the holotype. This species was originally described from the Hauterivian–Early Barremian of Germany.

Size: Intermediate.

Occurrence: DC353, 18980–19040ft. to 23280–23340ft. (Barremian–Kimmeridgian); VK117, 13770–13800ft. to 16560–16590ft. (Aptian–Barremian); CH265, not present.

Impletosphaeridium granulatum (Burger, 1980a) Islam, 1993

Plate VII, Fig. t

1980a *Cleistosphaeridium granulatum* Burger, p. 77, pl. 33, figs. 2–4, 6–10.

1993 *Impletosphaeridium granulatum* (Burger1980a) Islam, 1993, p.86.

Description: *Impletosphaeridium granulatum* is an intermediate, proximochorate, acavate cyst. The main central body is spheroidal to ovoidal in outline. Protruding from the shagreenate autophragm are numerous nontabular short solid accuminate spines. There is no discernible paratabulation, as such no evidence for the paracingulum and parasulcus are present. The archaeopyle is apical.

Remarks: This species was first recorded from the Albian of the Surat Basin, Western Australia.

Size: Intermediate.

Occurrence: DC353, 18980–19040ft. to 20060–20120ft. (Barremian–Hauterivian); VK117, 14640–14670ft. to 15540–15570ft. (Aptian–Barremian); CH265, not present.

Genus *MENDICODINIUM* Morgenroth, 1970

1970 *Mendicodinium* Morgenroth, p. 347–348.

TYPE: Morgenroth, 1970, pl.9, figs.5–6, as *Mendicodinium reticulatum*.

SYNOPSIS: The genus *Mendicodinium* is composed of intermediate, proximate to chorate cysts, with a subspherical outline. The autophragm is densely ornamented. There is no discernible paratabulation. The archaeopyle is epicystal.

Mendicodinium granulatum Kumar, 1986b

Plate VIII, Fig. a

1986b *Mendicodinium granulatum* Kumar, p. 393, pl. 3, fig. 6; text-fig. 7.

Description: *Mendicodinium granulatum* is an intermediate, proximate, acavate cyst. The autophragm is densely covered with a scabrate to granulate ornament. There is no discernible paratabulation. The archaeopyle is epicystal, but the epicyst remains attached to the hypocyst.

Remarks: In specimens recovered from the wells in this study the epicyst appears to recurve around the hypocyst to produce a marquise shape. This species was originally described from the Early Kimmeridgian–Tithonian of India.

Size: Intermediate.

Occurrence: DC353, 22760–22820ft. to 23460–23520ft. (Kimmeridgian–Oxfordian); VK117, reworked into Cretaceous strata between 16440–16470ft. to 19740–19770ft. (Barremian–Berriasian); CH265, not present.

Mendicodinium groenlandicum (Pocock and Sarjeant, 1972) Davey, 1979c

Plate VIII, Fig. b

1972 *Thuledinium groenlandicum* Pocock and Sarjeant, p. 352–354, pl. 2, figs. 1–9; text-fig. 2.

1979c *Mendicodinium groenlandicum* (Pocock and Sarjeant, 1972) Davey, p. 64.

Description: *Mendicodinium groenlandicum* is an intermediate, proximate, acavate cyst. The autophragm has a psilate to shagreenate ornament. There is no discernible paratabulation. The archaeopyle is epicystal, but the epicyst remains attached to the hypocyst.

Remarks: This species was originally described from the Middle Callovian of Denmark.

Size: Intermediate.

Occurrence: DC353, 22400–22460ft. to 23640–23700ft. (Kimmeridgian–Oxfordian); VK117, 13770–13800ft. (Aptian) one specimen possibly reworked; CH265, not present.

Genus *TANYOSPHAERIDIUM* Davey and Williams, 1966a

1966a *Tanyosphaeridium* Davey and Williams, p. 98.

TYPE: Davey and Williams, 1966a, pl. 6, fig. 7; text-fig. 20, as *Tanyosphaeridium variecalamum*.

SYNOPSIS: The genus *Tanyosphaeridium* is composed of intermediate to large, chorate cysts. They have an elongate ellipsoidal outline, with nontabular or intratabular tubular hollow processes. The processes are usually open and never interconnected. There is no discernible paratabulation. The archaeopyle is apical.

Tanyosphaeridium boletus Davey, 1974

Plate VIII, Fig. c

1974 *Tanyosphaeridium boletus* Davey, p. 61–62, pl. 6, fig. 7.

Description: *Tanyosphaeridium boletus* is an intermediate, chorate, acavate cyst, with an elongated ovoidal outline. The autophragm is psilate to finely granulate, which rises up to produce long hollow nontabular tubiform processes. Distally the processes recurve. The paratabulation is indiscernible. The archeopyle is apical.

Remarks: This species was initially described from the Barremian of Yorkshire, England.

Size: Intermediate.

Occurrence: DC353, 18860–18920ft. to 19700–19760ft. (Barremian–Hauterivian); VK117, 15540–15570ft. (Barremian) with caving at 18990–19020ft. (Valanginian); CH265, not present.

Tanyosphaeridium magneticum Davies, 1983

Plate VIII, Fig. d

1983 *Tanyosphaeridium magneticum* Davies, p. 25, pl. 8, figs. 1–8, 11–12; text-fig. 20.

Description: *Tanyosphaeridium magneticum* is an intermediate, chorate, acavate cyst, with an elongated ovoidal outline. The autophragm is finely granulate, which rises up to produce long tubiform processes. The paratabulation is indiscernible. The archeopyle is apical.

Remarks: This species was first recorded from the Valanginian of Artic Canada.

Size: Intermediate.

Occurrence: DC353, 19940–20000ft. to 20360–20420ft. (Hauterivian); VK117, 15840–15870ft. to 17490–17520ft. (Barremian–Hauterivian); CH265, not present.

Genus *VALENSIELLA* Eisenack, 1963

1963 *Valensiella* Eisenack, p. 100–101.

TYPE: Deflandre, 1947b, text-fig.22, as *Membranilarnax ovulum*.

SYNOPSIS: The genus *Valensiella* is composed of small to intermediate, proximate, holocavate cysts. They have an ellipsoidal outline, with a rugulate to reticulate autophragm, which is enclosed in a continuous ectophragm. There is no discernible paratabulation. The archaeopyle is apical.

Valensiella dictydia (Sarjeant, 1972) Lentin and Williams, 1993

Plate VIII, Fig. e

1972 *Chytroeisphaeridia dictydia* Sarjeant, p. 41, pl. 3, fig. 3; pl. 6, fig. 6.

1979d *Batiacasphaera dictydia* (Sarjeant, 1972) Davey, p. 217.

1980 *Escharisphaeridia dictydia* (Sarjeant, 1972) Erkmen and Sarjeant, p. 63.

1982 *Cassiculosphaeridia dictydia* (Sarjeant, 1972) Riley and Fenton, p. 199.

1993 *Valensiella dictydia* (Sarjeant, 1972) Lentin and Williams, p. 661.

Description: *Valensiella dictydia* is an intermediate, proximate, holocavate cysts. It has an ellipsoidal outline, with a large reticulate autophragm, which is enclosed in a continuous ectophragm. There is no discernible paratabulation. The archaeopyle is apical.

Remarks: This species was first described from the Bathonian–Callovian of east Greenland.

Size: Intermediate.

Occurrence: DC353, 23400–23460ft. (Kimmeridgian); VK117, not present; CH265, not present.

Genus *XIPHOPHORIDIUM* Sarjeant, 1966b

1966b *Xiphophoridium* Sarjeant, p. p. 146–147.

TYPE: Cookson and Eisenack, 1962, pl. 2, fig. 1, as *Hystrichodinium alatum*.

SYNOPSIS: The genus *Xiphophoridium* is composed of intermediate to large, proximochorate cysts. They have a subspherical to subpentagonal outline, with a finely ornamented autophragm. Paratabulation is indicated by high parasutural ridges, which is adorned with crestal spines. The archaeopyle is apical.

Xiphophoridium alatum (Cookson andEisenack, 1962) Sarjeant, 1966b

Plate VIII, Fig. f

1962 *Hystrichodinium alatum* Cookson and Eisenack, p. 487–488, pl. 2, figs. 1–4.

1966b *Xiphophoridium alatum* (Cookson andEisenack, 1962) Sarjeant, p. 147. Retained by Lentin and Williams (1981, p. 294).

1967 *Pyramidium alatum* (Cookson and Eisenack, 1962) Clarke and Verdier, p. 40.

1981 *Oodnadattia alata* (Cookson and Eisenack, 1962) Below, p. 107.

Description: *Xiphophoridium alatum* is an intermediate, proximochorate, suturocavate cyst, with a rounded subpentagonal outline. The psilate to shagreenate autophragm rises up at the parasutural boundaries to produce a crest with long spines and a denticulate margin. The crests make the gonyaulacoid paratabulation easy to observe the paracingulum and parasulcus. The archaeopyle is apical.

Remarks: This species was initially recorded from the Albian–Cenomanian sediments of Australia.

Size: Intermediate.

Occurrence: DC353, 17660–17720ft. to 17900–17960ft. (Albian–Aptian) with caving at 19460–19520ft. (Barremian); VK117, 13770–13800ft. to 14490–14520ft. (Aptian); CH265, not present.

Order PERIDINIALES Haeckel, 1894

Suborder PERIDINIINEAE (Autonym)

Family PERIDINIACEAE Ehrenberg, 1831

Subfamily DEFLANDREOIDEAE Bujak and Davies, 1983

Genus *ALTERBIDINIUM* Lentin and Williams, 1985

1985 *Alterbidinium* Lentin and Williams, p. 14.

TYPE: Vozzhennikova, 1967, pl. 77, fig. 2, as *Alterbia recticornis*.

SYNOPSIS: The genus *Alterbidinium* is composed of intermediate to large, cornucavate to circumcavate, proximate cysts. They have a subspherical to subpentagonal outline. The periphragm pulls away from the endophragm to produce one apical and two asymmetrical antapical horns. The periphragm is either psilate to finely ornamented. There is no discernible paratabulation. The archaeopyle is formed by the loss of an intercalary plate.

Alterbidinium acutulum (Wilson, 1967) Lentin and Williams, 1985

Plate VIII, Fig. g

1967 *Deflandrea acutula* Wilson, p. 225–226, figs. 11–12.

1985 *Alterbidinium acutulum* (Wilson, 1967) Lentin and Williams, p. 14.

Description: *Alterbidinium acutulum* is a proximate cyst with an elongated subpentagonal outline. The psilate to shagreenate periphragm pulls away from the endophragm down the sides of the cyst making it circumcavate and dorsoventrally compressed. It has one apical horn and two unequal antapical horns, with the left hand side being more elongated. Paratabulation is only indicated by the loss of the intercalary (2a) archeopyle.

Remarks: Whitney (1979, p. 125) and Lentin and Williams (1993, p. 14) consider *Albertia curvicornis* and *Albertia recticornis* to be taxonomic junior synonyms of this species. The nomenclatural type of the genus *Alterbidinium* remains the holotype of *Alterbidinium recticorne*. *Alterbidinium acutulum* was originally described from the Maasstrichtian of New Zealand.

Size: Intermediate.

Occurrence: DC353, not present; VK117, 13770–13800ft. (Aptian); CH265, not present.

Alterbidinium ioannidesii Pearce 2010

Plate VIII, Fig. h

2010 *Alterbidinium ioannidesii* Pearce, p. 66–67, figs. 1–6.

Description: *Alterbidinium ioannidesii* is a cornucavate to circumcavate, proximate cyst with an elongated subpentagonal outline. The finely reticulate to striate periphragm pulls away from the psilate endophragm making it cornucavate to circumcavate. The periphragm forms an apical horn and left antapical horn. Paratabulation is indicated by parasutural ridges. The archaeopyle is formed by the loss of an intercalary (2a) plate.

Remarks: The species was initially recorded from the Campanian of Norfolk, UK.

Size: Intermediate.

Occurrence: DC353, not present; VK117, not present; CH265, 10250–10260ft. (Aptian).

Genus *PALAEOCYSTODINIUM* Alberti, 1961

1961 *Palaeocystodinium* Alberti, p. 20.

TYPE: Alberti, 1961, pl. 7, fig. 12, as *Palaeocystodinium golzowense*.

SYNOPSIS: The genus *Palaeocystodinium* is composed of intermediate to large, proximate, cornucavate to circumcavate cysts. They have an elongated subspherical endophragm, surrounded by a periphragm which produces one single pointed apical and antapical horns. The paratabulation is usually only indicated by the loss of the intercalary archaeopyle. The paracingulum is generally not visable.

Palaeocystodinium? _denticulatum_ Alberti, 1961

Plate VIII, Fig. i

1961 *Palaeocystodinium*? *denticulatum* Alberti, p. 20–21, pl. 7, fig. 9.

Description: *Palaeocystodinium? denticulatum* is an intermediate, proximate, bicavate cyst, with a subspherical to elongated outline. The psilate to shagreenate endophragm is surrounded by a psilate to shagreenate periphragm, which pulls away to produce a single apical on centrally located antapical horn. The paratabulation can be obsereved, but only when the intercalary archaeopyle is lost.

Remarks: This species was first described from the Turonian of north and cental Germany.

Size: Intermediate.

Occurrence: DC353, not present; VK117, 13770–13800ft. to 15540–15570ft. (Aptian–Barremian); CH265, not present.

Genus *SPINIDINIUM* Cookson and Eisenack, 1962

1962 *Spinidinium* Cookson and Eisenack, p. 489.

TYPE: Cookson and Eisenack, 1962, pl. 1, figs. 1–2, as *Spinidinium styloniferum*.

SYNOPSIS: The genus *Spinidinium* is composed of small to intermediate, proximate to proximochorate, cornucavate or circumcavate cysts. They have a compressed peridinioid outline. The endophragm has a spherical outline, while the periphragm pulls away to produce one apical and two asymmetrical antapical horns. The paratabulation is indicated by intratabular or penitabular ornamentation. The archaeopyle is formed by the loss of an intercalary plate.

Spinidinium styloniferum Cookson and Eisenack, 1962

Plate VIII, Fig. j

1962 *Spinidinium styloniferum* Cookson and Eisenack, p. 489, pl. 1, figs. 1–5.

Description: *Spinidinium styloniferum* is an intermediate, proximate, cavate cyst, with a peridinioid outline. The finely granulate endophragm is spherical, surrounded by the psilate to granulate periphragm, covered in intratabular to nontabular spines. The spines are pointed distally. This species has one apical horn and two antapical horns with the right side being significantly reduced. The paratabulaution is indiscernible. The archaeopyle is formed by the loss of an intercalary plate.

Remarks: This species was initially described from the Aptian–?Albian sediments of Australia.

Size: Intermediate.

Occurrence: DC353, 18020–18080 to 19100–19160 (Aptian–Barremian); VK117, not present; CH265, not present.

Subfamily OVOIDINIOIDEAE (Norris, 1978b) Bujak and Davies, 1983

Genus *CORCULODINIUM* Batten and Lister, 1988

1988 *Corculodinium* Batten and Lister, p. 172.

TYPE: Batten and Lister, 1988, figs.3h–i, as *Corculodinium uniconicum*.

SYNOPSIS: The genus *Corculodinium* is composed of small to intermediate, proximate, cavate cysts. They have an inverted heart-shaped outline. The endophragm and periphragm are closely appressed, except where pericoels form to produce an apical horn and sometimes to form a small antapical off-set horn. There is no discernible paratabulation. The archaeopyle is unclear.

Corculodinium inaffectum (Drugg, 1978) Courtinat 2000

Plate VIII, Fig. k

1978 *Geiselodinium inaffectum* Drugg, p. 68, pl. 3, figs. 10–12.

1983 *Subtilisphaera*? *inaffecta* (Drugg, 1978) Bujak and Davies, p. 163.

2000 *Corculodinium inaffectum* (Drugg, 1978) Courtinat, p. 173.

Description: *Corculodinium inaffectum* has a subspherical shagreenate endocyst, and is bicavate. The periphragm is psilate to micro granulate. The epicyst has one centrally located apical horn, while the hypocyst has two rounded antapical horns. Both the epi and hypo cyst are roughly equal in size and there is a well-defined cingulum. However, there is no discernible parasulcus or paratabulation. The archaeopyle has not been observed.

Remarks: This species was originally described from the Early Kimmeridgian. Courtinat (2000, p.173) considered *Geiselodinium paeminosum* to be a taxonomic junior synonym.

Size: Intermediate.

Occurrence: DC353, 21860–21920 to 22160–22220 (Berriasian–Tithonian); VK117, not present; CH265, not present.

Genus *LEBERIDOCYSTA* Stover and Evitt, 1978

1978 *Leberidocysta* Stover and Evitt, p. 59–60.

TYPE: Cookson and Eisenack, 1962, pl. 7, fig. 2, as *Hexagonifera chlamydata*.

SYNOPSIS: The genus *Leberidocysta* is composed of intermediate, proximate, cavate cysts. They have a subspherical to ellipsoidal outline. The endophragm is relatively thick and bears low-relief ornamentation. Whereas the psilate to finely ornamented periphragm is thin walled, and commonly folded. There is no discernible paratabulation. The archaeopyle is apical.

Leberidocysta chalmydata (Cookson and Eisenack, 1962) Stover and Evitt, 1978

Plate VIII, Fig. l

1962 *Hexagonifera? chlamydata* Cookson and Eisenack, p. 496, pl. 7, figs. 1–3, 5–8.

1978 *Leberidocysta chlamydata* (Cookson and Eisenack, 1962) Stover and Evitt, p. 60. Retained by Lentin and Williams (1985, p. 214).

1984b *Polygonifera chlamydata* (Cookson and Eisenack, 1962) Mehrotra and Sarjeant, p. 48.

Description: *Leberidocysta chlamydata* is an intermediate, proximate, cavate cyst. The main cyst is spherical to ovoidal in outline. The endophragm has a foveolate appearance, while the periphragm has a psilate to shagreenate exterior. There is no discernible paratabulation. The archaeopyle is apical.

Remarks: This species was first described from the Albian–Cenomanian sediments of Australia.

Size: Intermediate.

Occurrence: DC353, 19460–19520ft. to 19760–19820ft. (Barremian–Hauterivian); VK117, 13770–13800ft. to 19740–19770ft. (Aptian–Berriasian); CH265, 7750–7760ft. to 11600–11610ft. (Aptian – Valanginian).

Leberidocysta defloccata (Davey and Verdier, 1973) Stover and Evitt, 1978

Plate VIII, Fig. m

1973 *Hexagonifera defloccata* Davey and Verdier, p. 198, pl. 3, figs. 6,8.

1973 *Thalassiphora defloccata* (Davey and Verdier, 1973) Lentin and Williams, p. 85.

1978 *Leberidocysta defloccata* (Davey and Verdier, 1973) Stover and Evitt, p. 60. Retained by Lentin and Williams (1985, p. 214).

1981 *Disphaeria defloccata* (Davey and Verdier, 1973) Yun Hyesu, p. 70.

1984b *Craspedodinium defloccatum* (Davey and Verdier, 1973) Mehrotra and Sarjeant, p. 48, 50.

Description: *Leberidocysta defloccata* is an intermediate, proximate, cavate cyst. The main cyst is spherical to ovoidal in outline. The endophragm has a fine granular appearance, while the periphragm is psilate to shagreenate. There is no discernible paratabulation. The archaeopyle is apical.

Remarks: This species was originally recorded form the Late Albian–Early Cenomanian of Spain.

Size: Intermediate.

Occurrence: DC353, 19640–19700ft. (Hauterivian) with caving between 21320–21380ft. to 22640–22700ft. (Valanginian–Kimmeridgian); VK117, 13770–13800ft. to 17640–17670ft. (Aptain–Hauterivian) with caving at 22990–23000ft. (Kimmeridgian); CH265, 112550–11260ft. (Hauterivian).

Genus *OVOIDINIUM* Davey, 1970

1970 *Ovoidinium* Davey, p. 351.

TYPE: Cookson and Hughes, 1964, pl. 5, fig. 4, as *Ascodinium verrucosum*.

SYNOPSIS: The genus *Ovoidinium* is composed of intermediate to large, proximate, bicavate cysts. They have a compressed peridiniod outline, with a short apical horn and reduced antapical horns; formed by the shrinkage of the endophragm away from the periphragm, which would otherwise be closely appressed. The paracingulum may be observed by a parallel furrow traversing the cyst. There is no discernible paratabulation. The archaeopyle is a combination, formed by the loss of the apical plates and intercalary plates.

Ovoidinium scabrosum (Cookson and Hughes, 1964) Davey, 1970

Plate VIII, Fig. n

1964 *Ascodinium scabrosum* Cookson and Hughes, p. 40–41, pl. 5, figs. 1–3.

1970 *Ovoidinium scabrosum* (Cookson and Hughes, 1964) Davey, p. 352.

Description: *Ovoidinium scabrosum* is an intermediate, proximate, bicavate cyst. The main cyst outline is subspherical, with a truncated antapex. Both the endophragm and periphragm are shagreenate to finely scabrate and in close proximity to one another. However, the periphragm pulls away in the antapical region, leaving a pericoel. Similarly, there is cavation under the apical horn as the endophragm shrinks back from the periphragm. There is no discernible paratabulation, however the paracingulum is visible by the means of two parallel ridges which traverse the cyst. The archaeopyle is apical.

Remarks: This species was originally recorded from the Late Albian–Early Cenomanian sediments of Cambridgeshire, England.

Size: Intermediate.

Occurrence: DC353, 18500–18560ft. to 19760–19820ft. (Barremian–Hauterivian); VK117, not present; CH265, 11600–11610ft. (Valanginian).

Ovoidinium verrucosum (Cookson and Hughes, 1964) Davey, 1970

Plate VIII, Fig. o

1964 *Ascodinium verrucosum* Cookson and Hughes, p. 41, pl. 5, figs. 4–7.

1970 *Ovoidinium verrucosum* (Cookson and Hughes, 1964) Davey, p. 351–352.

Description: *Ovoidinium verrucosum* is an intermediate, proximate, bicavate cyst. The main cyst outline is subspherical, with a truncated antapex. The endophragm is finely granular, while the periphragm is verrucate, they are both in close proximity to one another. However, the periphragm pulls away in the antapical region, leaving a cavation under the projection with a slanting asymmetrical base. Similarly, there is cavation under the apical horn as the endophragm shrinks back from the periphragm. There is no discernible paratabulation, however the paracingulum is visible by the means of two parallel ridges which traverse the cyst. The archaeopyle is apical.

Remarks: This species was originally recorded from the Late Albian–Early Cenomanian sediments of Cambridgeshire, England.

Size: Intermediate.

Occurrence: DC353, 20840–20900ft. (Valanginian); VK117, 13770–13800ft. to 18990–19020ft. (Aptain–Valanginian); CH265, 10250–10260ft. to 11250–11260ft. (Aptain–Hauterivian).

Subfamily PALAEOPERIDINIOIDEAE (Vozzhennikova, 1961) Bujak and Davies, 1983

Genus *LACINIADINIUM* McIntyre, 1975

1975 *Laciniadinium* McIntyre, p. 70.

TYPE: McIntyre, 1975, pl. 4, figs. 12–13, as *Laciniadinium orbiculatum*.

SYNOPSIS: The genus *Laciniadinium* is composed of intermediate, proximate cysts. They have a compressed subspherical to biconical outline, with or without apical and antapical horns. The autophragm is psilate or bears low-relief ornamentation. There is no discernible paratabulation. The archaeopyle is a combination, formed by the loss of an intercalary and three precingular plates.

Laciniadinium*? *aquiloniforme Schiøler *et al.,* 1997

Plate VIII, Fig. p

1997 *Laciniadinium*? *aquiloniforme* Schiøler *et al.,* p. 83, 85, pl. 2, figs. 9–12.

Description: *Laciniadinium*? a*quiloniforme* is an intermediate, proximate, bicavate cyst. It has a rhombus shaped outline. The shagreenate endophragm and periphragm are in close proximity to one another, except in the apical region where the periphragm pulls away to produce an accuminate apical horn, and similarly at the antapex. The paracingulum is indicated by a pair of low parallel ridges that traverse the cysts equator. The paratabulation is unclear as is the archaeopyle.

Remarks: This species has been given questionable assignment due to the undetermined archaeopyle. It was originally described from the Upper Maastrichtian of the Netherlands.

Size: Intermediate.

Occurrence: DC353, 19940–20000ft. (Hauterivian); VK117, not present; CH265, not present.

Genus *PALAEOHYSTRICHOPHORA* Deflandre, 1935

1935 *Palaeohystrichophora* Deflandre, p. 230.

TYPE: Deflandre, 1935, pl. 8, fig. 4, as *Palaeohystrichophora infusorioide***s.**

SYNOPSIS: The genus *Palaeohystrichophora* is composed of intermediate, proximate, bicavate cysts. The endocyst is subspherical to ellipsoidal in shape while the periphragm is a compressed peridinioid outline. The periphragm is covered in short to long hairlike spines. The paracingulum may be indicated by parallel ridges (surmounted by spines) that traverse the cyst. There is no discernible paratabulation. The archaeopyle is unclear.

Palaeohystrichophora granulata Mao Shaozhi and Norris, 1988

Plate VIII, Fig. q

1988 *Palaeohystrichophora granulata* Mao Shaozhi and Norris, p. 47, pl. 12, figs. 9–12.

Description: *Palaeohystrichophora granulata* is an intermediate, proximate, bicavate cyst, which is roughly subspherical in outline. It has a distinct apical horn and two unequally and weakly developed antapical horns. The endophragm is shagreenate to scabrate, while the periphragm is finely granulate with sporadically distributed short spines. The paracingulum is visible by means of two parallel ridges which traverse the cyst. The paratabulation in undiscernible, and the archaeopyle is unclear.

Remarks: This species was first described from the Late Cretaceous of the Xinjiang Province, China.

Size: Intermediate.

Occurrence: DC353, 17840–17900ft. (Aptian); VK117, 12600–12630ft. (Albian); CH265, not present.

Genus *PALAEOPERIDINIUM* Deflandre, 1934 ex Sarjeant, 1967

1934 (ex, 1967) *Palaeoperidinium* Deflandre, p. 968 (ex Sarjeant, p. 246–247)

TYPE: Ehrenberg, 1838, pl. 1, fig .4, as *Peridinium pyrophorum*.

SYNOPSIS: The genus *Palaeoperidinium* is composed of intermediate to large, proximate cysts, with a compressed peridiniod outline, forming one apical and two antapical horns. The endo- and periphragms are closely appressed to one another. Paratabulation is occasionally observable by pandasutura lines or intratabular ornamentation. The paracingulum can be observed by low parallel ridges traversing the cyst. The archaeopyle is a combination, formed by the loss of an apical plate, the intercalary plates and several precingular plates.

Palaeoperidinium cretaceum (Pocock, 1962, ex Davey, 1970) Lentin and Williams, 1976

Plate VIII, Fig. r

1970 *Astrocysta cretacea* Pocock, 1962, p. 80, pl. 14, figs. 219–221 ex Davey, p. 359.

1971 *Lejeunia*? *cretacea* (Pocock, 1962, ex Davey, 1970) Brideaux, p. 86.

1973 *Subtilisphaera cretacea* (Pocock, 1962, ex Davey, 1970) Jain and Millepied, p.27.

1976 *Palaeoperidinium cretaceum* (Pocock, 1962, ex Davey, 1970) Lentin and Williams, p. 110.

Description: *Palaeoperidinium cretaceum* is an intermediate, proximate, acavate cyst with a pentagonal outline. It has a broad based apical horn and two antapical horns (left side is longer). The epicyst is slightly longer than the hypocyst. When the cyst is well preserved, prominent intercalary bands are visible which reflects the peridiniod tabulation. The autophragm has a shagreenate ornamentation. The archeopyle is a combination made up of one precingular and an anterior intercalary plate (type 3’’3a).

Remarks: This species was first recorded from the Aptian–Albian strata of western Canada.

Size: Intermediate.

Occurrence: DC353, 17720–17780ft. to 17960–18020ft. (Aptian); VK117, 14370–14400ft. to 16140–16170ft. (Aptian–Barremian); CH265, 10250–10260ft. (Aptian).

Palaeoperidinium pyrophorum (Ehrenberg, 1838, ex Wetzel, 1933) Sarjeant, 1967

Plate VIII, Fig. s

1933 *Peridinium pyrophorum* Ehrenberg, 1838, pl. 1, figs. 1,4; ex Wetzel p. 164–165.

1967 *Palaeoperidinium pyrophorum* (Ehrenberg, 1838, ex Wetzel, 1933) Sarjeant, p. 246.

1967 *Peridinium basilium* Drugg, p. 13, pl. 1, figs. 9–11; pl. 9, figs. 1a–b.

1973 *Palaeoperidinium deflandrei* Lentin and Williams, p.105.

1967 *Pentagonum marginatum* Vozzhennikova, p. 107, pl. 46, figs. 1, 3–4, 6.

1976 *Palaeoperidinium marginatum* (Vozzhennikova, 1967) Lentin and Williams, p. 110.

1967 *Pentagonum sibiricum* Vozzhennikova, p.106–107, pl. 46, figs. 2, 5.

1976 *Palaeoperidinium sibiricum* (Vozzhennikova, 1967) Lentin and Williams, p. 111.

1967 *Peridinium conicum* var. *larjakiense* Vozzhennikova, p. 71–72, pl. 16, figs. 1a–b, 2a–b.

1981 *Palaeoperidinium larjakiense* (Vozzhennikova, 1967) Lentin and Williams, p. 210.

1973 *Palaeoperidinium deflandrei* subsp. *larjakiense* (Vozzhennikova, 1967) Lentin and Williams, p. 105.

1975 *Cooksoniella larjakiensis* (Vozzhennikova, 1967) Harker and Sarjeant, p. 224.

Description: *Palaeoperidinium pyrophorum* is an intermediate, proximate, acavate cyst with a pentagonal outline. It has a broad based apical horn and two antapical horns (left side is slightly longer) separated by a concavity. The epicyst and hypocyst are roughly equal in size. The autophragm has a reticulate ornamentation, and when the cyst is well preserved a peridiniod tabulation can be observed. The archeopyle is a combination made up of one precingular and an anterior intercalary plate (type 3’’3a).

Remarks: *Palaeoperidinium pyrophorum* was originally recoded from the Late Cretaceous of Hungary.

Size: Intermediate.

Occurrence: DC353, 17600–17660ft. to 19700–19760ft. (Albian–Hauterivian); VK117, 13770–13800ft. to 15540–15570ft. (Aptian–Barremian); CH265, 9812.5ft. to 10800–10810ft. (Aptian–Barremian).

Genus *SUBTILISPHAERA* Jain and Millepied, 1973

1973 *Subtilisphaera* Jain and Millepied, p. 26–27.

TYPE: Jain and Millepied, 1973, pl. 3, fig. 31, as *Subtilisphaera senegalensis*.

SYNOPSIS: The genus *Subtilisphaera* is composed of small to intermediate, proximate, cavate cysts. They have a subspherical to peridiniod outline, with or without a short apical horn and one or two antapical horns. The endophragm and periphragm are closely appressed, except where pericoels form to produce an apical horn and sometimes to form antapical horns. The paracingulum is indicated by a low parallel ridges that traverse the cyst. There is no discernible paratabulation. The archaeopyle is unclear.

Subtilisphaera perlucida (Alberti, 1959) Jain and Millepied, 1973

Plate VIII, Fig. t

1959 *Deflandrea perlucida* Alberti, p. 102, pl. 9, figs. 16–17.

1973 *Subtilisphaera perlucida* (Alberti, 1959) Jain and Millepied, p. 27.

Description: *Subtilisphaera perlucida* is an intermediate, proximate, circumcavate cyst. The psilate endophragm is spherical, while the psilate periphragm detaches to form one apical horn, a left antapical horn and right apical bulge with the pericoels extending to the cingulum in both the epi- and hypocysts. The paracingulum is clearly observable by means of two parallel ridges in the periphragm which circumvent the cyst. There is no discernible paratabulation. The archaeopyle is unclear.

Remarks: This species was first recorded from the Late Barremian of North and Central Germany.

Size: Small to intermediate.

Occurrence: DC353, 17600–17660ft. to 20600–20600ft. (Albian–Valanginian) with caving at 22760–22820ft. (Kimmeridgian); VK117, 12600–12630 to 18840–18870ft. (Albian–Valanginian) with caving at 20790–20800ft. and 23990–24000ft. (Tithonian and Undifferentiated strata respectively); CH265, 7750–7760ft. to 11600–11610ft. (Aptian–Hauterivian).

Subclass UNCERTAIN

Order UNCERTAIN

Suborder UNCERTAIN

Family UNCERTAIN

Subfamily UNCERTAIN

Genus *PROLIXOSPHAERIDIUM* Davey *et al.,* 1966

1966 *Prolixosphaeridium* Davey *et al.,* p. 171.

TYPE: Davey *et al.,* 1966, pl. 3, fig. 2; text-fig. 45, as *Prolixosphaeridium deirense*.

SYNOPSIS: The genus *Prolixosphaeridium* is composed of small to large, proximochorate to chorate cysts. They have an elongate ellipsoidal outline, with nontabular processes. The processes are usually simple and closed distally. There is no discernible paratabulation. The archaeopyle is apical.

Prolixosphaeridium anasillum Erkmen and Sarjeant, 1980

Plate IX, Fig. a

1980 *Prolixosphaeridium anasillum* Erkmen and Sarjeant, p. 64–65, pl. 4, figs. 2, 9; pl. 5, fig. 3.

Description: *Prolixosphaeridium anasillum* is an intermediate, chorate cyst with an elongated ovoidal outline. The densely granulate endophragm and periphragm are appressed close to one another, except where the periphragm pulls away to produce nontabular, acuminate processes. The paratabulation is not discernible. The archaeopyle is apical.

Remarks: This species was first recorded from the Callovian of Yorkshire, England.

Size: Intermediate.

Occurrence: DC353, reworked into younger strata between 19760–19820ft. to 23340–23400ft. (Hauterivian–Oxfordian); VK117, reworked into younger strata at 22790–22800ft. (Tithonian); CH265, not present.

Prolixosphaeridium conulum Davey, 1969a

Plate IX, Fig. b

1969a *Prolixosphaeridium conulum* Davey, p. 160–161, pl. 8, figs. 5–6.

Description: *Prolixosphaeridium conulum* is an intermediate, chorate, apiculocavate cyst with an elongated ovoidal outline. The finely granulate endophragm and periphragm are appressed close to one another, except where the periphragm pulls away to produce nontabular, acuminate to subconical psilate, hollow walled processes. The paratabulation is not discernible. The archaeopyle is apical.

Remarks: This species was originally described from the Cenomanian of Northern France.

Size: Intermediate.

Occurrence: DC353, 18200–18260ft. to 21320–21380ft. (Aptain–Valanginian); VK117, not present; CH265, not present.

Prolixosphaeridium parvispinum (Deflandre, 1937) Davey *et al.,* 1969

Plate IX, Fig. c

1937 *Hystrichosphaeridium xanthiopyxides* var. *parvispinum* Deflandre, p. 77, pl. 16 (al. pl. 13), fig. 5.

1958 *Hystrichosphaeridium parvispinum* (Deflandre, 1937) Cookson and Eisenack, p. 45.

1960 *Baltisphaeridium parvispinum* (Deflandre, 1937) Klement, p. 59.

1969 *Prolixosphaeridium parvispinum* (Deflandre, 1937) Davey *et al.,* p. 17.

Description: *Prolixosphaeridium parvispinum* is an intermediate, chorate, apiculocavate cyst with an elongated ovoidal outline. The finely granulate endophragm and periphragm are appressed close to one another, except where the periphragm pulls away to produce nontabular acuminate hollow processes. The paratabulation is not discernible. The archaeopyle is apical.

Remarks: This species was first recorded from the Late Aptian of France.

Size: Intermediate.

Occurrence: DC353, 18320–18380ft. to 21080–21140ft. (Barremian–Valanginian); VK117, 14490–14520ft. to 15840–15870ft. (Aptian–Barremian); CH265, not present.

Chapter 6 - Biostratigraphy and Correlation

6.1 Introduction

The Late Jurassic to Early Cretaceous (Oxfordian–Albian) strata of the EGoM yield rich palynomorph assemblages, with the largest proportion being composed of marine microplankton. Dinoflagellate cysts dominate throughout the sequence, with the largest variation of dinoflagellate species occurring in association with relatively large numbers of microforaminiferal test-linings. Due to the species richness of dinoflagellates cysts, they have been the focus of this study, with pollen and spores only being considered within the palynofacies. Foraminiferal test-linings are encountered throughout the Cretaceous and are high in abundance from the Hauterivian. The preservation of individual palynomorphs is considered here to be good. However, there is a large disparity between preservation at the bottom of the wells compared to the top. Amorphous organic matter dominates the palynological matter in all three wells, while the terrestrial input of opaque and translucent palynological matter, plant cuticle, spores and pollen is only present in minor quantities.

A new biostratigraphy based on dinoflagellate cysts has been produced for the EGoM. The dating of the cysts was determined by comparison with known stratigraphical ranges recognised from accurately dated onshore European sections. These were then combined with ranges established at Deep Sea Drilling Project (DSDP) sites in the North Atlantic, southeastern GoM and western Africa (Habib, 1978; Williams, 1978; Habib and Drugg, 1983; Riley and Fenton, 1984). These ranges can be viewed in Chart 1, any dinoflagellate cyst name changes and synonomies have been updated in accordance with Fensome *et al.,* (2008). This study has adopted a range approach rather than a zonation scheme, like that implemented in the North Sea. This is due to the large distances between each well. Although data has been recovered from the three wells, more data from these and other wells in the EGoM would be required to produce a robust zonation scheme.

The stratigraphical distribution and relative abundance of the dinoflagellate cysts recovered from VK117, DC353 and CH265 during this study are shown in Charts 2, 3 and 4 respectively. Furthermore, the biostratigraphic correlations can be evidenced in Chart 5. The chronostratigraphy used in Charts 2–8 has been inferred from the dinoflagellate cyst assemblages. All of the charts take into consideration the reworked and caved specimens in each well and preclude them from the presumed biostratigraphy. Reworked and caved taxa have been identified by the colourisation and preservation of the dinoflagellate cysts (i.e., the maturity). For example, some reworked Jurassic dinoflagellate cysts appear higher up in the stratigraphy, but are much darked in colour and are incomplete compared to the contemporaneous assemblage.

Throughout the interpretation of the wells, Table 3 should be refered to, as it provides quantative meaning to the written statements.

Count number	Description
1	Rare
2–5	Frequent
6–15	Common
16–25	Abundant
26+	Super Abundant

Table 3. Terms used in this study (max 200 counts).

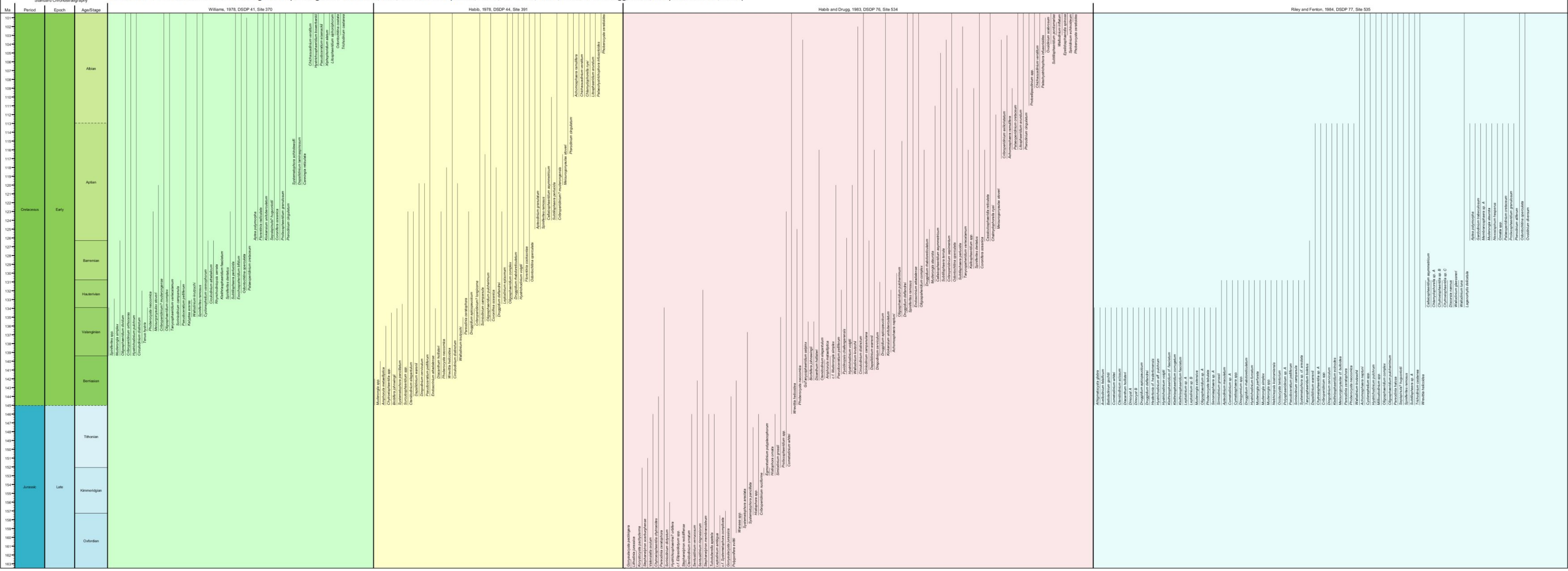
Chart 1

Please find enclosed in the pocket at the back.

Chart 2

Please find enclosed in the pocket at the back.

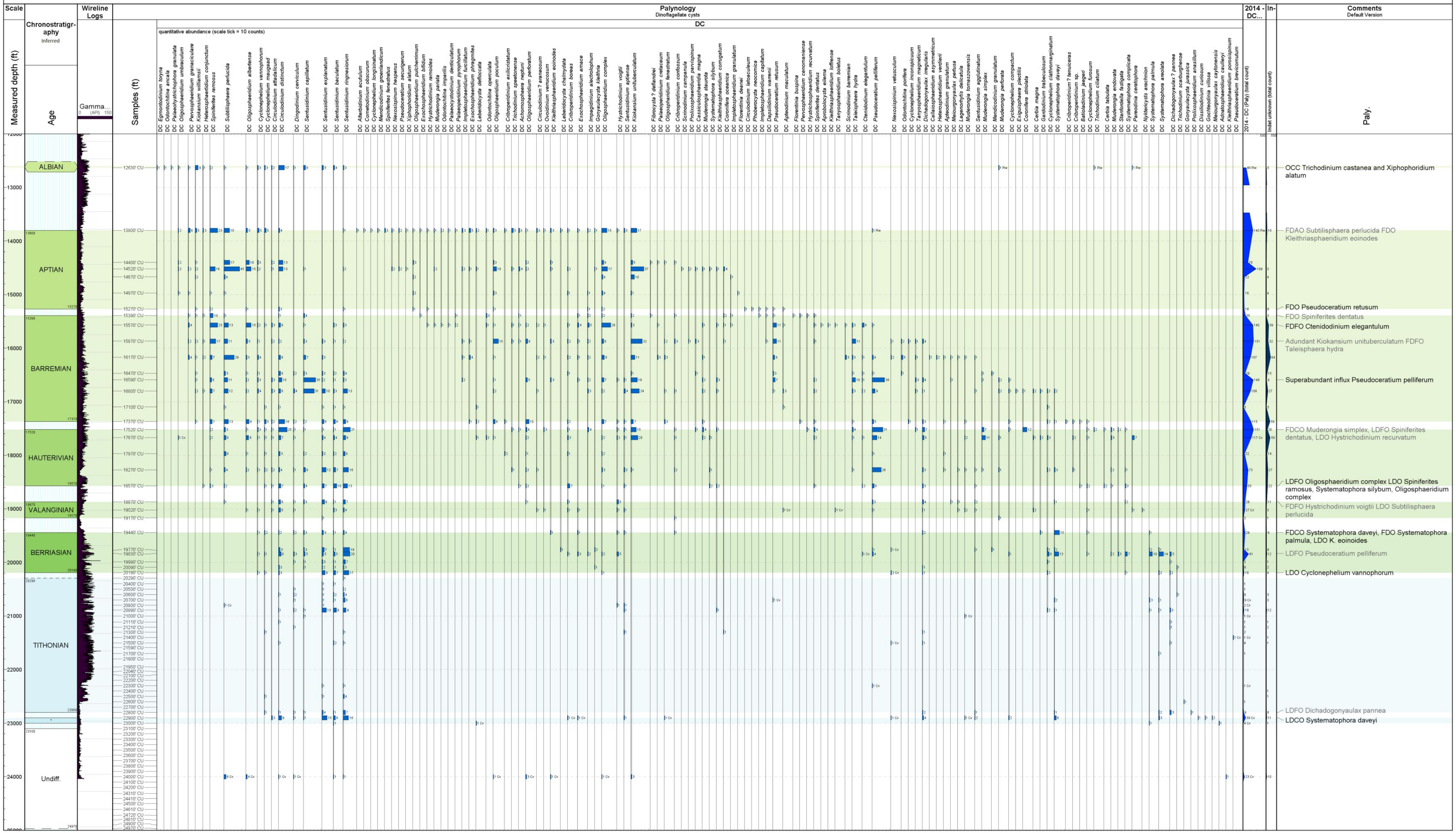
CHART 1 Established DSDP dinoflagellate cyst ranges for Sites 370, 391, 534 and 535 (Habib, 1978; Williams, 1978; Habib and Drugg, 1983; Riley and Fenton, 1984)



VK117

Scale: 1:10000 Interval: 12000' - 25000'

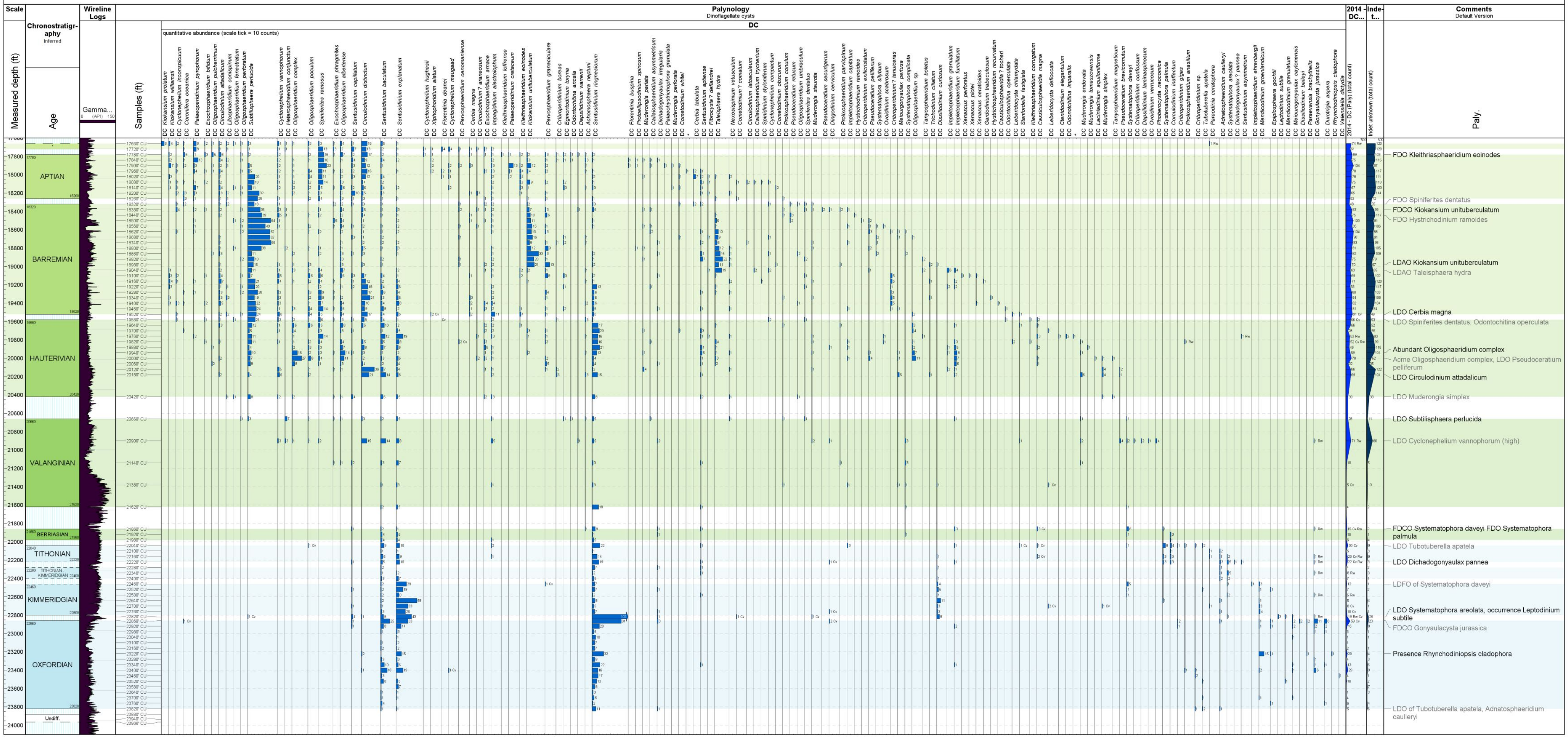
CHART 2 Stratigraphical distribution of dinoflagellate cysts recovered from Well VK117



DC353 — CHART 3

Scale: 1:6000 | Well Code: DC353 | Interval: 17600' - 24100'

Stratigraphical distribution of dinoflagellate cysts recovered from Well DC353



CH265

Scale: 1:6000 Interval: 7600' - 11750'

CHART 4 Stratigraphical distribution of dinoflagellate cysts recovered from Well CH265

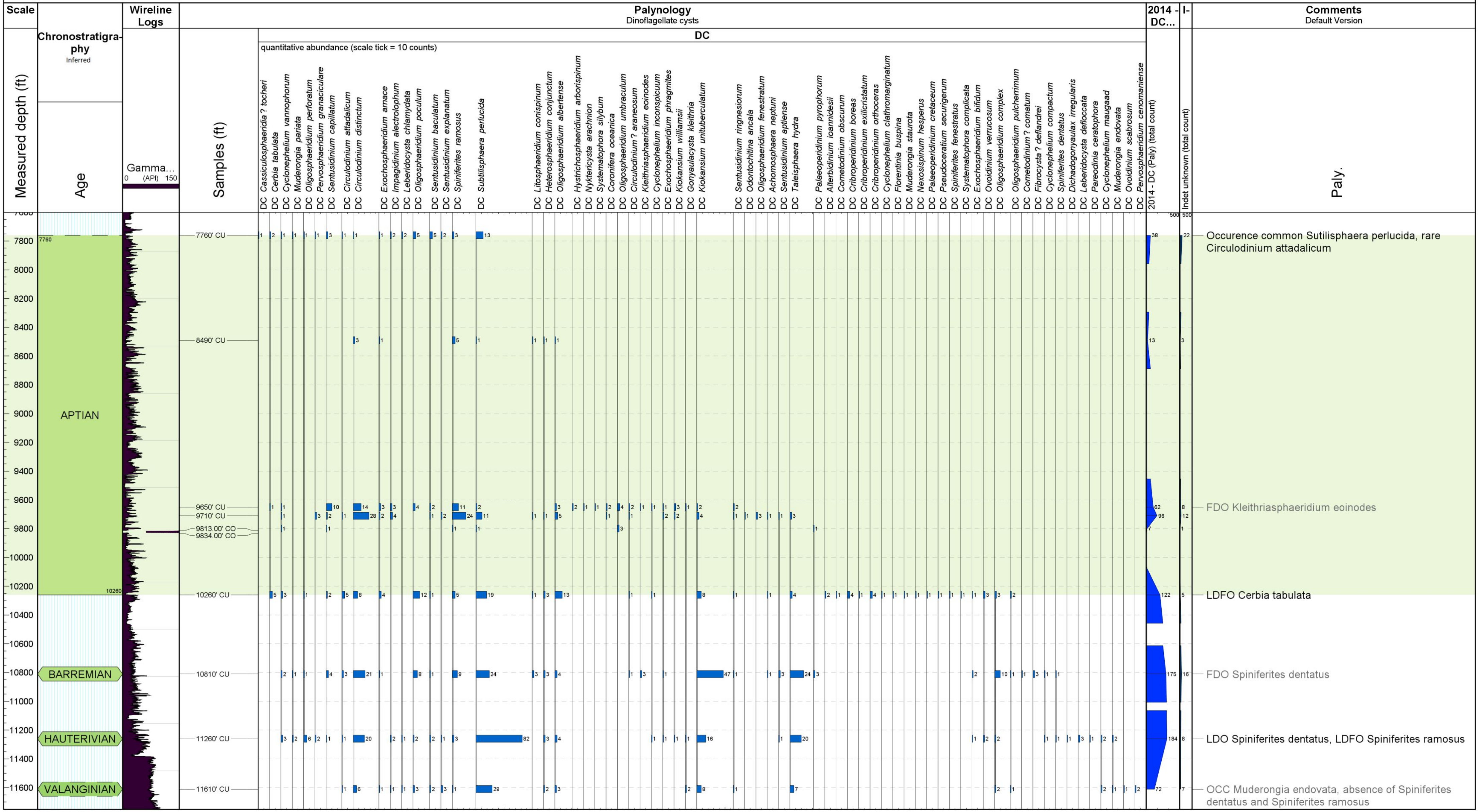
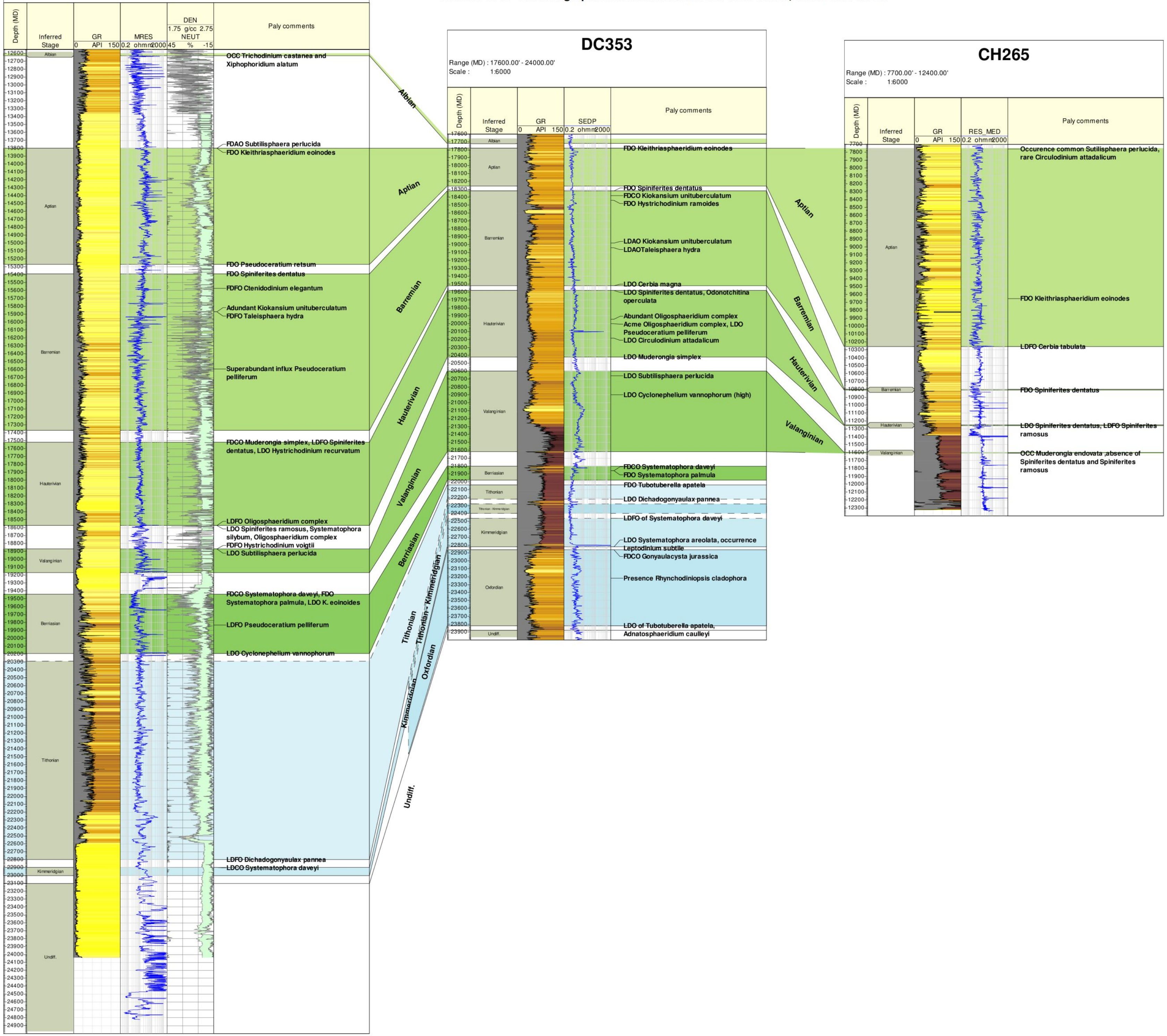


Chart 5 Biostratigraphical correlation between wells VK117, DC353 and CH265



6.2 Interpretation of VK117

6.2.1 Albian

In this work, the Albian is defined as everything above the top of the first downhole occurance (FDO) markers for the Aptian.

6.2.2 Aptian

The top of the Aptian at 13770–13800ft. is supported by the FDO of *Kleithriasphaeridium eoinodes*, which is comparable to Riley and Fenton (1984). Similarly, the first downhole abundant occurance (FDAO) of *Subtilisphaera perlucida* (Williams, 1978) also occurs at 13770–13800ft. Although *Oligosphareidium pulcherrimum* was first described from the Albian of Australia (Deflandre and Cookson, 1955), and is thought by Riley and Fenton (1984) to be an Albian species, it is confined to the Aptian of this well. The base of the Aptian (15240–15270ft.) is defined by the FDO of *Pseudoceratium retsum*, which according to Brideaux (1977) is confined to the Aptian and Barremian. This is concordant with VK117 (except for one instance of caving in to Jurassic sediments).

6.2.3 Barremian

The FDO of *Spiniferites dentatus* gives positive evidence to suggest the top of the Barremian at 15360–15390ft. This is equivalent to samples from the West coast of Africa and the southeastern GoM (Williams, 1978; Riley and Fenton, 1984).

Williams (1978) commented that a tentative Barremian age should be assigned to *Kiokansium unituberculatum* (as *Cleistosphaeridium polypes*), although it had the potential to be Aptian in age. While not thought of as a marker herein, it should be commented that large numbers have been recorded from the Late Hauterivian, through to the latest Aptian. Similarly, *Taleisphaera hydra* is well represented in the Barremian, particularly the Middle Barremian (Duxbury, 1979a).

Ctenidodinium elegantum is confined here between the Barremian and Hauterivian (FDO at 15540–15570ft. to LDO at 18540–18570ft.). This is concurrent with findings made by Millioud (1969). Similarly, Williams *et al.,* (1993) agrees that *Ctenidodinium elegantum* specimens from the Northern Hemisphere have a range top in the Barremian.

The *Phoberocysta neocomica* Subzone reported in Habib (1978) displays comparable results to this well. This Subzone observes the FDO of *Dapsilidinium warrenii* at 15240–15270ft. (Aptian) as well as the LDO at 15840–15870ft. (Barremian). Also present in the *Phoberocysta neocomica* Subzone are *Spiniferites ramosus* (FDAO at 13770–13800ft. to the LDFO at 18540–18570ft.) and *Callaiosphaeridium asymmetricum* (16140–16170ft.) which both occur in this Well. Therefore, it is here considered that the *Phoberocysta neocomica* Subzone (Habib, 1978) encorporates the Barremian interval and gives positive evidence to suggest it is equal to the earliest Hauterivian (18540–18570ft.) to earliest Aptian intervals (15240–15270ft.) in Well VK117.

6.2.4 Hauterivian

During the Hauterivian section of the wellthere is an increase in microforaminiferal test-linings and the dinoflagellate cyst community begins to diversify. The upper limit of the Hauterivian is supported by the FDAO's of *Muderongia simplex* at 17490–17520ft., which is comparable to the stratigraphic range of the southeastern GoM DSDP Site 353 (Riley and Fenton, 1984). The last downhole occurance (LDO) of *Spiniferites dentatus* at 17490–17520ft. (Gocht, 1959; Williams, 1978; Harding, 1990) further supports the boundary between the Hauterivian and the Barremian. More support for the age of this interval is the LDO of *Odonotchitina operculata*. This matches the data from Williams (1978) in which this species ranges from the Hauterivian into younger sediments. Similarly, the *Odonotchitina operculata* zone from Habib (1978) approximates its age to the Late Hauterivian, allowing the species to terminate around the Early Albian, which is comparable to the end range of latest Aptian in VK117.

Pseudoceratium pelliferum is restricted between the Valanginian to Hauterivian off the west coast of Africa (Williams, 1978). However, here it extends down into the Berriasian and up into the Aptian, with particularly large numbers recorded throughout the Hauterivian and Barremian. According to Williams (1978) *Circulodinium attadalicum* (as *Cyclonephelium attadalicum*) ranges from the Hauterivian to the Barremian. However, in VK117 it is present from the Valanginian through to the Albian, with the majority of specimens clustered between the Valanginian to the Barremian, and some caving into the Kimmeridgian sediments.

The base of the Hauterivian is determined here by the LDO of *Spiniferites ramosus* at 18540–18570ft. This is slightly younger than that recorded by Riley and Fenton (1984), who considered it no older than Valanginian, and Habib and Drugg (1983) who reported occurrences to extend into the very latest Valanginian. The last downhole frequent occurance (LDFO) of *Oligosphaeridium complex* is situated at 18540–18570ft., the base of the Hauterivian. This is comparable to the criteria used by Williams (1978) at DSDP Site 367 and Habib (1978) at DSDP Site 391.

6.2.5 Valanginian

The LDO of *Subtilisphaera perlucida* provides evidence to suggest that 18840–18870ft. is the top of the Valanginian. The occurance of this species within the lastest Valanginian is contemporaneous with Williams' (1978) observations of the Speeton Clay and DSDP Site 367, as well as Riley and Fenton (1984, as *Subtilisphaera* sp. A) from the southeastern GoM. Although *Muderongia tomasowensis* is generally confined to the Valanginian (Alberti, 1961; Davies, 1983), here it appears to extend up into the Barremian (possibly reworked) and possibly be caved down into Jurassic sediments. However, the LDFO is recorded at a sample depth of 18990–19020ft., and as such places the Valanginian in its vicinity.

Hystrichodinium voigtii ranges from the Tithonian to Aptian, and its FDFO in this Well supports a Valanginian age. This range is comparable to the *Druggidium deflandrei* Zone in Habib (1978), however, here it is also visible in high numbers in the Berriasian.

6.2.6 Berriasian

The top of the Berriasian is evidenced by the FDCO of *Systematophora daveyi* (at, 19410–19440ft.) which has an age range from the Late Kimmeridgian through to the Late Berriasian in northwest Europe and Russia (Harding *et al.,* 2011; and references there in). However, Harding *et al.,* (2011) suggests that *Systematophora palmula* is also a reliable marker for the Late Berriasian in the Northern Hemisphere, which has a FDO of, 19410–19440ft. in VK117. Also coinciding with the FDCO of *Systematophora daveyi* is the LDO of *Kleithriasphaeridium eoinodes* at, 19410–19440ft. (except for caving into the Jurassic sediments), which is consistent with findings made by Williams (1978) and Williams and Bujak (1979) to support a Berriasian age. It should be noted here that *Kleithriasphaeridium eoinodes* (as *Kleithriasphaeridium simplicispinum,* Riley and Fenton, 1984) was found from the latest Valanginian, so there is some disparity here.

The LDO of *Cyclonephelium vannophorum* at a depth of, 20180–20190ft. supports the base of the Berriasian, which is consistent with findings made by Williams (1978). Within this Berriasian section *Pseudoceratium pelliferum* makes its LDFO, which once again is consistent with the oldest approximate age made by both Williams (1978) and Riley and Fenton (1984). However, there is one instance of caving, into the Jurassic and possible reworking into the latest Aptain.

6.2.7 Tithonian

The base of the Tithonian is indicated by last downhole frequent occurance (LDFO) of *Dichadogonyaulax pannea* at 22790–22800ft. This is known from equivalent sediments in the UK (as *Leptodinium panneum*, Norris, 1965b), North America (as *Dichadogonyaulax pannea*, Benson, 1985) and Canada (as *Ctenidodinium panneum*, Williams, 1975) and has a range, which extends into the Berriasian, where it makes its FDO at, 19800–19830ft.

6.2.8 Kimmeridgian

The top of the Kimmeridgian is supported by the LDCO of *Systematophora daveyi* at 22890–22900ft. This is concordant with Harding *et al.,* (2011) where this species ranges from the Late Kimmeridgian.

6.2.9 23100ft. and Below

It is unclear what is happening past this point as there is only one data set (23990–24000ft.) which appears to be caved. Only four of the identified 13 dinoflagellate cysts appear to be at the correct age appropriate interval.

6.3 Interpretation of DC353

6.3.1 Albian

The Albian is positioned above the FDO of *Kleithriasphaeridium eoinodes* (Riley and Fenton, 1984).

6.3.2 Aptian

The FDO of *Kleithriasphaeridium eoinodes* at 17720–17780ft. provides positive evidence of Aptian age, comparable to findings made by Riley and Fenton (1984) in the southeastern GoM. *Subtilisphaera perlucida* becomes a dominant part of the dinoflagellate assemblage downhole from the top Aptian in this Well, although it does range into the earliest Albian in this instance (Williams, 1978; Davey, 1979b). The base of the Aptian is supported by the the FDO of *Spiniferites dentatus* at 18200–18260ft. (Williams, 1978; Riley and Fenton, 1984).

6.3.3 Barremian

The Barremian age is recorded from 18260–18320ft. to 19460–19520ft. It is a thick section of sediments defined at the top by the FDO of *Spiniferites dentatus* which is comparable to studies from the West coast of Africa and the southeastern GoM (Williams, 1978; Riley and Fenton, 1984). The base of the Barremian is considered here to be at, 19460–19520ft. where *Cerbia magna* has it LDO (Duxbury, 2001).

Williams (1978) commented that a tentative Barremian age should be assigned to *Kiokansium unituberculatum* (as *Cleistosphaeridium polypes*), although it had the potential to be Aptian in age. While not considered as a marker, it should be commented that large numbers have been recorded from the Hauterivian, through to the largest numbers recorded in the Barremian interval. Similarly, *Taleisphaera hydra* is well represented in the Barremian, particularly the Middle Barremian (Duxbury, 1979a). The presence of *Hystrichodinium ramoides* at 18380–18440ft. also supports a Barremian age (Costa and Davey, 1992).

6.3.4 Hauterivian

Although not well constrained, the Hauterivian interval is supported by the LDO of *Spiniferites dentatus* and LDO of *Odonotchitina operculata* at, 19520–19580ft. This is akin to the data from Gocht (1959), Williams (1978) and Harding (1990) for *Spiniferites dentatus*. Additionally, the data in Williams (1978) supports *Odonotchitina operculata* ranging from the Hauterivian into younger sediments. Also, the *Odonotchitina operculata* zone from Habib (1978) approximates its age to the Late Hauterivian and younger.

Within the Hauterivian interval and into younger samples there is a notable increase in microforaminiferal test-linings and the dinoflagellate cyst community begins to diversify. *Circulodinium attadalicum* is also present and has its LDO within this Hauterivian section, which is consistent with findings made by Williams (1978). However, it extends up into the Albian sediments here. The increasing prevealence of *Spiniferites ramosus* within this interval is consistent with findings made by Riley and Fenton (1984) in which they illustrate this species becoming more prevalent in the stratigraphy from the Hauterivian onwards. The highest numbers and frequency of *Oligosphaeridium complex* are also recorded within this interval, sharing similarities to the West coast of Africa (Williams, 1978 at DSDP Site 367) and the Blake-Bahama basin (Habib, 1978 at DSDP Site 391). Also worth noting is *Pseudoceratium pelliferum,* which is restricted between the Valanginian to Hauterivian off the West coast of Africa. However, here it is restricted between the Hauterivian and Barremian, and has its LDO within this Hauterivian section (Williams, 1978).

6.3.5 Valanginian

The LDO of *Subtilisphaera perlucida* observed at, 20600–20660ft., supports evidence for Valanginian age similarly observed in Well VK117. The same evidence is recorded in Williams' (1978) study on the Speeton Clay and DSDP Site 367, as well as Riley and Fenton (1984, as *Subtilisphaera* sp. A) from the southeastern GoM. Within this Valanginian interval is the LDO of *Cyclonephelium vannophorum*, which is higher up in the stratigraphy compare to Well VK117.

6.3.6 Berriasian

The top of the Berriasian in this Well is based on two palynological events observed at 21800–21860ft. (1) The FDCO of *Systematophora daveyi*, as reported in the northwest Europe and Russia (Harding *et al.,* 2011). (2) FDO *Systematophora palmula* considered as a reliable marker for the Late Berriasian in the Northern Hemisphere by Harding *et al.,* (2011).

6.3.7 Tithonian

The top of the Tithonian can be placed at 21980–22040ft. owing to the FDO of *Tubotuberella apatela*, a species which according to Habib and Drugg (1983) does not range into younger sediments. The base of the Tithonian is tentatively placed at 22160–22220ft. due to the single occurrence of *Dichadogonyaulax pannea*. This species has been recorded in equivalent age sediments in the UK as *Leptodinium panneum* (Norris, 1965b), North America as *Dichadogonyaulax pannea* (Benson, 1985) and Canada as *Ctenidodinium panneum* (Williams, 1975).

6.3.7.122220–22400ft

The absence of marker species in this interval is due to the low recovery in samples, and as such it was decided to attribute an age ranging from Kimmeridgian to Tithonian.

6.3.8 Kimmeridgian

Similarly, to Well VK117, the top of the Kimmeridgian is supported by the LDFO of *Systematophora daveyi* at 22400–22460ft. This is concurrent with Harding *et al.,* (2011) where this species has its LDO in the Late Kimmeridgian. The base of the Kimmeridgian is supported by the LDO of *Systematophora areolata* at 22760–22820ft., comparable with Klement's (1960) study. According to Riding (2005), *Systematophora areolata* is thought to range from the Late Oxfordian to Early Kimmeridgian. *Leptodinium subtile* is also a known Early Kimmeridgian species from southwest Germany (Klement, 1960) and is recorded in the same sample as *Systematophora areolata.*

6.3.9 Oxfordian

The top of the Oxfordian is supported by the FDCO of *Gonyaulacysta jurassica*, which is comparable to the findings made by Habib and Drugg (1983) from the Blake-Bahama basin, in which they noted the boundary between the Kimmeridgian and Oxfordian to be located where the FDO of *Gonyaulacysta jurassica* occured. However, it should be noted that *Gonyaulacysta jurassica* is recorded in this Well from younger Early Cretaceous strata but they are considered to be reworked specimens. Also present within the Oxfordian interval is *Rhynchodiniopsis cladophora,* a known Early Oxfordian species reported from sediments from northern France (Deflandre, 1939; Williams *et al.,* 1993). The base of the Oxfordian is supported by the LDO of *Adnatosphaeridium caulleyi* at 22800–23820ft., which is known from the Early Oxfordian of northern France (Deflandre, 1939, as *Hystrichosphaeridium caulleryi*). However, it should be noted that the base is only tentatively placed here, as there was no recovery from samples below this depth. The LDO of *Tubotuberella apatela* is recorded at 22800–23820ft.

6.4 Interpretation of CH265

Due to the small quantity of samples taken from Well CH265 and the low recovery each sample yielded, this Well was considerabley more difficult to interpret. Thus, less confidence is given to the interpretation.

6.4.1 Aptian

The first sample analysed in this Well is attributed an Aptian age based on the the common occurrence of *Sutilisphaera perlucida.* The base of the Aptian is supported by the LDO of *Cerbia tabulata* at 10250–10260ft.

6.4.2 Barremian

The FDO of *Spiniferites dentatus* at 10800–10810ft. provides positive evidence to suggest a Barremian age. This is equivalent to the studies conducted by Williams (1978) off the West coast of Africa and by Riley and Fenton (1984) in the southeastern GoM.

6.4.3 Hauterivian

The LDO of *Spiniferites dentatus* and the LDAO of *Spiniferites ramosus* support a Hauterivian age at 11250–11260ft. (Gocht, 1959; Williams, 1978; Harding, 1990). The presence of *Spiniferites ramosus* is consistent with Riley and Fenton (1984), in which they illustrate this species becoming more prevalent in the stratigraphy from the Hauterivian into younger sediments above. *Circulodinium attadalicum* is also present within this Hauterivian section, which is consistent with findings made by Williams (1978).

6.4.4 Valanginian

The Valanginian is thought to be represented in sample 11600–11610ft. due to the absence of *Spiniferites dentatus* and *Spiniferites ramosus;* together with the presence of *Muderongia endovata* (Riding *et al.,* 2001) a known Valanginian species.

6.5 Correlation

The challenging nature of the data owing to high thermal maturation and poor preservation of the palynomorph assemblages, meant that the general recovery of palynomorphs was low. This factor in combination with the absence of lithostratigraphical data means that only a tentative correlation can be made between the three wells, as shown in Chart 5. This correlation is based on a combination of the presence of known stratigraphical marker species (Chart 6, VK117; Chart 7, DC353 and Chart 8, CH265). More data is required to be fully confident with interval boundaries.

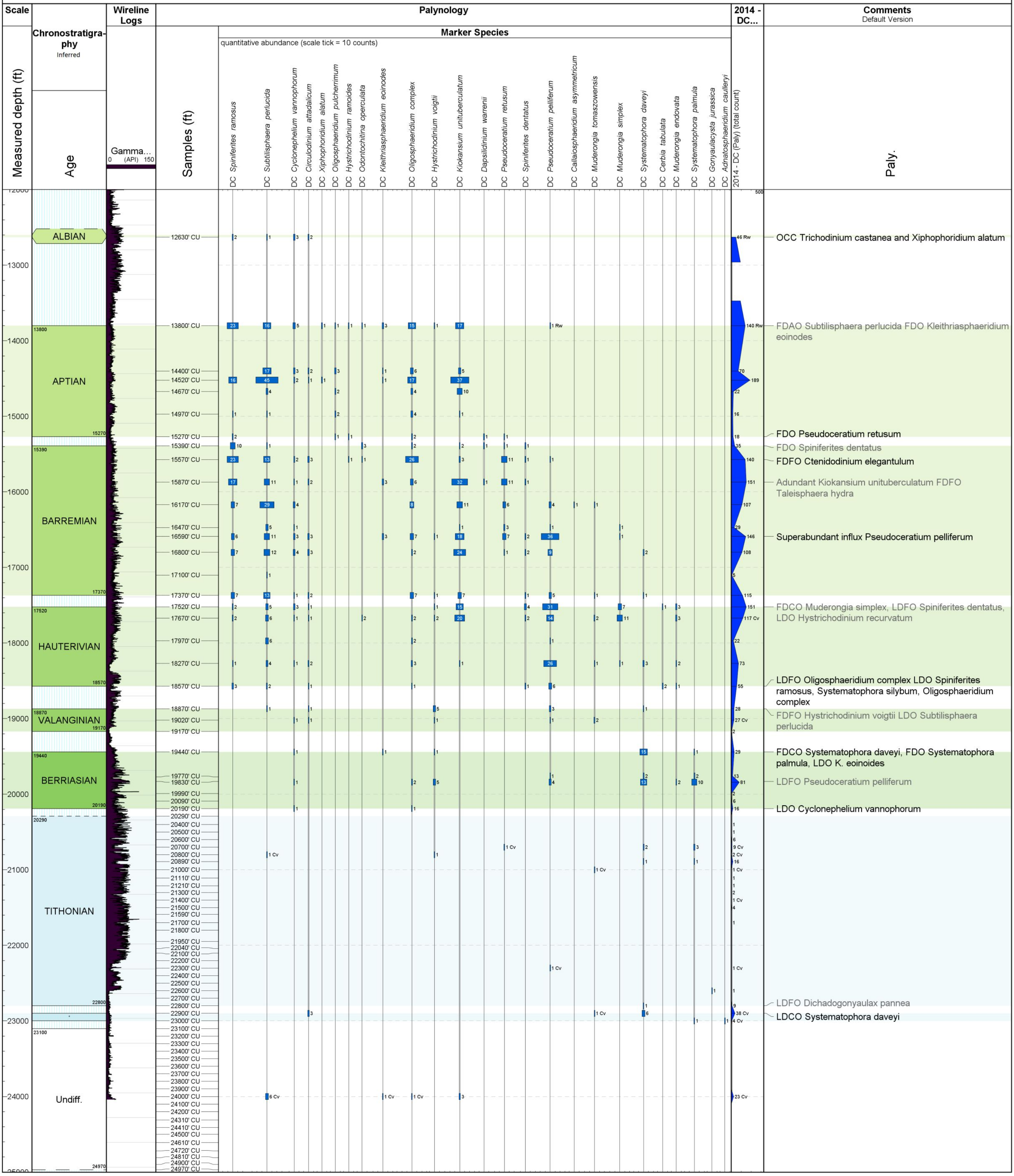
When this dataset is compared to previous studies (Chart 1), it should be noted that although not identical, similar findings have been observed between these three EGoM Wells and the southwestern GoM site (Riley and Fenton, 1984), as well as the DSDP sites off the West coast of Africa. This can be observed in Chart 9. These sites most likely proved comparable due to the relatively short distances between the palaeogeographical localities when the samples were deposited throughout the Jurassic and Cretaceous.

VK117

Stephanie Wood
Scale: 1:10000

Interval: 12000' - 25000'

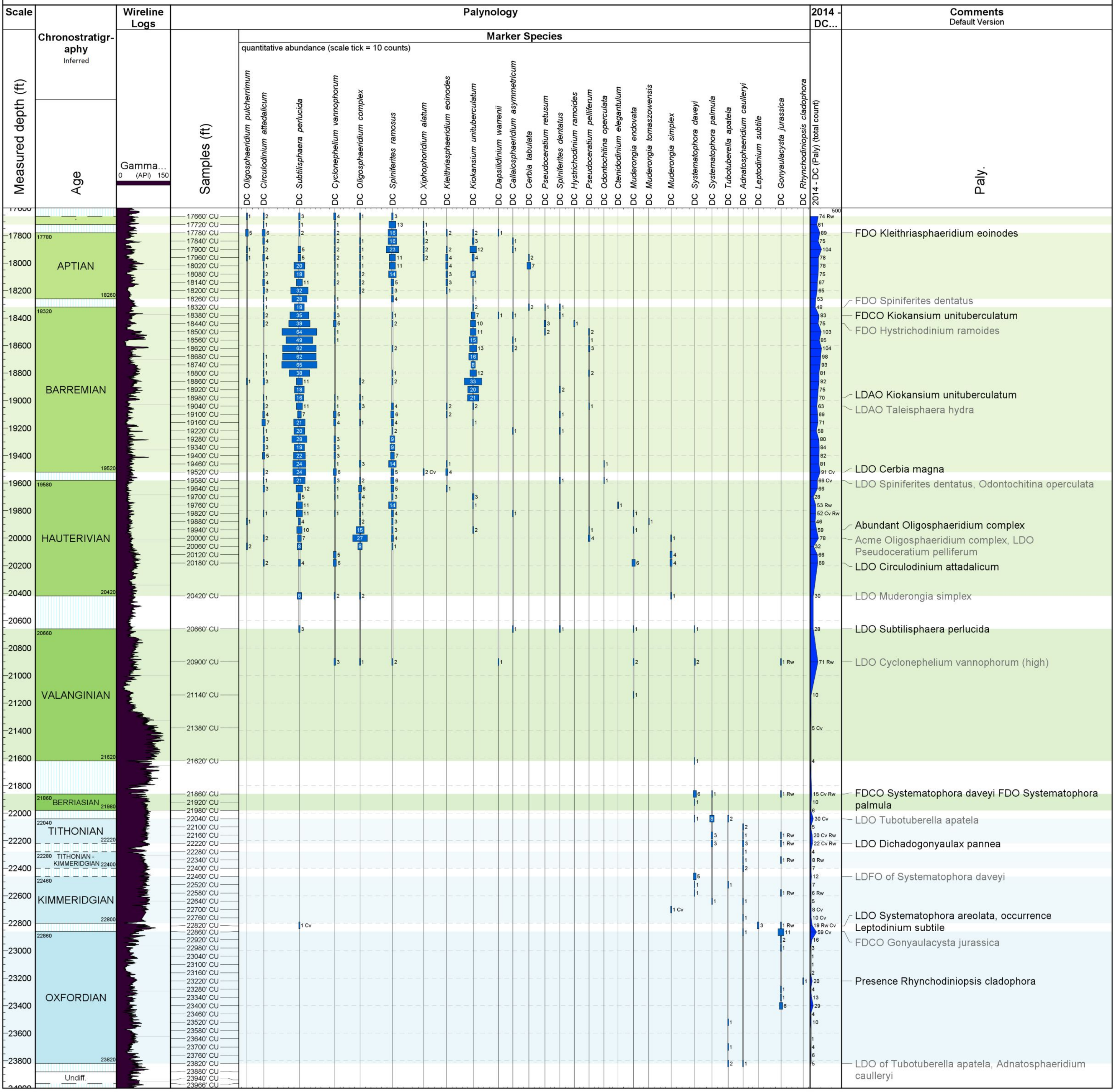
CHART 6 Stratigraphical marker species recovered from Well VK117



DC353

Stephanie Wood
Scale: 1:6000
Interval: 17600' - 24000'

CHART 7 Stratigraphical marker species recovered from Well DC353



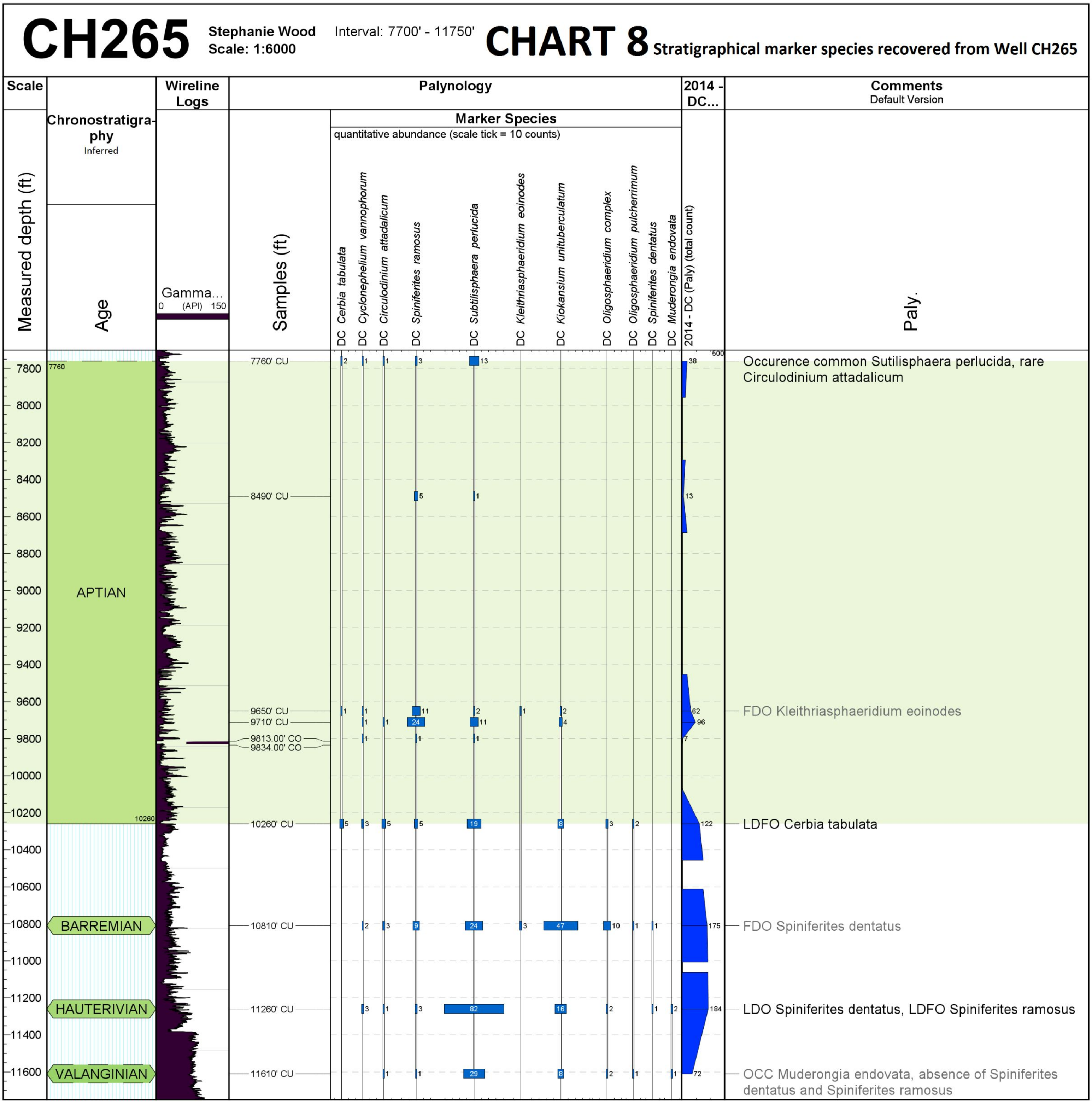
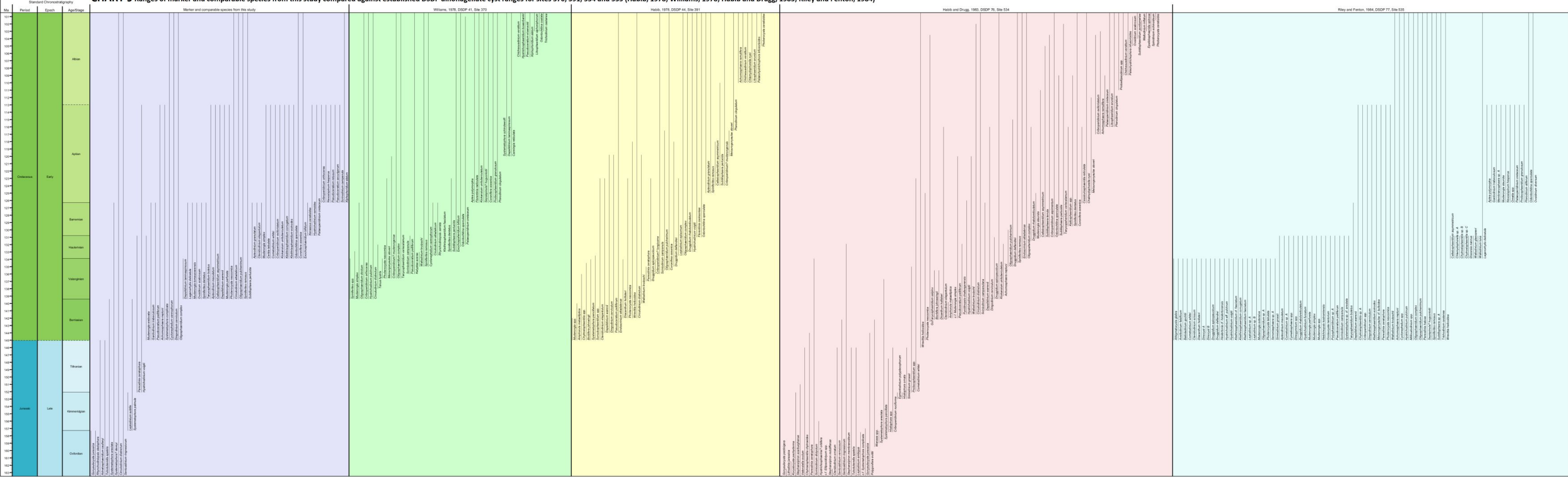

CH265
Stephanie Wood
Scale: 1:6000
Interval: 7700' - 11750'
CHART 8 Stratigraphical marker species recovered from Well CH265
Scale
Measured depth (ft)
Chronostratigraphy
Inferred
Age
Wireline Logs
Gamma...
0 (API) 150
Palynology
Samples (ft)
Marker Species
quantitative abundance (scale tick = 10 counts)
DC Cerbia tabulata
DC Cyclonephelium vannophorum
DC Circulodinium attadalicum
DC Spiniferites ramosus
DC Subtilisphaera perlucida
DC Kleithriasphaeridium eoinodes
DC Kiokansium unituberculatum
DC Oligosphaeridium complex
DC Oligosphaeridium pulcherrimum
DC Spiniferites dentatus
DC Muderongia endovata
2014 - DC...
2014 - DC (Paly) (total count)
Comments
Default Version
Paly.
7800
8000
8200
8400
8600
8800
9000
9200
9400
9600
9800
10000
10200
10400
10600
10800
11000
11200
11400
11600
7760
APTIAN
10260
BARREMIAN
HAUTERIVIAN
VALANGINIAN
7760' CU
8490' CU
9650' CU
9710' CU
9813.00' CO
9834.00' CO
10260' CU
10810' CU
11260' CU
11610' CU
500
38
13
62
96
7
122
175
184
72
Occurence common Sutilisphaera perlucida, rare Circulodinium attadalicum
FDO Kleithriasphaeridium eoinodes
LDFO Cerbia tabulata
FDO Spiniferites dentatus
LDO Spiniferites dentatus, LDFO Spiniferites ramosus
OCC Muderongia endovata, absence of Spiniferites dentatus and Spiniferites ramosus

CHART 9 Ranges of marker and comparable species from this study compared against established DSDP dinoflagellate cyst ranges for sites 370, 391, 534 and 535 (Habib, 1978; Williams, 1978; Habib and Drugg, 1983; Riley and Fenton, 1984)



Chapter 7 – Palynofacies

7.1 Introduction

Palynofacies are the associations of the kerogen and palynological materials found in rock and sediment samples. They are considered to be geologically or biologically connected to the origin of the original kerogen and palynological particles. The kerogen fraction of the palynofacies is often termed the palynodebris. The palynodebris, when studied alongside the palynomorphs, allows a more detailed analysis into subtle variations recorded in sedimentary environments, as well as the source of the organic matter and its preservation state (Tyson, 1995; Traverse, 2007b). The data assembled for the interpretation of the palynofacies is much more diverse than count data alone.

This chapter utilises Tyson Ternary Kerogen Plots (after Tyson, 1985, 1989, 1993, 1995) whereby the palynodebris and palynomorphs are reduced to three groups; Amorphous Organic Matter (AOM), Phytoclasts (opaque and translucent equidimensional and needle shaped phytoclasts and plant cuticle) and Palynomorphs (pollen, spores, dinoflagellate cysts, acritarchs, foram linings and algae). This allows a basic palynofacies and depositional environment to be assigned. These assignments are given under Roman numeral headings as displayed in Figure 33. The Tyson Ternary Kerogen Plots are compared to Dow (1982) Ternary Liptinite–Vitrinite–Inertinite (LVI) Plots (Litpinite; plant cuticle, pollen, spores, dinoflagellate cysts, acritarchs, foram linings and algae. Vitrinite; translucent equidimensional and needle shaped phytoclasts. Inertinite; opaque equidimensional and needle shaped phytoclasts) to identify kerogen association.

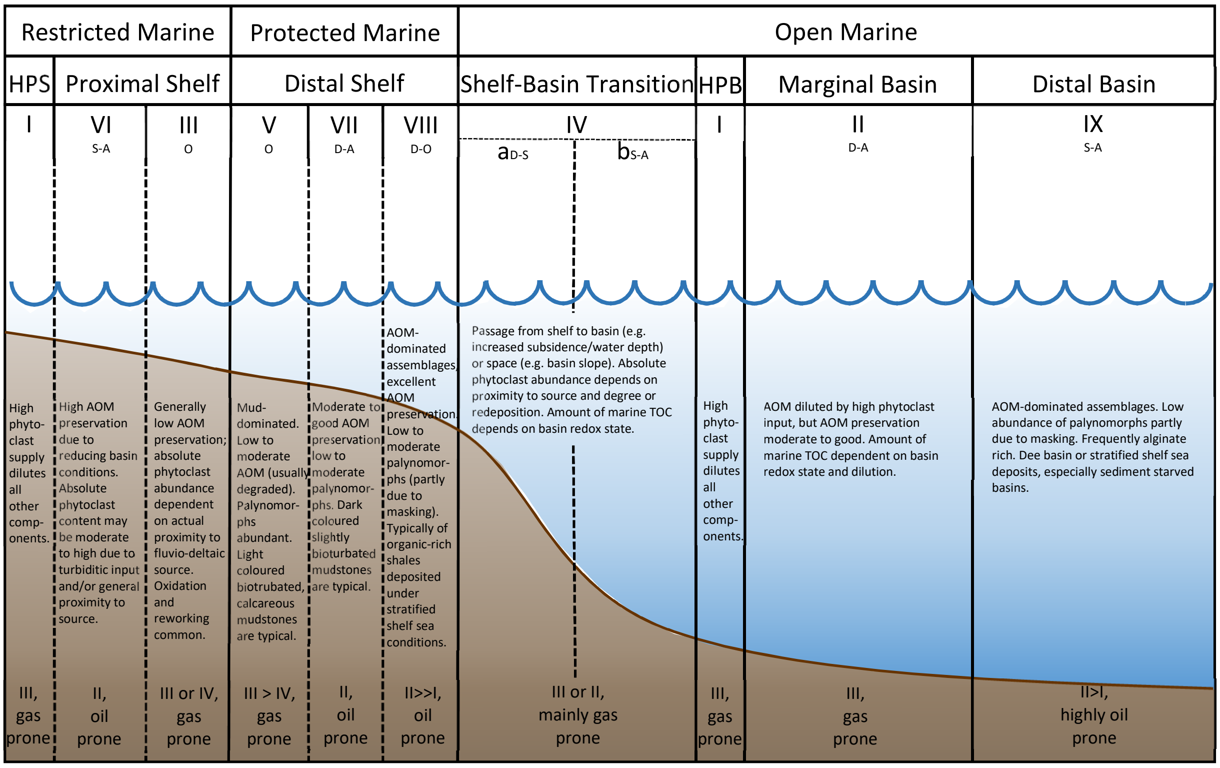


Figure 33. Illustrated key to marine palynofacies fields distinguished on Tyson Ternary plots. S, suboxic; A, anoxic; O, oxic; D, dysoxic.

7.2 Palynofacies Classification

As previously mentioned in Chapter 3 the palynofacies were grouped into twelve categories based on their morphological affinities. These are now explained in more detail.

7.2.1 Opaque Equidimensional Phytoclasts

Plate IX, figure d

The opaque equidimensional phytoclasts group comprises structured phytoclasts which are opaque in nature whereby the width of the fragment is less than three times the length of the main body. This group of phytoclasts includes oxidised and carbonised woody tissues (subjected to high temperatures). The more equidimensional the phytoclast suggests a higher energy environment in which the phytoclast would have undergone attrition. For example, a near shore environment.

7.2.2 Opaque Needle Shaped Phytoclasts

Plate IX, figure e

The opaque needle shaped phytoclasts are structured whereby the length of the fragment is more than three times the width of the main area. Similarly, the opaque needle shaped group includes oxidised and carbonised woody tissues. The more pronounced the elongate in shape the phytoclast, suggests a low energy environment, such as those experienced further offshore.

7.2.3 Translucent Equidimensional Phytoclasts

Plate IX, figure f

As the name suggests the translucent equidimensional phytoclast assemblage allows light to pass through under observation. The width is equal to or less than three times the length of the main fragment area and they have no definitive biostructures, but are likely to be non-fibrous lengths of cell wall or woody tissue.

7.2.4 Translucent Needle Shaped Phytoclasts

Plate IX, figure g

The translucent needle shaped phytoclasts have a width more than three times their length, and allow light to permeate through them. They too, have no definitive biostructures, but are probable non-fibrous lengths of cell wall or woody tissue.

7.2.4 Plant cuticle

Plate IX, figure h

Encompassed within this phytoclast group are all the fragments which have definitive biostructures: Thin and narrow tubes, pitted structures, spiral structures and cellular sections. These biostructures are attributed to fungal hyphae, plant tracheids, roots of plants or plant cuticle.

7.2.6 Pollen

Plate IX, figure i

Pollen is the first group of palynomorphs considered. It is produced by flowering plants during reproduction, however, if unsuccessful the pollen which has a sporopollenin wall will become preserved in the sediment. The presence of pollen in palynofacies indicates a terrestrial input. The ratio of marine fossils (in this case dinoflagellate cysts, acritarchs, foram linings and algae) to terrestrial palynomorphs (pollen and spores) can be used to derive a signal of terrestrial input into marine sediments.

7.2.7 Spores

Plate IX, figure j

Spores are unicellular, produced by non flowering plants and are composed of sporopollenin. They represent a terrestrial input into sediment. All of the spores found in this research posess trilete marks.

7.2.8 Amorphous organic matter (AOM)

Plate IX, figure k

AOM encompases all the structureless heterogeneous and homogeneous palynodebris. It has a fluffy cloud like appearance, which can be speckled at times and come in a variety of colours. The AOM represents the decaying fraction of non-carbonised, biogenic material, from both animal and plant remains. In this study the AOM present at deeper well depths is dark brown to almost black, while the further up well the colour transitions throughout the orange brown spectrum to pale yellow. This colour change is due to thermal maturity decreasing up-well and will be examined more closely in Chapter 8.

7.2.9 Dinoflagellate Cysts

Plates I–VIII, figures a–t and Plate IX, figures a–c

Dinoflagellate cysts make up the third group of palynomorphs, this time indicating a marine setting. Within the dinoflagellate cyst palynomorph assemblage further sorting of genera and species can be undertaken. Chorate dinoflagellate cysts are more commonly found in deep water settings, while proximate dinoflagellate cysts are more abundant in shallow, high energy water settings (which can even be brackish or even fresh water) (Traverse, 2007b). Due to the delicate nature of the dinoflagellate cysts recovered from the samples, the oxygen levels of the bottom sea water at the time of deposition can also be approximated. 'Diamond shapes' are left imprinted onto the cyst wall due to pyrite growth in a dysoxic environment during lithification. The pyrite crystals are then removed as a result of acid interaction during the processing of the rock samples. These 'rectangular shapes' are not present in oxic water environments.

7.2.10 Acritarchs

Plate IX, figure l

Acritarchs are the fourth group of palynomorphs. They were originally assigned as a microfossil group by Evitt (1963) and were defined as:

> "*small microfossils of unknown and probably varied biological affinities consisting of a central cavity enclosed by a wall of single or multiple layers and of chiefly organic composition; symmetry, shape, structure and ornamentation varied; central cavity closed or communicating with the exterior by varied means*."

In this study, the acritarchs recovered had an acanthomorph morphology, whereby they had long thin straight processes protruding from a central smooth body (Wall, 1965). Acritarchs are also an excellent indication of a marine setting.

7.2.11 Foram Linings

Plate IX, figure m

Forams are calcareous microfossils. During processing the interaction between the microfossils and the acids cause the outer carbonate shell is dissolved, leaving behind the organic foram lining. Although foram linings are not actually a palynomorph group, they do fall under the microfossil umbrella. Therefore, in this study they will be included in the collective palynomorph group during palynofacies analysis and interpretation. Foram linings are indicative of a marine setting.

7.2.12 Algae

Plate IX, figure n

The algae in this study are small (<20µm) and unicellular, and make up the fifth group of palynomorphs. It is thought that their cell wall is made from a kind of sporopollenin. They too support a marine setting.

7.3 Interpretation of VK117

Well VK117 is situated closest to the modern day shoreline on a relic horst. Figure 34 shows a break down of each palynodebris and palynomorph group. To reveal more about the palynofacies groupings the data from Figure 34 has been divided into three groups; AOM, Phytoclasts and Palynomorphs as described in section 6.1, to produce a Tyson Ternary Kerogen Plot. The results of which are shown in Figure 35.

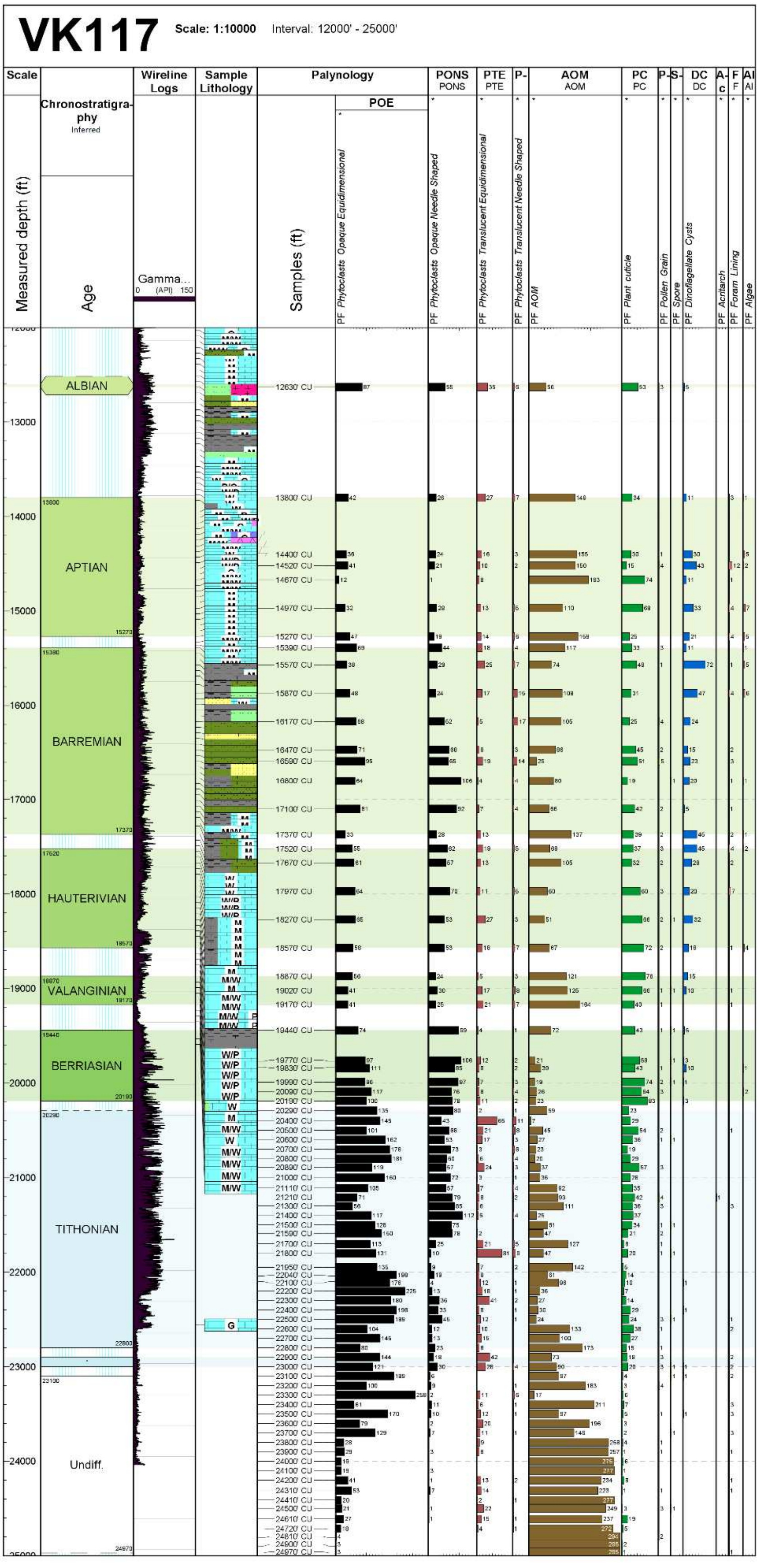


Figure 34. Chart to show the quantataive breakdown of 300 counts of each individual palynodebris and palynomorph group in each sample for Well VK117.

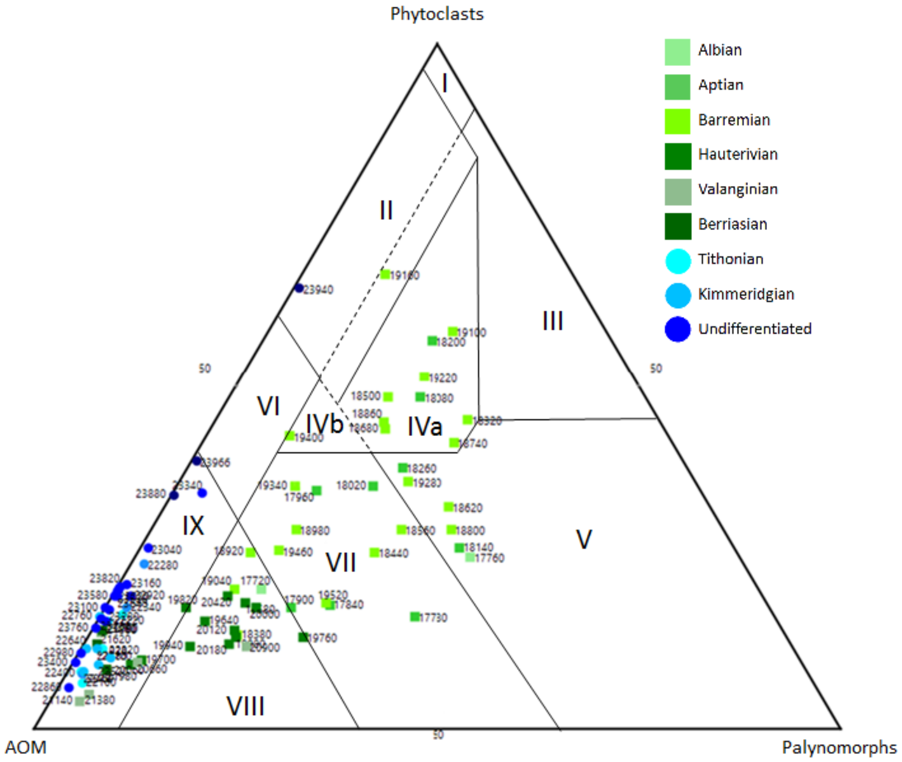


Figure 35. Tyson Ternary Kerogen Plot for Well VK117 (after Tyson, 1985, 1989, 1993 and, 1995) Sample depths refer to the lowermost depth of each sample.

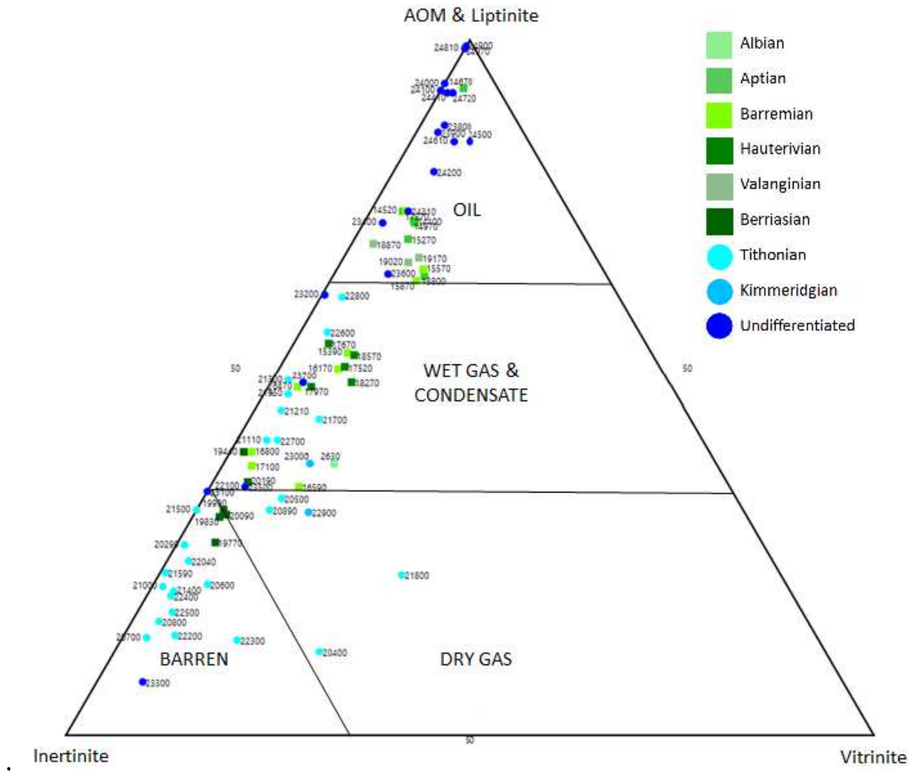


Figure 36. Dow Ternary Kerogen Plot for Well VK117 (after Dow and O'Connor, 1982) Sample depths refer to the lowermost depth of each sample.

The Roman numerical break down of the Tyson Ternary Plot is there to aid palynofacies identification and depositional environment reconstruction. In the deepest samples of the Well, the points are heavily clustered in section IX on Figure 35 (undifferentiated age – dark blue onthe plot). This suggests that the palynodebris and palynomorphs where deposited in a distal suboxic–anoxic basin environment, which had a heavily stratified water column. This environment suggests a highly oil prone kerogen material. This is also corroborated by Figure 36, in which the majority of these samples fall within the Oil boundary on the LVI Ternary Kerogen Plot (after Dow and O'Connor, 1982).

Samples from the Kimmeridgian and Berriasian are confined to section II (Figure 35), as are the majority of the Tithonian samples. This long almost static period in the EGoM's palaeoenvironment history is reconstructable as a marginal dysoxic–anoxic basin, which is likely to be gas prone. During this 18Ma period the amount of AOM recorded becomes diluted by the higher volume of phytoclasts, and the marine palynomorphs remain low in number partly due to the redox state but also to the dilution effect. However, the gas available in these sections is not easy to identify. Figure 36 suggests that the gas present is a mix of either wet gas and condensate or a smaller portion is dry gas, with the majority of the Tithonian samples advising against any hydrocarbon deposits.

The samples taken from Valanginian strata all fall within section VI (Figure 35). The clustering in setion VI highly suggests a proximal suboxic–anoxic shelfal palaeoenvironment, which is indicative of oil prone rocks (Figure 36). The AOM is still present in fairly high quantities due to reducing basin conditions. However, the phytoclast input has increased either due to the proximity to source of the phytoclast input which is most likely or a turbiditic input.

During the Hauterivian all but the uppermost sample fall within section II on Figure 35, thus having the same palaeoenvironment as during the Kimmeridgian and Berriasian, and most of the Tithonian. As such it is likely to be gas prone and comprised of either wet gas and/or condensate (Figure 36). The top sample, however, falls within section IVa, suggesting a palaeoenvironment that exhibited dysoxic–suboxic oxygen concentrations while transitioning from a shelf to basin setting.

The lowest sample from the Barremian interval indicates the same palaeoenvironmental conditions as the uppermost Hauterivian sample. Further into the Barremian interval, sample 17340–17370ft. plots within section VII (Figure 35), indicating deposition at the distal margin of the shelf under dysoxic–anoxic conditions and as such this sample has the potential to bare oil (Figure 36). The majority of the Barremian interval falls within section II, advocating a marginal dysoxic–anoxic basin on account of the large phytoclast input. This is likely to be gas prone comprised of wet gas and/or condensate (Figure 36). However, samples 15540–15570ft. and 15840–15870ft. fall within the confines of section IVa (Figure 35) and as such, suggests a period during the Barremian when the relative sea level rose. This produced a palaeoenvironment where this area was in transition from a shelf to basin, under dysoxic–suboxic conditions. Before conditions returned to a marginal dysoxic–anoxic basin setting (section II at sample 15360–15390ft.) by the end of the Barremian.

The Aptian was a time of considerable sea level fluctuations, within the EGoM, as suggested by the four different sections the samples fall under. At the begining of the Aptian sample 15240–15270ft. falls into category VII (Figure 35) suggesting it was deposited at the distal margin of the shelf under dysoxic–anoxic conditions, and as such has the potential to bare oil(Figure 36). The following sample (14940–14970ft.) was deposited in slightly deeper conditions (section IVa, Figure 35) whereby this area was in transition from a shelf to basin, under dysoxic–suboxic conditions. Continuing upwards, sample 14640–14670ft. was deposited under distal, suboxic–anoxic basin conditions and falls into category IX. Following on, samples 14490–14520ft. and 14379–14400ft. record the shallowing of the sea level once more whereby the samples where deposited in a distal dysoxic–anoxic shelf (section VII, Figure 35) environment. The top of the Aptian (sample 13770–13800ft.) records proximal suboxic–anoxic shelf palaeoenvironment falling within category VI. All of the Aptian samples are have the potential to bare oil, which is corroborated by Figure 36.

The Albian sample, at a depth of 12600–12630ft. is located in section II of the Tyson Ternary Kerogen Plot (Figure 35) once again indicating a deepening of the sea level. This sample was deposited at the margin of a dysoxic–anoxic basin and has the potential to produce gas.

7.4 Interpretation of DC353

Well DC353 is situated in a relic graben, and is situated further offshore from the modern shoreline when compared with Well VK117. Figure 37 shows a break down of each palynodebris and palynomorph group. Similarly, to the previous Well, the palynofacies groupings from Figure 37 have been divided into three groups; AOM, Phytoclasts and Palynomorphs as described in section 6.1, to produce a Tyson Ternary Kerogen Plot (Figure 38), as well as a LVI Ternary Kerogen Plot (after Dow and O'Connor, 1982; Figure 38). The Roman numerical break down of the ternary plot in Figure 38 is there to aid palynofacies identification and depositional environment reconstruction.

Samples from the Middle Jurassic? through to the end of the Valanginian are concentrated in section IX on Figure 38. This suggests that the palynodebris and palynomorphs where deposited in a distal suboxic–anoxic basin environment, which is most likey to have had a strongly stratified water column. Under these conditions AOM dominates the assemblage which masks, in part, the palynomorph contingent. It is thought that the basin may be deep and/or have a strongly stratified water column, which is characteristic of a sediment starved basin. This depositional environment suggests a highly oil prone kerogen material. This is also corroborated by Figure 39, in which the majority of these samples (all but two) fall within the oil boundary on the LVI Ternary Kerogen Plot (after Dow and O'Connor, 1982). The dinoflagellate cysts recorded evidence of poor preservation owing to pyrite crystal growth on the cyst surface, assumed to be a result of diagenetic processes during lithification. This pyritic evidence from the dinoflagellate cysts, coupled with the large quantities of AOM advocates a dysoxic palaeoenvironment.

The upper half of the Well, from the Hauterivian to Albian, shows quite a different story, with an incursion of palynomorphs and phytoclasts, while there is a reduction in AOM, suggesting a shallowing in depositional environment.

All but two of the Hauterivian samples fall within the boundary of section VIII (Figure 38), with the other two samples falling with section IX. Section VIII indicates a depositional palaeoenvironment akin to a distal dysoxic–oxic shelf. Under these conditions AOM once again dominates the assemblage, with palynomorphs becoming more prominent in theses samples (compared to section IX), but are still masked by the abundant AOM. These palaeoconditions are typical of organic rich shales that are deposited under stratified shelf sea conditions. Under these conditions, the kerogen is likely to be oil prone. When plotted on the LVI ternary plot, all Hauterivian samples have the potential to bare oil (Figure 39).

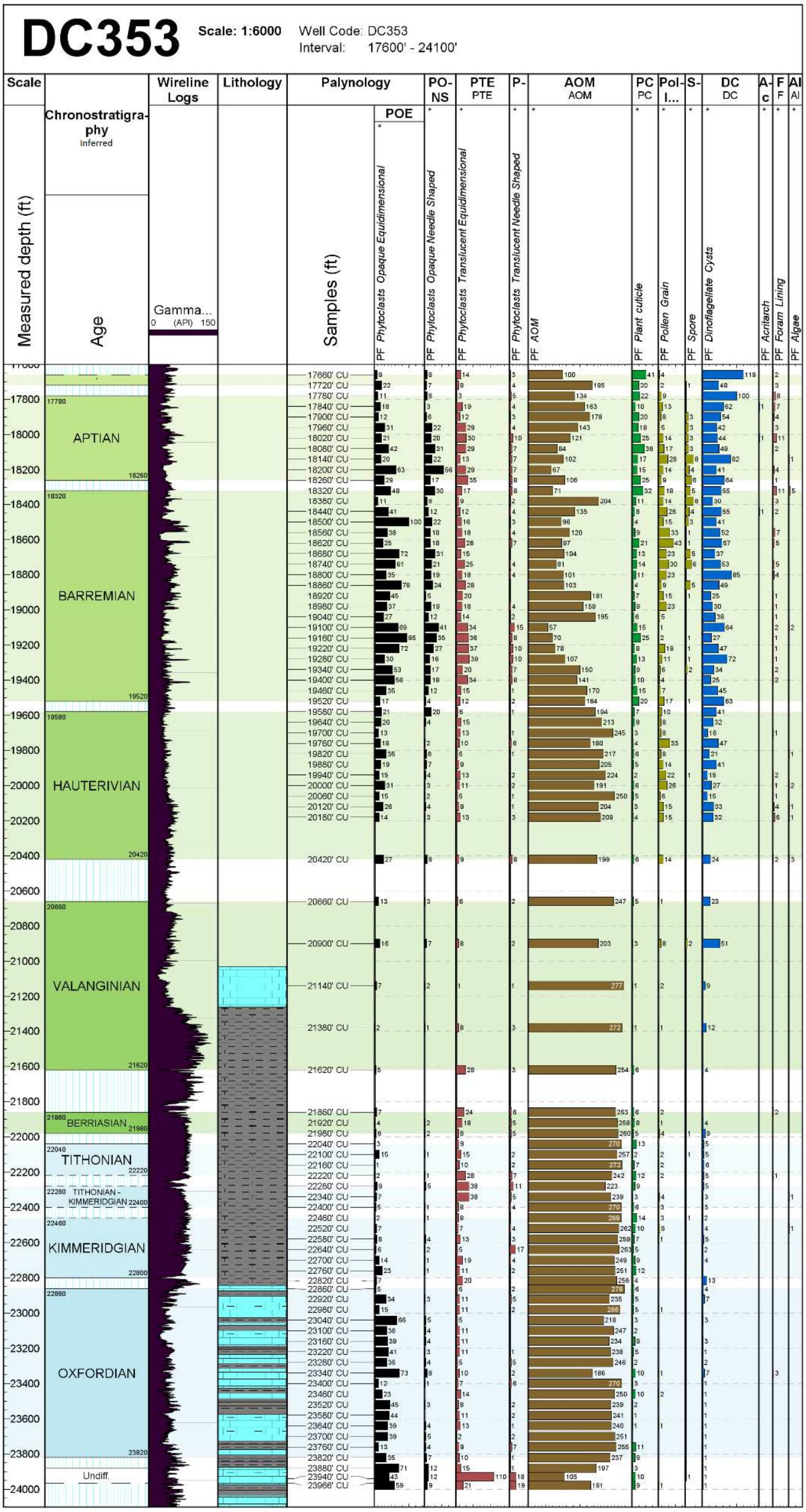


Figure 37. Chart to show the quantataive breakdown of 300 counts of each individual palynodebris and palynomorph group in each sample for Well DC353.

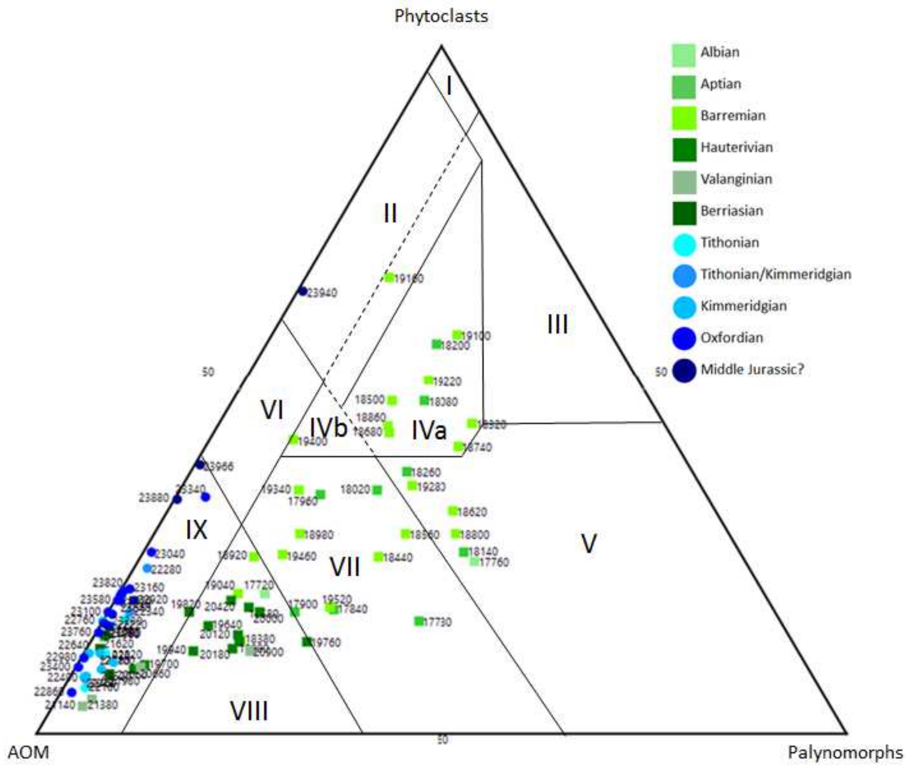


Figure 38. Tyson Ternary Kerogen Plot for Well DC353 (after Tyson, 1985, 1989, 1993 and, 1995) Sample depths refer to the lowermost depth of each sample.

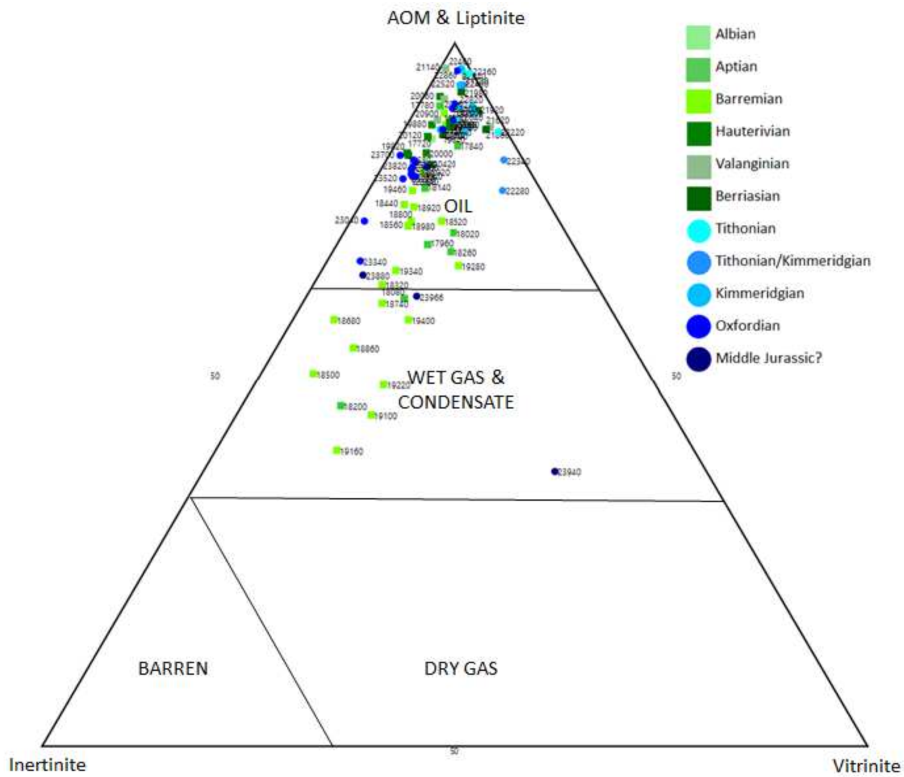


Figure 39. Dow Ternary Kerogen Plot for Well DC353 (after Dow and O'Connor, 1982) Sample depths refer to the lowermost depth of each sample.

Samples from the Barremian do not plot under one particular section, but instead are dispersed throughout sections II, IVa, IVb, V, VII and VIII in no particular order. Samples 18980–19040ft., 18860–18920ft. and 18320–18380ft. plot in section VIII and share the same depositional environment with most of the Hauterivian interval. Whereas samples, 19460–19520ft., 19400–19460ft., 19280–19340ft., 18920–18980ft., 18500–18560ft. and 18380–18440ft. all plot in section VII indicative of a distal dysoxic–anoxic shelf. AOM is well preserverd and palynomorphs generaly have higher counts. Both sets of samples deposited under the conditions prevailing in sections VII and VIII plot are likely to bare oil (Figure 39). Samples, 19220–19280ft., 18740–18800ft. and 18560–18620ft. are plotted within section V on the Tyson Tenary Kerogen Plot (Figure 38) which describes a mud dominated (distal) oxic shelf depositional palaeoenvironment, whereby the fraction of AOM is reducing in comparison to the palynomorphs. As such the kerogen material is likely to be gas prone according to the Tyson Plot (Figure 38), however the same samples suggest they have the potential to bare oil in the Dow (1982) LVI Plot (Figure 39) – the reason for this is unknown.

Samples, 19160–19220ft., 19040–19100ft., 18800–18860ft., 18680–18740ft., 18620–18680ft., 18440–18500ft. and 18260–18320ft. all plot in category IVa in Figure 38, suggesting a shelf to basin transition with a dysoxic–suboxic palaeoenvironment, while sample, 19340–19400ft. falls into category IVb, suggesting a similar palaeoenviromnent but was deposited during a time of lower oxygen conditions (suboxic–anoxic). Section IV generally suggests a depositional environment which is indicative of a shelf to basin transition, whereby the phytoclast contingent is abundant dependant on the proximity to source, and there is only a small volume of marine palynomorphs present, compared to terrestrial palynomorphs (this is easier to view in Figure 37). This depositional environment suggests a mainly gas prone kerogen material is likely to be present, however oil prone kerogen may also be present. When samples from section IV are plotted on an LVI plot (Dow and O'Connor, 1982; Figure 39) it can be said that all samples have the potential to contain wet gas and condensate except sample 18260–18320ft., which is likely to bare oil. Finally, sample, 19100–19160ft. within the Barremian section is plotted in section II of the Tyson Ternary Plot (Figure 38) and is indicative of a marginal basin palaeoenvironment with dysoxic–anoxic conditions. Here the AOM is diluted by a high phytoclast input and to a less extent the marine palynomorphs. Under these conditions, the kerogen is likely to be gas prone. This is complimented by the LVI ternary plot, where sample 19100–19160ft. has the potential to contain wet gas and condensate (Figure 39). The mixture of depostional environments within the Barremian section is comparable to that inferred on the Sligo Formation. The lower part of the Sligo Formation was deposited during high energy shelfal conditions relative to other formations while the upper section consists of interbedded sands, siltstone, shales and mudstones (Warner and Moody, 1992; Phelps *et al.,* 2010).

The lower samples from the Aptian (18200–18260ft., 18140–18200ft., 18080–18140ft. and 18020–18080ft.) alternate between sections V and IVa. Samples 18200–18260ft. and 18080–18140ft. plot within section V which infers a distal oxic shelf palaeoenvironment, whereby palynomorphs are more prominent and the kerogen present, according to Figure 38 (Tyson Ternary Plot) is likely to be gas prone. However, when compared to the LVI Plot (Dow and O'Connor, 1982) both samples have th potential to bare oil. The other two samples (18140–18200ft. and 18020–18080ft.) fall within section IVa (Figure 38) and infer a transional deposional palaeoenvrionment from shelf to basin under dysoxic–suboxic conditions. The phytoclast richness depends on the immediacy to the source. The Tyson Plot (Figure 38) suggests the presence of gas prone kerogen. However, the Dow (1982; LVI) Plot divides the two samples, whereby sample 18140–18200ft. is likely to bare wet gas and condensate window, while sample 18020–18080ft. has the potential to contain oil. The top half of the Aptian: samples 17960–18020ft., 17900–17960ft., 17840–17900ft. and 17720–17780ft. plot within section VII (Figure 38), infering a distal shelf palaeoenvironment deposited under dysoxic–anoxic conditions. All four samples show good AOM preservation with moderate quantities of palynomorphs present. Both Figures 38 and 39 imply oil producing kerogen material from these samples.

The Albian samples (17600–17760ft. and 17660–17720ft.) once again plot in two different depositional environments. Sample 17600–17760ft. was deposited in a mud dominated distal oxic shelf environment (section V; Figure 38), which is typical of bioturbated calcareous mudstones, and is likely to be gas prone (Figure 38). However, the LVI Plot (Dow and O'Connor, 1982; Figure 39) contradicts this and suggests the kerogen has the potential to bare oil. On the other hand, the shallowest sample seems to be deposited further offshore in a distal dysoxic–oxic shelf palaeoenvironmnet (section VIII; Figure 38). Both plots (Figures 38 and 39) agree that this sample has the potential to contain oil producing kerogen.

7.5 Interpretation of CH265

Well CH265 is situated on a relic horst off the coast of western Florida. Figure 40 shows a break down of each palynodebris and palynomorph group. To reveal more about the palynofacies groupings the data from Figure 40 has been divided into three groups; AOM, Phytoclasts and Palynomorphs as described in section 6.1, to produce a Tyson Ternary Kerogen Plot. The results of which are shown in Figure 41. The plot is broken down into sections labelled by Roman numerals to aid palynofacies identification and depositional environment reconstruction.

All but one sample from Well CH265 is clusted in section IX in Figure 41. Section IX suggests that the palynodebris and palynomorphs where deposited in a distal suboxic–anoxic basin palaeoenvironment under a stratified water column. This environment advocates highly oil prone kerogen material. This is also corroborated by Figure 42, in which all but one Aptian sample (9834ft.) has the potential to bare oil when plotted on the LVI Ternary Kerogen Plot (after Dow and O'Connor, 1982).

The Barremian sample (10800–10810ft.) falls into section VIII on the Tyson Ternay Plot (Figure 41), which suggests a brief period of shallowing, as the sample was deposited in a distal shelf paleoenvironemnt with dysoxic–oxic conditions prevailing. Whereby, compared to the other samples from this Well, the palynomorphs where present in greater number. This preservational paleoenvironment is typical of organic rich shales which form under a stratified sea shelf conditions. Both the Tyson and Dow Ternary Plots (Figures 41 and 42) suggest that the Barremian sample has oil producing potential.

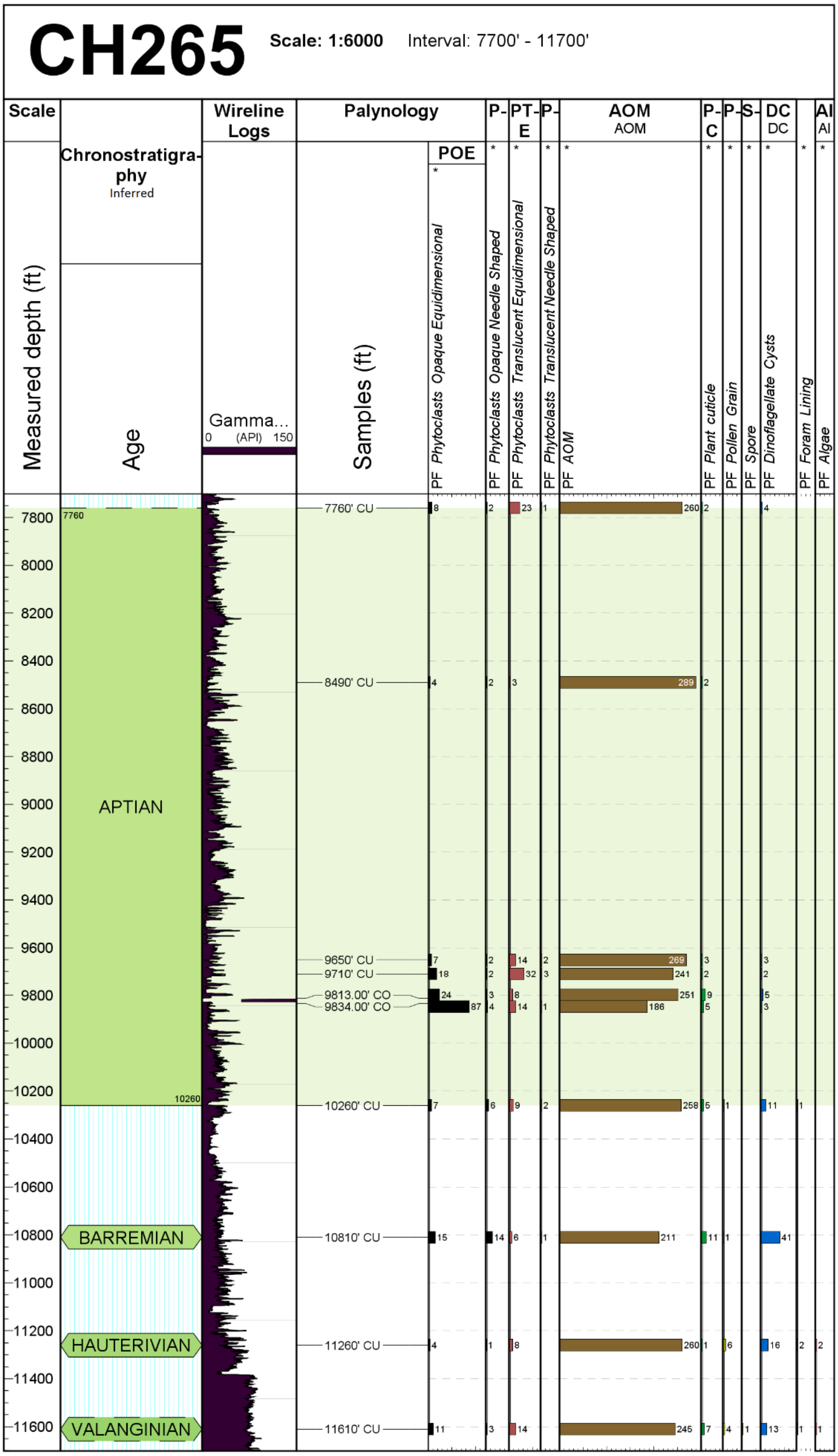


Figure 40. Chart to show the quantataive breakdown of 300 counts of each individual palynodebris and palynomorph group in each sample for Well CH265.

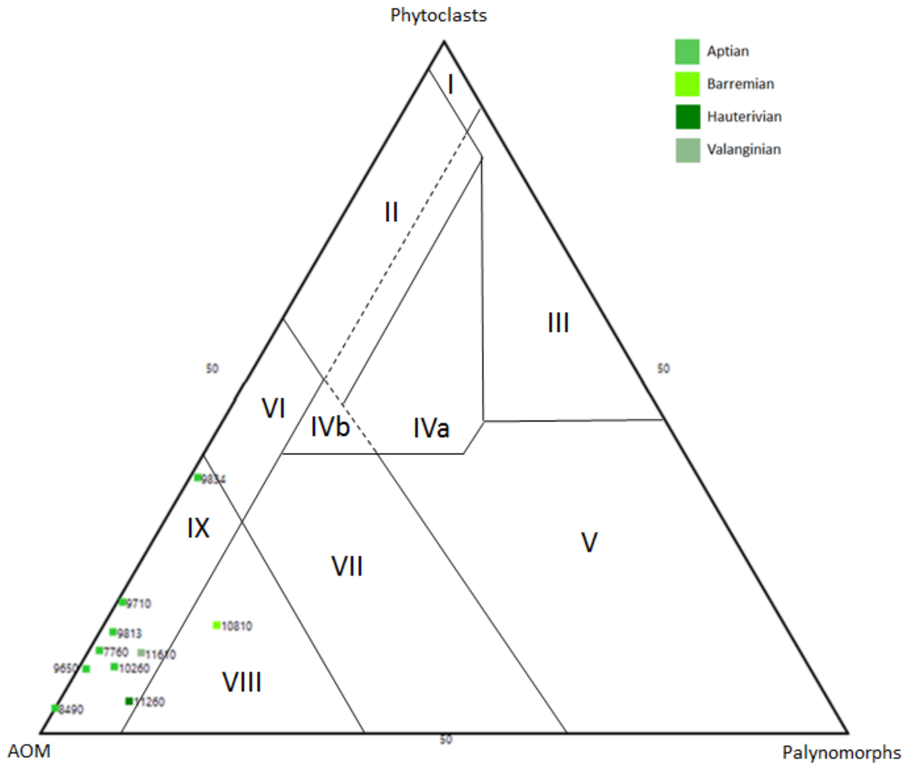


Figure 41. Tyson Ternary Kerogen Plot for Well CH265 (after Tyson, 1985, 1989, 1993 and, 1995) Sample depths refer to the lowermost depth of each sample.

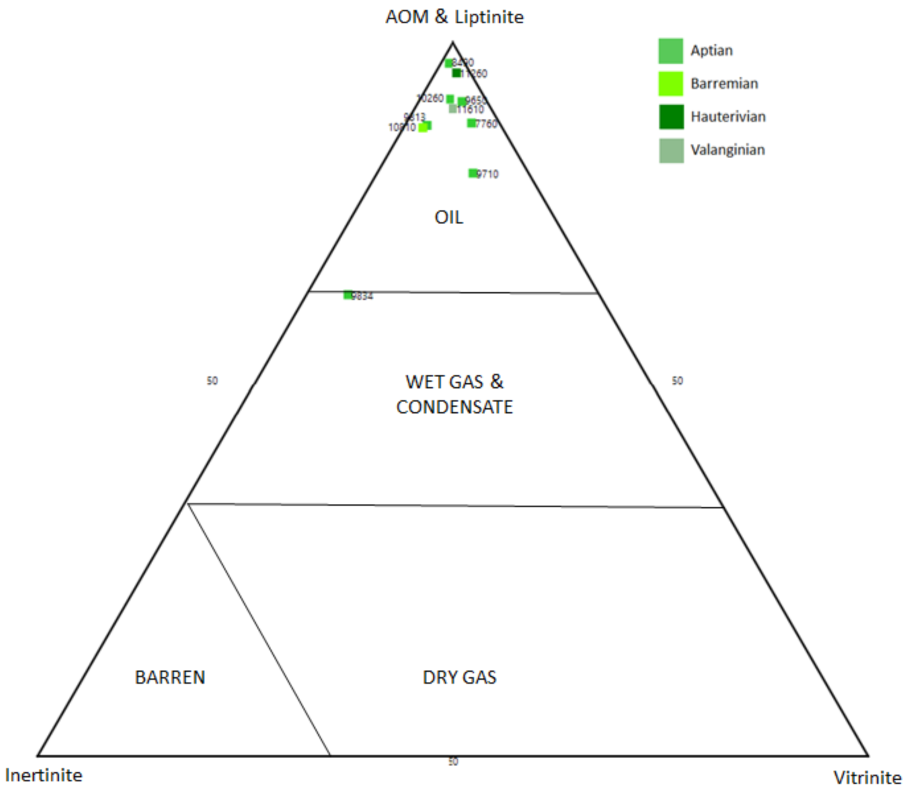


Figure 42. Dow Ternary Kerogen Plot for Well CH265 (after Dow and O'Connor, 1982) Sample depths refer to the lowermost depth of each sample.

7.6 Interpretation summary between the wells

The Jurassic samples in wells DC353 and VK117 were deposited under open marine conditions. Well DC353 in the relic graben has a naturally deeper setting and as expected the samples from the Oxfordian through to the Valanginian largely plot as being deposited in a distal basin under reduced suboxic–anoxic conditions. Similarly, the deeper samples from Well VK117 were set down in a distal basin palaeoenvironment. However, Well VK117 is located on a historic horst and displays a naturally shallower palaeodepositional environment throughout the Kimmeridgian, Tithonian and Berriasian. As such, samples from these three stages were deposited predominantly in a marginal basin palaeoenvironment under reduced dysoxic–anoxic conditions.

The Valanginian sections examined from wells DC353 and CH265 (currently the furthest offshore to the modern-day shoreline) imply a marginal basin palaeoenvironment deposited under reduced dysoxic–anoxic conditions. Valanginian samples from Well VK117 suggest that they were deposited in a proximal shelf environment under suboxic–anoxic conditions.

Further up Well, the Hauterivian samples show more variation in depositional conditions. Samples analysed from DC353, suggest a distal shelf palaeoenvironment deposited under dysoxic–oxic conditions. Whereas, the two wells located over relic horsts, imply a deeper open marine setting; samples from VK117 are akin to a marginal basin setting, while CH265 samples generally imply a distal basin palaeoenvironment.

The Barremian sample from CH265 suggests a brief period of 'shallowing' to produce a marginal basin palaeoenvironment, before returing to a distal basin setting during the Aptain. Barremian and Aptian samples from DC353 suggest evidence of some sea level fluctuations. Some sections were deposited in a distal shelf palaeoenvironment similar to that in the Hauterivian. However, they might have been subject to various redox conditions. During this time, there were brief interludes of shelf–basin transition under reduced dysoxic–suboxic–anoxic conditions. The Barremian interval from VK117 also displays brief interludes of shelf–basin transition suggesting shallowing at a time when most of the samples where deposited in a largely marginal basin palaeoenvironment.

The samples aquired from the Aptian of VK117 imply a mostly distal shelf palaeoenvironment deposited under dysoxic–anoxic conditions with evidence of periods of fluctuating relative sea level as recorded in DC353.

The sample attributed to the Albian in VK117, suggests a deepening towards a marginal basin palaeoenvironment, whereas the Albian aged samples from Well DC353 do not suggest any changes from a general distal shelf environment.

In summary, Well CH265 was largely deposited in a distal basin setting, except for a shallowing period during the Barremian. This shallowing event can also be observed in wells VK117 and DC353. Post Barremian, the general palynofacies data yielded from these wells evidences a higher degree of sea level fluctuations.

Chapter 8 – Palynomorph Darkness Index

8.1 Introduction

The hydrocarbon industry uses dinoflagellate cyst biostratigraphical analysis as a routine tool (Stover *et al.,* 1996; Williams *et al.,* 2004; Ji *et al.,* 2011) not only because dinoflagellates have a high stratigraphical resolution, but also because their remains together with other palynomorphs are a key constituent of hydrocarbon source rocks (Ayres *et al.,* 1982, Sluijs *et al.,* 2005). The colour of the fossilised dinoflagellate cysts can also be used to reconstruct the thermal history of the encasing rock, and as such, is a powerful tool in source rock evaluation in hydrocarbon exploration. The organic dinosporin (closely related to sporopollenin; Traverse, 2007b) walls of the dinoflagellate cysts can be assigned to differing burial temperature regimes based on their colour, because with increasing maturity and an increase in carbon concentration the colour of dinoflagellate cysts irreversibly change from pale yellow, through orange and brown, until it is black and completely opaque (Pross *et al.,* 2007).

The ability to calculate and thus quantify this colour change is termed the Palynomorph Darkness Index (PDI; Goodhue and Clayton, 2010). Although previous workers attempted to quantify the colour change, it was either deemed too expensive to use as a routine tool or the scarcity of the equipment available meant it was not viable (Marshall, 1991, Yule *et al.,* 1999). Goodhue and Clayton (2010) also recognised this flaw and therefore proposed a new way to determine the thermal maturity of a palynomorph by integrating the Red, Green and Blue (RGB) intensities to produce a grey scale which could then be converted into the PDI.

This chapter reports on the PDI calculated for wells VK117 and CH265 to ascertain an additional proxy for the likelihood of oil and/or gas producing samples present within the wells. The PDI calculations will also be compared to vitrinite reflectance (Ro %) in order to determine if dinoflagellate cysts in this study are suitable for PDI analysis. The PDI values for Well DC353 were unobtainable due to the dye introduced during the slide preparation technique by Shell.

8.2 PDI Calculations

Goodhue and Clayton (2010) explained that to calculate the PDI, the grey scale needs to be established by converting the RGB intensities. This is determined in the same way as used by the National Television System Committee (NTSC) and the Joint Photographic Experts Group (JPEG).

$$Y = 0.299R + 0.587G + 0.114B$$

In the above equation, Y is the calculated greyscale and RGB are the red, green and blue intensities respectively. However, as Goodhue and Clayton (2010) outline, when viewed down a microscope or as an image the palynomorph colour is determined by transmitted light, as such the white background intensities are less than 255 for each RGB intensity. Therefore, a correction needs to be added to the equation to take this into account.

$$Y_a = (0.299R * 255/R_b) + (0.587G * 255/G_b) + (0.114B * 255/B_b)$$

Where Y_a is the adjusted greyscale value and the R_b, G_b and B_b values are the measured white background intensities.

In line with previous studies, Goodhue and Clayton (2010 and references there in) utilise a numerical scale to represent the PDI, where pale and low maturity palynomorphs have a low percentage PDI and dark and high maturity palynomorphs have a high percentage PDI (range is from 0–100%).

$$PDI (\%) = 100 – (100 Y_a / 255)$$

Similar, to the methods utilised by Goodhue and Clayton (2010) two different types of material were used to determine the PDI. The initial material analysed was that of the same photographic filters used in the, 2010 study (Goodhue and Clayton 2010). The other material analysed was the slides from wells VK117 and CH265. These samples are unoxidised and unstained material. The palynomorph colour and darkness are not determined by thermal maturity alone, but instead are affected by the wall thickness of each species, as well as ornamentational features. Therefore, the species chosen to calculate the PDI need to have a simple morphology, ideally with no ornamentation and be long ranging. Consequently, the species chosen here is *Sentusidinium explanatum.* This study using the PDI will be the first of its kind to use dinoflagellates as the palynomorph group under investigation.

Unlike the initial study, there was not the luxury of using three different microscopes to determine the PDI. As such a Meiji MT500 series binocular biological microscope was employed, with a Lumenera Infinity five-megapixel camera attached to it. The camera had no filters applied and the automatic white balance was switched off. To obtain a baseline measurement, the microscope was switched on and left for ten minutes for the bulb to heat up to optimum brightness. Then with an empty slide in focus the condenser diaphragm was adjusted to obtain a white background with the RGB values as close to 255, 255, 255 as possible, but not exactly, as that would mean the background would be over exposed. An image was taken and 25 randomly selected areas were measured to obtain average RGB values, as well as the white background value. 25 measurements was the point at which the cumulative average began to stabilise (Figure 43). The RGB values for the photographic filters were obtained in a similar way, only this time the filter was resting on the light source beneath the condenser unit.

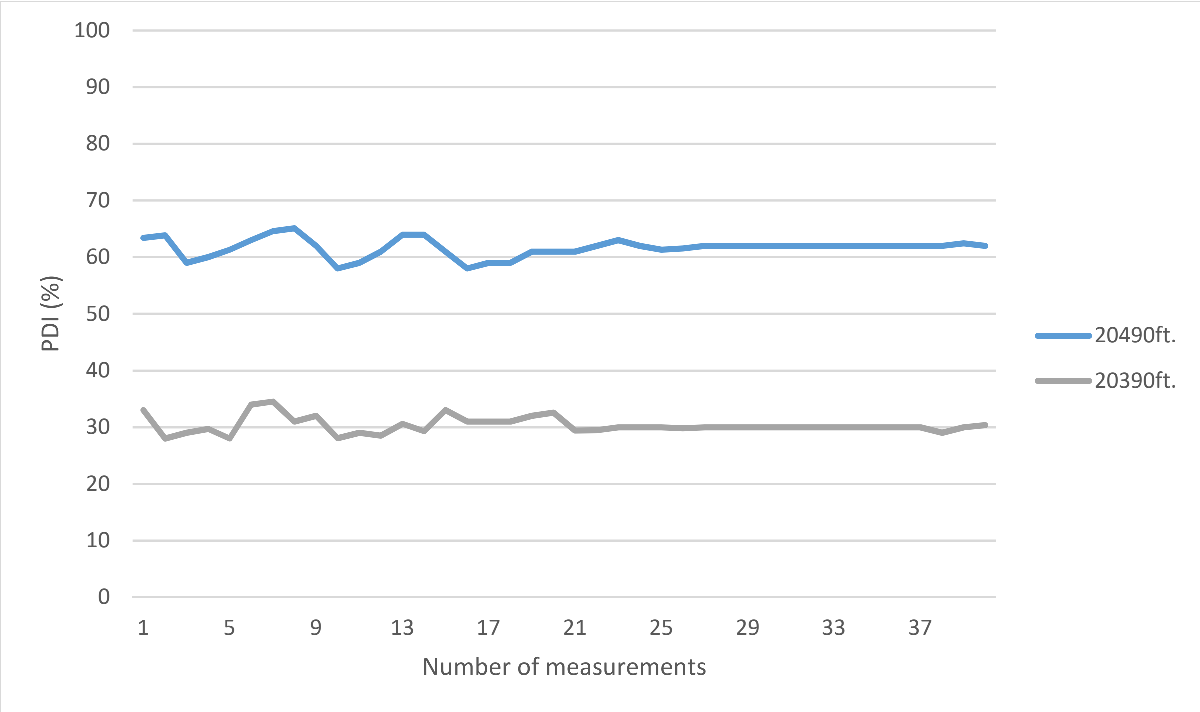


Figure 43. PDI cumulative average of two *Sentusidinium explanatum* specimens from two depths in Well VK117.

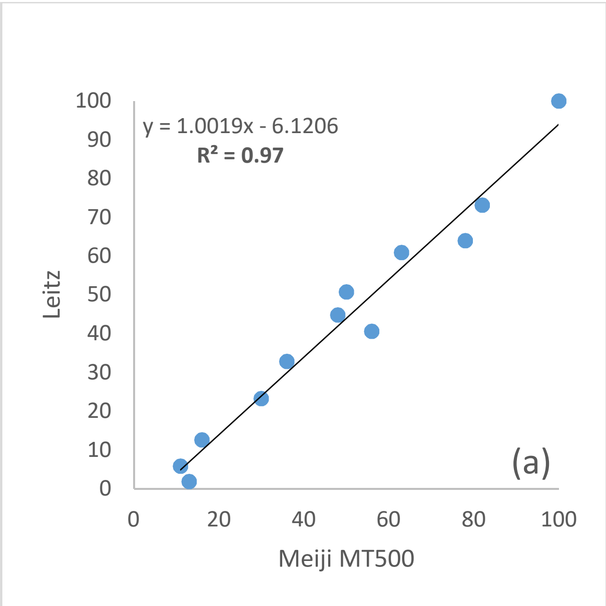
8.3 PDI Photographic Filter Results

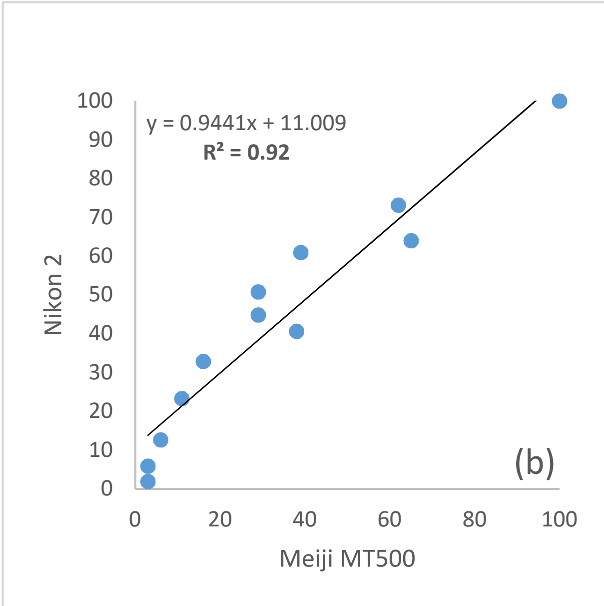
The RGB photographic filters results are displayed in Table 4. When these values are compared to the three microscopes used in Goodhue and Clayton (2010, Table 1) there is excellent linear correlation (R^2 = 0.97) between the Meiji MT500 and Leitz microscopes. Whereas, the linear correlation between the Meiji MT500 and Nikon 2 is good at R^2 = 0.92, and R^2 = 0.88 against the Nikon 1.

SYSTEM:		**Meiji MT500**			
BACKGROUND	**Rb**	**Gb**	**Bb**		
	249	249	249		
FILTER:	**R**	**G**	**B**	**GYa**	**PDIa**
Cokin A001	255	252	140	250	**2**
Cokin A002	244	100	113	151	**41**
Cokin A003	179	36	104	92	**64**
Cokin A004	73	105	96	100	**61**
Cokin A005	102	43	77	68	**73**
Cokin A006	232	237	181	240	**6**
Cokin A020	101	113	181	126	**51**
Cokin A022	159	152	211	171	**33**
Cokin A024	214	205	231	223	**13**
Pastel Violet	162	109	174	141	**45**
Panchron Grun	178	212	93	196	**23**
Black background	0	0	0	0	**100**

Table 4. Data from Meiji MT500 for Figure 43

These results confirm the statement made by Goodhue and Clayton (2010) "*results suggest that it should be possible to obtain closely comparable results from different types of equipment with suitable calibration.*"





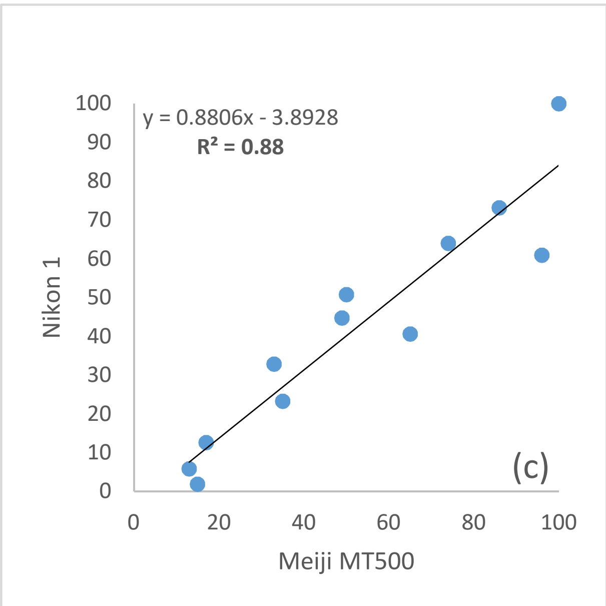


Figure 444. Correlation of calculated PDI values from RBG values of photographic filters on the three microscopes used in the, 2010 Goodhue and Clayton study and the Meiji MT500 series microscope: (a) Meiji MT500 v. Leitz, showing a linear correlation where R^2 = 0.97; (b) Meiji MT500 v. Nikon 2, showing a linear correlation where R^2 = 0.92; (c) Meiji MT500 v. Nikon 1, showing a linear correlation where R^2 = 0.88.

8.4 PDI Results and Discussion

The PDI results for wells VK117 and CH265 are displayed in Table 5. The PDI value is the average taken from the number of *Sentusidinium explanatum* specimens measured.

The results for Well VK117 (Figure 46) shows a progressive increase in PDI corresponding to the gradual darkening of *Sentusidinium explanatum* down well and thus a positive correlation. Though, it should be noted that the correlation is weak (R^2 = 0.23). The correlation is even weaker in Well CH265 (Figure 45) (R^2 = 0.05), most likely due to the lack of data.

Depth	No. *S. explanatum*	PDI (%)	Vitrinite Reflectance (Ro %)
VK117 12600-12630	5	18	Barren
VK117 15840-15870	2	21	Barren
VK117 16140-16170	2	37	1.24
VK117 16440-16470	3	30	Barren
VK117 16560-16590	2	43	1.24
VK117 16770-16800	8	29	Barren
VK117 17070-17100	1	32	1.23
VK117 17340-17370	5	31	1.27
VK117 17490-17520	1	39	No Data
VK117 17640-17670	4	46	1.38
VK117 17940-17970	3	39	1.4
VK117 18240-18270	9	37	1.68
VK117 18540-18570	6	43	1.67
VK117 18840-18870	9	33	1.75
VK117 19140-19170	1	39	Barren
VK117 19410-19440	4	46	2.24
VK117 19740-19770	7	42	Barren
VK117 19800-19830	5	40	2.55
VK117 19980-19990	3	69	2.11
VK117 20080-20090	2	54	2.3
VK117 20180-20190	9	42	1.91
VK117 20390-20400	1	30	2.21
VK117 20490-20500	1	62	2
VK117 20590-20600	2	36	2.03
VK117 20690-20700	1	42	2.27
VK117 20790-20800	1	39	2.58
VK117 20880-20890	13	39	2.47
VK117 22290-22300	1	23	2.83
VK117 22490-22500	1	68	3.03
VK117 22890-22900	14	38	3.29
CH265 7750-7760	2	9	No Data
CH265 9700-9710	2	12	Barren
CH265 11250-11260	1	7	No Data
CH265 11600-11610	3	8	No Data

Table 5. Average PDI results for selected sample depths in wells VK117 and CH265

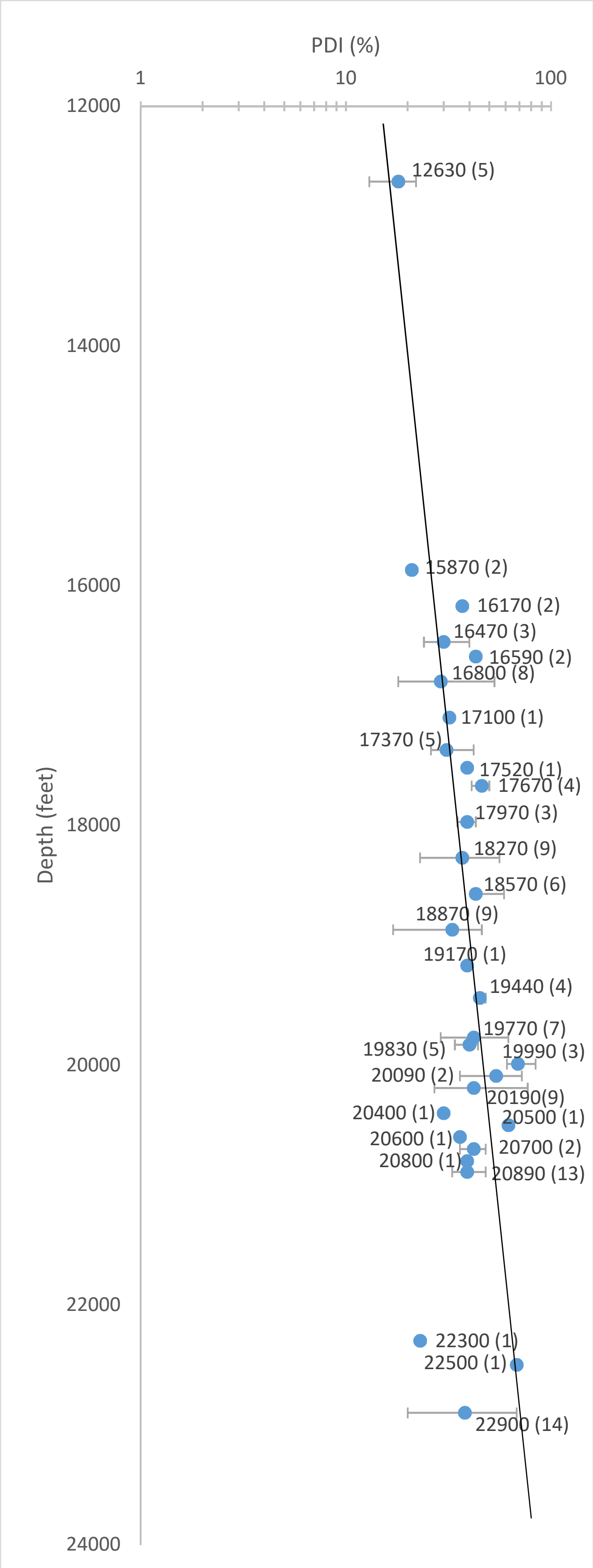


Figure 466. PDI results for VK117 plotted against depth. (x) is the number of specimens measured.

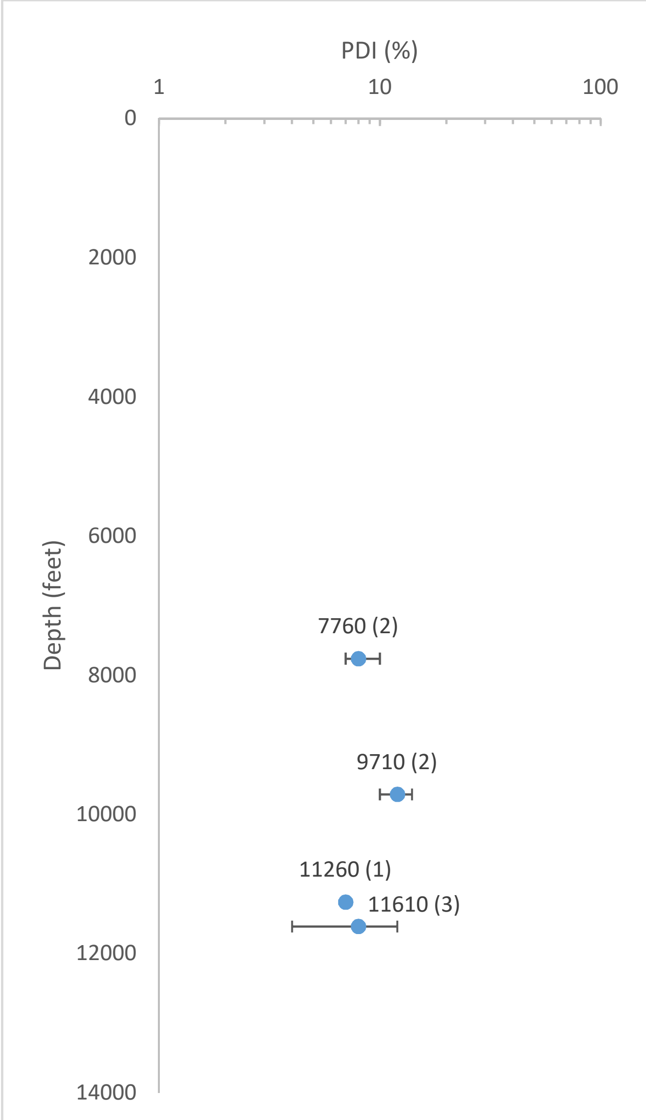


Figure 455. PDI results for CH265 plotted against depth. (x) is the number of specimens measured.

Vitrinite, which consists largely of diagenetically thermally altered lignin and cellulose from terrestrial plants and humic peat, is more abundant in organic rich sedimentary rocks. As wells VK117 and CH265 represent a largely carbonate and sandstone sequence, it would be expected that the vitrinite content is likely to be low. Therefore, Shell USA did not have any thermal maturity data to accompany the recovered samples. However, 34 samples from wells VK117 and CH265 were sent to Applied Petroleum Technology (UK, Colwyn Bay) to asses the likelihood of a vitrinite reflectance (Ro %) reading being established. Of the 34 samples sent off, 30 samples were considered suitable for vitrinite reflectance analysis, 29 samples from Well VK117 and one from Well CH265. The vitrinite reflectance analysis procedure and full histogram results can be viewed in Appendix 2. An overview of the vitrinite reflectance is displayed in Table 5. Six of the samples from Well VK117 came back with a barren result, as did the only sample from Well CH265. Therefore, further comparisons between PDI and vitrinite reflectance is only possible for 23 samples from Well VK117.

As evidenced in Figure 47 there is an excellent correlation between well depth and vitrinite reflectance ($R^2 = 0.91$). Yet, when the PDI and vitrinite reflectance are plotted against each other (Figure 48), there is once again a weak correlation ($R^2 = 0.04$). This suggests that *Sentusidinium explanatum* may not be a suitable palynomorph in this study. However, this is the first study using dinoflagellate cysts to calculate PDI, and as such it would ill advised to rule it out altogether for future projects. Further work is recommended to ascertain if a robust correlation can or can not be achieved between PDI an vitrinite reflectance using *Sentusidinium explanatum* as the palynomorph under investigation.

Figure 48 does however, illustrate the potential samples in Well VK117 that fall within the oil and gas windows. Samples in Well VK117 between 16140–16170ft. to 17340–17370ft. have the potential to generate oil and samples between 17640–17670ft. to approximately 21000ft. have the potential to produce gas. Any sample which has a vitrinite reflectance over 2.5% is considered too thermally mature, and as such barren.

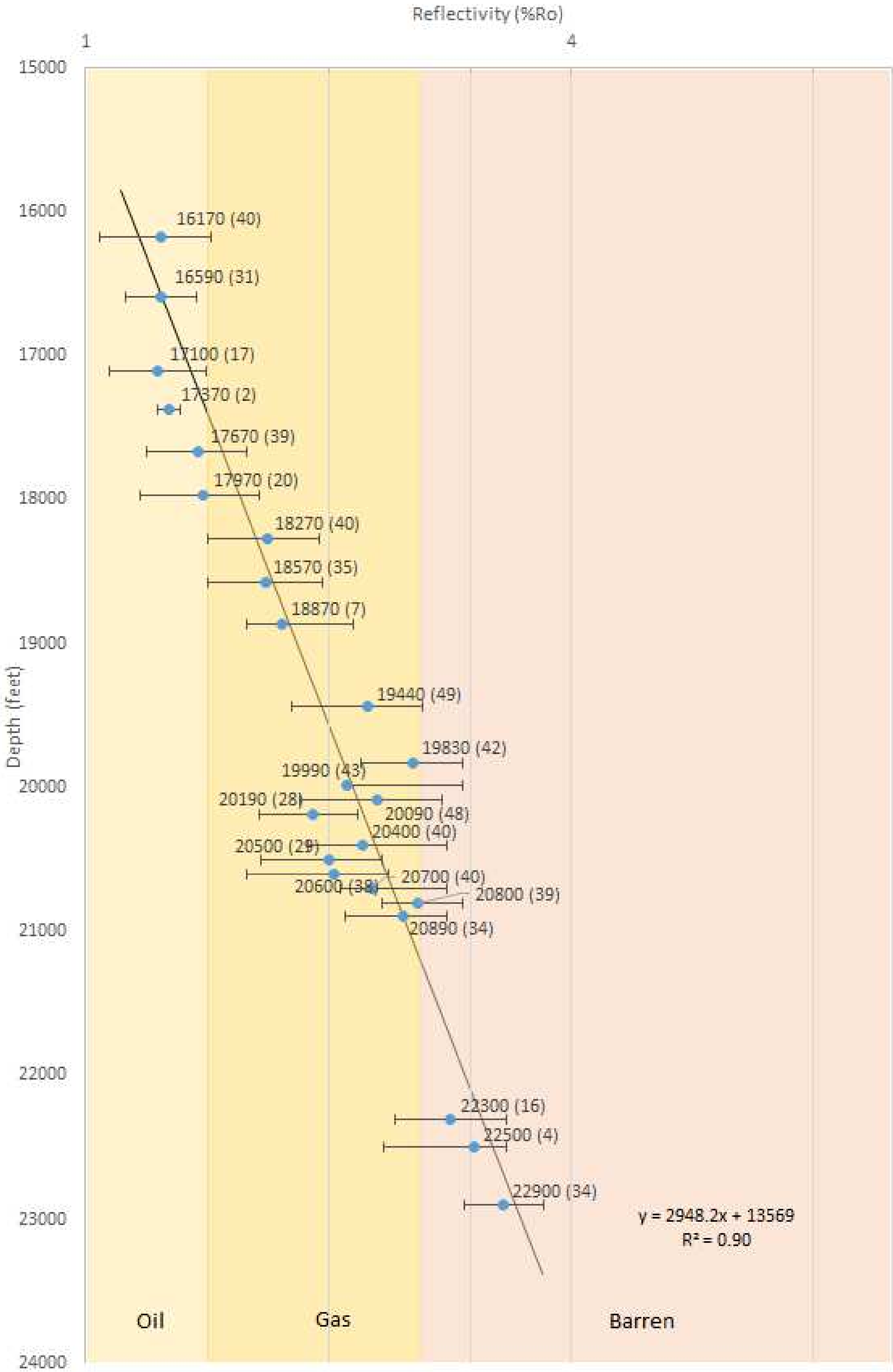


Figure 477. Average vitrinite reflectance plotted against depth in Well VK117. (x) is the number of measurable vitrinite reflectance points.

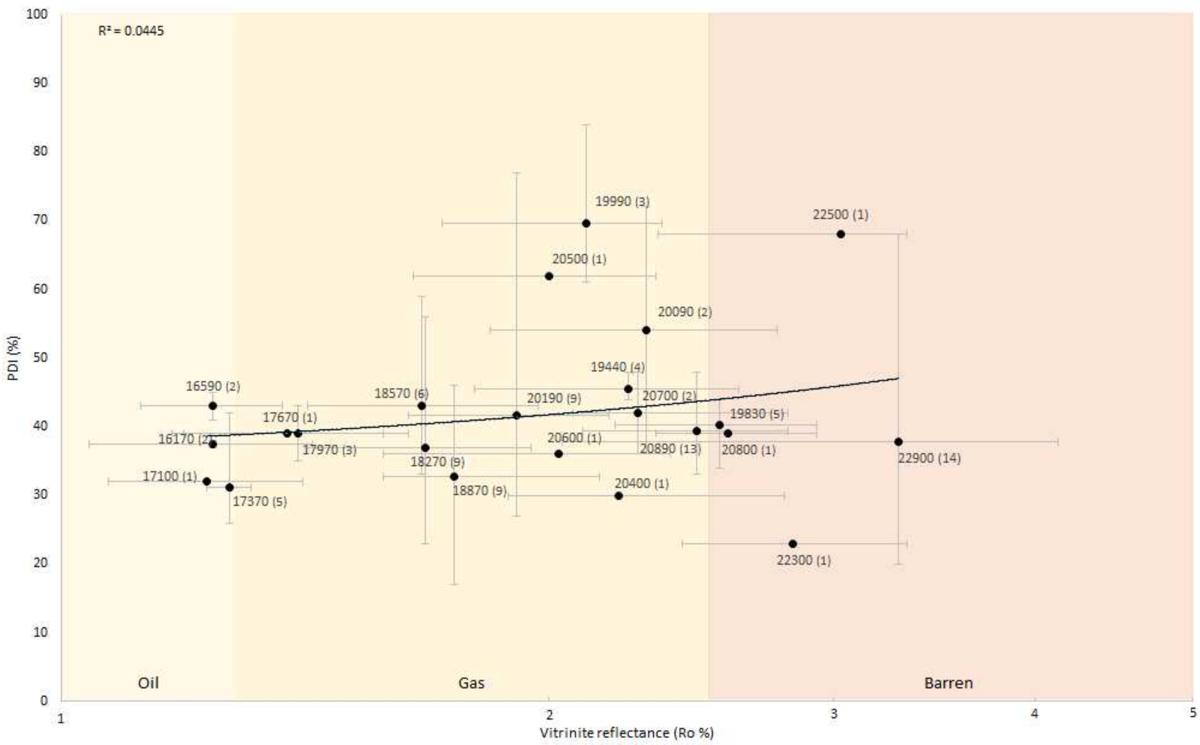


Figure 488. Vitrinite reflectance plotted against the calculated PDI values for Well VK117 taken from Table 5. (x) is the number of specimens measured.

Chapter 9 – Discussion and Conclusions

The three objectives outlined in the introduction have been achieved. As such a tentative correlation has been made between the three wells to produce a working biostratigraphical model based on dinoflagellate cysts.

1. Of the dinoflagellate cysts recorded, 164 were described at species level, and only two at generic level. The dinoflagellate communities are comparable to palaeo deposits from the North Atlantic, southeastern GoM and western Africa (Chart 9), although some marked differences have been noted and discussed in Chapter 6.
2. The range charts (Charts 2, 3 and 4) illustrate that although the EGoM has a large proportion of long ranging taxa, where reworking and caving is common, the ranges of several dinoflagellate cysts are restricted. The ranges and variations observed in the assemblages throughout the Late Jurassic into the Early Cretaceous enables a chronostratigraphical interpretation of the studied wells to be achieved. Caving is more prevalent into Jurassic strata in wells VK117 and DC353.
3. The palynofacies data presented in Chapter 7 demonstrates a marine transgression during the Late Jurassic in wells VK117 and DC353, which suggests a change to open marine (marginal (II) and distal (IX) basin) palaeodepositional environments. The first half of the Early Cretaceous recorded in wells VK117 and DC353 shows evidence for a shallowing succession before fluctuations in depositional depth and distance from the palaeo-shoreline become apparent throughout the Barremian. This palynofacies flux during the second half of the Early Cretaceous is thought to relate to continued thermal subsidence of the lithosphere, sedimentation rates and the progradation of a carbonate shelf margin. For the same interval, samples from CH265 have been interpreted to be deposited in an open marine (distal basin) setting.

Despite the palynofacies analysis and interpretations discussed in Chapter 7, it was not possible to confidently assign a kerogen thermal maturity. Therefore, PDI analysis following Goodhue and Clayton's (2010) study, was performed to produce a more accurate thermal maturity prognosis for wells VK117 and CH265. The PDI could not be ascertained for Well DC353 due to stain introduced during the laboratory preparation by Shell. Although the PDI was determined for Well CH265, the robustness of the data could not be verified due to either no vitrinite reflectance data, or a low confidence in the data. The correlation between well depth and PDI proved weak in Well VK117, further emphasised by the poor correlation between PDI and vitrinite reflectance. As such it is recommended that further studies are needed to asses if a robust correlation can or cannot be achieved between PDI and vitrinite reflectance using *Sentusidinium explanatum* as the palynomorph, before PDI (based on *Sentusidinium explanatum*) can be used as an alternative indicator of thermal maturity. The vitrinite reflectance analysis did however, prove useful in assigning a thermal maturity to 23 samples from Well VK117, with most of the samples falling in the gas window, and others plotting in either the oil window or being considered barren. Although the vitrinite refelctance and Ternary Plot data do not always agree on the same hydrocarbon potential, they do agree that the majority of the samples from Well VK117 are likely to be source rocks for oil and gas.

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Plate I

The scale bar in Figure a represents, 20 µm, and is the same scale as all other Figures unless otherwise stated. All specimens are upright, and in dorso-ventral view.

a. *Muderongia endovata* Riding *et al.,* 2001. Specimen from VK117, sample 17490–17520 ft. England finder ref. O37/1.
b. *Muderongia pariata* Duxbury, 1983. Specimen from CH265, sample 11250–11260 ft. England finder ref. V34/3.
c. *Muderongia perforata* Alberti, 1961. Specimen from VK117, sample 17640–17670 ft. England finder ref. M34.
d. *Muderongia simplex* Alberti, 1961. Specimen from VK117, sample 17640–17670 ft. England finder ref. R43.
e. *Muderongia staurota* Sarjeant, 1966a. Specimen from VK117, sample 17640–17670 ft. England finder ref. R47/3.
f. *Muderongia tomaszowensis* Alberti, 1961. Specimen from VK117, sample, 20990–21000 ft. England finder ref. V49.
g. *Nyktericysta arachnion* Bint, 1986. Specimen from VK117, sample 18990–19020 ft. England finder ref. U27/4.
h. *Odonotchitina ancala* Bint, 1986. Specimen from DC353, sample 17720–17780 ft. England finder ref. X36/1.
i. *Odonotchitina imparalis* (Duxbury, 1980) Jain and Khowaja-Ateequzzaman, 1984. The scale bar represents 10 µm. Specimen from DC353, sample, 19700–19760 ft. England finder ref. P37/4.
j. *Odonotchitina operculata* (Wetzel, 1933) Deflandre and Cookson, 1955. The scale bar represents 10 µm. Specimen from VK117, sample 15360–15390 ft. England finder ref. K27/1.
k. *Odonotchitina porifera* Cookson, 1956. The scale bar represents 10 µm. Specimen from VK117, sample 15840–15870 ft. England finder ref. O35.
l. *Phoberocysta neocomica* (Gocht, 1957) Millioud, 1969. Specimen from DC353, sample, 20840–20900 ft. England finder ref. P30/3.
m. *Pseudoceratium brevicornutum* Herngreen *et al.,* 2000. Specimen from DC353, sample, 20060–20120 ft. England finder ref. U38/4.
n. *Pseudoceratium pelliferum* Gocht, 1957. The scale bar represents, 20 µm. Specimen from VK117, sample 18240–18270 ft. England finder ref. O46/1.
o. *Pseudoceratium retusum* Brideaux, 1977. Specimen from VK117, sample 15840–15870 ft. England finder ref. W42/1.
p. *Pseudoceratium securigerum* (Davey and Verdier, 1974) Bint, 1986. Specimen from VK117, sample 13770–13800 ft. England finder ref. U26.
q. *Xenascus ceratioides* (Deflandre1937) Lentin and Williams, 1973. Specimen from DC353, sample, 19040–19100 ft. England finder ref. P26.
r. *Xenascus perforatus* (Vozzhennikova, 1967) Yun Hyesu, 1981. Specimen from DC353, sample, 19040–19100 ft. England finder ref. P37.
s. *Xenascus plotei* Below, 1981. Specimen from DC353, sample, 19040–19100 ft. England finder ref. L26/3.
t. *Aprobolocysta eilema* Duxbury, 1977. Specimen from VK117, sample 15540–15570 ft. England finder ref. L45/3.

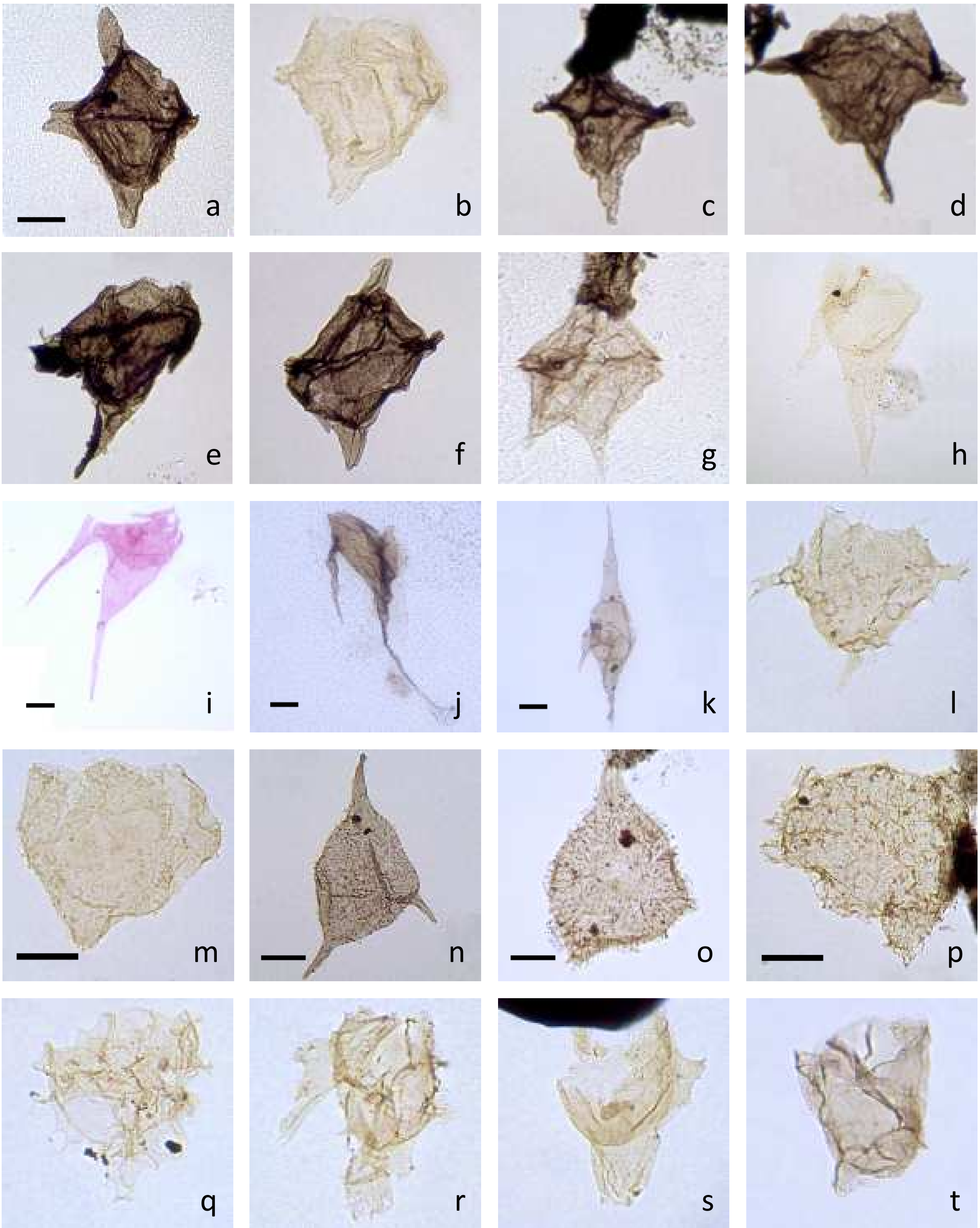

Plate I

Plate II

The scale bar in Figure a represents, 20 µm, and is the same scale as all other Figures unless otherwise stated. All specimens are upright, and in dorso-ventral view.

a. *Batioladinium jaegeri* (Alberti, 1961) Brideaux, 1975. Specimen from VK117, sample 18540–18570 ft. England finder ref. T42.

b. *Paraevansia brachythelis* (Fensome, 1979) Below, 1990. Specimen from DC353, sample 22800–22860 ft. England finder ref. V41.

c. *Gochteodinia villosa* (Vozzhennikova, 1967) Norris, 1978b. Specimen from VK117, sample 22890–22900 ft. England finder ref. D45/4.

d. *Pareodinia ceratophora* Deflandre, 1947b. Specimen from VKI117, sample 17640–17670 ft. England finder ref. P42/1.

e. *Hystrichosphaeridium arborispinum* Davey and Williams, 1966a. Specimen from CH265, sample 9640–9650 ft. England finder ref. W31.

f. *Hystrichosphaeridium recurvatum* (White 1842) Lejeune-Carpentier, 1940. Specimen from VK117, sample 15360–15390 ft. England finder ref. H29.

g. *Taleisphaera hydra* Duxbury, 1979a. Specimen from VK117, sample 16560–16590 ft. England finder ref. Y35.

h. *Apteodinium granulatum* Eisenack, 1958. Specimen from VK117, sample 18240–18270 ft. England finder ref. W35/2.

i. *Apteodinium maculatum* Eisenack and Cookson, 1960. Specimen from VK117, sample 16770–16800 ft. England finder ref. V44/1.

j. *Cribroperidinium boreas* (Davey, 1974) Helenes, 1984. Specimen from CH265, sample 10250–10260 ft. England finder ref. J22/4.

k. *Cribroperidinium confossum* (Duxbury, 1977) Helenes, 1984. Specimen from VK117, sample 18240–18270 ft. England finder ref. F37/2.

l. *Cribroperidinium exilicristatum* (Davey, 1969) Stover and Evitt, 1978. Specimen from CH265, sample 10250–10260 ft. England finder ref. R45/2.

m. *Cribroperidinium orthoceras* (Eisenack, 1958) Davey, 1969. Specimen from CH265, sample 10250–10260 ft. England finder ref. V24/2.

n. *Cribroperidinium*? *gigas* (Raynaud, 1978) Helenes, 1984. Specimen from DC353, sample 21980–22040 ft. England finder ref. J40.

o. *Cribroperidinium*? *tenuiceras* (Eisenack, 1958) Poulsen, 1996. Specimen from DC353, sample, 19340–19400 ft. England finder ref. U27.

p. *Cribroperidinium sp.* Specimen from DC353, sample 23760–23820 ft. England finder ref. E47/2.

q. *Florentinia buspina* (Davey and Verdier, 1976) Duxbury, 1980. Specimen from VK117, sample 15360–15390 ft. England finder ref. K35.

r. *Florentinia deanei* (Davey and Williams, 1966a) Davey and Verdier, 1973. Specimen from DC353, sample, 19520–19580 ft. England finder ref. W29/1.

s. *Achomosphaera neptuni* (Eisenack, 1958) Davey and Williams, 1966. Specimen from VK117, sample 15360–15390 ft. England finder ref. O31.

t. *Exiguisphaera plectilis* Duxbury, 1980. Specimen from VK117, sample 16770–16800 ft. England finder ref. U43/4.

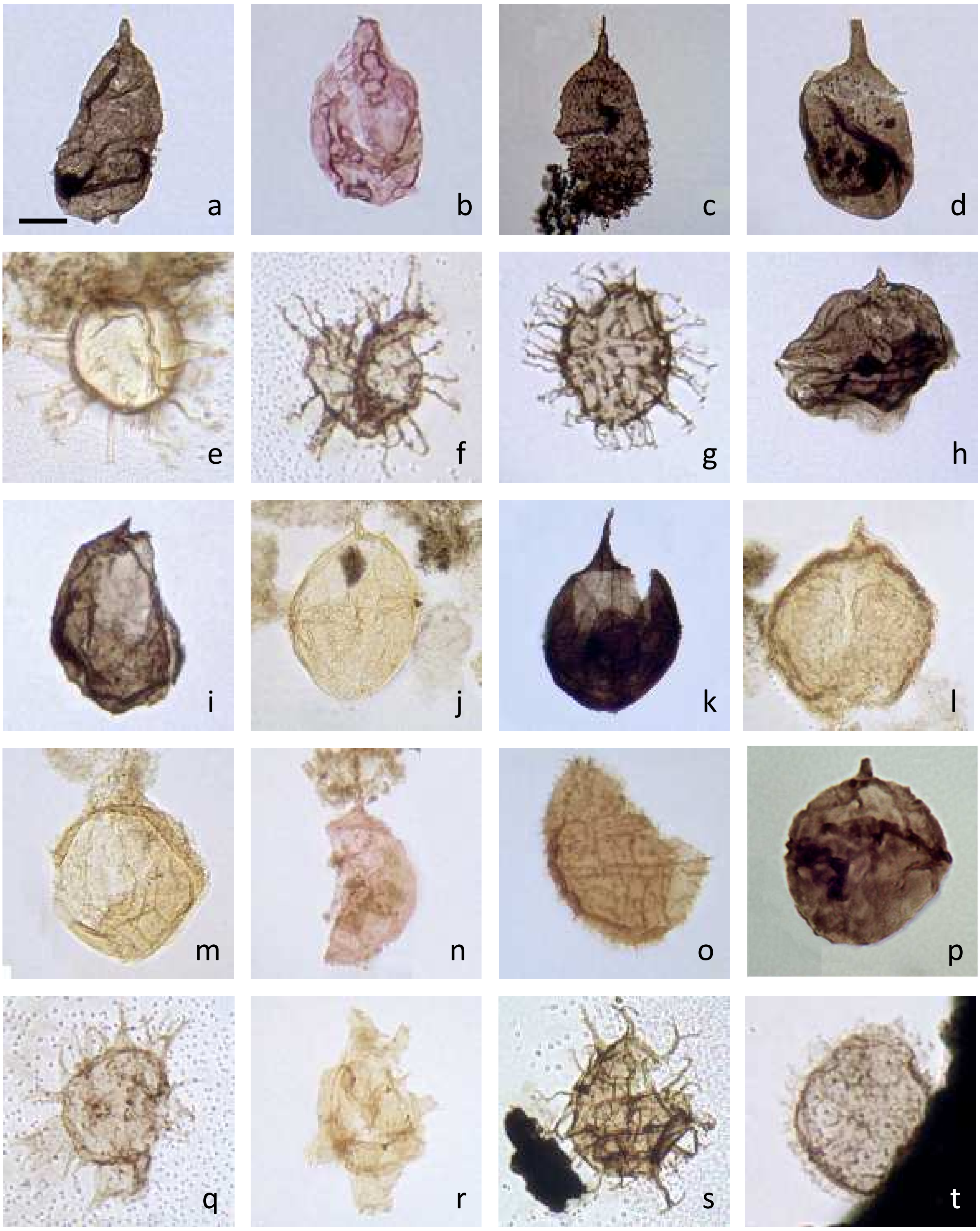

Plate II

Plate III

The scale bar in Figure a represents, 20 µm, and is the same scale as all other Figures unless otherwise stated. All specimens are upright, and in dorso-ventral view.

a. *Impagidinium alectrolophum* (Sarjeant, 1966b) Stover and Evitt, 1978. Specimen from DC353, sample 18800–18860 ft. England finder ref. S41.

b. *Spiniferites dentatus* (Gocht, 1959) Lentin and Williams, 1973. Specimen from VK117, sample 17490–17520 ft. England finder ref. R55/2.

c. *Spiniferites fenestratus* Duxbury, 2001. Specimen from VK117, sample 13770–13800 ft. England finder ref. N40.

d. *Spiniferites ramosus* (Ehrenberg, 1838) Mantell, 1854. Specimen from DC353, sample, 19640–19700 ft. England finder ref. T28.

e. *Tubotuberella apatela* (Cookson and Eisenack, 1960) Ioannides *et al.,* 1977. Specimen from DC353, sample 22460–22520 ft. England finder ref. F42/1.

f. *Ctenidodinium elegantulum* Millioud, 1969. Specimen from VK117, sample 16770–16800 ft. England finder ref. R44.

g. *Dichadogonyaulax irregularis* Benson, 1985. Specimen from VK117, sample 15840–15870 ft. England finder ref. U39.

h. *Dichadogonyaulax*? *pannea* (Norris, 1965b) Sarjeant, 1969. Specimen from VK117, sample 21490–21500 ft. England finder ref. T43/1

i. *Durotrigia aspera* Bailey and Partington, 1991. Specimen from DC353, sample 22800–22860 ft. England finder ref. U44/3.

j. *Egmontodinium toryna* Cookson and Eisenack, 1960. Specimen from DC353, sample, 20600–20660 ft. England finder ref. F42.

k. *Gonyaulacysta jurassica* (Deflandre, 1939) Norris and Sarjeant, 1965. Specimen from DC353, sample 22760–22820 ft. England finder ref. V35.

l. *Gonyaulacysta*? *kleithria* Duxbury, 1983. Specimen from VK117, sample 14490–14520 ft. England finder ref. T40/4.

m. *Kleithriasphaeridium corrugatum* Davey, 1974. Specimen from DC353, sample, 19760–19820 ft. England finder ref. E27/4.

n. *Kleithriasphaeridium eoinodes* (Eisenack, 1958) Davey, 1974. Specimen from DC353, sample 17900–17960 ft. England finder ref. O34/3.

o. *Kleithriasphaeridium loffrense* Davey and Verdier, 1976. Specimen from VK117, sample 15540–15570 ft. England finder ref. W49/3.

p. *Kleithriasphaeridium porosispinum* Davey, 1982. Specimen from VK117, sample 23990–24000 ft. England finder ref. J36/2.

q. *Leptodinium subtile* Klement, 1960. Specimen from DC353, sample 22760–22820 ft. England finder ref. R31/1.

r. *Litosphaeridium conispinum* Davey and Verdier, 1973. Specimen from DC353, sample 18260–18320 ft. England finder ref. L40.

s. *Meiourogonyaulax caytonensis* (Sarjeant, 1959) Sarjeant, 1969. Specimen from DC353, sample 22800–22860 ft. England finder ref. M33/2.

t. *Meiourgonyaulax pertusa* (Duxbury, 1977) Below, 1981. Specimen from DC353, sample 21320–21380 ft. England finder ref. C46/3.

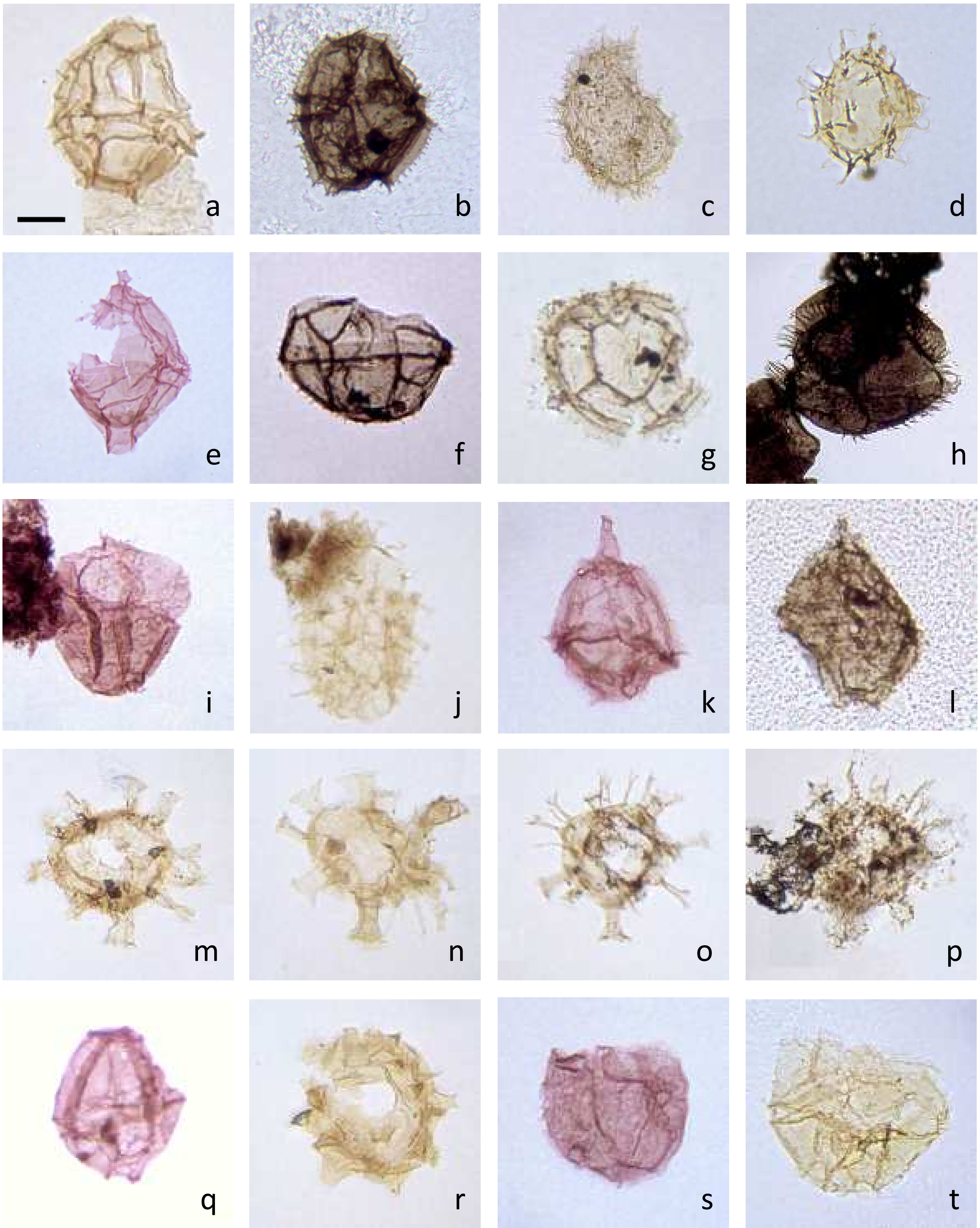

Plate III

Plate IV

The scale bar in Figure a represents, 20 µm, and is the same scale as all other Figures unless otherwise stated. All specimens are upright, and in dorso-ventral view.

a. *Oligosphaeridium albertense* (Pocock, 1962) Davey and Williams, 1969. Specimen from CH265, sample 10800–10810 ft. England finder ref. O37/2.
b. *Oligosphaeridium complex* (White 1842) Davey and Williams, 1966a. Specimen from VK117, sample 18240–18270 ft. England finder ref. W47.
c. *Oligosphaeridium fenestratum* Duxbury, 1980. Specimen from DC353, sample 18740–18800 ft. England finder ref. W27.
d. *Oligosphaeridium perforatum* (Gocht, 1959) Davey and Williams, 1969. Specimen from CH265, sample 10800–10810 ft. England finder ref. V39.
e. *Oligosphaeridium poculum* Jain, 1977. Specimen from VK117, sample 17340–17370 ft. England finder ref. V48.
f. *Oligosphaeridium pulcherrimum* (Deflandre and Cookson, 1955) Davey and Williams, 1966a. Specimen from VK117, sample 14640–14670 ft. England finder ref. J54.
g. *Oligosphaeridium umbraculum* Duxbury, 2001. Specimen from VK117, sample 14490–14520 ft. England finder ref. T33.
h. *Oligosphaeridium sp.* Specimen from DC353, sample 18620–18680 ft. England finder ref. J43.
i. *Rhynchodiniopsis cladophora* (Deflandre, 1939) Below, 1981. Specimen from DC353, sample 23160–23220 ft. England finder ref. K30/3.
j. *Stanfordella fastigiata* (Duxbury, 1977) Helenes and Lucas-Clark, 1997. Specimen from VK117, sample, 19800–19830 ft. England finder ref. N25/2.
k. *Systematophora areolata* Klement, 1960. Specimen from VK117, sample, 19800–19830 ft. England finder ref. R36
l. *Systematophora complicata* Neale and Sarjeant, 1962. Specimen from VK117, sample 18540–18570 ft. England finder ref. N35.
m. *Systematophora palmula* Davey, 1982. Specimen from VK117, sample, 19800–19830 ft. England finder ref. M53/1.
n. *Systematophora silybum* Davey, 1979a. Specimen from VK117, sample 17640–17670 ft. England finder ref. P31/2.
o. *Systematophora*? *daveyi* Riding and Thomas, 1988. Specimen from VK117, sample 18240–18270 ft. England finder ref. R41/2.
p. *Cometodinium obscurum* Deflandre and Courteville, 1939. Specimen from VK117, sample 13770–13800 ft. England finder ref. R22/2.
q. *Cometodinium whitei* (Deflandre and Courteville, 1939) Stover and Evitt, 1978. Specimen from DC353, sample, 19640–19700 ft. England finder ref. L34.
r. *Cometodinium*? *comatum* Srivastava, 1984. Specimen from DC353, sample 18200–18260 ft. England finder ref. W34.
s. *Coronifera oceanica* Cookson and Eisenack, 1958. Specimen from VK117, sample 15840–15870 ft. England finder ref. Q34/3.
t. *Coronifera striolata* (Deflandre, 1937) Stover and Evitt, 1978. Specimen from VK117, sample 17490–17520 ft. England finder ref. S45/3.

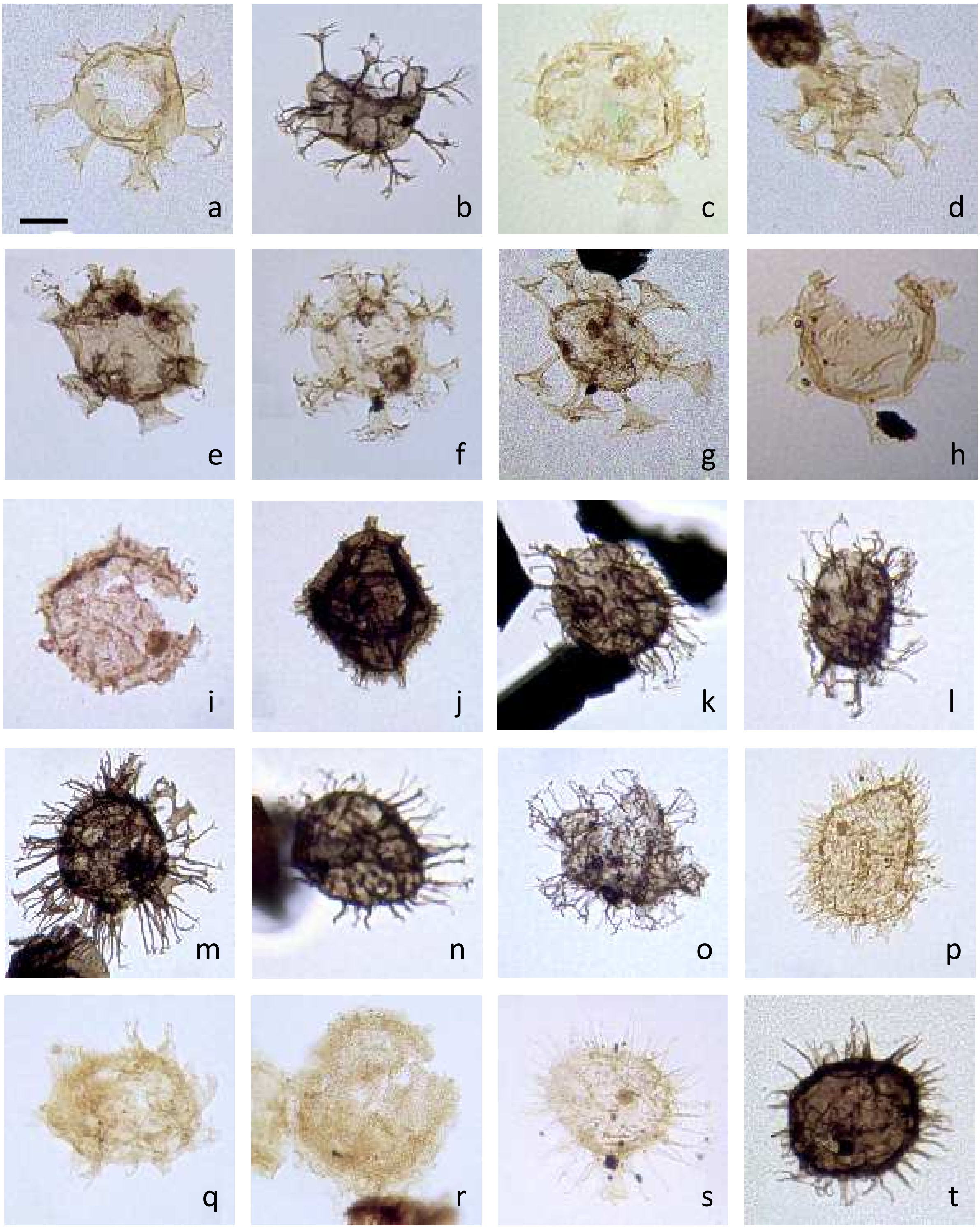

Plate IV

Plate V

The scale bar in Figure a represents, 20 µm, and is the same scale as all other Figures unless otherwise stated. All specimens are upright, and in dorso-ventral view.

a. *Callaiosphaeridium asymmetricum* (Deflandre and Courteville, 1939) Davey and Williams, 1996b. Specimen from VK117, sample 16560–16590 ft. England finder ref. E50.

b. *Callaiosphaeridium trycherium* (Duxbury, 1980). Specimen from DC353, sample 18980–19040 ft. England finder ref. J35/2.

c. *Dissilodinium curiosum* Burger and Sarjeant, 1995. Specimen from DC353, sample 22760–22820 ft. England finder ref. S31/3.

d. *Dissilodinium baileyi* Feist-Burkhardt and Monteil, 2001. Specimen from DC353, sample 22800–22860 ft. England finder ref. J30.

e. *Fibrocysta? deflandrei* (Lejeune-Carpentier, 1941) Lejeune-Carpentier and Sarjeant, 1981. Specimen from CH265, sample 10800–10810 ft. England finder ref. R46.

f. *Hystrichodinium ramoides* Alberti, 1961. Specimen from VK117, sample 15540–15570 ft. England finder ref. Q43/1.

g. *Hystrichodinium voigtii* Alberti, 1961 (Davey, 1974). Specimen from VK117, sample 18840–18870 ft. England finder ref. U29.

h. *Kiokansium prolatum* Duxbury, 1983. Specimen from DC353, sample 17600–17660 ft. England finder ref. W40.

i. *Kiokansium unituberculatum* (Tasch in Tasch *et al.,* 1964) Stover and Evitt, 1978. Specimen from CH265, sample 10800–10810 ft. England finder ref. N38.

j. *Kiokansium williamsii* Singh, 1983. Specimen from DC353, sample 17780–17840 ft. England finder ref. V34/3.

k. *Lagenorhytis delicatula* (Duxbury, 1977) Duxbury, 1979b. Specimen from VK117, sample 18240–18270 ft. England finder ref. Y35.

l. *Nexosispinium hesperus* Davey, 1979b. Specimen from CH265, sample 10250–10260 ft. England finder ref. X32/1.

m. *Nexosispinium vetusculum* (Davey, 1974) Davey, 1979b. Specimen from DC353, sample, 19400–19460 ft. England finder ref. P32/1.

n. *Pervosphaeridium cenomaniense* (Norvick, 1976) Below, 1982a. Specimen from VK117, sample 17340–17370 ft. England finder ref. S49/1.

o. *Pervosphaeridium granaciculare* Fensome *et al.,* 2009. Specimen from DC353, sample, 19220–19280 ft. England finder ref. O36/2.

p. *Pervosphaeridium pseudhystrichodinium* (Deflandre, 1937) Yun Hyesu, 1981. Specimen from DC353, sample 17900–17960 ft. England finder ref. N45/1.

q. *Protoellipsodinium spinosum* Davey and Verdier, 1971. Specimen from DC353, sample 17840–17900 ft. England finder ref. T31/3.

r. *Scriniodinium barremianum* Duxbury, 2001. Specimen from VK117, sample 15540–15570 ft. England finder ref. R40.

s. *Scriniodinium campanula* Gocht, 1959. Specimen from VK117, sample 16140–16170 ft. England finder ref. T42/1.

t. *Adnatosphaeridium caulleryi* (Deflandre, 1939) Williams and Downie, 1969. Specimen from DC353, sample 22220–22280 ft. England finder ref. F44.

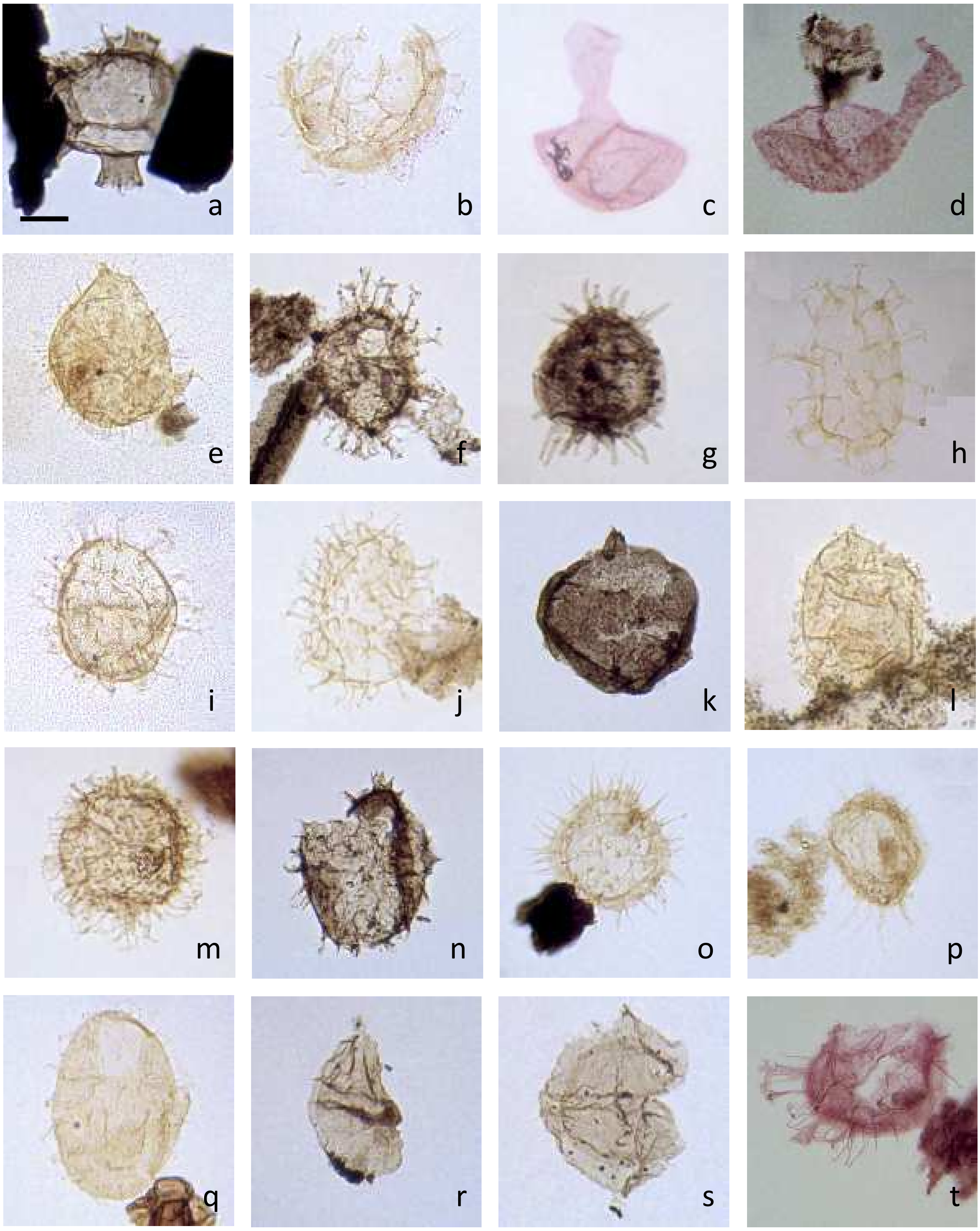

Plate V

Plate VI

The scale bar in Figure a represents, 20 µm, and is the same scale as all other Figures unless otherwise stated. All specimens are upright, and in dorso-ventral view.

a. *Sentusidinium agglutinatum* (McIntyre and Brideaux, 1980) comb. nov. Specimen from VK117, sample 22790–22800 ft. England finder ref. L38.

b. *Sentusidinium aptiense* (Burger, 1980a) Burger, 1980b. Specimen from VK117, sample 16770–16800 ft. England finder ref. T40.

c. *Sentusidinium asymmetrum* (Fenton *et al.,* 1980) Lentin and Williams, 1981. Specimen from DC353, sample 22160–22220 ft. England finder ref. W31.

d. *Sentusidinium baculatum* (Dodekova, 1975) Sarjeant and Stover, 1978. Specimen from DC353, sample, 19400–19460 ft. England finder ref. P42.

e. *Sentusidinium capillatum* (Davey, 1975) Lentin and Williams, 1981. Specimen from VK117, sample 18240–18270 ft. England finder ref. T50/3.

f. *Sentusidinium explanatum* Bujak in Bujak *et al.,* 1980, comb. nov. Specimen from DC353, sample, 19220–19280 ft. England finder ref. O30/1.

g. *Sentusidinium ringnesiorum* (Manum and Cookson, 1964) comb. nov. Specimen from VK117, sample 22790–22800 ft. England finder ref. F35/4.

h. *Circulodinium attadalicum* (Cookson and Eisenack, 1962) Helby, 1987. Specimen from CH265, sample 7750–7760 ft. England finder ref. K44/4.

i. *Circulodinium distinctum* (Deflandre and Cookson, 1955) Jansonius, 1986. Specimen from VK117, sample 21490–21500 ft. England finder ref. N41.

j. *Circulodinium latoaculeum* (Yun Hyesu, 1981) Prince *et al.,* 1999. Specimen from DC353, sample 18020–18080 ft. England finder ref. P32/2.

k. *Circulodinium*? *araneosum* (Brideaux, 1977) Fauconnier in Fauconnier and Masure, 2004. Specimen from DC353, sample, 19940–20000ft. England finder ref. Y51/3.

l. *Cyclonephelium clathromarginatum* Cookson and Eisenack, 1962. Specimen from VK117, sample, 19980–19990 ft. England finder ref. M32/3.

m. *Cyclonephelium compactum* Deflandre and Cookson, 1955. Specimen from CH265, sample 10800–10810 ft. England finder ref. V54/3.

n. *Cyclonephelium formosum* Iosifova, 1992. Specimen from VK117, sample 17490–17520 ft. England finder ref. R27/2.

o. *Cyclonephelium hughsii* Clarke and Verdier, 1967. Specimen from DC353, sample 17720–17780 ft. England finder ref. Q32/2.

p. *Cyclonephelium inconspicuum* Duxbury, 1983. Specimen from DC353, sample 18320–18380 ft. England finder ref. R24.

q. *Cyclonephelium longispinatum* (Davey, 1978) Fauconnier in Fauconnier and Masure, 2004. Specimen from VK117, sample 13770–13800 ft. England finder ref. O42/2.

r. *Cyclonephelium maugaad* Below, 1981. Specimen from DC353, sample 18080–18140 ft. England finder ref. T49.

s. *Cyclonephelium vannophorum* Davey, 1969. Specimen from DC353, sample, 20840–20900 ft. England finder ref. P28.

t. *Dingodinium cerviculum* Cookson and Eisenack, 1958. Specimen from VK117, sample, 19410–19440 ft. England finder ref. C37/2.

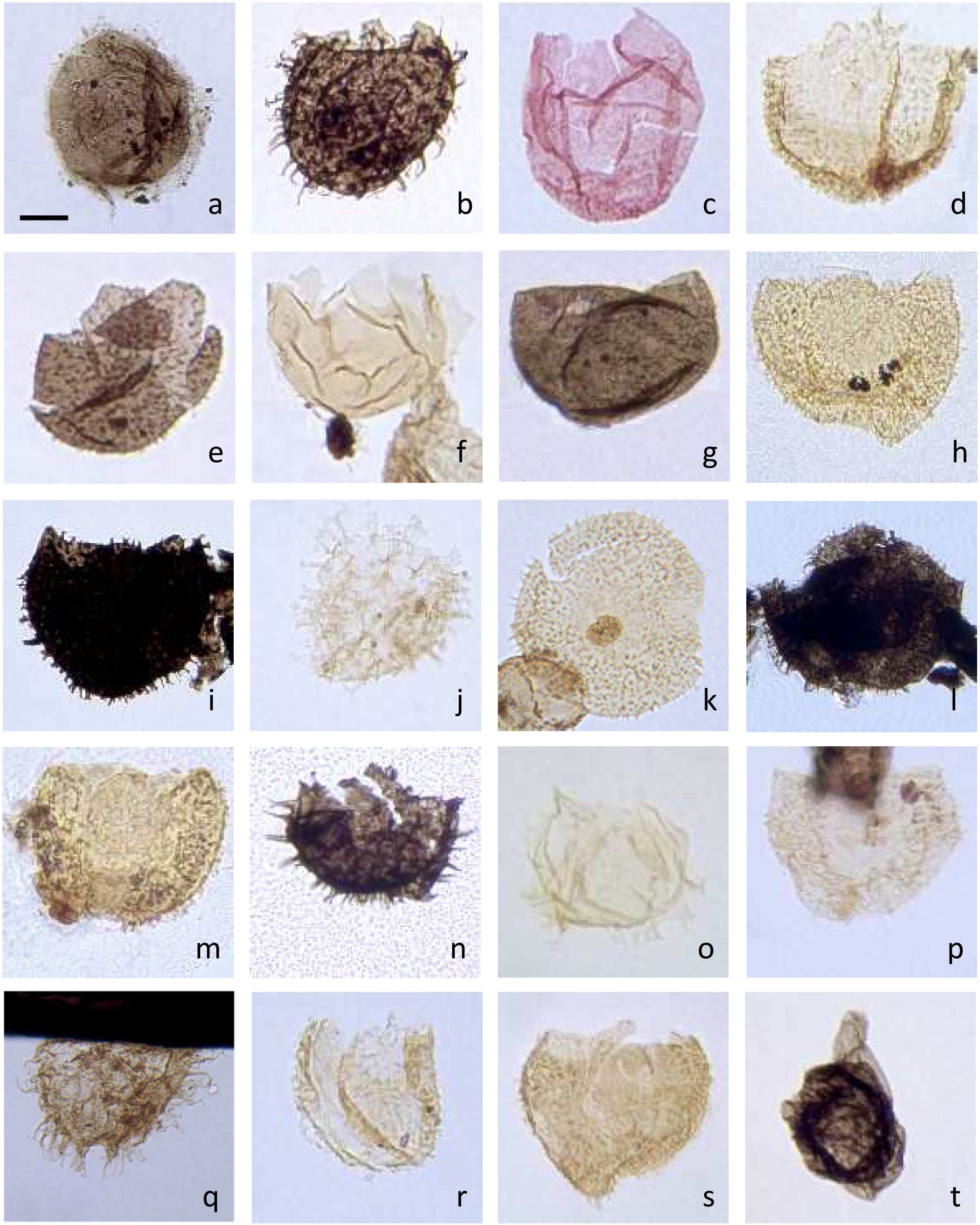

Plate VI

Plate VII

The scale bar in Figure a represents, 20 µm, and is the same scale as all other Figures unless otherwise stated. All specimens are upright, and in dorso-ventral view.

a. *Cerbia magna* Duxbury, 2001. Specimen from DC353, sample, 19040–19100 ft. England finder ref. N30/4.
b. *Cerbia tabulata* (Davey and Verdier, 1974) Below, 1981. Specimen from DC353, sample 17900–17960 ft. England finder ref. T33.
c. *Trichodinium ciliatum* (Gocht, 1959) Eisenack and Klement, 1964. Specimen from VK117, sample 18240–18270 ft. England finder ref. L51.
d. *Trichodinium scarburghense* (Sarjeant, 1964) Williams *et al.,* 1993. Specimen from VK117, sample, 20590–20600 ft. England finder ref. D35/3.
e *Trichodinium speetonense* Davey, 1974. Specimen from VK117, sample 13770–13800 ft. England finder ref. V22.
f. *Cassiculosphaeridia magna* Davey, 1974. Specimen from DC353, sample 21800–21860 ft. England finder ref. S39/1.
g. *Cassiculosphaeridia*? *tocheri* Schiøler, 1993. Specimen from DC353, sample, 19340–19400 ft. England finder ref. R44.
h. *Dapsilidinium laminaspinosum* (Davey and Williams, 1966a) Lentin and Williams, 1981. Specimen from DC353, sample, 20840–20900 ft. England finder ref. K35/3.
i. *Dapsilidinium warrenii* (Habib, 1976) Lentin and Williams, 1981. Specimen from VK117, sample 15360–15390 ft. England finder ref. Q36.
j. *Epiplosphaera gochtii* (Fensome, 1979) Brenner, 1988. Specimen from DC353, sample 22800–22860 ft. England finder ref. G42/3.
k. *Exochosphaeridium arnace* Davey and Verdier, 1973. Specimen from DC353, sample, 19760–19820 ft. England finder ref. K41.
l. *Exochosphaeridium bifidum bifidum* (Clarke and Verdier, 1967) Clarke *et al.,* 1968. Specimen from DC353, sample 17600–17660 ft. England finder ref. V42/1.
m. *Exochosphaeridium phragmites* Davey *et al.,* 1966. Specimen from DC353, sample 17900–17960 ft. England finder ref. N39.
n. *Gardodinium trabeculosum* (Gocht, 1959) Alberti, 1961. Specimen from VK117, sample 17640–17670 ft. England finder ref. Q36/2.
o. *Heterosphaeridium conjunctum* Cookson and Eisenack, 1968. Specimen from DC353, sample 18380–18440 ft. England finder ref. T46.
p. *Heterosphaeridium verdieri* Yun Hyesu, 1981. Specimen from VK117, sample 16140–16170 ft. England finder ref. T41/1.
q. *Impletosphaeridium capitatum* Fensome *et al.,* 2009. Specimen from VK117, sample 15240–15270 ft. England finder ref. D51/1.
r. *Impletosphaeridium ehrenbergii* (Deflandre, 1947a) Islam, 1993. Specimen from DC353, sample 22400–22460 ft. England finder ref. H36.
s. *Impletosphaeridium furcillatum* (Prössl, 1992) Williams *et al.,* 1998. Specimen from DC353, sample, 19940–20000 ft. England finder ref. E37.
t. *Impletosphaeridium granulatum* (Burger1980a) Islam, 1993. Specimen from VK117, sample 15540–15570 ft. England finder ref. V48.

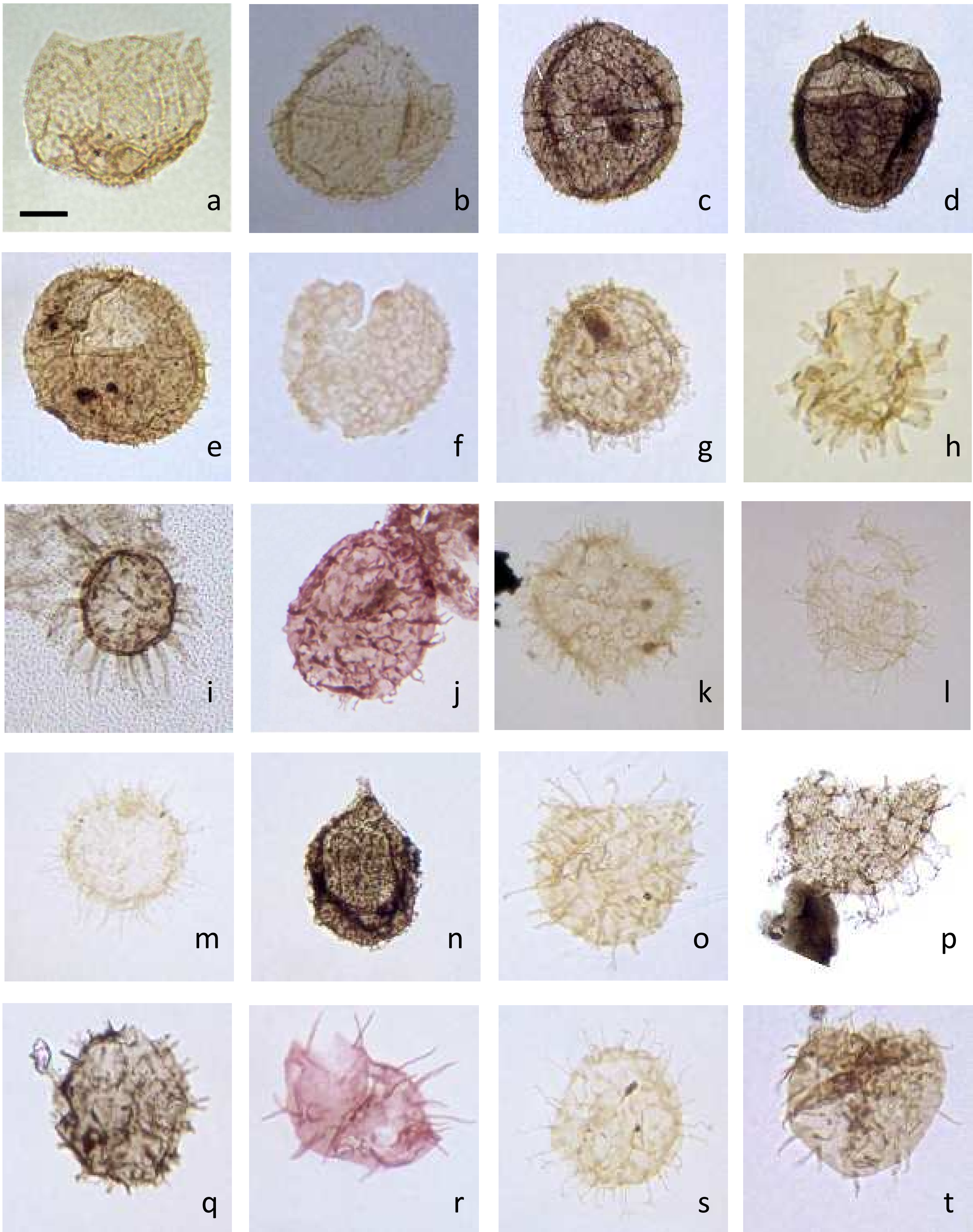

Plate VII

Plate VIII

The scale bar in Figure a represents, 20 µm, and is the same scale as all other Figures unless otherwise stated. All specimens are upright, and in dorso-ventral view.

a. *Mendicodinium granulatum* Kumar, 1986b. Specimen from VK117, sample, 19740–19770 ft. England finder ref. J44/2.
b. *Mendicodinium groenlandicum* (Pocock and Sarjeant, 1972) Davey, 1979c. Specimen from DC353, sample 22640–22700 ft. England finder ref. C45/4.
c. *Tanyosphaeridium boletus* Davey, 1974. Specimen from VK117, sample 18990–19020 ft. England finder ref. N33/1.
d. *Tanyosphaeridium magneticum* Davies, 1983. Specimen from VK117, sample 17490–17520 ft. England finder ref. V49.
e. *Valensiella dictydia* (Sarjeant, 1972) Lentin and Williams, 1993. Specimen from DC353, sample 23400–23460 ft. England finder ref. D37.
f. *Xiphophoridium alatum* (Cookson andEisenack, 1962) Sarjeant, 1966b. Specimen from DC353, sample 17900–17960 ft. England finder ref. S35/1.
g. *Alterbidinium acutulum* (Wilson, 1967) Lentin and Williams, 1985. Specimen from VK117, sample 13770–13800 ft. England finder ref. X26.
h. *Alterbidinium ioannidesii* Pearce, 2010. Specimen from CH265, sample 10250–10260 ft. England finder ref. O53.
i. *Palaeocystodinium*? *denticulatum* Alberti, 1961. Specimen from VK117, sample 13770–13800 ft. England finder ref. X53/1.
j. *Spinidinium styloniferum* Cookson and Eisenack, 1962. Specimen from DC353, sample, 19100–19160 ft. England finder ref. K32/2.
k. *Corculodinium inaffectum* (Drugg, 1978) Courtinat, 2000. Specimen from DC353, sample 21920–21980 ft. England finder ref. T41.
l. *Leberidocysta chalmydata* (Cookson and Eisenack, 1962) Stover and Evitt, 1978. Specimen from DC353, sample, 19760–19820 ft. England finder ref. S41.
m. *Leberidocysta defloccata* (Davey and Verdier, 1973) Stover and Evitt, 1978. Specimen from VK117, sample 13770–13800 ft. England finder ref. Q34/2.
n. *Ovoidinium scabrosum* (Cookson and Hughes, 1964) Davey, 1970. Specimen from DC353, sample, 19700–19760 ft. England finder ref. Q32/4.
o. *Ovoidinium verrucosum* (Cookson and Hughes, 1964) Davey, 1970. Specimen from CH265, sample 10250–10260 ft. England finder ref. W43.
p. *Laciniadinium*? *aquiloniforme* Schiøler *et al.,* 1997. Specimen from DC353, sample, 19940–20000 ft. England finder ref. Y41.
q. *Palaeohystrichophora granulata* Mao Shaozhi and Norris, 1988. Specimen from VK117, sample 12600–12630 ft. England finder ref. J22/4.
r. *Palaeoperidinium cretaceum* (Pocock, 1962, ex Davey, 1970) Lentin and Williams, 1976. Specimen from VK117, sample 15540–15570 ft. England finder ref. N34.
s. *Palaeoperidinium pyrophorum* (Ehrenberg, 1838, ex Wetzel, 1933) Sarjeant, 1967. Specimen from VK117, sample 15540–15570 ft. England finder ref. K49/1.
t. *Subtilisphaera perlucida* (Alberti, 1959) Jain and Millepied, 1973. Specimen from DC353, sample 18560–18620 ft. England finder ref. T45.

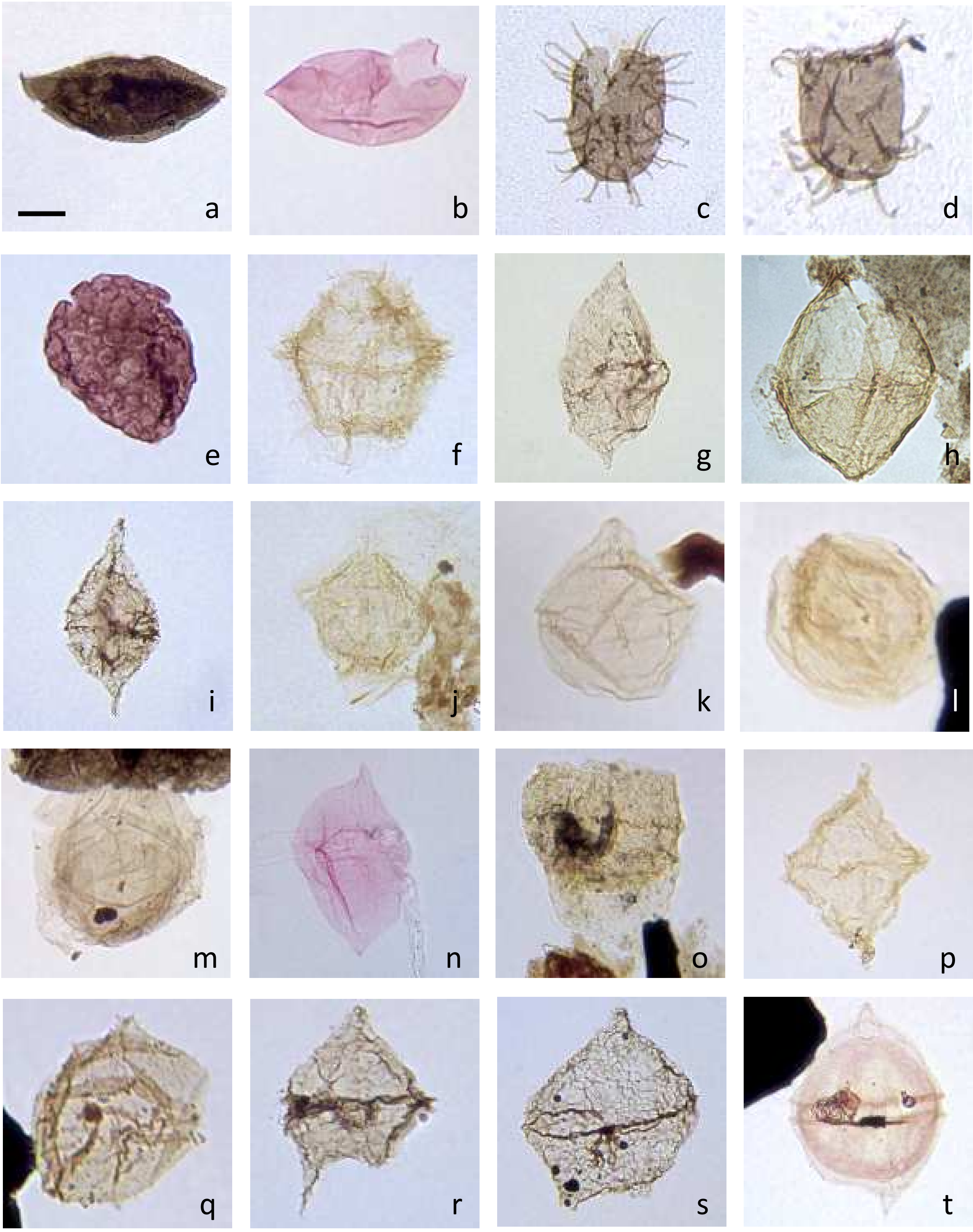

Plate VIII

Plate IX

The scale bar in Figure a represents, 20 µm, and is the same scale as all other Figures unless otherwise stated. All specimens are upright, and in dorso-ventral view.

a. *Prolixosphaeridium anasillum* Erkmen and Sarjeant, 1980. Specimen from DC353, sample 21980–22040 ft. England finder ref. D41/3.
b. *Prolixosphaeridium conulum* Davey, 1969. Specimen from DC353, sample 18320–18380 ft. England finder ref. Q28/1.
c. *Prolixosphaeridium parvispinum* (Deflandre, 1937) Davey *et al.,* 1969. Specimen from DC353, sample 21080–21140 ft. England finder ref. O31/4.
d. Opaque Equidemensional Phytoclast. Specimen from VK117, sample, 20080–20090ft. England finder ref. M30.
e. Opaque Needle Shaped Phytoclast. Specimen from VK117, sample 22690–22700ft. England finder ref. N31/3.
f. Translucent Equidemensional Phytoclast. Specimen from CH265, sample 9700–9710ft. England finder ref. J55.
g. Translucent Needle Shaped Phytoclast. Specimen from VK117, sample 15240–15270ft. England finder ref. H47.
h. Plant cuticle. Specimen from VK117, sample, 20080–20090ft. England finder ref. F32/3.
i. Pollen. *Classopollis* Pflug, 1953. Specimen from VK117, sample, 19800–19830ft. England finder ref. S33/1.
j. Spore. *Retitriletes austroclavatidites* (Cookson, 1953) Döring *et al.,* in Krutzsch 1963. Specimen from DC353, sample, 19760–19820ft. England finder ref. O41/1.
k. Amorphous Organic Matter. Specimen from VK117, sample 15240–15270ft. England finder ref. G38/3.
l. Acritarchs. Specimen from DC353, sample 22860–22920ft. England finder ref. H35/1.
m. Foram Linings. Specimen from CH265, sample 7750–7760ft. England finder ref. M51/4.
n. Algae. Specimen from DC353, sample 23340–23400ft. England finder ref. G29.

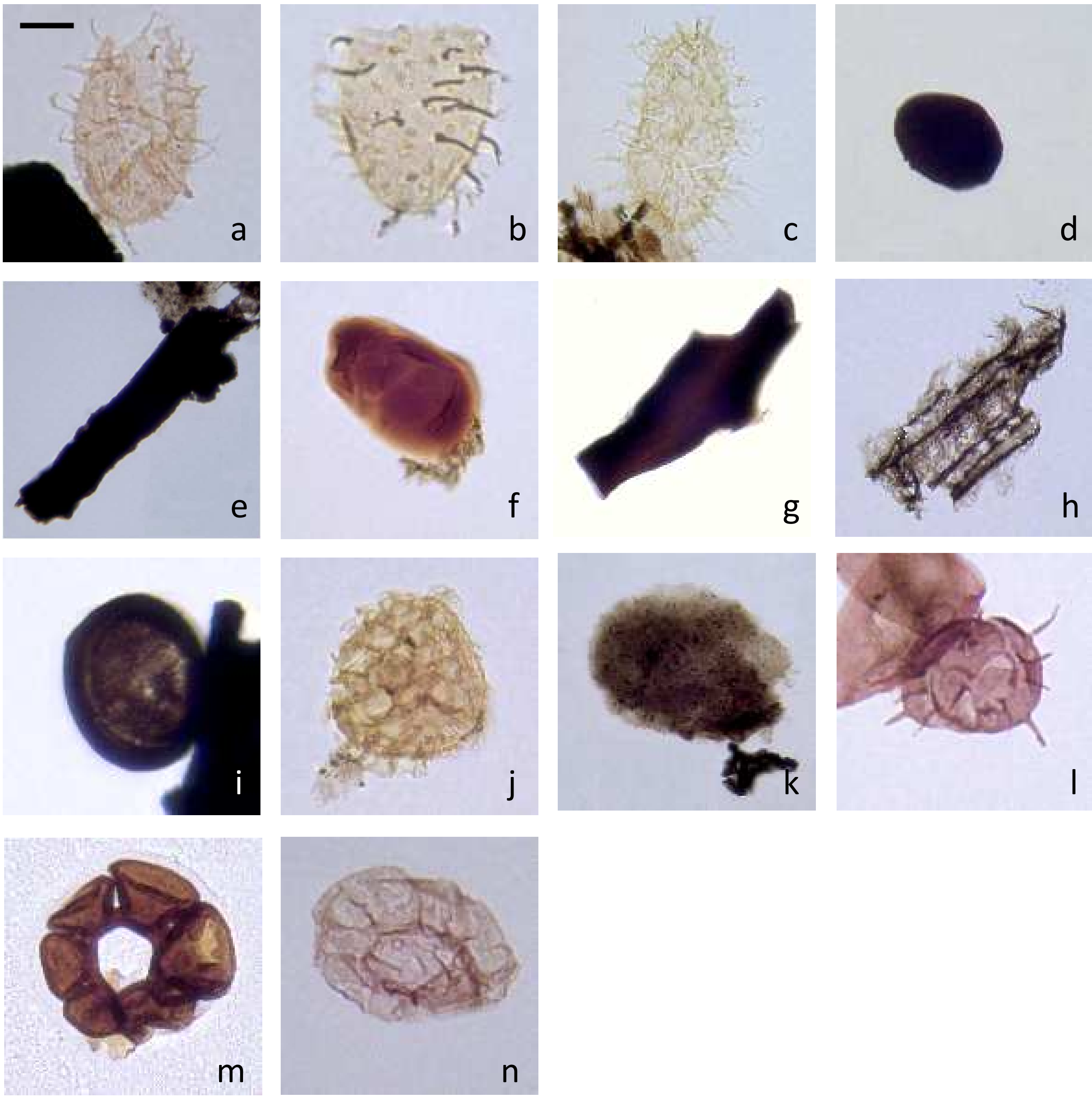

Plate IX

Appendix 1

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A review of the *Sentusidinium* complex of dinoflagellate cysts

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ABSTRACT

The Jurassic to Neogene (Miocene) dinoflagellate cyst genus *Sentusidinium* has a relatively simple overall morphology. This genus, together with *Batiacasphaera*, *Kallosphaeridium* and *Pentafidia*, comprises the *Sentusidinium* complex. This is distinct from the superficially similar laterally asymmetrical and subspheroidal/lenticular *Cyclonephelium* complex. The genus *Sentusidinium* is an acavate, subcircular, proximate to proximochorate, sexiform gonyaulacacean genus with an apical archaeopyle and typically low relief ornamentation. Since the erection of *Sentusidinium* in 1978, three similar genera have been established, which we consider to be taxonomic junior synonyms of that genus: *Barbatacysta*, *Escharisphaeridia* and *Pilosidinium*. However, we deem the Early Cretaceous to Miocene genera *Batiacasphaera*, *Kallosphaeridium* and *Pentafidia* are deemed to be separate from *Sentusidinium*. We refine the definition of the Early Cretaceous to Miocene genus *Batiacasphaera* to circumscribe cysts with a reticulate to rugulate autophragm and an apical archaeopyle with a free operculum. By contrast, *Kallosphaeridium* has a ventrally attached apical archaeopyle with five plates that can be interpreted as type $(4A1I)_{@}$ or type $(5A)_{@}$; it also has a small operculum relative to the overall cyst diameter. The six accepted *Kallosphaeridium* species are confined to the Palaeogene. The Australian genus *Pentafidia* is unusual in appearing to only have five precingular plates; this comprises two species from the Jurassic–Cretaceous transition of Western Australia. Therefore, we emend *Sentusidinium* to restrict it to acavate, proximate or proximochorate dinoflagellate cysts with an autophragm devoid of, or covered with, highly variable, non-linear ornamentation and a type (tA) apical archaeopyle. Occasionally the elements of ornamentation may be connected, but rarely is a cingulum indicated, and the tabulation is never clearly evident. A kalyptra may be occasionally present. The operculum is free. Following a comprehensive literature review, we accept 17 species in *Batiacasphaera*. In *Kallosphaeridium* we accept six species confidently and consider six species to be problematical. We list 38 (34 accepted and four problematical) species of *Sentusidinium*. *Kallosphaeridium*? *helbyi* is here transferred to *Cyclonephelium* without question. The species *Batiacasphaera angularis* is occasionally tabulate and hence we transfer it, with question, to *Meiourgonyaulax*. The *Sentusidinium* complex is clearly polyphyletic, and all genera considered herein belong to the order Gonyaulacales. *Batiacasphaera*, *Kallosphaeridium* and *Pentafidia* cannot be confidently assigned to a family, whereas *Sentusidinium* belongs to the Gonyaulacaceae. The number of species within the complex has been reduced from 137 to 68; furthermore, all infraspecific taxa have been eliminated.

1. Introduction

Many species of acavate, subspheroidal to lenticular, sexiform gonyaulacalean dinoflagellate cysts with apical archaeopyles, low-relief ornamentation and generally no or very weak development of parasutures have been described from the Mesozoic and Cenozoic. These can be divided into two groups, the *Cyclonephelium* complex and the *Sentusidinium* complex. The *Sentusidinium* complex is characterised by laterally symmetrical cysts that belong mostly to the family Gonyaulacaceae; this complex, which is the focus of the present study, comprises the genera *Barbatacysta*, *Batiacasphaera*, *Escharisphaeridia*, *Kallosphaeridium*, *Pentafidia*, *Pilosidinium* and *Sentusidinium*. The *Cyclonephelium* complex consists typically of laterally asymmetrical, subspheroidal to lenticular cysts that belong to the family Areoligeraceae; this complex is the focus of a separate ongoing study and includes the genera *Aptea*, *Canningia*, *Canninginopsis*, *Cerbia*, *Circulodinium*, *Cyclonephelium*, *Senoniasphaera* and *Tenua*. The genera *Prolixosphaeridium*, *Bourkidinium* and *Tanyosphaeridium* are similar to *Sentusidinium* in having process-bearing cysts with apical archaeopyles. However, all three genera have markedly elongate cyst bodies and generally longer, nontabular processes. Consequently, we do not consider them in this paper.

Due to the relatively simple morphology of cysts in the *Sentusidinium* complex and the large number of species, individual taxa are

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difficult to consistently recognise. The principal criterion for identification is the nature of the ornamentation. We aim to simplify the *Sentusidinium* complex at the generic and specific levels and to determine the most stratigraphically useful species.

2. A brief history of the *Sentusidinium* complex

The first genus to be described in the *Sentusidinium* complex was *Kallosphaeridium*, which was established by de Coninck (1969) and emended by Jan du Chêne et al. (1985). *Kallosphaeridium* comprises proximate cysts with a five-plate archaeopyle that can be interpreted as apical (5A) or combination (4A1I); the operculum is attached ventrally. Drugg (1970, p. 813) proposed *Batiacasphaera* for proximate cysts with "rod-shaped elements, either separate or arranged to form a reticulum", and with an apical archaeopyle. This genus was later emended by Morgan (1975) and Dörhöfer and Davies (1980) (see Section 3). *Sentusidinium* was erected by Sarjeant and Stover (1978) for proximate to proximochorate cysts with an apical archaeopyle and low-relief ornamentation. Erkmen and Sarjeant (1980) transferred psilate forms with apical archaeopyles, including some previously assigned to *Sentusidinium*, to their new genus *Escharisphaeridia*. *Pentafidia*, described by Backhouse (1988), consists of proximate cysts with an apical archaeopyle, but is described as having only five (in contrast to the more normal "gonyaulacoid" six) precingular plates. Courtinat (1989) established *Barbatacysta* and *Pilosidinium*, and also emended *Sentusidinium* to simplify its description (see Section 3). *Barbatacysta* and *Pilosidinium* were defined on minor details of ornamentation, and are clearly very similar to *Sentusidinium*. More recently, Sangiorgi et al. (2009) noted the similarities between their new genus *Arcticacysta* and genera of the *Sentusidinium* complex. However, these similarities are superficial, as *Arcticacysta* belongs to the Peridiniales, and is thus excluded from this study.

Given the relatively simple morphology of cysts in the *Sentusidinium* complex, we consider it contains too many genera and species. Consequently, we retain only the genera *Batiacasphaera*, *Kallosphaeridium*, *Pentafidia* and *Sentusidinium*. *Sentusidinium*, the main focus of this taxonomic review, has a type (4A) apical archaeopyle and a free operculum and an autophragm that is either psilate or ornamented (Fig. 1), with generally isolated elements (for example granula, spines or short processes). *Batiacasphaera* has ornamentation that is rugulate to reticulate, or consists of isolated elements that are aligned to form a rugulate to reticulate pattern. Some authors (for example Fensome et al., 2009) have cited shallow accessory archaeopyle sutures between precingular plates as distinctive for *Batiacasphaera*. However, in our survey of species within the *Sentusidinium* complex, we have found this feature almost impossible to apply meaningfully; hence we do not use it herein as a genus-diagnostic feature. *Kallosphaeridium* has an apical (5A) or combination (4A1I) archaeopyle and a ventrally attached operculum (Fig. 2). *Pentafidia* has apparently only five precingular plates.

In the following systematic section, *Batiacasphaera*, *Kallosphaeridium*, *Pentafidia* and *Sentusidinium* are discussed in detail and emendations and synonyms among species are proposed, along with the newly determined stratigraphical ranges (Fig. 3a–e).

Throughout the systematics we use the three categories of size outlined by Stover and Evitt (1978, p. 5): small (<50 μm), intermediate (50–100 μm), and large (>100 μm). The use of an asterisk denotes the type species for each genus. We also use the concepts of "accepted", "provisionally accepted" and "problematical" species as in Stover and Evitt (1978, p. 5). Provisionally accepted species do not belong to the respective genus with certainty and have a question mark following the generic name. Problematical species are even more doubtfully assigned to the genus. Stover and Evitt denoted problematical species with quotation marks around the generic abbreviation and did not use a question mark. We add a question mark after the generic name, as leaving it out might be seen to imply that such species are less questionable than provisionally accepted species, which is clearly not the case; and we omit quotation marks as their use might lead to problems with nomenclatural validity (see McNeill et al., 2012, Article 36.1) and confusion with their different usage in the DINOFLAJ2 database (Fensome et al., 2008). An asterisk before the taxonomic name denotes the type species. The accepted, provisionally accepted and problematical species are listed along with the age and geographical location from which they were first described. Copies of the original holotypes can be viewed in Plates I to VI.

3. Systematic palaeontology

Division DINOFLAGELLATA (Bütschli, 1885) Fensome et al., 1993
Subdivision DINOKARYOTA Fensome et al., 1993
Class DINOPHYCEAE Pascher, 1914
Subclass PERIDINIPHYCIDAE Fensome et al., 1993
Order GONYAULACALES Taylor, 1980
***Genus Batiacasphaera* Drugg, 1970 emend. nov.**
Type: *Batiacasphaera compta* Drugg, 1970.
1970 *Batiacasphaera* Drugg, p. 813.
1975 *Batiacasphaera* Drugg, 1970 emend. Morgan, p. 161.
1980 *Batiacasphaera* Drugg, 1970 emend. Dörhöfer and Davies, p. 40.

Original diagnosis: Tract spherical to subspherical with an angular apical archaeopyle. The ornamentation consists of rod–shaped elements, either separate or arranged to form a reticulum. In the latter case, they may be fused (Drugg, 1970, p. 813).

Emended diagnosis: Proximate, acavate gonyaulacalean dinoflagellate cysts with a subspheroidal to ovoidal central body in dorso-ventral view. The autophragm bears nontabulate ornament that is rugulate to reticulate, or isolated elements that align. The archaeopyle is apical, with a free operculum.

Emended description: Small to intermediate, acavate, proximate dinoflagellate cysts that are subspherical to ovoidal in shape, occasionally elongate. The autophragm is generally thick and bears a rugulate to reticulate ornament, or bears typically rod-shaped elements that are arranged, or may fuse, to form a reticulum or polygonal, semi-polygonal or rugulate pattern. The presumed gonyaulacacean tabulation is only indicated by the apical archaeopyle, which normally has a free operculum. Typically, accessory archaeopyle sutures are not, or only weakly, developed, but may be better developed in some species. The cingulum and sulcus are not indicated.

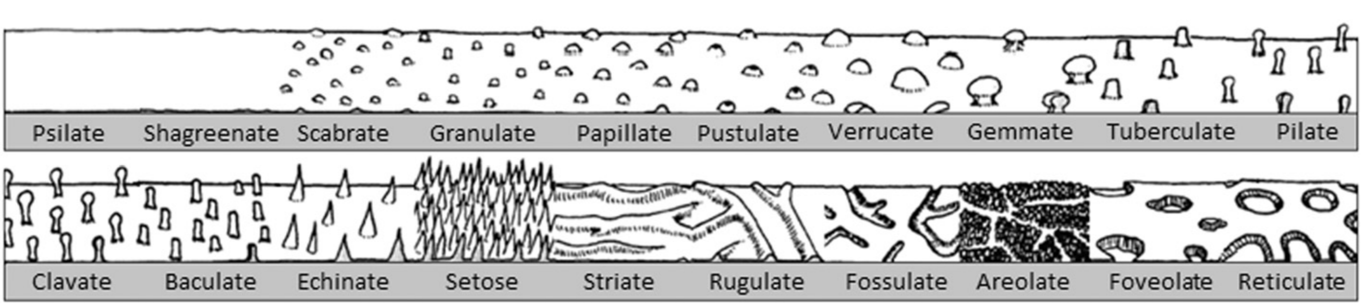

Fig. 1. Surface ornamentation terminology applied to dinoflagellate cysts. (Modified from Williams et al., 1978).

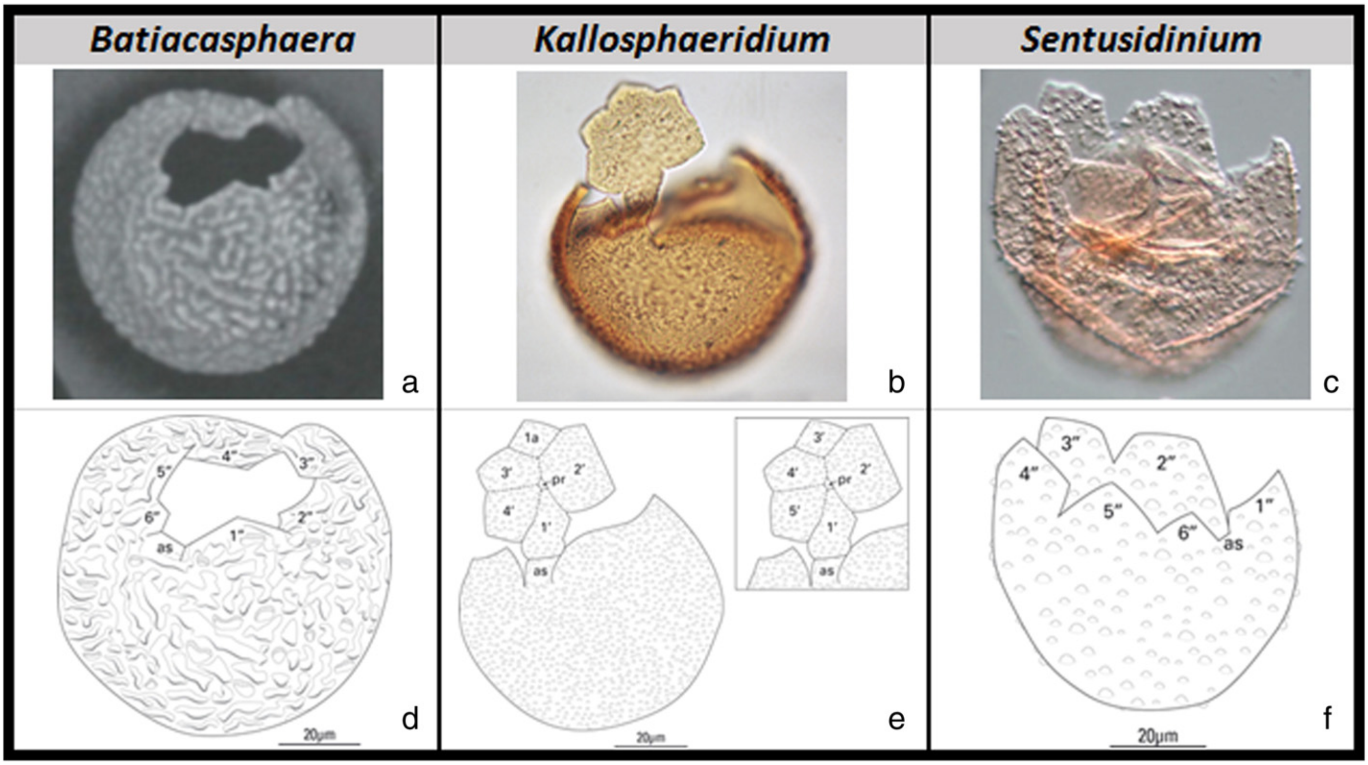

Fig. 2. Line drawings and photographs to illustrate the morphological differences between *Batiacasphaera*, *Kallosphaeridium* and *Sentusidinium*. a, Scanned image of *Batiacasphaera edwardsiae* Louwye et al., 2008. Note the characteristic rugulate ornamentation and the lack of accessory archaeopyle sutures and the small operculum. The genus *Batiacasphaera* exhibits a reticulate to rugulate autophragm; b, Photomicrograph of *Kallosphaeridium* sp. cf. *K. capulatum* Stover, 1977. Note the attached operculum, comprising five major plates. The inset in e is an alternative plate interpretation (Jan du Chêne et al., 1984, fig. 1); c, Photomicrograph of *Sentusidinium verrucosum* Sarjeant, 1968. Note the large, free operculum and the prominent accessory archaeopyle sutures; d, Interpreted line drawing of *Batiacasphaera edwardsiae* Louwye et al., 2008; e, Interpreted line drawing of *Kallosphaeridium* sp. cf. *K. capulatum* Stover, 1977; f, Interpreted line drawing of *Sentusidinium verrucosum* Sarjeant, 1968.

Comments: Morgan (1975, p. 161) gave an emended description for *Batiacasphaera* in which he noted the lenticular shape and that the ornamentational elements may fuse to form rugulae. We consider the shape to be more subspheroidal than lenticular, but do accept forms in *Batiacasphaera* with linear ornament consisting of fused elements. Dörhöfer and Davies (1980, p. 40) indicated that they were emending *Batiacasphaera* but provided neither an emended diagnosis or description nor a clear statement of their generic concept.

We restrict *Batiacasphaera* to species within the *Sentusidinium* complex that have a generally reticulate to rugulate ornamentation. Drugg (1970) originally diagnosed *Batiacasphaera* as having an "angular apical archaeopyle", implying that the accessory archaeopyle sutures between precingular plates are absent or weakly developed. We found that across the *Sentusidinium* complexes, using this feature as a defining one at generic level was very difficult to apply. So we re-assign species similar to the type in terms of accessory archaeopyle suture development, such as *Batiacasphaera baculata*, but with isolated, non-aligned sculptural elements, to *Sentusidinium*. The lack of well-developed accessory archaeopyle sutures can give the superficial impression of a precingular archaeopyle, especially in poorly preserved or obliquely oriented specimens; however, closer examination of better specimens reveals the shape of an apical archaeopyle. The holotype of *Batiacasphaera compta*, the type of *Batiacasphaera*, shows an unconventional outline to its archaeopyle and is thus difficult to interpret precisely in terms of tabulation. However, other specimens of *Batiacasphaera compta*, and other species of the genus show a conventional type (tA) archaeopyle.

Fensome and Williams (2004, p. 73–78) listed 49 species of *Batiacasphaera*. However, only 17 of these species have a rugulate to reticulate autophragm, and these are all Early Cretaceous to Late Miocene in age. They are listed below in the accepted species list and summarised in Table 1.

Comparison: *Batiacasphaera* differs from all three other genera in the *Sentusidinium* complex by its strongly developed reticulate to regulate ornamentation.

Accepted species:

Batiacasphaera bergenensis Schreck and Matthiessen, 2014 (Early–Middle Miocene, Iceland) Plate I, 1–9.

Batiacasphaera cassiculus Wilson, 1988 (Middle Eocene, New Zealand) Plate I, 10.

**Batiacasphaera compta* Drugg, 1970 (Late Eocene, USA) Plate I, 11–12.

Batiacasphaera cooperi Hannah et al., 1998 (Miocene, Antarctica) Plate II, 1–2.

Batiacasphaera dictyophora Ruiqi et al., 1992 (Late Cretaceous, China) Plate I, 13.

Batiacasphaera edwardsiae Louwye et al., 2008 (Middle Miocene, Ireland) Plate I, 14–20.

Batiacasphaera grandis Roncaglia et al., 1999 (Late Cretaceous, New Zealand) Plate II, 3.

Batiacasphaera imperfecta Stover and Helby, 1987a (Early Cretaceous, Australia) Plate II, 5–6.

Batiacasphaera kekerengensis Schiøler and Wilson, 1998 (Late Cretaceous, New Zealand) Plate II, 4.

Batiacasphaera microreticulata Chenglong, 1999 (Eocene, Taiwan) Plate II, 7–8.

Batiacasphaera reticulata Davey, 1979 (Late Cretaceous, South Africa) Plate II, 9.

Batiacasphaera retirugosa Jinli et al., 1997 ex He et al., 2009 (Middle–Late Eocene, China) Plate II, 10.

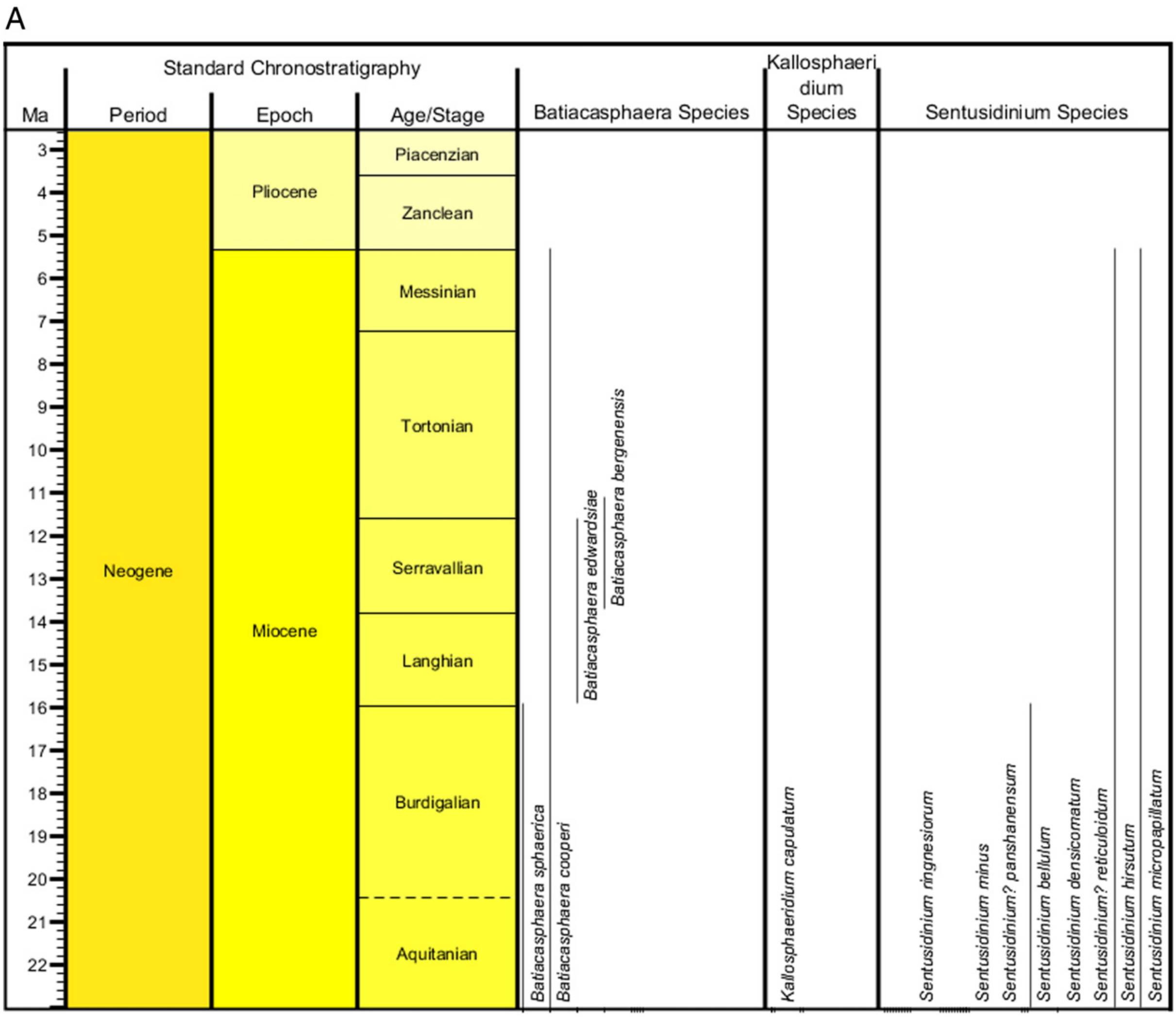

Fig. 3. a. Neogene range chart to display the stratigraphical significance of the newly arranged *Sentusidinium* complex. **b**. Paleogene range chart to display the stratigraphical significance of the newly arranged *Sentusidinium* complex. **c**. Late Cretaceous range chart to display the stratigraphical significance of the newly arranged *Sentusidinium* complex. **d**. Early Cretaceous range chart to display the stratigraphical significance of the newly arranged *Sentusidinium* complex. **e**. Jurassic range chart to display the stratigraphical significance of the newly arranged *Sentusidinium* complex.

Batiacasphaera rugulata Schiøler and Wilson, 1998 (Late Cretaceous, New Zealand) Plate II, 11.
Batiacasphaera saidensis Below, 1981 (Early Cretaceous, Morocco) Plate II, 13–14.
Batiacasphaera solida Slimani, 2003 (Late Cretaceous, Belgium) Plate II, 12.
Batiacasphaera sphaerica Stover, 1977 (Early Miocene, Atlantic Ocean) Plate II, 17.
Batiacasphaera subtilis Stover and Helby, 1987b (Early Cretaceous, Australia) Plate II, 15–16.

Reattributed and synonymised species:

Batiacasphaera agglutinata (McIntyre and Brideaux, 1980) Jan du Chêne et al., 1985, to *Sentusidinium* as *Sentusidinium agglutinatum* (McIntyre and Brideaux, 1980) comb. nov. herein.
Batiacasphaera angularis Stevens and Helby, 1987, to *Meiourogonyaulax* as *Meiourogonyaulax angularis* (Stevens and Helby, 1987) comb. nov. herein.
Batiacasphaera asperata Backhouse, 1987, considered a taxonomic junior synonym of *Sentusidinium euteichum*.
Batiacasphaera baculata Drugg, 1970, to *Sentusidinium* as *Sentusidinium bifidum* (Jiabo, 1978) He et al., 1989.
Batiacasphaera? *bellula* (Jiabo, 1978) Jan du Chêne et al., 1985, retained as *Sentusidinium bellulum* (Jiabo, 1978) Jinli et al., 1997.
Batiacasphaera biornata (Jiabo, 1978) Jan du Chêne et al., 1985, considered a taxonomic junior synonym of *Sentusidinium baculatum* (Dodekova, 1975) Sarjeant and Stover, 1978.
Batiacasphaera biornata subsp. *biornata* (autonym), considered a taxonomic junior synonym of *Sentusidinium baculatum*.
Batiacasphaera biornata subsp. *conispicula* Liu Zhili and Zheng Yuefang in Zhili et al., 1992, considered a taxonomic junior synonym of *Sentusidinium baculatum*.
Batiacasphaera biornata subsp. *crassa* (Jiabo, 1978) Lentin and Williams, 1989, considered a taxonomic junior synonym of *Sentusidinium bifidum* (Jiabo, 1978) He et al., 1989.
Batiacasphaera brachyspinosa (Zheng Yuefang and Liu Xuexian in Zhili et al., 1992) He et al., 2009, considered a taxonomic junior synonym of *Sentusidinium bifidum* (Jiabo, 1978) He et al., 1989.
Batiacasphaera consolida Pan Zhaoren in Jinli et al., 1997 ex He et al., 2009, considered a taxonomic junior synonym of *Sentusidinium bellulum*.

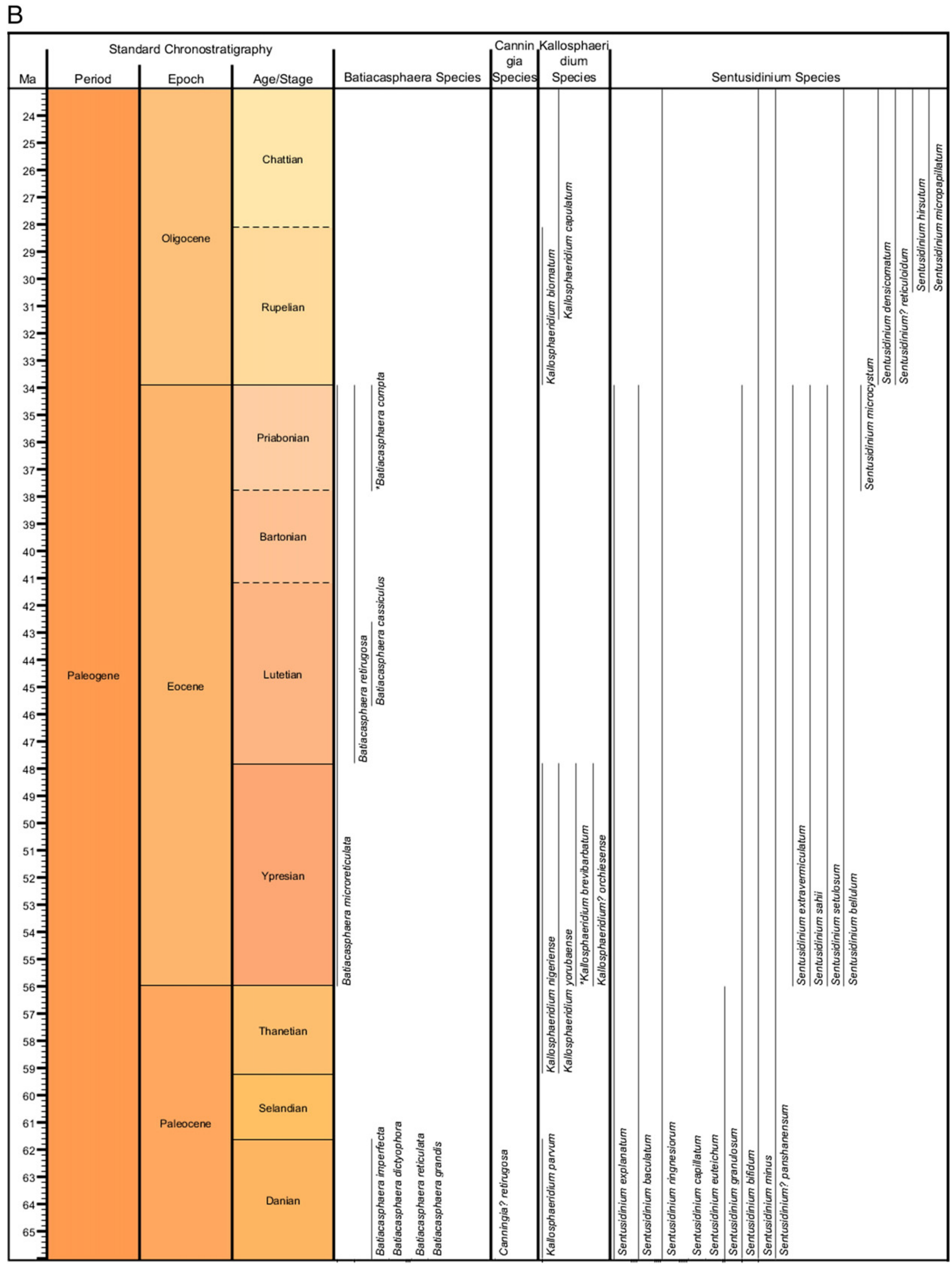

Fig. 3 (*continued*).

Batiacasphaera conspicula (Liu Zhili and Zheng Yuefang in Zhili et al., 1992) He et al., 2009, considered a taxonomic junior synonym of *Sentusidinium baculatum*.

Batiacasphaera curiosa (Bujak, 1984) Jan du Chêne et al., 1985, considered a taxonomic junior synonym of *Sentusidinium sahii* (Khanna and Singh, 1981) comb. nov. herein.

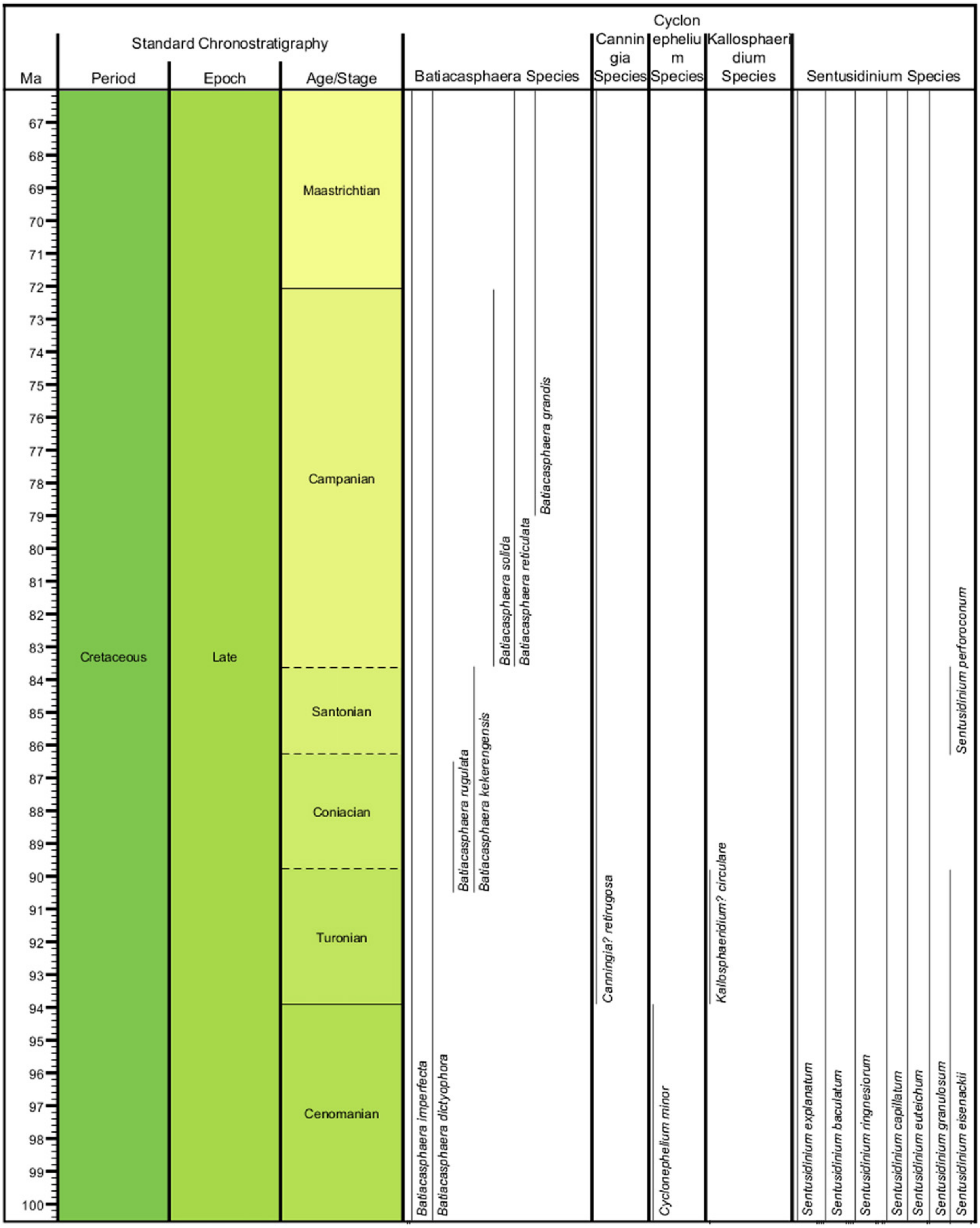

Fig. 3 (*continued*).

Batiacasphaera deheinzelinii Louwye, 1999, considered a taxonomic junior synonym of *Sentusidinium hirsutum* (Stover, 1977) comb. nov. herein.

Batiacasphaera euteiches (Davey, 1969a) Davey, 1979, to *Sentusidinium* as *Sentusidinium euteichum* (Davey, 1969a) comb. nov. herein.

Batiacasphaera explanata (Bujak in Bujak et al., 1980) Islam, 1983, to *Sentusidinium* as *Sentusidinium explanatum* (Bujak in Bujak et al., 1980) herein.

Batiacasphaera extravermiculata Chenglong, 1999, to *Sentusidinium* as *Sentusidinium extravermiculatum* (Chenglong, 1999) comb. nov. herein.

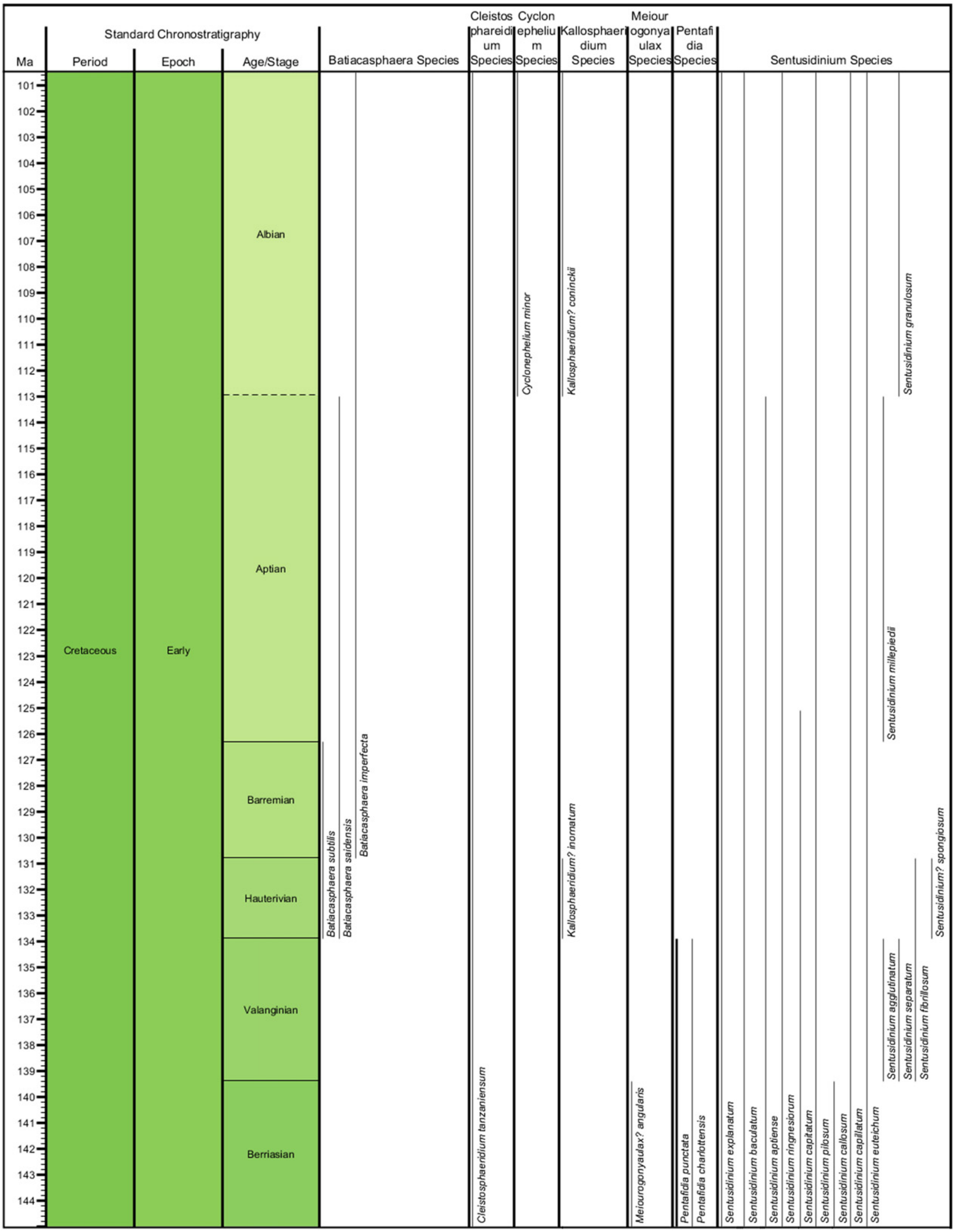

Fig. 3 (*continued*).

Batiacasphaera floralis He et al., 2005, considered a taxonomic junior synonym of *Sentusidinium ringnesiorum* (Manum and Cookson, 1964) comb. nov. herein.

Batiacasphaera gemmata Head et al., 1989, considered a taxonomic junior synonym of *Sentusidinium bellulum* (Jiabo, 1978) Jinli et al., 1997.

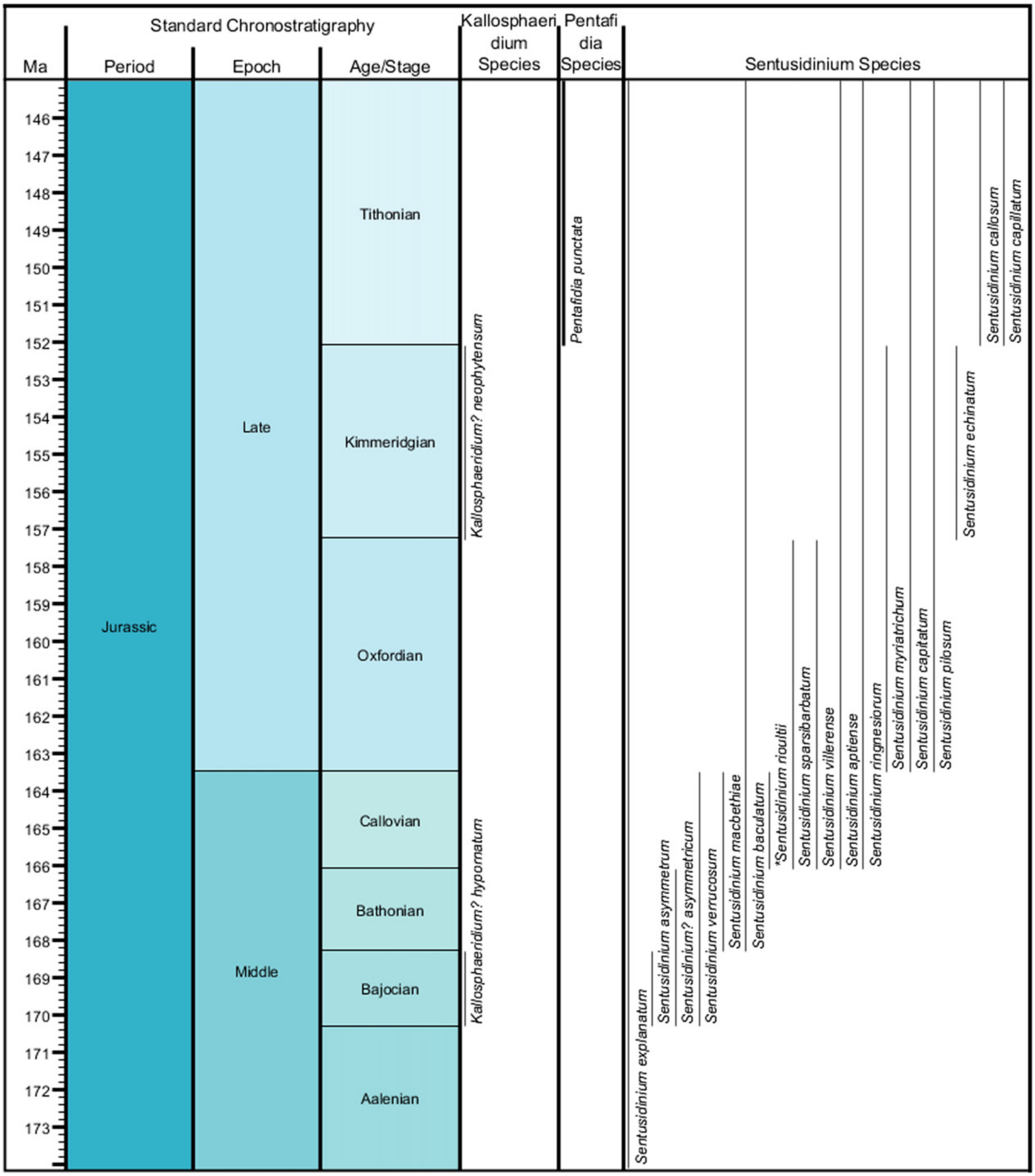

Fig. 3 (*continued*).

Batiacasphaera granofoveolata Pan Zhaoren in Jinli et al., 1997 ex He, considered a taxonomic junior synonym of *Sentusidinium ringnesiorum* (Manum and Cookson, 1964) comb. nov. herein.

Batiacasphaera granospina He, 1991, considered a taxonomic junior synonym of *Sentusidinium granulosum* (Cookson and Eisenack, 1974) comb. nov. herein.

Batiacasphaera granulata Chenglong, 1999, considered a taxonomic junior synonym of *Sentusidinium extravermiculatum* (Chenglong, 1999) comb. nov. herein.

Batiacasphaera granulosa (Cookson and Eisenack, 1974) Jansonius, 1989, to *Sentusidinium* as *Sentusidinium granulosum* (Cookson and Eisenack, 1974) comb. nov. herein.

Batiacasphaera henanensis He Chengquan, Zhu Shenzhao and Jin Guangxing in He et al., 1989, considered a taxonomic junior synonym of *Sentusidinium ringnesiorum* (Manum and Cookson, 1964) comb. nov. herein.

Batiacasphaera hirsuta Stover, 1977, to *Sentusidinium* as *Sentusidinium hirsutum* (Stover, 1977) comb. nov. herein.

Batiacasphaera hystricosa Mao Shaozhi and Norris, 1988, considered a taxonomic junior synonym of *Sentusidinium baculatum* (Dodekova, 1975) Sarjeant and Stover, 1978.

Batiacasphaera? *kutharensis* (Khanna and Singh, 1981) Lentin and Williams, 1993, considered a taxonomic junior synonym of *Sentusidinium bifidum* (Jiabo, 1978) He et al., 1989.

Batiacasphaera laevigata (Smelror, 1988) Feist-Burkhardt and Monteil, 1997, considered a taxonomic junior synonym of *Sentusidinium explanatum* (Bujak in Bujak et al., 1980) comb. nov. herein.

Batiacasphaera macrogranulata Morgan, 1975, considered a taxonomic junior synonym of *Sentusidinium ringnesiorum* (Manum and Cookson, 1964) comb. nov. herein.

Batiacasphaera macropyla He et al., 2009, considered a taxonomic junior synonym of *Sentusidinium ringnesiorum* (Manum and Cookson, 1964) comb. nov. herein.

Batiacasphaera mica Harding, 1990, considered a taxonomic junior synonym of *Sentusidinium ringnesiorum* (Manum and Cookson, 1964) comb. nov. herein.

Batiacasphaera micropapillata Stover, 1977, to *Sentusidinium* as *Sentusidinium micropapillatum* (Stover, 1977) comb. nov. herein.

Batiacasphaera minuta (Matsuoka, 1983) Matsuoka and Head, 1992, considered a taxonomic junior synonym of *Sentusidinium micropapillatum* (Stover, 1977) comb. nov. herein.

Batiacasphaera norvickii (Burger, 1980a) Lentin and Williams, 1989, considered a taxonomic junior synonym of *Sentusidinium ringnesiorum* (Manum and Cookson, 1964) comb. nov. herein.

Batiacasphaera oblongata Jinli et al., 1997 ex He et al., 2009, considered a taxonomic junior synonym of *Batiacasphaera retirugosa* Jinli et al., 1997 ex He et al., 2009.

Batiacasphaera oligacantha He Chengquan, Zhu Shenzhao and Jin Guangxing in He et al., 1989, considered a taxonomic junior synonym of *Sentusidinium baculatum* (Dodekova, 1975) Sarjeant and Stover, 1978.

Batiacasphaera ovata Backhouse, 1987, considered a taxonomic junior synonym of *Batiacasphaera subtilis* Stover and Helby, 1987b.

Batiacasphaera rifensis Slimani et al., 2008, considered a taxonomic junior synonym of *Batiacasphaera imperfecta* Stover and Helby, 1987a.

Batiacasphaera? *sahii* (Khanna and Singh, 1981) Lentin and Williams, 1993, to *Sentusidinium* as *Sentusidinium sahii* (Khanna and Singh, 1981) comb. nov. herein.

Batiacasphaera setulosa Chenglong, 1999, to *Sentusidinium* as *Sentusidinium setulosum* (Chenglong, 1999) comb. nov. herein.

Batiacasphaera setulosa var. *minima* Chenglong, 1999, considered a taxonomic junior synonym of *Sentusidinium setulosum* Chenglong, 1999 comb. nov. herein.

Batiacasphaera? *simlaensis* (Khanna and Singh, 1981) Lentin and Williams, 1993, considered a taxonomic junior synonym of *Sentusidinium minus* (Jiabo, 1978) He et al., 1989.

Batiacasphaera sinensis Lentin and Williams, 1989 to *Sentusidinium* as *Sentusidinium minus* (Jiabo, 1978) He et al., 1989.

Batiacasphaera sparsa He, 1991, considered a taxonomic junior synonym of *Sentusidinium ringnesiorum* (Manum and Cookson, 1964) comb. nov. herein.

Batiacasphaera spumosa (Brideaux, 1977) Below, 1981, considered a taxonomic junior synonym of *Sentusidinium capillatum* (Davey, 1975) Lentin and Williams, 1981.

Batiacasphaera tuberculata He, 1991, considered a taxonomic junior synonym of *Sentusidinium ringnesiorum* (Manum and Cookson, 1964) comb. nov. herein.

Batiacasphaera verrucatum Jinli et al., 1997 ex He et al., 2009, considered a taxonomic junior synonym of *Sentusidinium bellulum* (Jiabo, 1978) Jinli et al., 1997.

Batiacasphaera xinjiangensis He, 1991, considered a taxonomic junior synonym of *Sentusidinium ringnesiorum* (Manum and Cookson, 1964) comb. nov. herein.

Batiacasphaera imperfecta Stover and Helby, 1987b (Plate II, 5–6)

1987b *Batiacasphaera imperfecta* Stover and Helby, p. 261–262, fig. 2A–O.

2008 *Batiacasphaera rifensis* Slimani et al., p. 338–340, fig. 9A–F.

Remarks: *Batiacasphaera imperfecta* and *Batiacasphaera rifensis* are both subspherical to elongate, small to intermediate, ovoidal cysts with a thick wall. Both are described from the Cretaceous as having an imperfect or irregular reticulum. Therefore, we consider *Batiacasphaera imperfecta* to be the taxonomic senior synonym of *Batiacasphaera rifensis*.

Batiacasphaera microreticulata Chenglong, 1999 (Plate II, 7–8)

1999 *Batiacasphaera microreticulata* Chenglong, p. 180–182, figs. 66–69, 82–83.

1999 *Batiacasphaera microreticulata* var. *microreticulata* (autonym). Chenglong, p. 180–181, figs. 66–67.

1999 *Batiacasphaera microreticulata* var. *minima* Chenglong, p. 182, figs. 82–83.

Remarks: Chenglong (1999) distinguished two varieties of *Batiacasphaera microreticulata*. *Batiacasphaera microreticulata* var. *minima* is slightly smaller than *Batiacasphaera microreticulata* var. *microreticulata* and has a somewhat thinner autophragm. We consider that these minor differences are insufficient to justify differentiation and hence synonymise the two varieties under the species.

Batiacasphaera reticulata Davey, 1969b (Plate II, 9)

1969b *Chytroeisphaeridia reticulata* Davey, p. 14, pl. 4, figs. 3–4, 6.

1978 *Fromea reticulata* (Davey, 1969b) Stover and Evitt, p. 48.

1979d *Batiacasphaera reticulata* (Davey, 1969b) Davey, p. 217.

1997 *Batiacasphaera*? *reticulata* (Davey, 1969b) Mohr and Mao Shaozhi, p. 58.

Remarks: We retain this species in *Batiacasphaera* without question. Mohr and Mao Shaozhi (1997, p. 58–60) questioned the generic assignment because they interpreted the type material as having two wall layers. However, it seems clear to us that this species merely has a thick autophragm, as originally interpreted by Davey (1969b, p. 14).

Batiacasphaera retirugosa Jinli et al., 1997 ex He et al., 2009 (Plate II, 10)

1997 *Batiacasphaera retirugosa* Jinli et al., p. 48–49, pl. 42, fig. 3; name not validly published, as there was no English or Latin description.

1997 *Batiacasphaera oblongata* Jinli et al., p. 49, pl. 42, fig. 6; name not validly published, as there was no English or Latin description.

2009 *Batiacasphaera retirugosa* Jinli et al., 1997 ex He et al., p. 649.

2009 *Batiacasphaera oblongata* Jinli et al., 1997 ex He et al., p. 649.

Remarks: *Batiacasphaera retirugosa* and *Batiacasphaera oblongata* are both subspherical to elongate-ovoidal cysts with a thin wall and a fine reticulum. They are both intermediate in size, and from the Middle to Late Eocene of China (Fig. 3b). We thus consider *Batiacasphaera oblongata* to be conspecific with *Batiacasphaera retirugosa*.

Batiacasphaera subtilis Stover and Helby, 1987b (Plate II, 15–16)

1987 *Batiacasphaera subtilis* Stover and Helby, p. 228–230, figs. 2A–F, 3A–L.

1987 *Batiacasphaera ovata* Backhouse, 1987, p. 215, figs. D–F.

Remarks: *Batiacasphaera ovata* and *Batiacasphaera subtilis* were both described from the Early Cretaceous (Hauterivian to Barremian) of Western Australia in the same volume (Jell, 1987), by Stover and Helby (1987) and Backhouse (1987) respectively. Both taxa circumscribe cysts that are elongate-ovoidal with dark, thick walls, the autophragm being thickest in the equatorial region; and they are similar in size and stratigraphical range. Accordingly, we consider them to be conspecific. Although *Batiacasphaera ovata* precedes *Batiacasphaera subtilis* in print order in Jell (1987), nomenclatural priority does not apply as both were published simultaneously. We consider *Batiacasphaera subtilis* to have been more fully described and illustrated and so give it precedence.

Genus *Canningia* Cookson and Eisenack, 1960

Type: *Canningia reticulata* Cookson and Eisenack, 1960.

Canningia? retirugosa He, 1991

1991 *Canningia retirugosa* He, p. 56, pl. 8, fig. 11.

2009 *Kallosphaeridium retirugosa* (He, 1991) He et al., 2009, p. 164.

Remarks: This species was transferred to *Kallosphaeridium* by He et al. (2009). Although the morphology of the holotype is unclear, it does not seem to accord with *Kallosphaeridium*, and so we retain the species provisionally in *Canningia*.

Genus *Cleistosphaeridium* Davey et al., 1966

Type: *Cleistosphaeridium diversispinosum* Davey et al., 1966.

Cleistosphaeridium tanzaniense (Msaky, 2011) comb. nov.

2011 *Sentusidinium tanzaniensis* Msaky, p. 110–111, pl. 7, figs. 1–3.

Remarks: This species from the earliest Cretaceous of offshore Tanzania has an apical archaeopyle, a subspherical to elongate-oval outline, and is covered in numerous nontabular processes. The distal ends of some processes appear to be dolabrate, i.e. have asymmetrical bifurcations, a characteristic of *Cleistosphaeridium* (Eaton et al., 2001), and thus we transfer this species to that genus.

Genus *Cyclonephelium* Deflandre and Cookson, 1955

Type: *Cyclonephelium compactum* Deflandre and Cookson, 1955.

Cyclonephelium minor (Cookson and Hughes, 1964) comb. nov.

Basionym: *Canningia minor* Cookson and Hughes, 1964.

1964 *Canningia minor* Cookson and Hughes, p. 43, pl. 8, figs. 1–3, 5.

1978 *Canningia*? *minor* subsp. *minor* Cookson and Hughes, 1964. Stover and Evitt, p. 25.

Plate I. 1–9. *Batiacasphaera bergenensis* Schreck and Matthiessen, 2014. The holotype is from the Middle Miocene (Serravallian) of the Eastern Iceland Plateau (Schreck and Matthiessen, 2014). The specimen is in slightly oblique apical view; images 1 to 9 represent a succession of photomicrographs from high to low focus respectively. The scale bar represents 20 µm.

10. *Batiacasphaera cassiculus* Wilson, 1988. The holotype is from the Middle Eocene (Porangan) of Waipawa Section, Hawkes Bay, New Zealand (Wilson, 1988). The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 µm.

11-12 *Batiacasphaera compta* Drugg, 1970. The holotype is from the Late Eocene Yazoo Formation, Mississippi, USA. The specimen is in dorso-ventral view; image 11 is in high focus, showing ornamentation, image 12 is in low focus showing the operculum. The scale bar represents 20 µm.

13. *Batiacasphaera dictyophora* Ruiqi et al., 1992. The holotype is from the Late Cretaceous of China. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 µm.

14-20. *Batiacasphaera edwardsiae* Louwye et al., 2008. The holotype is from the Middle Miocene (Serravallian) of the Porcupine Basin, offshore southwestern Ireland. The specimen is in slightly oblique apical view; images 14 to 16 represent a succession of photomicrographs from low to high focus respectively (image 16 is rotated 90° clockwise relative to images 14 and 15); images 17 and 18 show the internal and external view of the archaeopyle respectively; images 19 and 20 show the ornamentation. The scale bar represents 10 µm.

Plate II. 1–2. *Batiacasphaera cooperi* Hannah et al., 1998. The holotype is from the Miocene of McMurdo Sound, Antarctica. The specimen is in slightly oblique dorso-ventral view; 1 and 2 are in low and high focus respectively. The scale bar represents 20 µm. (see on page 72)

3. *Batiacasphaera grandis* Roncaglia et al., 1999. The holotype is from the Late Cretaceous (Hamurian) of Birch Hollow, northern Canterbury, New Zealand. The specimen is upright, and is in dorso-ventral view. The scale bar represents 30 µm.

4. *Batiacasphaera kekerengensis* Schiøler and Wilson, 1998. The holotype is from the Late Cretaceous (Teratan–Hamurian) of Paton Formation, south Marlborough, New Zealand. The specimen is upright, and is in dorso-ventral view. The scale bar represents 30 µm.

5-6. *Batiacasphaera imperfecta* Stover and Helby, 1987a. The holotype is from the Early Cretaceous (Barremian–Early Aptian) of the Houtman–1 well, Western Australia. The specimen is in slightly oblique apical view; 5 and 6 are in high and low focus respectively. The scale bar represents 20 µm.

7-8. *Batiacasphaera microreticulata* Chenglong, 1999. The holotype is from the Eocene (OK-1 well) of Taiwan. The specimen is upright, and is in dorso-ventral view; 7 and 8 are in high and low focus respectively. The scale bar represents 10 µm.

9. *Batiacasphaera reticulata* Davey, 1969b. The holotype is from the Late Cretaceous (Campanian/Maastrichtian) of Natal, South Africa. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 µm.

10. *Batiacasphaera retirugosa* Xu et al., 1997 ex He et al., 2009. The holotype is from the Middle to Late Eocene of China. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 µm.

11 *Batiacasphaera rugulata* Schiøler and Wilson, 1998. The holotype is from the Late Cretaceous of Marlborough, New Zealand. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 µm.

12. *Batiacasphaera solida* Slimani, 2003. The holotype is from the Late Cretaceous of Turnhout, Belgium. The specimen is upright, and is in dorso-ventral view. The scale bar represents 30 µm.

13-14. *Batiacasphaera saidensis* Below, 1981. The holotype is from the Early Cretaceous of southwest Morocco. The specimen is in slightly oblique apical view; 13 and 14 are in high and low focus respectively. The scale bar represents 20 µm.

15-16. *Batiacasphaera subtilis* Stover and Helby, 1987. The holotype is from the Early Cretaceous of Western Australia. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 µm.

17. *Batiacasphaera sphaerica* Stover, 1977. The holotype is from the Early Miocene of the Blake Plateau, Atlantic Ocean. The specimen is in an oblique apical view. The scale bar represents 20 µm.

18-20. *Kallosphaeridium nigeriense* Jan du Chêne et al., 1985. The holotype is from the Late Paleocene to Early Eocene (Thanetian to Ypresian) of Nigeria. The specimen is upright, and is in dorso-ventral view; images 18 to 20 represent a series of photomicrographs from high to low focus respectively. The scale bar represents 20 µm.

Plate III. 1–2. *Kallosphaeridium biornatum* Stover, 1977. The holotype is from the Early Oligocene of the Blake Plateau, Atlantic Ocean. The specimen is upright, and is in dorso-ventral view; images 1 and 2 are in high and low focus respectively. The scale bar represents 20 µm. (see on page 73)

3-4. *Kallosphaeridium brevibarbatum* de Coninck, 1969. The holotype is from the Early Eocene of Belgium. The specimen is upright, and is in dorso-ventral view; images 3 and 4 are in high and low focus respectively. The scale bar represents 20 µm.

5-6. *Kallosphaeridium capulatum* Stover, 1977. The holotype is from the Middle to Late Oligocene of the Blake Plateau, Atlantic Ocean. The specimen is upright, and is in dorso-ventral view; images 5 and 6 are in high and low focus respectively. The scale bar represents 20 µm.

7-8. *Kallosphaeridium yorubaense* Jan du Chêne and Adediran, 1985. The holotype is from the Late Paleocene to Early Eocene of Nigeria. The specimen is upright, and is in dorso-ventral view; image 8 shows details of the operculum. The scale bar represents, 20 µm in image 7 and 10 µm in image 8.

9-10. *Kallosphaeridium parvum* Jan du Chêne, 1988. The holotype is from the Early Paleocene of Senegal. The specimen is upright, and is in dorso-ventral view; images 10 and 11 are in high and low focus respectively. The scale bar represents 20 µm.

11. *Kallosphaeridium*? *circulare* (Cookson and Eisenack, 1971) Helby, 1987. The holotype is from the Middle Cretaceous of Western Australia. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 µm.

12. *Kallosphaeridium*? *hypornatum* Prauss, 1989. The holotype is from the Middle Jurassic of northwestern Germany. The specimen is upright, and is in lateral view. The scale bar represents 20 µm.

13-14. *Kallosphaeridium*? *coninckii* Burger, 1980a. The holotype is from the Early Cretaceous of the Surat Basin, Australia. The specimen is upright, and is in lateral view; image 14 is a line drawing of the photomicrograph displayed in figure 13. The scale bar represents 20 µm.

15-16. *Kallosphaeridium*? *inornatum* Batten and Lister, 1988. The holotype is from the Early Cretaceous of Sussex, UK. The specimen is upright, and is in dorso-ventral view; images 15 and 16 are in high and low focus respectively. The scale bar represents 20 µm.

17. *Kallosphaeridium*? *neophytensum* (Ioannides et al., 1977) comb. nov. herein. The holotype is from the Late Jurassic of Dorset, UK. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 µm.

18-20. *Kallosphaeridium*? *orchiesense* de Coninck, 1975. The holotype is from the Early Eocene of Belgium. The specimen is upright, and is in dorso-ventral view; images 1 to 3 represent a series of photomicrographs from low to high focus respectively. The scale bar represents 20 µm.

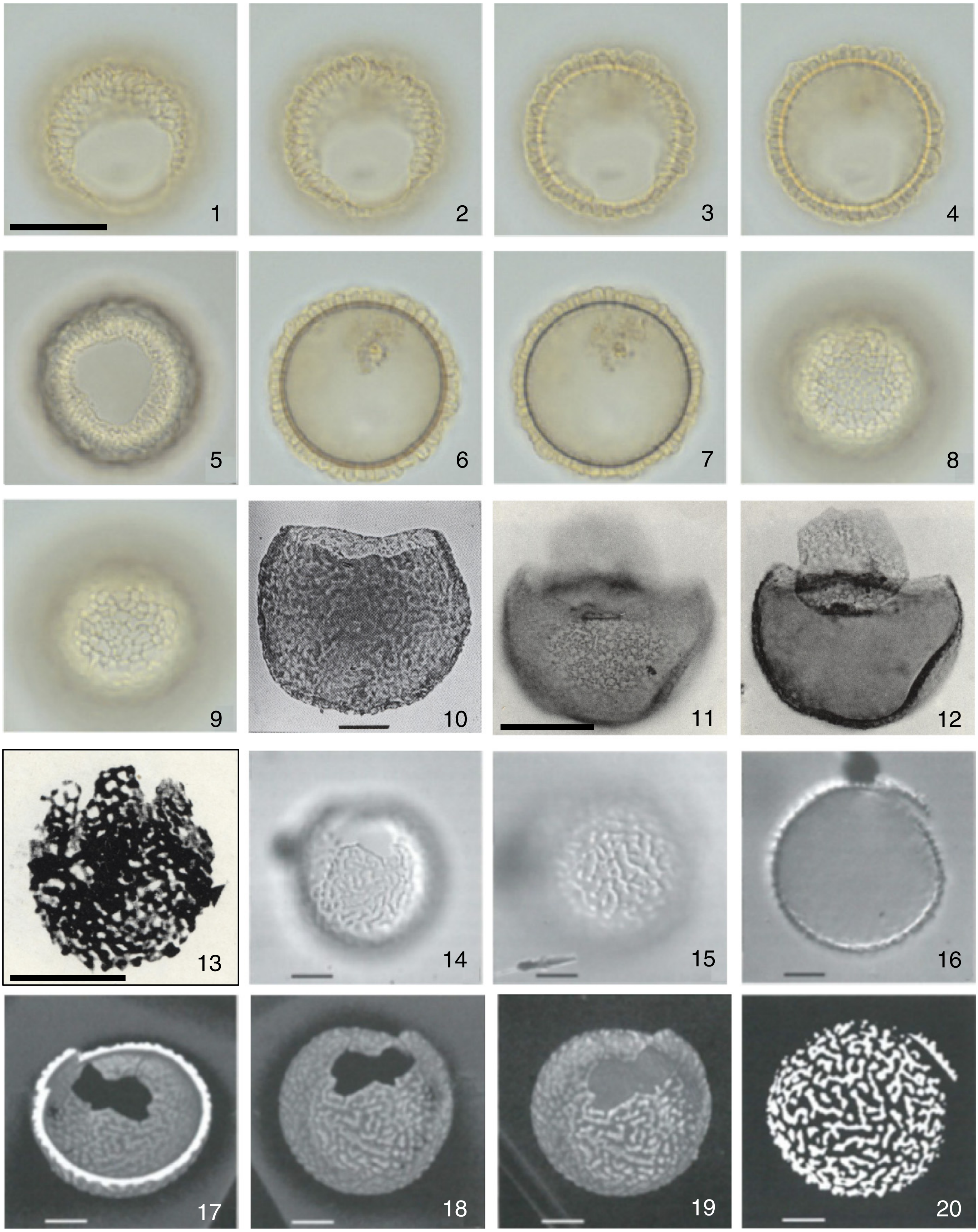

Plate I.

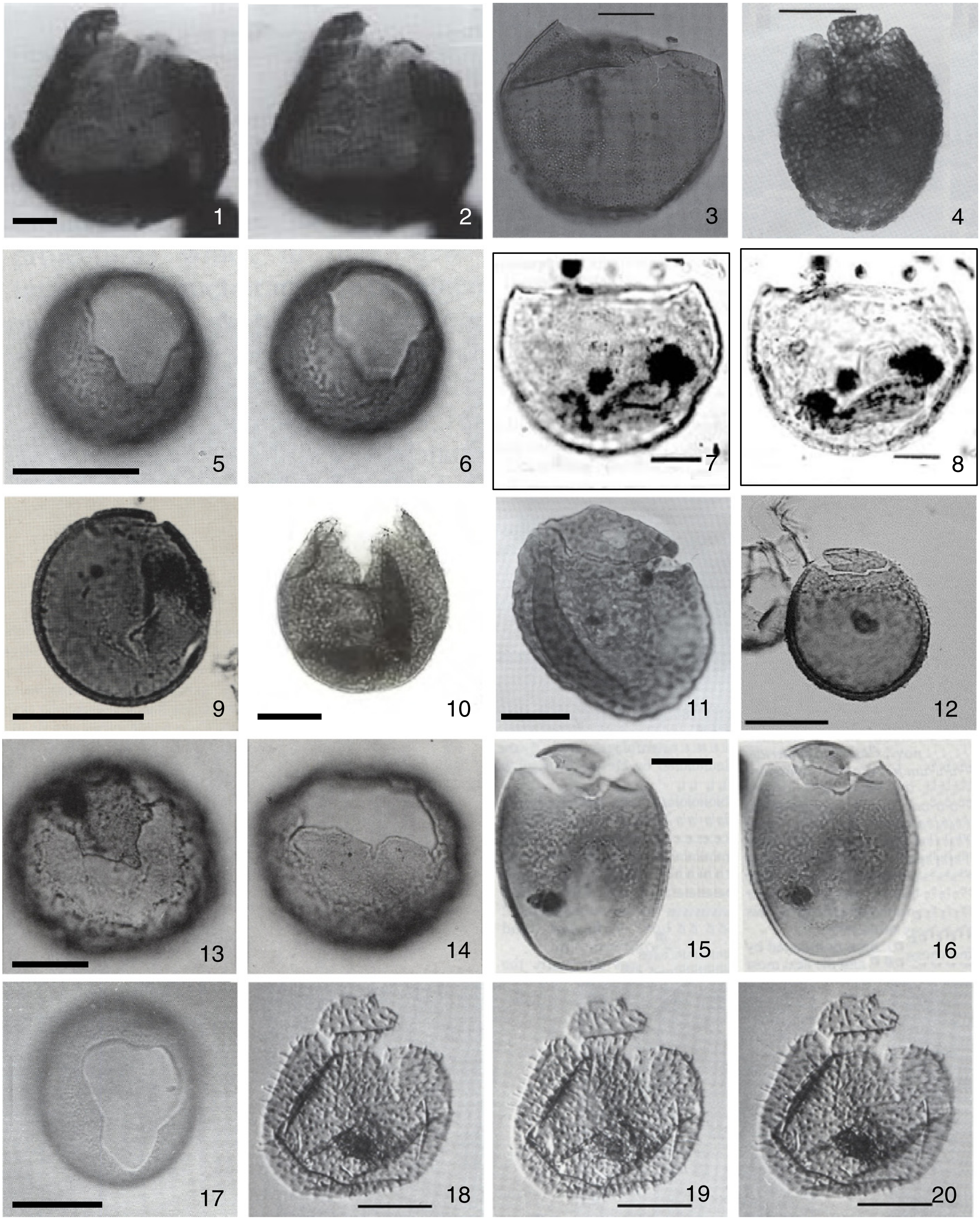

Plate II. *(caption on page 70).*

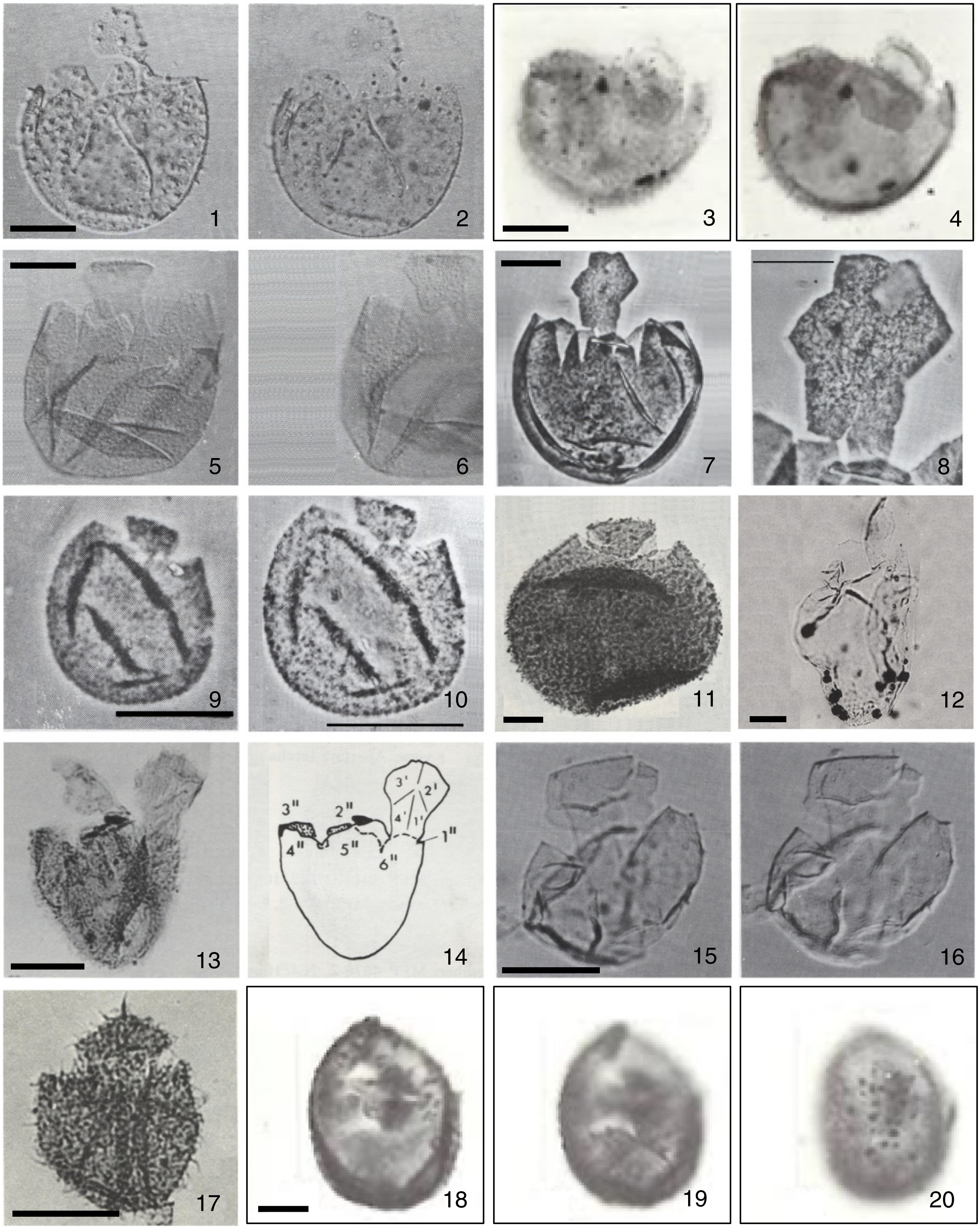

Plate III. *(caption on page 70).*

Plate IV. 1–3. *Sentusidinium agglutinatum* (McIntyre and Brideaux, 1980) comb. nov. herein. The holotype is from the Early Cretaceous of the Northwest Territories, Canada. The specimen is upright, and is in dorso-ventral view; images 5 to 7 represent a series of photomicrographs from high to low focus respectively. The scale bar represents 20 μm.

4. *Sentusidinium asymmetrum* (Fenton et al., 1980) Lentin and Williams, 1981. The holotype is from the Middle Jurassic of Dorset, UK. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

5-7. *Sentusidinium aptiense* (Burger, 1980a) Burger, 1980b. The holotype is from the Early Cretaceous of Western Australia. The specimen is upright, and is in dorso-ventral view; images 5 to 7 represent a series of photomicrographs depicting details of cyst ornamentation. The scale bar represents 20 μm in image 5, and 10 μm in images 6 and 7.

8. *Sentusidinium bellulum* (Jiabo, 1978) Xu et al., 1997. The holotype is from the Eocene of Bohai Coast, China. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

9-11. *Sentusidinium baculatum* (Dodekova, 1975) Sarjeant and Stover, 1978. The holotype is from the Middle Jurassic of northeastern Bulgaria. The specimen is upright, and is in dorso-ventral view; images 9 to 11 represent a series of photomicrographs from high to low focus respectively. The scale bar represents 20 μm.

12. *Sentusidinium bifidum* (Jiabo, 1978) He et al., 1989. The holotype is from the Late Eocene of China. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

13. *Sentusidinium callosum* (Dodekova, 1994) comb. nov. herein. The holotype is from the Late Jurassic to Early Cretaceous of north Bulgaria. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

14. *Sentusidinium capillatum* (Davey, 1975) Lentin and Williams, 1981. The holotype is from the Late Cretaceous of Ghana. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

15. *Sentusidinium capitatum* Cookson and Eisenack, 1960 comb. nov. herein. The holotype is from the Late Jurassic of Australia. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

16. *Sentusidinium densicomatum* (Maier, 1959) Sarjeant, 1983. The holotype is from the Middle Oligocene of Germany. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

17. *Sentusidinium echinatum* (Gitmez and Sarjeant, 1972) Sarjeant and Stover, 1978. The holotype is from the Late Jurassic of Dorset, U.K. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

18-19. *Sentusidinium eisenackii* (Boltenhagen, 1977) Fauconnier and Masure, 2004. The holotype is from the Late Cretaceous of Gabon. The specimen is upright, and is in dorso-ventral view; images 18 and 19 are in high to low focus respectively. The scale bar represents 20 μm.

20. *Sentusidinium euteichum* (Davey, 1969a) comb. nov. herein. The holotype is from the Late Cretaceous of Calais, France. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

Plate V. 1. *Sentusidinium explanatum* (Bujak in Bujak et al., 1980) comb. nov. herein. The holotype is from the Middle Eocene of the Isle of Wight, U.K. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm. (see on page 76)

2-4. *Sentusidinium extravermiculatum* (Chenglong, 1999) comb. nov. herein. The holotype is from the Eocene of Taiwan. The specimen is upright, and is in dorso-ventral view; images 2 to 4 represent a series of photomicrographs from high to low focus respectively. The scale bar represents 20 μm.

5-6. *Sentusidinium fibrillosum* Backhouse, 1988. The holotype is from the Early Cretaceous of the Perth Basin, Australia. The specimen is upright, and is in dorso-ventral view; images 5 and 6 are in high to low focus respectively. The scale bar represents 20 μm.

7. *Sentusidinium granulosum* (Cookson and Eisenack, 1974) comb. nov. herein. The holotype is from the Cretaceous of Australia. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

8. *Sentusidinium micropapillatum* (Stover, 1977) comb. nov. herein. The holotype is from the Oligocene to Early Miocene of the Blake Plateau, Atlantic Ocean. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

9-10. *Sentusidinium hirsutum* (Stover, 1977) comb. nov. herein. The holotype is from the Oligocene of the Blake Plateau, Atlantic Ocean. The specimen is upright, and is in dorso-ventral view; images 9 and 10 are in high to low focus respectively. The scale bar represents 20 μm.

11-12. *Sentusidinium macbethiae* (Mantle, 2009) comb. nov. herein. The holotype is from the Middle Jurassic of Timor Sea, Australia. The specimen is upright, and is in dorso-ventral view; images 11 and 12 are in high to low focus respectively. The scale bar represents 10 μm.

13-14. *Sentusidinium microcystum* (Bujak in Bujak et al., 1980) Islam, 1993. The holotype is from the Late Eocene of Isle of Wight, UK. The specimen is upright, and is in dorso-ventral view; images 13 and 14 are in high to low focus respectively. The scale bar represents 20 μm.

15-16. *Sentusidinium millepiedii* Fensome and Williams, 2004. The holotype is from the Early Cretaceous of Senegal basin, Africa. The specimen is upright, and is in dorso-ventral view; images 15 and 16 are in high to low focus respectively. The scale bar represents 20 μm.

17. *Sentusidinium minus* (Jiabo, 1978) He Chengquan, Zhu Shenzhao and Jin Guangxing in He et al., 1989. The holotype is from the Palaeogene of the Bohai Coast, China. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

18. *Sentusidinium myriatrichum* Fensome, 1979. The holotype is from the Late Jurassic of eastern Greenland. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

19. *Sentusidinium perforoconum* (Yun Hyesu, 1981) Islam, 1993. The holotype is from the Late Cretaceous of the USA. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

20. *Sentusidinium pilosum* (Ehrenberg, 1854) Sarjeant and Stover, 1978. The holotype is from the Late Jurassic to Early Cretaceous of Poland. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

Plate VI. 1. *Sentusidinium ringnesiorum* (Manum and Cookson, 1964) comb. nov. herein. The holotype is from the Late Cretaceous of Ellef Ringnes Island, Nunavut, Canada. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm. (see on page 77)

2. *Sentusidinium rioultii* Sarjeant, 1968. The holotype is from the Middle Jurassic of France. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

3. *Sentusidinium sahii* (Khanna and Singh, 1981) comb. nov. herein. The holotype is from the Early to Middle Eocene of the Simla Hills, India. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

4. *Sentusidinium sparsibarbatum* Erkmen and Sarjeant, 1980. The holotype is from the Middle Jurassic of Dorset, UK. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

5-6. *Sentusidinium separatum* McIntyre and Brideaux, 1980. The holotype is from the Early Cretaceous of Canada. The specimen is upright, and is in dorso-ventral view; images 5 and 6 are in high to low focus respectively. The scale bar represents 20 μm.

7-8. *Sentusidinium setulosum* (Chenglong, 1999) comb. nov. herein. The holotype is from the Eocene of Taiwan. The specimen is upright, and is in dorso-ventral view; images 7 and 8 are in high to low focus respectively. The scale bar represents 20 μm.

9. *Sentusidinium verrucosum* (Sarjeant, 1968) Sarjeant and Stover, 1978. The holotype is from the Middle to Late Jurassic of Normandy, France. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

10. *Sentusidinium villerense* (Sarjeant, 1968) Sarjeant and Stover, 1978. The holotype is from the Middle to Late Jurassic of France. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

11. *Sentusidinium*? *asymmetricum* (Pocock, 1972) comb. nov. herein. The holotype is from the Middle Jurassic of Alberta, Canada. The specimen is upright and in dorso-ventral view. The scale bar represents 20 μm.

12. *Sentusidinium*? *panshanensum* (Jiabo, 1978) Islam, 1993. The holotype is from the Palaeogene of the Bohai Coast, China. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

13. *Sentusidinium*? *reticuloidum* (Jiabo, 1978) comb. nov. herein. The holotype is from the Oligocene of the Bohai Coast, China. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

14-16. *Sentusidinium*? *spongiosum* (Batten and Lister, 1988) comb. nov. herein. The holotype is from the Early Cretaceous of Sussex, UK. The specimen is upright, and is in dorso-ventral view. The scale bar represents 20 μm.

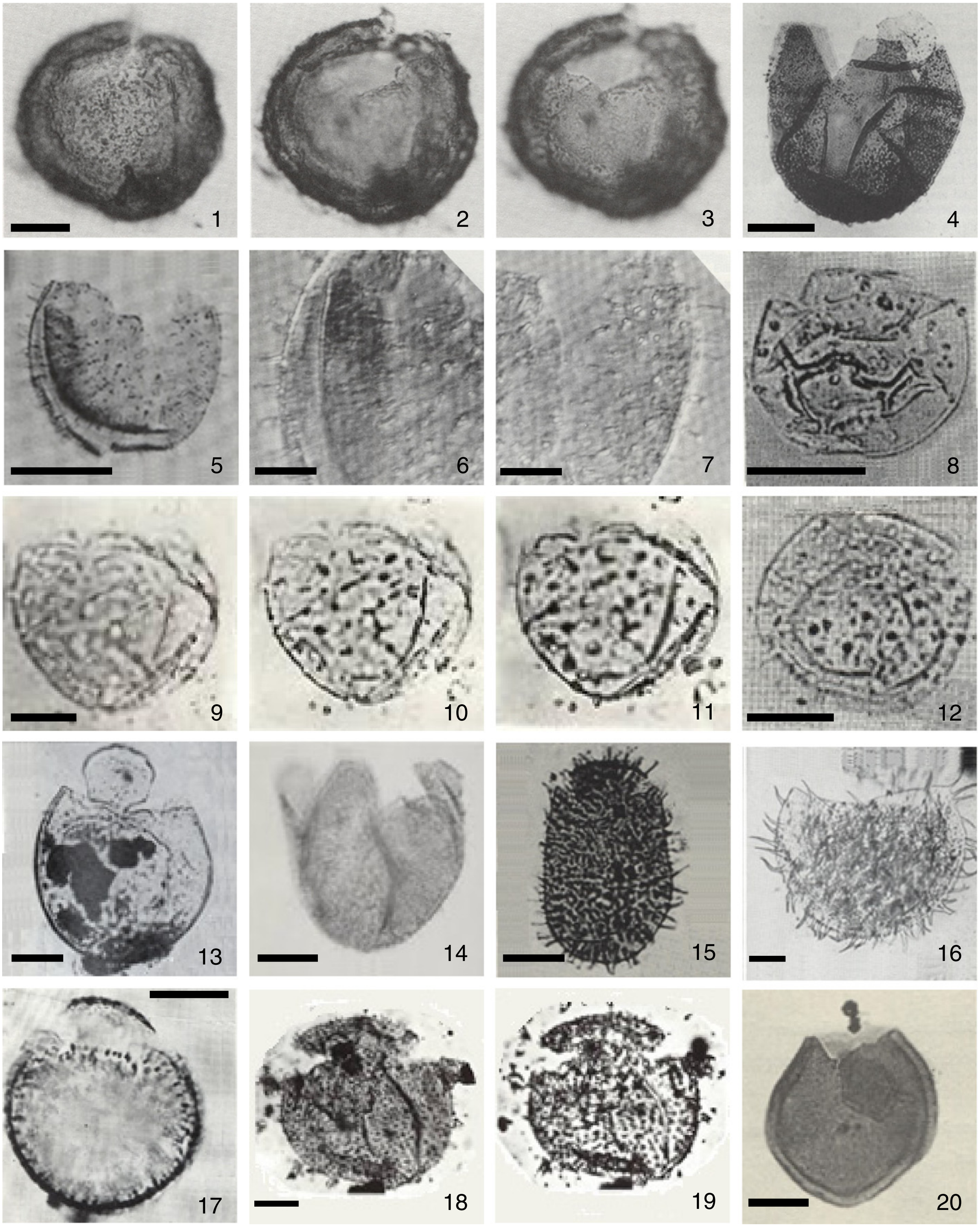

Plate IV.

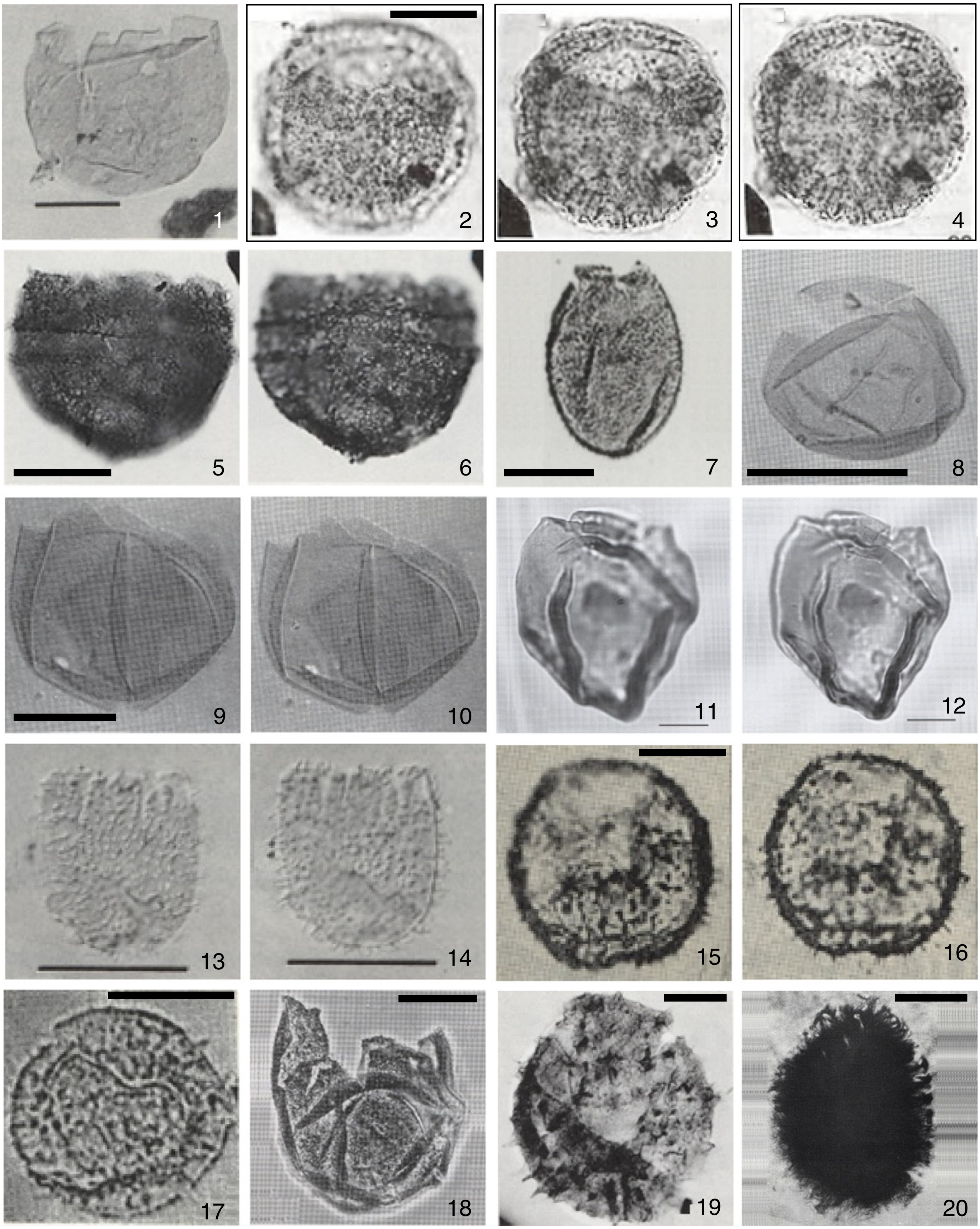

Plate V. *(caption on page 74).*

1980 *Chytroeisphaeridia minor* subsp. *minor* (Cookson and Hughes, 1964) Morgan, p. 19.

1989 *Kallosphaeridium*? *helbyi* Lentin and Williams, p. 206 subsp. *helbyi* autonym.

Remarks: This species clearly belongs in the *Cyclonephelium* complex. It is asymmetrical and lenticular, with an apical protuberance (Cookson and Hughes, 1964, pl. 8, figs. 1–3, 5). Therefore, we formally transfer this species to *Cyclonephelium*. Lentin and Williams (1989) questionably transferred this species to *Kallosphaeridium* but had to change the epithet because the name *Kallosphaeridium minor* was preoccupied. However, the epithet "*minor*" was legitimate in the basionym (*Canningia minor*) and is not preoccupied in *Cyclonephelium*, so the correct name for the new combination is *Cyclonephelium minor*.

Genus *Kallosphaeridium* de Coninck, 1969 emend. nov.

Type: *Kallosphaeridium brevibarbatum* de Coninck, 1969 emend. Jan du Chêne et al., 1985.

1969 *Kallosphaeridium* de Coninck, p. 44.

1985 *Kallosphaeridium* de Coninck, 1969 emend. Jan du Chêne et al., p. 8–9.

Original diagnosis: Kyste de dinoflagellé à peu prés globuleux, présentant un archaeopyle apical avec l'opercule attaché. Les sutures accessoires éventuelles indiquent six plaques précingulaires dont l'opercule s'est détaché. Il n'y a pas d'autres traces d'une tabulation. Des poil ornent éventuellement la coque (de Coninck, 1969, p. 44).

Translation of original diagnosis: Globular dinoflagellate cyst with an apical archaeopyle and an attached operculum. Accessory sutures

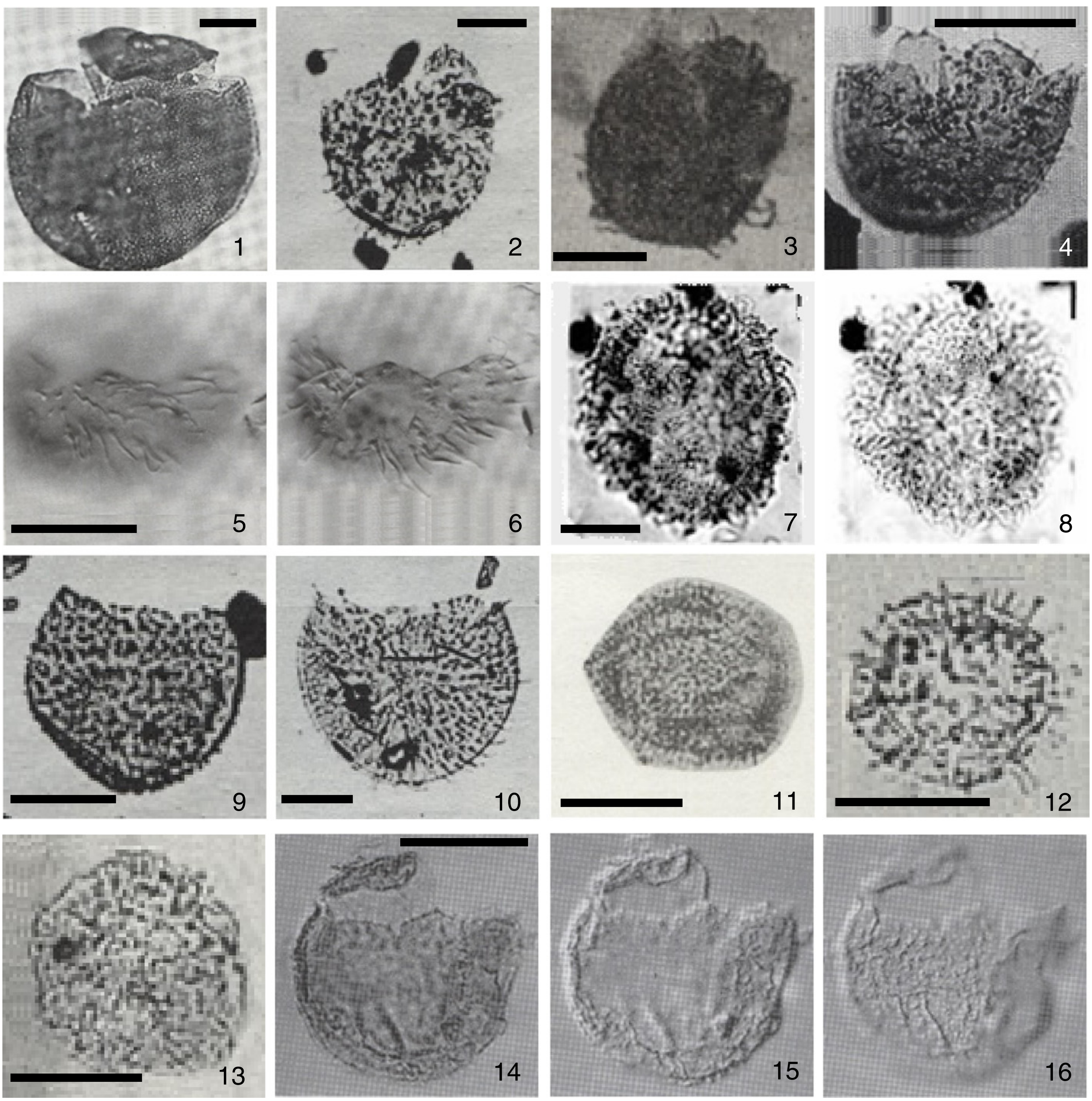

Plate VI. *(caption on page 74).*

may indicate six precingular plates, from which the operculum is detached. There are no other indications of tabulation. Hair-like processes may ornament the shell (translation by SELW and JBR).

Emended diagnosis: Acavate, subspheroidal to ovoidal, nontabulate, proximate–proximochorate cysts, psilate or bearing ornamentation of low to moderate relief. The archaeopyle is apical or combination, type $(5A)_@$ or type $(4A1I)_@$, with an attached operculum.

Emended description: Proximate to proximochorate acavate dinoflagellate cysts with a subspheroidal to ovoidal central body. The autophragm may either be psilate or bear nontabular elements of low to moderate relief. The archaeopyle involves the four standard gonyaulacalean apical plates plus an additional single dorsal plate that may or may not reach the apex. Thus the archaeopyle can be interpreted as type $(5A)_@$ or type $(4A1I)_@$; the operculum is attached ventrally, with deep accessory archaeopyle sutures between the six precingular plates typically present. The archaeopyle and operculum are relatively narrow; the overall operculum width/cyst diameter (OW/CD) is <0.5 and normally between 0.4 and 0.3.

Comments: The principal characteristics of *Kallosphaeridium* are the small, ventrally attached operculum and the five-plate archaeopyle with associated accessory archaeopyle sutures. In well-preserved specimens, the middorsal 1a/3′ plate should be readily observable from the outline of the operculum. The operculum tends to be narrow relative to the overall cyst diameter. *Kallosphaeridium* is largely speciated on the nature of its ornamentation, the most variable feature within the genus.

In terms of the standard gonyaulacalean tabulation, the five plates involved in the archaeopyle include the four standard apicals, homologues 1′ to 4′, plus a smaller dorsal plate, inserted partially or perhaps sometimes wholly between the second and third apical homologues. The additional plate may be a homologue of one of the small dorsal anterior intercalary plates (so-called K plates of Evitt, 1985; see also Fensome et al., 1993, figs. 84–85) of some gonyaulacaceans.

The emendation by Jan du Chêne et al. (1985, p. 8–9) provided more details than were given by de Coninck (1969), especially with regard to the archaeopyle and tabulation. Jan du Chêne et al. (1985, fig. 2.) discussed the overall operculum width/cyst diameter (OW/CD) in *Kallosphaeridium*. Cysts in this genus consistently have a relatively small archaeopyle and operculum; Jan du Chêne et al. (1985) noted that the OW/CD ratio is <0.5, and typically between 0.4 and 0.3.

Twenty-one species of *Kallosphaeridium* were listed by Fensome and Williams (2004, p. 375–377). Of these, we consider six to be accepted species and six to be provisional; these are included below in the species lists as well as in Table 2. All six unequivocal species of *Kallosphaeridium* are of Palaeogene age and from the North Atlantic region. Of the six provisional species, the type material of *Kallosphaeridium*? *orchiesense* is also Palaeogene (Eocene), while the other five questionable species were described from the Mesozoic of Australia and Europe (Table 2).

Fensome et al. (1993) assigned *Kallosphaeridium* questionably to the subfamily Cribroperidinioideae, but for reasons discussed under Phylogenetic affinities below, we prefer to leave its subfamilial affinity as uncertain.

Comparison: *Kallosphaeridium* is characterised by its relatively small operculum, attached ventrally, and the five-plate archaeopyle consistently with accessory archaeopyle sutures. The archaeopyle was interpreted to be apical $(5A)_@$, or a combination apical $(4A1I)_@$ by Jan du Chêne et al. (1985). The evidence for the five plate archaeopyle is the marked angulation in the middorsal area (Jan du Chêne et al., 1985, fig. 1A–B). The additional dorsal plate was interpreted as either the 1a or the 3′ plate by these authors. No other genus in the *Sentusidinium* complex has a five plate archaeopyle.

Accepted species:

Kallosphaeridium biornatum Stover, 1977 (Early Oligocene, Atlantic Ocean) Plate III, 1–2.

**Kallosphaeridium brevibarbatum* de Coninck, 1969 (Early Eocene, Belgium) Plate III, 3–4.

Kallosphaeridium capulatum Stover, 1977 (Middle–Late Oligocene, Atlantic Ocean) Plate III, 5–6.

Kallosphaeridium nigeriense Jan du Chêne et al., 1985 (Late Paleocene–Early Eocene, Nigeria) Plate II, 18–20.

Kallosphaeridium parvum Jan du Chêne, 1988 (Early Paleocene, Senegal) Plate III, 9–10.

Kallosphaeridium yorubaense Jan du Chêne and Adediran, 1985 (Late Paleocene–Early Eocene, Nigeria) Plate III, 7–8.

Provisionally accepted species:

These species are provisionally accepted because the presence of the middorsal (1a/3′) plate on the attached operculum has not been confirmed.

Kallosphaeridium? *circulare* (Cookson and Eisenack, 1971) Helby, 1987 (Late Cretaceous, Australia) Plate III, 11.

Kallosphaeridium? *coninckii* Burger, 1980a (Late Cretaceous, Australia) Plate III, 13–14.

Kallosphaeridium? *hypornatum* Prauss, 1989 (Middle Jurassic, Germany) Plate III, 12.

Kallosphaeridium? *inornatum* Batten and Lister, 1988 (non Prauss, 1989) (Early Cretaceous, UK) Plate III, 15–16.

Kallosphaeridium? *neophytensum* (Ioannides et al., 1977) comb. nov. herein (Late Jurassic, UK) Plate III, 17.

Kallosphaeridium? *orchiesense* de Coninck, 1975 (Early Eocene, Belgium) Plate III, 18–20.

Reattributed and synonymised species:

Kallosphaeridium? *aspersum* (Jiabo, 1978) Sarjeant and Stancliffe, 1994, considered a taxonomic junior synonym of *Sentusidinium*? *reticuloidum* (Jiabo, 1978) comb. nov. herein.

Kallosphaeridium callosum Dodekova, 1994, to *Sentusidinium* as *Sentusidinium callosum* (Dodekova, 1994) comb. nov. herein.

Kallosphaeridium dolomiticum Torricelli, 2000, considered a taxonomic junior synonym of *Sentusidinium aptiense* (Burger, 1980a) Burger, 1980b.

Kallosphaeridium? *granulatum* (Norvick, 1976) Stover and Evitt, 1978, considered a taxonomic junior synonym of *Sentusidinium ringnesiorum* (Manum and Cookson, 1964) comb. nov., herein.

Kallosphaeridium? *helbyi* Lentin and Williams, 1989, to *Cyclonephelium* as *Cyclonephelium minor* Cookson and Hughes, 1964 comb. nov. herein.

Kallosphaeridium? *helbyi* Lentin and Williams, 1989 subsp. *helbyi* (autonym), now redundant.

Kallosphaeridium? *helbyi* subsp. *psilatum* (Burger, 1980a) Lentin and Williams, 1989, considered a taxonomic synonym of *Sentusidinium explanatum* (Bujak in Bujak et al., 1980) comb. nov. herein.

Kallosphaeridium jiyangense Jinli et al., 1997, considered a taxonomic junior synonym of *Sentusidinium minus* (Jiabo, 1978) He et al., 1989.

Kallosphaeridium praussii Lentin and Williams, 1993 nom subst. pro. *Kallosphaeridium inornatum* Prauss, 1989, considered a taxonomic junior synonym of *Sentusidinium explanatum* (Bujak in Bujak et al., 1980) comb. nov. herein.

Kallosphaeridium? *reticuloidum* (Jiabo, 1978) Sarjeant and Stancliffe, 1994, to *Sentusidinium* as *Sentusidinium*? *reticuloidum* (Jiabo, 1978) comb. nov. herein.

Kallosphaeridium retirugosum (He Chegquan, 1991) He Chegquan et al., 2009, retained in *Canningia*.

Kallosphaeridium? *ringnesiorum* (Manum and Cookson, 1964) Helby, 1987, to *Sentusidinium* as *Sentusidinium ringnesiorum* (Manum and Cookson, 1964) comb. nov. herein.

Kallosphaeridium? *romaense* (Burger, 1980a) Burger, 1980b, considered a taxonomic junior synonym of *Sentusidinium capillatum* (Davey, 1975) Lentin and Williams, 1981.

Kallosphaeridium? *spongiosum* Batten and Lister, 1988, to *Sentusidinium* as *Sentusidinium*? *spongiosum* (Batten and Lister, 1988) comb. nov. herein.

Kallosphaeridium? coninckii Burger, 1980a (Burger, 1980b) (Plate III, 13–14)

1980a *Membranosphaera coninckii* Burger, p. 74, pl. 26, figs. 5, 6a–b.

1980b *Kallosphaeridium coninckii* (Burger, 1980a) Burger, p. 277.

Remarks: *Kallosphaeridium*? *coninckii* was originally described from the Albian of the Surat Basin in eastern Australia by Burger (1980a), as having a subspherical outline and a dense covering of short acicular spines. We consider it to be a provisionally accepted species of *Kallosphaeridium* because, although it has an attached operculum, it lacks evidence of a fifth apical or an anterior intercalary plate in the operculum.

Kallosphaeridium hypornatum Prauss, 1989 (Plate III, 12)

1989 *Kallosphaeridium hypornatum* Prauss, p. 40–41, pl. 6, figs. 1–4; text-fig. 16.

Remarks: The ellipsoidal species *Kallosphaeridium*? *hypornatum* from the Middle Jurassic of northwest Germany (Fig. 3e) has a very distinctive antapex with baculate, rugulate, scabrate or verrucate, ornamentation, compared to the rest of the psilate autophragm. We consider this species to be provisionally accepted as a species of *Kallosphaeridium* due to the lack of evidence for a fifth apical or an anterior intercalary plate in the attached operculum.

Kallosphaeridium? neophytensum (Ioannides et al., 1977) comb. nov. herein (Plate III, 17)

Basionym: *Pilosidinium neophytensum* (Ioannides et al., 1977) Courtinat, 1989, p., 191.

1977 *Tenua neophytensa* Ioannides et al., p. 463, pl. 6, figs. 5, 8–9.

1978 *Sentusidinium*? *neophytensum* (Ioannides et al., 1977) Sarjeant and Stover, p. 50.

1989 *Pilosidinium neophytensum* (Ioannides et al., 1977) Courtinat, p. 191.

Remarks: *Kallosphaeridium*? *neophytensum*, originally described from the Kimmeridgian (Fig. 3e) of southern England, has an elongate outline with a dense covering of short processes and a prominent apical spine. As this species is not an areoligeracean, and we herein consider *Pilosidinium* to be a synonym of *Sentusidinium*, we transfer it in *Kallosphaeridium* because of its attached operculum. However, because it is not clear that a fifth plate is present in the operculum, we consider the new assignment to be provisional.

Kallosphaeridium? orchiesense de Coninck, 1975 (Plate III, 18–20)

1975 *Kallosphaeridium orchiesense* de Coninck, p. 101–102, pl. 18, figs. 15–17.

Remarks: *Kallosphaeridium*? *orchiesense* was first described from the Early Eocene (Fig. 3b) of Belgium as having a subspherical cyst with a granular autophragm surmounted by small short spines. It also has a small attached operculum, but the fifth apical or anterior intercalary plate is not visible, and so we only provisionally accept it as a species of *Kallosphaeridium*.

Genus *Meiourogonyaulax* Sarjeant, 1966

Type: *Meiourogonyaulax valensii* Sarjeant, 1966.

Meiourogonyaulax*? *angularis (Stevens and Helby, 1987) comb. nov.

1987 *Batiacasphaera angularis* Stevens and Helby, p. 165–166, figs. 2A–I, 3A–B.

Remarks: This species from the earliest Cretaceous of offshore northern Australia is highly variable in morphology. Typically, it is somewhat elongate, has equatorial bulges and is rounded heptagonal to subovoidal in dorso-ventral outline. The autophragm is variably ornamented and occasionally possesses low sutural ridges, which indicate a gonyaulacacean tabulation (Stevens and Helby, 1987, fig. 2A–I). We do not consider this species assignable to *Batiacasphaera* because it lacks a reticulate or rugulate autophragm and is angular-elongate in outline. The occurrence of rare specimens with tabulation means that this species has a greater affinity with *Meiourogonyaulax*. However, we questionably include the species in *Meiourogonyaulax* because the holotype lacks sutural ridges (Stevens and Helby, 1987, fig. 2A–B).

Genus *Pentafidia* Backhouse, 1988

Type: *Pentafidia charlottensis* Backhouse, 1988.

1988 *Pentafidia* Backhouse, p. 103–104.

Original diagnosis: Cysts subcircular to ovoid, paratabulation indicated only by archaeopyle. Autophragm smooth, punctate, or bearing fine non-tabular surface features. Archaeopyle apical, type [tA], primary and accessory archaeopyle sutures indicating 5 precingular and 4 apical paraplates (Backhouse, 1988, p. 103–104).

Comments: *Pentafidia* is an acavate, ovoid, proximate, nontabular gonyaulacalean dinoflagellate cyst with an apical archaeopyle. Therefore, it closely resembles the other genera in the *Sentusidinium* complex. It is most similar to the psilate representatives of *Sentusidinium* that were previously assigned to *Escharisphaeridia*. However, according to Backhouse (1988), *Pentafidia* has five precingular plates, inferred from the number of accessory archaeopyle sutures between these plates. This situation is extremely unusual in that almost all other gonyaulacalean genera have six precingulars (Evitt, 1985). It is possible that the number of precingular plates was misinterpreted (see Section 4), since one well-preserved specimen of *Pentafidia charlottensis* appears to have six (Backhouse, 1988, p. 37, fig. 9).

There are two species of this genus, *Pentafidia charlottensis* and *Pentafidia punctata*. Both were described from the latest Jurassic–earliest Cretaceous (Tithonian–Berriasian) of the Perth Basin, Western Australia by Backhouse (1988, fig. 35).

Accepted species:

Pentafidia charlottensis Backhouse, 1988 (latest Jurassic to earliest Cretaceous, Australia)

Pentafidia punctata Backhouse, 1988 (latest Jurassic to earliest Cretaceous, Australia)

Genus *Sentusidinium* Sarjeant and Stover, 1978 emend. nov.

Type: *Sentusidinium rioultii* (Sarjeant, 1968) Sarjeant and Stover, 1978.

1978 *Sentusidinium* Sarjeant and Stover, p. 49–50.

1980 *Escharisphaeridia* Erkmen and Sarjeant, p. 62–63.

1989 *Sentusidinium* Sarjeant and Stover, 1978, emend. Courtinat, p. 192.

1989 *Barbatacysta* Courtinat, p. 185.

1989 *Pilosidinium* Courtinat, p. 190.

Original diagnosis: Proximate to proximo-chorate cysts, subspherical to ellipsoidal; wall single-layered or apparently so, and bearing short, usually evenly distributed nontabular projections such as coarse granulae, tuberculae, verrucae, baculae, or spines with blunt, acuminate, capitate or branched tips. These surface features are generally isolate, but some adjacent projections may have confluent bases and/or interconnected tips. The length of the projections is consistently less than one-half, and typically less than one-third, of the shortest diameter of the cyst. Paratabulation is indicated mainly by the type A apical archaeopyle, whose principal suture is generally zigzag (although the angulation may not be readily apparent on uncompressed specimens). Short, longitudinally directed accessory archaeopyle sutures are frequently present, their positions denoting the anterior boundaries between precingular paraplates. The operculum is free, its constituent paraplates not differentiated. An equatorial alignment of some projections, delimiting a lightly ornamented or unornamented paracingulum, may sometimes be observed; but this is usually inconspicuous and may not be developed. Other indications of paratabulation are lacking. Overall size is generally <100 μm (Sarjeant and Stover, 1978, p. 49–50).

Table 1
Accepted species for *Batiacasphaera*. * denotes the type. Size guide S < 50 µm, I 50 > 100 µm, L > 100 µm (Evitt, 1978, p. 57).

Species name	Author(s)	Original holotype	Defining features	Size (S, I, L)	Original publication age	Location	Plate (herein)
Batiacasphaera bergenensis	Schreck and Matthiessen, 2014	Plate 1, 1–9	Subspherical, thick wall, pronounced irregular reticulation.	S-I	Early to Middle Miocene	Eastern Iceland Plateau	Plate I, 1–9
Batiacasphaera cassiculus	Wilson, 1988	Plate 2, 5	Subspherical, thick wall, reticulation.	I	Middle Eocene	Hawkes Bay, New Zealand	Plate I, 10
**Batiacasphaera compta*	Drugg, 1970	Figures 6A–B	Subspherical, thin wall and fine reticulation.	I	Late Eocene	Alabama, USA	Plate I, 11–12
Batiacasphaera cooperi	Hannah et al., 1998	Figures 4J–K	Subspherical, dense reticulation.	I	Miocene	McMurdo Sound, Antarctica	Plate II, 1–2
Batiacasphaera dictyophora	Gao Ruiqi et al., 1992	Plate 1, 4	Subspherical, large coarse reticulation.	S	Late Cretaceous	China	Plate I, 13
Batiacasphaera edwardsiae	Louwye et al., 2008	Plate 1, 1–7	Subspherical, thin wall, irregular rugulation to microreticulation.	I	Middle Miocene	Porcupine Basin, Southwest Ireland	Plate I, 14–20
Batiacasphaera grandis	Roncaglia et al., 1999	Figure 18, no. 1	Large size, uniform microreticulation.	I-L	Late Cretaceous	Birch Hollow, New Zealand	Plate II, 3
Batiacasphaera imperfecta	Stover and Helby, 1987a, 1987b	Figures 2A–B	Elongate, thick wall, imperfect reticulation.	S-I	Early Cretaceous	Western Australia	Plate II, 5–6
Batiacasphaera kekerengensis	Schiøler and Wilson, 1998	Plate 17, 2	Elongate, thick wall and uniform reticulation.	I	Late Cretaceous	Marlborough, New Zealand	Plate II, 4
Batiacasphaera microreticulata	Chenglong, 1999	Figures 66–67	Subspherical, thick wall, microreticulation.	I	Eocene	Taiwan	Plate II, 7–8
Batiacasphaera reticulata	Davey, 1969b	Plate 4, 3	Elongate, thick wall, microreticulation.	S	Late Cretaceous	Natal, South Africa	Plate II, 9
Batiacasphaera retirugosa	Jinli et al., 1997; ex He et al., 2009	Plate 42, 6	Subspherical to ovoidal, thin wall and a fine reticulation.	I	Middle to Late Eocene	China	Plate II, 10
Batiacasphaera rugulata	Schiøler and Wilson, 1998	Plate 6, 11	Subspherical, coarse irregular reticulation.	I	Late Cretaceous	Marlborough, New Zealand	Plate II, 11
Batiacasphaera saidensis	Below, 1981	Plate 10, 2a–b, text-15	Subspherical, thick wall, reticulate.	S-I	Early Cretaceous	Southwest, Morocco	Plate II, 13–14
Batiacasphaera solida	Slimani, 2003	Plate 1, 1	Subspherical, thick wall, fine reticulation.	I	Late Cretaceous	Turnhout, Belgium	Plate II, 12
Batiacasphaera sphaerica	Stover, 1977	Plate 1, 4	Small subspherical, fine microreticulation.	S	Early Miocene	Blake Plateau, Atlantic Ocean	Plate II, 17
Batiacasphaera subtilis	Stover and Helby, 1987a, 1987b	Figures 2A–B	Elongate, dark, thick walls at the cingulum, thinning towards the apex and antapex, fine reticulation.	I	Early Cretaceous	Western Australia	Plate II, 15–16

Emended diagnosis: Proximate to proximochorate, acavate gonyaulacacean dinoflagellate cysts with a subspheroidal to ovoidal central body. The autophragm may be psilate or bear isolated, nontabular sculptural elements that are usually of low to moderate relief and evenly distributed. Archaeopyle apical, type (tA), normally with a detached operculum; deep accessory archaeopyle sutures between the six precingular plates are typically present.

Emended description: Small to intermediate, proximate to proximochorate, acavate gonyaulacacean dinoflagellate cysts. The dorso-ventral outline subspherical, oval or elongate oval. The autophragm is variable in thickness and devoid of ornament or covered by numerous, mostly isolated nontabular sculptural elements of low to moderate relief. The ornamentation is highly variable between species: for example, the autophragm may be psilate, shagreenate, scabrate, granulate, papillate, pustulate, verrucate, gemmate, tuberculate, pilate, clavate, baculate, echinate or setose (Fig. 1). Smooth (psilate and shagreenate) forms are less common than ornamented forms. The elements are typically evenly distributed, nontabular and short. Rarely, the ornamentation may be concentrated locally. Occasionally individual elements may be proximally confluent; distal connections or trabeculae are extremely rare. Occasionally a kalyptra may be developed. The archaeopyle is apical, type (tA), with a free operculum, although in some cases the operculum does not always fully detach; accessory archaeopyle sutures between the precingular plates are typically well developed, particularly those of Late Jurassic age. The shapes of the archaeopyle and operculum and the angular principal archaeopyle suture are strongly indicative of the standard sexiform gonyaulacacean tabulation. Very rarely, the ornamentation may partially reflect and indicate the cingulum, but other indications of the tabulation are rarely if ever developed.

Comments: Sarjeant and Stover (1978, p. 49–50) derived the generic name *Sentusidinium* from the Latin *sentus*, meaning thorny. The genus was emended by Courtinat (1989, p. 192), who gave a more concise diagnosis than the original, and presented a tabulation formula. He considered that the ornament (which he considered to consist of processes) is both intratabular and sutural. In our view, sutural ornamentation in *Sentusidinium* is extremely rare; only a few species exhibit alignment of the ornamentation to indicate the cingulum (e.g. *Sentusidinium fibrillosum*). The overwhelming majority of the low-to-moderate-relief elements on cysts assigned to *Sentusidinium* are nontabular. Indeed, if tabulation is developed to any degree, assignment to another genus, such as *Meiourogonyaulax*, would be appropriate.

We regard the genera *Barbatacysta*, *Escharisphaeridia* and *Pilosidinium* to be taxonomic junior synonyms of *Sentusidinium*. The genus *Escharisphaeridia* was described by Erkmen and Sarjeant (1980) for psilate forms previously included in *Chytroeisphaeridia* that clearly have an apical archaeopyle. We consider forms of the *Sentusidinium* complex that are smooth, and do not conform to the morphologies of *Pentafidia* or *Kallosphaeridium*, to be attributable to *Sentusidinium*.

Barbatacysta was erected by Courtinat (1989, p. 185) for 'bearded cysts' with a granular or verrucate autophragm, which have conical, subconical, buccinate, tubular or evexate intratabular processes that are distally acuminate, capitate, bifurcate or foliate. Courtinat (1989, p. 190) also introduced *Pilosidinium*, distinguishing it on the presence of capitate or bifurcate conical granules or spines, which may be interconnected and/or sutural. However, our appraisal of the species in *Pilosidinium* revealed that the processes are consistently isolated and nontabular. Consequently, we consider that the generic concepts of both *Barbatacysta* and *Pilosidinium* fall within the circumscription of *Sentusidinium*.

Table 2
Accepted and provisionally accepted species for *Kallosphaeridium*. * denotes the type species. Size guide S < 50 μm, I 50 > 100 μm, L > 100 μm (Evitt, 1978, p. 57).

Species name	Author(s)	Original holotype	Defining features	Size (S, I, L)	Original publication age	Location	Plate (herein)
Accepted species							
Kallosphaeridium biornatum	Stover, 1977	Plate 1, 9–10	Subspherical, small attached operculum, with nontabular cones and short spines.	I	Early Oligocene	Blake Plateau, Atlantic Ocean	Plate III, 1–2
**Kallosphaeridium brevibarbatum*	de Coninck, 1969	Plate 13, 14–15.	Subspherical, small attached operculum, densely covered in hair-like structures.	I	Early Eocene	Belgium	Plate III, 3–4
Kallosphaeridium capulatum	Stover, 1977	Plate 1, 12–13	Subspherical, small attached operculum, with a granulate autophragm.	S-I	Mid to Late Oligocene	Blake Plateau, Atlantic Ocean	Plate III, 5–6
Kallosphaeridium nigeriense	Jan du Chêne et al., 1985	Plate 4, 1–3	Subspherical, small attached operculum, looks similar to *K. biornatum* but is more spinose.	I	Late Paleocene to Early Eocene	Nigeria	Plate II, 18–20
Kallosphaeridium parvum	Jan du Chêne, 1988	Plate 13, 7–8	Subspherical, small attached operculum, with variable ornament ranging from dense grana to coarse verrucae.	S	Early Paleocene	Senegal	Plate III, 9–10
Kallosphaeridium yorubaense	Jan du Chêne and Adediran, 1985	Plate 6, 11–12	Subspherical, small attached operculum, thin wall, with numerous dense low thin projections.	I	Late Paleocene to Early Eocene	Nigeria	Plate III, 7–8
Provisionally accepted species							
Kallosphaeridium? circulare	Cookson and Eisenack, 1971	Plate 8, 6	Large subspherical cyst, with tubercles. Small attached operculum, however, 1a plate is not visible.	I-L	Middle Cretaceous	Western Australia	Plate III, 11
Kallosphaeridium? coninckii	Burger, 1980a	Plate 26, 6a–b	Subspherical, with a dense covering of short acicular spines. Operculum attached.	S-I	Early Cretaceous	Surat Basin, Australia	Plate III, 13–14
Kallosphaeridium? hypornatum	Prauss, 1989	Plate 6, 1	Ellipsoidal, with rugulate, verrucate, baculate or scabrate ornamentation confined to the antapex. Large attached operculum.	I	Middle Jurassic	Northwest Germany	Plate III, 12
Kallosphaeridium? inornatum	Batten and Lister, 1988	Figures 3a–b	Subspherical, with psilate to scabrate ornamentation. Large attached operculum. Fresh water species.	S	Early Cretaceous	Sussex, UK	Plate III, 15–16
Kallosphaeridium? neophytensum	Ioannides et al., 1977	Plate 5, 5	Elongate, with a dense covering of short processes with a prominent apical long process.	S	Late Jurassic	Dorset, UK	Plate III, 17
Kallosphaeridium? orchiesense	de Coninck, 1975	Plate18, 15–17	Subspherical cyst with a granular autophragm surmounted by small short spines. Small attached operculum, however, 1a plate is not visible.	I	Early Eocene	Belgium	Plate III, 18–20

The synonymy of *Barbatacysta*, *Escharisphaeridia* and *Pilosidinium* with *Sentusidinium* has clearly necessitated the transfer of their constituent species into *Sentusidinium*. During the course of our taxonomic review, it became clear that many of the species in the newly expanded *Sentusidinium* are superfluous. As a consequence, 59 species are considered to be taxonomic junior synonyms of other species of *Sentusidinium*, the 38 species in *Sentusidinium* that we consider to be separate are discussed below. Of those 38, we consider that 34 belong unquestionably to *Sentusidinium* and four are problematical.

The 34 species that we include in *Sentusidinium* without question collectively have a stratigraphical range from the Jurassic to the Palaeogene (Fig. 3a–e); no exclusively Miocene species have been described. Most of the Jurassic species were described originally from Europe. However, all but one of the Cretaceous forms were described from Africa, Australia and North America; while most of the Palaeogene taxa were described from China and India.

Comparison: *Kallosphaeridium* has an attached five-plate operculum, in contrast to the usually free, more conventionally gonyaulacacean four-plate operculum of *Sentusidinium*. *Batiacasphaera* has a reticulate to rugulate ornament. *Pentafidia* apparently has five precingular plates rather than six.

Accepted species:

Sentusidinium agglutinatum (McIntyre and Brideaux, 1980) comb. nov. herein (Early Cretaceous, Canada) Plate IV, 1–3.
Sentusidinium aptiense (Burger, 1980a) Burger, 1980b (Early Cretaceous, Australia) Plate IV, 5–7.
Sentusidinium asymmetrum (Fenton et al., 1980) Lentin and Williams, 1981 (Middle Jurassic, UK) Plate IV, 4.
Sentusidinium baculatum (Dodekova, 1975) Sarjeant and Stover, 1978 (Middle Jurassic, Bulgaria) Plate IV, 9–11.
Sentusidinium bellulum (Jiabo, 1978) Jinli et al., 1997 (Eocene, China) Plate IV, 8.
Sentusidinium bifidum (Jiabo, 1978) He et al., 1989 (Late Eocene, China) Plate IV, 12.
Sentusidinium callosum (Dodekova, 1994) comb. nov. herein (Late Jurassic–Early Cretaceous, Bulgaria) Plate IV, 13.
Sentusidinium capillatum (Davey, 1975) Lentin and Williams, 1981 (Late Cretaceous, Ghana) Plate IV, 14.
Sentusidinium capitatum Cookson and Eisenack, 1960 comb. nov. herein (Late Jurassic, Australia) Plate IV, 15.
Sentusidinium densicomatum (Maier, 1959) Sarjeant, 1983 (Middle Oligocene, Germany) Plate IV, 16.
Sentusidinium echinatum (Gitmez and Sarjeant, 1972) Sarjeant and Stover, 1978 (Late Jurassic, UK) Plate IV, 17.
Sentusidinium eisenackii (Boltenhagen, 1977) Fauconnier and Masure, 2004 (Late Cretaceous, Gabon) Plate IV, 18–19.
Sentusidinium euteichum (Davey, 1969a) comb. nov. herein (Late Cretaceous, France) Plate IV, 20.
Sentusidinium explanatum (Bujak in Bujak et al., 1980) comb. nov. herein (Middle Eocene, UK) Plate V, 1.
Sentusidinium extravermiculatum (Chenglong, 1999) comb. nov. herein (Eocene, Taiwan) Plate V, 2–4.
Sentusidinium fibrillosum Backhouse, 1988 (Early Cretaceous, Australia) Plate V, 5–6.
Sentusidinium granulosum (Cookson and Eisenack, 1974) comb. nov. herein (Cretaceous, Australia) Plate V, 7.
Sentusidinium hirsutum (Stover, 1977) comb. nov. herein (Oligocene, North Atlantic) Plate V, 9–10.
Sentusidinium macbethiae (Mantle, 2009) comb. nov. herein (Middle Jurassic, Timor Sea) Plate V, 11–12.
Sentusidinium microcystum (Bujak in Bujak et al., 1980) Islam, 1993 (Late Eocene, UK) Plate V, 13–14.
Sentusidinium micropapillatum (Stover, 1977) comb. nov. herein (Oligocene–Early Miocene) Plate V, 8.
Sentusidinium millepiedii Fensome and Williams, 2004 nom. subst. pro. *Sentusidinium? brevispinosum* (Jain and Millepied, 1975) Islam, 1993 (Late Cretaceous, Africa) Plate V, 15–16.

Sentusidinium minus (Jiabo, 1978) He Chengquan, Zhu Shenzhao and Jin Guangxing in He et al., 1989 (Palaeogene, China) Plate V, 17.

Sentusidinium myriatrichum Fensome, 1979 (Late Jurassic, Greenland) Plate V, 18.

Sentusidinium perforoconum (Yun Hyesu, 1981) Islam, 1993 (Late Cretaceous, USA) Plate V, 19.

Sentusidinium pilosum (Ehrenberg, 1854) Sarjeant and Stover, 1978 (Late Jurassic–Early Cretaceous, Poland) Plate V, 20.

Sentusidinium ringnesiorum (Manum and Cookson, 1964) comb. nov. herein (Late Cretaceous, Canada) Plate VI, 1.

**Sentusidinium rioultii* Sarjeant, 1968 (Middle Jurassic, France) Plate VI, 2.

Sentusidinium sahii (Khanna and Singh, 1981) comb. nov. herein (Early–Middle Eocene, India) Plate VI, 3.

Sentusidinium separatum (McIntyre and Brideaux, 1980) Lentin and Williams, 1981 (Early Cretaceous, Canada) Plate VI, 5–6.

Sentusidinium setulosum (Chenglong, 1999) comb. nov. herein (Eocene, Taiwan) Plate VI, 7–8.

Sentusidinium sparsibarbatum Erkmen and Sarjeant, 1980 (Middle Jurassic, UK) Plate VI, 4.

Sentusidinium verrucosum (Sarjeant, 1968) Sarjeant and Stover, 1978 (Middle–Late Jurassic, France) Plate VI, 9.

Sentusidinium villersense (Sarjeant, 1968) Sarjeant and Stover, 1978 (Middle–Late Jurassic, France) Plate VI, 10.

Problematical species:

These species are problematical due to the lack of evidence regarding the presence of an apical archaeopyle.

Sentusidinium? *asymmetricum* (Pocock, 1972) comb. nov. herein (Middle Jurassic, Canada) Plate VI, 11.

Sentusidinium? *panshanensum* (Jiabo, 1978) Islam, 1993 (Palaeogene, China) Plate VI, 12.

Sentusidinium? *reticuloidum* (Jiabo, 1978) comb. nov. herein (Oligocene, China) Plate VI, 13.

Sentusidinium? *spongiosum* (Batten and Lister, 1988) comb. nov. herein (Early Cretaceous, UK) Plate VI, 14–16.

Reattributed and synonymised species:

Sentusidinium conispinosum Jinli et al., 1997, considered a taxonomic junior synonym of *Sentusidinium minus* (Jiabo, 1978) He et al., 1989.

Sentusidinium densispinum He et al., 1989, considered a taxonomic junior synonym of *Sentusidinium*? *panshanensum* (Jiabo, 1978) Islam, 1993.

Sentusidinium erythrocomum Erkmen and Sarjeant, 1980, considered a taxonomic junior synonym of *Sentusidinium aptiense* (Burger, 1980a) Burger, 1980b.

Sentusidinium fibrosum Kumar, 1987, considered a taxonomic junior synonym of *Sentusidinium bifidum* Jiabo, 1978.

Sentusidinium fungosum Harding, 1990, considered a taxonomic junior synonym of *Sentusidinium aptiense* (Burger, 1980a) Burger, 1980b.

Sentusidinium minutum He, 1991, considered a taxonomic junior synonym of *Sentusidinium sahii* (Khanna and Singh, 1981) comb. nov. herein.

Sentusidinium qingzangense He et al., 2005, considered a taxonomic junior synonym of *Sentusidinium capillatum* (Davey, 1975) Lentin and Williams, 1981.

Sentusidinium reticuloides Jinli et al., 1997, considered a taxonomic junior synonym of *Sentusidinium minus* (Jiabo, 1978) He et al., 1989.

Sentusidinium shenxianense He et al., 1989, considered a taxonomic junior synonym of *Sentusidinium*? *panshanensum* (Jiabo, 1978) Islam, 1993.

Sentusidinium spatiosum Dodekova, 1994, considered a taxonomic junior synonym of *Sentusidinium ringnesiorum* (Manum and Cookson, 1964) comb. nov. herein.

Sentusidinium stipulatum Mao Shaozhi and Norris, 1988, considered a taxonomic junior synonym of *Sentusidinium minus* (Jiabo, 1978) He et al., 1989.

Sentusidinium tanzaniensis Msaky, 2011, to *Cleistosphaeridium* as *Cleistosphaeridium tanzaniense* (Msaky, 2011) comb. nov. herein.

Sentusidinium agglutinatum (McIntyre and Brideaux, 1980) comb. nov. (Plate IV, 1–3)

1980 *Batiacasphaera agglutinata* McIntyre and Brideaux, p. 25, pl. 12, figs. 5–12.

Remarks: The species *Batiacasphaera agglutinata* was originally described from Valanginian strata (Fig. 3d) of the Northwest Territories in Canada by McIntyre and Brideaux (1980). It is unusual in having a prominent kalyptra. This species is relatively large and the autophragm is granulate to sporadically rugulate. It conforms with our concept of *Sentusidinium* rather than of *Batiacasphaera*, necessitating its transfer here.

Sentusidinium aptiense (Burger, 1980a) Burger, 1980b (Plate IV, 5–7)

1980a *Tenua aptiense* Burger, p. 76, pl. 23, figs. 1, 5; pl. 24, fig. 1.

1980 *Sentusidinium erythrocomum* Erkmen and Sarjeant, p. 56, 58, pl. 2, fig. 11; pl. 3, figs. 1–6, 8–11; pl. 4, fig. 5.

1980b *Sentusidinium aptiense* (Burger, 1980a) Burger, p. 277.

1986a *Batiacasphaera aptiensis* (Burger, 1980a) Kumar, 1986a, p. 32.

1998 *Sentusidinium fungosum* Harding, 1990 ex Harding in Williams et al., p. 557.

2000 *Kallosphaeridium dolomiticum* Torricelli, p. 261–262, pl. 4, figs. 9, 12.

2004 *Pilosidinium aptiense* (Burger, 1980a) Courtinat in Fauconnier and Masure, p. 447.

Remarks: *Sentusidinium aptiense* was first described from the Early Cretaceous (Aptian) of the Surat Basin, Australia, by Burger (1980a) and is characterised by its cover of distinctive hollow spines. We consider *Kallosphaeridium dolomiticum*, *Sentusidinium erythrocomum* and *Sentusidinium fungosum* to be taxonomic junior synonyms of *Sentusidinium aptiense* as they also exhibit hollow nontabular spines and are similar in all other aspects. *Tenua aptiense* and *Sentusidinium erythrocomum* were both published during February 1980, but the former was published first on February 15th (Burger, 1980a) and hence has priority over Erkmen and Sarjeant, 1980, which was published on February 29th (Geobios, 13:1). The stratigraphical range of *Sentusidinium aptiense* as now constituted is Middle Jurassic (Callovian) to Early Cretaceous (Aptian) and the species has a global distribution (Fig. 3d–e).

Sentusidinium asymmetrum (Fenton et al., 1980) Lentin and Williams, 1981 (Plate IV, 4)

Basionym: *Tenua asymmetra* Fenton et al., 1980, p. 160, 162, pl. 16, figs. 1, 3, 5.

1980 *Tenua asymmetra* Fenton et al., p. 160, 162, pl. 16, figs. 1, 3, 5.

1981 *Sentusidinium asymmetrum* (Fenton et al., 1980) Lentin and Williams, p. 253.

2004 *Pilosidinium asymmetrum* (Fenton et al., 1980) Courtinat in Fauconnier and Masure, p. 447.

Remarks: *Sentusidinium asymmetricum* has irregularly distributed ornament of low relief that is densest in the antapical region. In some specimens, the ornament is sparse in the middorsal and midventral areas, with intermediate amounts laterally (Fenton et al., 1980, p. 16, figs. 3, 5). This species clearly belongs in *Sentusidinium*.

The type material is from the latest Bajocian of Dorset, England, and the species is a reliable marker for the Bajocian–Bathonian transition (Fenton et al., 1980; Feist-Burkhardt and Monteil, 1997). Prauss (1989) reported *Sentusidinium* cf. *asymmetricum* from the Bajocian of northwestern Germany.

Sentusidinium baculatum (Dodekova, 1975) Sarjeant and Stover, 1978 (Plate IV, 9–11)

Basionym: *Tenua baculata* Dodekova, 1975, p. 28–29, pl. 6, figs. 1–3; text-fig. 7.

1975 *Tenua baculata* Dodekova, p. 28–29, pl. 6, figs. 1–3; text-fig. 7.

1978 *Sentusidinium baculatum* (Dodekova, 1975) Sarjeant and Stover, p. 50.

1978 *Tenua biornata* Jiabo, p. 52, pl. 22, figs. 21–29; pl. 23, figs. 1–4.

1981 *Kallosphaeridium biparatum* Lentin and Williams, p. 160.

1985 *Batiacasphaera biornata* (Jiabo, 1978) Jan du Chêne et al., p. 15.

1988 *Batiacasphaera hystricosa* Mao Shaozhi and Norris, p. 40, pl. 8, figs. 17–20.

1989 *Barbatacysta baculata* (Dodekova, 1975) Courtinat, p. 185.

1989 *Sentusidinium biornatum* (Jiabo, 1978) He et al., p. 67.

1989 *Batiacasphaera oligacantha* He et al., p. 39, pl. 7, fig. 13.

1992 *Sentusidinium biornatum* subsp. *conispicula* Liu Zhili and Zheng Yuefang in Zhili et al., p. 84–85, pl. 9, figs. 10–11.

2004 *Batiacasphaera biornata* subsp. *conispicula* (Liu Zhili and Zheng Yuefang in Zhili et al., 1992) Fensome and Williams, p. 74.

2009 *Batiacasphaera conspicula* (Liu Zhili and Zheng Yuefang in Zhili et al., 1992) He et al., p. 328.

2009 *Sentusidinium biornatum* subsp. *biornatum* (Jiabo, 1978) He et al., p. 249.

Remarks: Dodekova (1975, p. 29) described the ornamentation of *Sentusidinium baculatum* (as *Tenua baculata*) from the Middle Jurassic of Bulgaria, as consisting of rare, short processes of varying types (also see Dodekova, 1975, text-fig. 7). Sarjeant and Stover (1978) transferred it to *Sentusidinium*, and we retain it as such. Courtinat (1989) transferred the species to *Barbatacysta*, which we include as a taxonomic junior synonym of *Sentusidinium*. We consider *Sentusidinium baculatum* to be the senior synonym of *Batiacasphaera conispicula*, *Batiacasphaera hystricosa*, *Batiacasphaera oligacantha* and *Sentusidinium biornatum* subsp. *biornatum*. The stratigraphical range of *Sentusidinium baculatum* is Middle Jurassic (Bathonian) to Late Eocene (Fig. 3b–e).

Sentusidinium bellulum (Jiabo, 1978) Jinli et al., 1997 (Plate IV, 8)

1978 *Tenua bellula* Jiabo, p. 51, pl. 23, figs. 14–16.

1981 *Kallosphaeridium*? *bellulum* (Jiabo, 1978) Lentin and Williams, p. 160.

1985 *Batiacasphaera*? *bellula* (Jiabo, 1978) Jan du Chêne et al., p. 15.

1989 *Batiacasphaera gemmata* Head et al., p. 488, pl. 9, figs. 1–4.

1997 *Sentusidinium bellulum* (Jiabo, 1978) Jinli et al., p. 46.

1997 *Pyxidinopsis consolida* Pan Zhaoren in Jinli et al., p. 72, pl. 37, fig. 12; pl. 38, figs. 11, 16; name not validly published, as there was no English or Latin description.

1997 *Sentusidinium*? *verrucatum* Jinli et al., p. 47, pl. 35, figs. 12a–b, 13a–b, 15a–b, 16a–b, 17–20, 21a–b; name not validly published, as there was no English or Latin description.

2009 *Pyxidinopsis consolida* Pan Zhaoren in Jinli et al., 1997 ex He et al., 2009, p. 648.

2009 *Batiacasphaera verrucatum* Jinli et al., 1997 ex He et al. p. 650.

Remarks: *Sentusidinium bellulum* is distinguished by its relatively sparse covering of prominent gemmae. It therefore cannot be accommodated in *Batiacasphaera*. We regard *Batiacasphaera gemmata* and *Batiacasphaera consolida* as taxonomic junior synonyms of *Sentusidinium bellulum*. As now circumscribed, *Sentusidinium bellulum* ranges from the Oligocene to the Miocene (Fig. 3a–b).

Sentusidinium bifidum (Jiabo, 1978) He et al., 1989 (Plate IV, 12)

Basionym: *Tenua bifidis* Jiabo, p. 51–52, pl. 22, figs. 7–16.

1970 *Batiacasphaera baculata* Drugg, p. 814, fig. 6F.

1978 *Tenua bifidis* Jiabo, p. 51–52, pl. 22, figs. 7–16.

1978 *Tenua biornata* subsp. *crassa* Jiabo, p. 52, pl. 23, figs. 1–4.

1981 *Kallosphaeridium biparatum* subsp. *crassum* (Jiabo, 1978) Lentin and Williams, p. 160.

1981 *Tenua kutharensis* Khanna and Singh, p. 389–390, figs. 1.3, 1.5; text-fig. 1.

1981 *Cleistosphaeridium bifide* (Jiabo, 1978) Lentin and Williams, p. 48.

1987 *Sentusidinium fibrosum* Kumar, p. 243–244, pl. 1, figs. 5, 7, 8, 11, text-fig. 6.

1989 *Batiacasphaera biornata* subsp. *crassa* (Jiabo, 1978) Lentin and Williams, p. 34.

1989 *Sentusidinium*? *bifidum* (Jiabo, 1978) He et al., p. 66–67, pl. 16, figs. 17–23.

1989 *Sentusidinium biornatum* subsp. *crassum* (Jiabo, 1978) Lentin and Williams, p. 34.

1992 *Sentusidinium brachyspinosum* Zheng Yuefang and Liu Xuexian in Zhili et al., p. 85, pl. 18, figs. 12–17.

1993 *Batiacasphaera kutharensis* (Khanna and Singh, 1981) Lentin and Williams, p. 55.

2009 *Batiacasphaera brachyspinosa* (Zheng Yuefang and Liu Xuexian in Zhili et al., 1992) He Chegquan et al., p. 327.

Remarks: The earliest name for this species is *Batiacasphaera baculata*, that species being described by Drugg (1970) from the Late Eocene of Mississippi. However, that name cannot be transferred to *Sentusidinium* because it is already preoccupied by *Sentusidinium baculatum* (Dodekova, 1975) Sarjeant and Stover, 1978. Among the names that we consider synonymous with *Batiacasphaera baculata* Drugg, the earliest is *Tenua bifidis* Jiabo, 1978, now *Sentusidinium*? *bifidum* (Jiabo, 1978) He et al., 1989. We agree that this species belongs in *Sentusidinium* because it has an autophragm ornamented with relatively low density, short baculae rather than a reticulate or rugulate ornament, and we accept it in that genus without question. In our view *Batiacasphaera baculata* Drugg, *Sentusidinium fibrosum*, *Batiacasphaera biornata* subsp. *crassa*, *Batiacasphaera brachyspinosa* and *Batiacasphaera kutharensis* are all taxonomic synonyms of *Sentusidinium*? *bifidum* based on their respective type materials. The species is confined to the Palaeogene (Fig. 3b).

Sentusidinium callosum (Dodekova, 1994) comb. nov. (Plate IV, 13)

1994 *Kallosphaeridium callosum* Dodekova, p. 22–23, pl. 4, figs. 7–9.

Remarks: This species was first described from the Late Jurassic of Bulgaria by Dodekova (1994). The absence of an anterior intercalary plate precludes its attribution to *Kallosphaeridium*, and from its general morphology it clearly belongs in *Sentusidinium*. *Sentusidinium callosum* closely resembles *Sentusidinium explanatum*, both species having a smooth autophragm. However, Dodekova (1994, p. 22) noted coarse ornamentation on some specimens of *Sentusidinium callosum*, which she termed 'uncertain foveolae', and interpreted this as possibly representing bacterial activity. Therefore, we retain *Sentusidinium callosum* due to this uncertainty.

Sentusidinium capillatum (Davey, 1975) Lentin and Williams, 1981 (Plate IV, 14)

1975 *Tenua capillata* Davey, p. 155–156, pl. 2, figs. 4, 7.

1977 *Canningia spumosa* Brideaux, p. 12, pl. 3, figs. 9–14.

1980a *Membranosphaera romaensis* Burger, p. 74, pl. 27, figs. 1–3.

1980b *Kallosphaeridium*? *romaense* (Burger, 1980a) Burger, p. 277.

1981 *Sentusidinium capillatum* (Davey, 1975) Lentin and Williams, p. 253.

1981 *Batiacasphaera spumosa* (Brideaux, 1977) Below, p. 26.

1983 *Sentusidinium filiatum* Davies, p. 29–30, pl. 10, figs. 5–6, 8–9; text–fig. 27.

1989 *Pilosidinium filiatum* (Davies, 1983) Courtinat, p. 191.

1992 *Pilosidinium cactosum* Quattrocchio and Sarjeant, 1992, p. 91–92.

2004 *Pilosidinium capillatum* Courtinat in Fauconnier and Masure, 2004, p. 448.
2005 *Sentusidinium qingzangense* He et al., p. 64–65.

Remarks: *Sentusidinium capillatum* is subcircular to subovoidal in outline and normally thin-walled. The autophragm is setose, being very densely covered by short (c. 2 μm), slender spines. We consider *Sentusidinium capillatum* to be the taxonomic senior synonym of *Batiacasphaera spumosa*, *Kallosphaeridium*? *romaense*, *Pilosidinium cactosum*, *Pilosidinium filiatum and Sentusidinium qingzangense*. The absence of a reticulate or rugulate autophragm and of an anterior intercalary plate excludes *Sentusidinium capillatum* from *Batiacasphaera* and *Kallosphaeridium* respectively. The overall stratigraphical range of *Sentusidinium capillatum* is Late Jurassic to Late Cretaceous (Fig. 3c–e).

Sentusidinium capitatum (Cookson and Eisenack, 1960) comb. nov. (Plate IV, 15)

Basionym: *Hystrichosphaeridium capitatum* Cookson and Eisenack, 1960, p. 252, pl. 39, fig. 9.
1960 *Hystrichosphaeridium capitatum* Cookson and Eisenack, p. 252, pl. 39, fig. 9.
1971 *Prolixosphaeridium capitatum* (Cookson and Eisenack, 1960) Singh, 1971, p. 342.
1972 *Tenua capitata* (Cookson and Eisenack, 1960) Gitmez and Sarjeant, p. 189.
1980 *Batiacasphaera capitata* (Cookson and Eisenack, 1960) Dörhöfer and Davies, p. 40.
1980 *Sentusidinium creberbarbatum* Erkmen and Sarjeant, p. 52–54, fig. 2.
1989 *Barbatacysta creberbarbata* (Erkmen and Sarjeant, 1980) Courtinat, p. 186.
2005 *Barbatacysta capitata* (Cookson and Eisenack, 1960) Schrank, 2005, p. 548.

Remarks: *Sentusidinium capitatum* has an elongate outline and possesses a dense cover of short spines that are distally capitate. Although this species has an elongate outline suggesting an assignment to *Prolixosphaeridium*, we prefer to assign it to *Sentusidinium* because of its numerous processes in the antapical region and lack of distinct rows of processes (see Davey et al., 1966, p. 172). Morphologically, this species belongs in *Sentusidinium* rather than *Batiacasphaera*. We consider *Sentusidinium creberbarbatum* to be a taxonomic junior synonym. *Sentusidinium capitatum* has a stratigraphical range through the Late Jurassic.

Sentusidinium densicomatum (Maier, 1959) Sarjeant, 1983 (Plate IV, 16)
1959 *Galea densicomata* Maier, p. 307–308, pl. 29, figs. 7–8.
1961 *Baltisphaeridium densicomatum* (Maier, 1959) Gerlach, p. 193.
1966 *Impletosphaeridium densicomatum* (Maier, 1959) Morgenroth, 1966, p. 33.
1983 *Sentusidinium densicomatum* (Maier, 1959) Sarjeant, p. 111.
2004 *Pilosidinium densicomatum* (Maier, 1959) Courtinat in Fauconnier and Masure, 2004, p. 448.

Remarks: *Sentusidinium densicomatum* was first recorded from Oligocene and Miocene sediments of Germany (Maier, 1959). It is characterised by having a granular autophragm and hair-like projections. Specimens of this species are intermediate to large and subspherical in shape. We retain the species in *Sentusidinium* as it is now considered to be the taxonomic senior synonym of *Pilosidinium*.

Sentusidinium echinatum (Gitmez and Sarjeant, 1972) Sarjeant and Stover, 1978 (Plate IV, 17)
1972 *Tenua echinata* Gitmez and Sarjeant, p. 190, pl. 1, figs. 1, 9.
1978 *Sentusidinium echinatum* (Gitmez and Sarjeant, 1972) Sarjeant and Stover, p. 50.
1980 *Batiacasphaera echinata* (Gitmez and Sarjeant, 1972) Dörhöfer and Davies, p. 40.
1989 *Pilosidinium echinatum* (Gitmez and Sarjeant, 1972) Courtinat, p. 190.

Remarks: *Sentusidinium echinatum* is readily identifiable on the basis of its subspherical shape and echinate ornamentation. Gitmez and Sarjeant (1972) described this species from the Late Jurassic of southern England and likened it to a "prickly ball". We retain the species in *Sentusidinium*, since *Batiacasphaera* has a rugulate to reticulate autophragm and we consider *Pilosidinium* to be a taxonomic junior synonym of *Sentusidinium*.

Sentusidinium eisenackii (Boltenhagen, 1977) Fauconnier and Masure, 2004 (Plate IV, 18–19)
1977 *Tenua eisenackii* Boltenhagen, p. 56–58, pl. 5, figs. 5–8.
1977 *Tenua eisenackii* var. *eisenackii* (autonym); (see Boltenhagen, p. 56–58, pl. 5, figs. 5, 6).
1977 *Tenua eisenackii* var. *vermiculata* Boltenhagen, p. 57–58, pl. 5, figs. 7, 8.
1981 *Sentusidinium eisenackii* (Boltenhagen, 1977) Lentin and Williams, p. 253.
1981 *Sentusidinium eisenackii* subsp. *eisenackii* (autonym).
1981 *Sentusidinium eisenackii* subsp. *vermiculatum* (Boltenhagen, 1977) Lentin and Williams, p. 253.
2004 *Sentusidinium eisenackii*? subsp. *vermiculatum* (Boltenhagen, 1977) Courtinat in Fauconnier and Masure, p. 487.

Remarks: *Sentusidinium eisenackii* is a relatively large subspherical form originally described from the Late Cretaceous of Gabon by Boltenhagen (1977). It possesses a granular autophragm surmounted by a distinctive dense covering of low-relief elements, which can be variable in width. Many of the elements are distally hooked or recurved, and others may coalesce. The ornamentation is similar to that of *Sentusidinium baculatum*, but the latter species lacks hooked or recurved elements. We consider that the two subspecies, *Tenua eisenackii* subsp. *vermiculatum* and *Tenua eisenackii* subsp. *eisenackii*, do not warrant distinction. The synonymy of *Sentusidinium spiculatum* Jingxian and Wangping, 1980 with *Sentusidinium eisenackii* by Courtinat in Fauconnier and Masure (2004) is not followed here because the former species has simpler ornamentation. Rather, we consider *Sentusidinium spiculatum* to be synonymous with *Sentusidinium millepiedii* (see below).

Sentusidinium euteichum (Davey, 1969a) comb. nov. (Plate IV, 20)

Basionym: *Chytroeisphaeridia euteiches* Davey, 1969a, p. 141, pl. 3, figs. 8–9.
1969a *Chytroeisphaeridia euteiches* Davey, p. 141, pl. 3, figs. 8–9.
1979 *Batiacasphaera euteiches* (Davey, 1969a) Davey, p. 217.
1987 *Batiacasphaera asperata* Backhouse, p. 215, figs. 10A–C, 14E.

Remarks: *Sentusidinium euteichum* is subspherical and has a thick autophragm surmounted by granular ornamentation. Therefore, it cannot be accommodated in *Batiacasphaera* due to its lack of a reticulate or rugulate ornament. We consider *Batiacasphaera asperata* to be a taxonomic junior synonym of *Sentusidinium euteichum*, which thus now has a stratigraphical range through the Cretaceous (Fig. 3c–d).

Sentusidinium explanatum Bujak in Bujak et al., 1980, comb. nov. (Plate V, 1)

Basionym: *Chytroeisphaeridia explanata* Bujak in Bujak et al., 1980, p. 44, pl. 13, figs. 13–14.
1980a *Canningia minor* Cookson and Hughes, 1964 var. *psilata* Burger, p. 71, pl. 25, figs. 5–11.
1980 *Chytroeisphaeridia explanata* Bujak in Bujak et al., p. 44, pl. 13, figs. 13–14.
1983 *Batiacasphaera explanata* (Bujak in Bujak et al., 1980) Islam, p. 235.
1985 *Chytroeisphaeridia minor* (Cookson and Hughes, 1964) Morgan, 1980 subsp. *psilata* (Burger, 1980a) Lentin and Williams, p. 58.
1986b *Escharispharidia psilata* Kumar, p. 383, 385, pl. 2, fig. 2; text-fig. 3.
1988 *Escharisphaeridia laevigata* Smelror, p. 152–153, fig. 10G–H.

1989 *Kallosphaeridium*? *helbyi* Lentin and Williams, 1989 subsp. *psilatum* (Burger, 1980a) Lentin and Williams, p. 206.

1989 *Kallosphaeridium inornatum* Prauss, p. 41–42, pl. 5, figs. 4–6; pl. 6, fig. 18; text-fig. 17 (an illegitimate name; see below)

1993 *Kallosphaeridium praussii* Lentin and Williams, p. 365.

1997 *Batiacasphaera laevigata* (Smelror, 1988) Feist-Burkhardt and Monteil, p. 40.

Remarks: This taxon was first described as *Canningia minor* var. *psilata* from the Lower Cretaceous of the Surat Basin, eastern Australia by Burger (1980a). It was elevated to subspecies status by Lentin and Williams (1985). It was raised to species rank by Kumar (1986b), but not before other species had been proposed that we consider synonymous with it. Among these synonyms, the earliest at specific rank is *Chytroeisphaeridia explanata* Bujak in Bujak et al., 1980, which we therefore transfer to *Sentusidinium* as the correct name for this taxon at specific rank. (*Canningia minor* var. *psilatum* and *Batiacasphaera explanata* were both published in 1980; the former in a paper issued February 15th and the latter in December; but, regardless, the latter name has priority at species rank.)

Sentusidinium explanatum has a distinctive psilate to finely scabrate autocyst, with a subspherical to slightly elongate outline. We consider *Sentusidinium explanatum* to be the taxonomic senior synonym of *Batiacasphaera laevigata* (as first proposed by Poulsen, 1996, p. 80) and *Kallosphaeridium praussii*, (a substitute name for *Kallosphaeridium inornatum* Prauss) as well as *Canningia minor* var. *psiliata* (=*Escharisphaeridia psilata*); all of these taxa lack ornamentation.

The stratigraphical range of *Sentusidinium explanatum* is Middle Jurassic (Aalenian) to Late Eocene and the species has a global distribution (Fig. 3b–e).

Sentusidinium extravermiculatum (Chenglong, 1999) comb. nov. (Plate V, 2–4)

Basionym: *Batiacasphaera extravermiculata* Chenglong, 1999, p. 183–185, figs. 87–95.

1999 *Batiacasphaera extravermiculata* Chenglong, p. 183–185, figs. 87–95.

1999 *Batiacasphaera granulata* Chenglong, p. 186, figs. 78–81.

Remarks: *Sentusidinium extravermiculatum* is a spherical dinoflagellate cyst from the Eocene of Taiwan. It is characterised by its sponge like appearance owing to its extremely dense covering of clava and bacula. Because of the nature of its ornamentation, we transfer the species to *Sentusidinium*. Moreover, we consider *Batiacasphaera granulata* to be a taxonomic junior synonym of *Sentusidinium extravermiculatum*.

Sentusidinium fibrillosum Backhouse, 1988 (Plate V, 5–6)

1988 *Sentusidinium*? *fibrillosum* Backhouse, p. 107–108, pl. 41, figs. 3–6.

Remarks: *Sentusidinium fibrillosum* is a subspherical cyst, described from the Early Cretaceous of the Perth Basin, Australia. It has an autophragm surmounted by interlocking fibres and truncate spines, and is characterised by its distinct cingular ridges. We consider *Sentusidinium fibrillosum* to be a fully accepted species of *Sentusidinium*.

Sentusidinium granulosum (Cookson and Eisenack, 1974) comb. nov. (Plate V, 7)

Basionym: *Palaeostomocystis granulosa* Cookson and Eisenack, 1974, p. 79, pl. 28, fig. 10.

1974 *Palaeostomocystis granulosa* Cookson and Eisenack, p. 79, pl. 28, fig. 10.

1978 *Fromea granulosa* (Cookson and Eisenack, 1974) Stover and Evitt, p. 48.

1989 *Batiacasphaera granulosa* (Cookson and Eisenack, 1974) Jansonius, p. 67.

1991 *Batiacasphaera granospina* He, p. 53, pl. 6, figs. 22–23.

Remarks: The species *Sentusidinium granulosum* is characterised by an elongate ovoidal outline, with a narrow apical archaeopyle and dense granular ornament. This ornamentation precludes *Sentusidinium granulosum* from being retained in *Batiacasphaera* due to its lack of reticulate or rugulate ornament. Owing to the markedly similar morphology of *Batiacasphaera granospina*, this species is considered here to be a taxonomic junior synonym of *Sentusidinium granulosum*. Therefore, the stratigraphic range of *Sentusidinium granulosum* can now be seen in Fig. 3b–c, to be Early Cretaceous to Paleocene (Cookson and Eisenack, 1974; He, 1991).

Sentusidinium hirsutum (Stover, 1977) comb. nov. (Plate V, 9–10)

Basionym: *Batiacasphaera hirsuta* Stover, 1977, p. 72–73, pl. 1, figs. 1–3.

1977 *Batiacasphaera hirsuta* Stover, p. 72–73, pl. 1, figs. 1–3.

1999 *Batiacasphaera deheinzelinii* Louwye, p. 177, pl. 2, figs. 1–7.

Remarks: *Sentusidinium hirsutum* is a small dinoflagellate cyst first described from the Oligocene of the North Atlantic. It is defined by its subspherical cyst body, which is covered by dense, thin, hair-like projections. We transfer the species to *Sentusidinium* because it lacks a reticulate or rugulate autophragm. *Batiacasphaera deheinzelinii*, a Miocene species from Europe, appears to be morphologically indistinguishable from *Sentusidinium hirsutum* and hence we consider these two species to be synonyms.

Sentusidinium macbethiae (Mantle, 2009) comb. nov. (Plate V, 11–12)

2009 *Batiacasphaera macbethiae* Mantle, p. 100–101, pl. 8; figs. 1, 3–5.

Remarks: *Sentusidinium macbethiae* was first described from the Middle Jurassic of the Timor Sea, off northern Australia. It has a psilate to finely scabrate autophragm, with a subspherical to slightly elongate outline and closely resembles *Sentusidinium explanatum*. However, *Sentusidinium macbethiae* has a distinctive centrally located accumulation body (Mantle, 2009), which *Sentusidinium psilatum* lacks. Due to the absence of a reticulate or rugulate autophragm, this species cannot be retained in *Batiacasphaera*.

Sentusidinium microcystum (Bujak in Bujak et al., 1980) Islam, 1993 (Plate V, 13–14)

1980 *Tenua microcysta* Bujak in Bujak et al., p. 88, 90, pl. 22, figs. 2–5.

1981 *Cleistosphaeridium microcystum* (Bujak in Bujak et al., 1980) Lentin and Williams, p. 49.

1993 *Sentusidinium microcystum* (Bujak in Bujak et al., 1980) Islam, p. 88.

2004 *Pilosidinium microcystum* (Bujak in Bujak et al., 1980) Courtinat in Fauconnier and Masure, 2004, p. 448.

Remarks: *Sentusidinium microcystum* is a small elongate dinoflagellate cyst. Its autophragm is covered by short, slender, hollow spines which have capitate distal terminations. The species should be retained in *Sentusidinium*, as we consider *Pilosidinium* to be a junior synonym of this genus.

Sentusidinium micropapillatum (Stover, 1977) comb. nov. (Plate V, 5–8)

Basionym: *Batiacasphaera micropapillata* Stover, 1977, p. 73, pl. 1, figs. 7–8.

1977 *Batiacasphaera micropapillata* Stover, p. 73, pl. 1, figs. 7–8.

1983 *Tectatodinium minutum* Matsuoka, p. 127, pl. 5, fig. 6, pl. 6, fig. 7a–b.

1992 *Batiacasphaera minuta* (Matsuoka, 1983) Matsuoka and Head, p. 167.

Remarks: *Sentusidinium micropapillatum* is a small cyst with a subspherical outline and a papillate to granulate autophragm. The absence of a rugulate to reticulate autophragm precludes its retention in *Batiacasphaera*. We concur with Head in Head and Wrenn (1992, p. 3), who considered *Batiacasphaera minuta* to be a possible junior synonym of *Batiacasphaera micropapillata* and here complete the transfer. This species has a stratigraphical range of Oligocene to Miocene (Fig. 3a–b) (Stover, 1977; Matsuoka, 1983).

Sentusidinium millepiedii Fensome and Williams, 2004 (Plate V, 15–16)

1975 *Cleistosphaeridium brevispinosum* Jain and Millepied, p. 150, pl. 5, figs. 80–82.

1993 *Sentusidinium brevispinosum* (Jain and Millepied, 1975) Islam, p. 87.

2004 *Sentusidinium*? *millepiedii* Fensome and Williams, p. 601 nom. subst. pro. *Sentusidinium*? *brevispinosum* (Jain and Millepied) Islam.

Remarks: This species is relatively small with a narrow archaeopyle and apparently a small antapical concavity (Jain and Millepied, 1975, pl. 5, figs. 80, 81). It was originally described from the Early Cretaceous of Senegal and was transferred to *Sentusidinium* by Islam (1993, p. 87). However, the name *Sentusidinium brevispinosum* is a junior homonym of *Sentusidinium brevispinosum* Courtinat in Courtinat and Gaillard, 1980. Therefore, Fensome and Williams (2004, p. 601) proposed the substitute name *Sentusidinium*? *millepiedii*. It is no longer considered to be a problematical species because it fulfills our generic criteria for *Sentusidinium*.

Sentusidinium minus (Jiabo, 1978) He et al., 1989 (Plate V, 17)

1978 *Tenua hystrix* Eisenack, 1958 subsp. *minor* Jiabo, p. 52–53, pl. 23, figs. 5–7.

1981 *Kallosphaeridium*? *minus* (Jiabo, 1978) Lentin and Williams, p. 161.

1981 *Tenua simlaensis* Khanna and Singh, p. 389–390, fig. 1, nos. 8–9; text-fig. 2.

1985 *Batiacasphaera minor* (Jiabo, 1978) Jan du Chêne et al., p. 15.

1988 *Sentusidinium stipulatum* Mao Shaozhi and Norris, p. 40–41, pl. 8, figs. 21–22.

1989 *Sentusidinium minus* (Jiabo, 1978) He et al., p. 68.

1993 *Batiacasphaera*? *simlaensis* (Khanna and Singh, 1981) Lentin and Williams, p. 56.

1997 *Kallosphaeridium jiyangense* Jinli et al., p. 100, pl. 18, fig. 11; pl. 20, fig. 7; name not validly published: no English or Latin description.

1997 *Sentusidinium conispinosum* Jinli et al., p. 47, pl. 34, fig. 6a–b; pl. 35, figs. 14a–b, 16a–b; pl. 36, fig. 15a–b; name not validly published: no English or Latin description.

1997 *Sentusidinium reticuloides* Jinli et al., p. 47, pl. 16, figs. 3–4; pl. 17, figs. 3–4; pl. 18, figs. 12–15; pl. 19, figs. 7–9; name not validly published: no English or Latin description.

2009 *Kallosphaeridium jiyangense* Jinli et al., 1997 ex He et al., p. 656.

2009 *Sentusidinium conispinosum* Jinli et al., 1997 ex He et al., p. 662.

2009 *Sentusidinium reticuloides* Jinli et al.1997 ex He et al., p. 662.

Remarks: *Sentusidinium minus* is a subspheroidal cyst with an apical archaeopyle, first described as *Tenua hystrix* subsp. *minor* from the Palaeogene of China. (The epithet was subsequently corrected in Latin to *minus*). It has a distinct foveolate–granular autophragm, from which arise numerous spines. The spines are thin, hollow or solid, up to 10 μm in length and with various terminations. The taxon was raised to specific rank as *Kallosphaeridium*? *minus* by Lentin and Williams (1981), then transferred to *Batiacasphaera* by Jan du Chêne et al. (1985, p. 15). However, the combination *Batiacasphaera minor* was an illegitimate junior homonym of *Batiacasphaera minor* (Cookson and Hughes, 1964) Dörhöfer and Davies, 1980. So, Lentin and Williams (1989) erected *Batiacasphaera sinensis* as a substitute name. Its lack of a reticulate or rugulate autophragm means that the species cannot be accommodated in *Batiacasphaera*. He et al. (1989) retained it in *Sentusidinium*, which accords with our views. The species *Batiacasphaera*? *simlaensis* from northern India, and *Kallosphaeridium jiyanense*, *Sentusidinium conispinosum*, *Sentusidinium reticuloides* and *Sentusidinium stipulatum* from China, are all morphologically indistinguishable from *Sentusidinium minus*. Hence, we treat all five species as taxonomic junior synonyms of *Sentusidinium minus*.

Sentusidinium myriatrichum Fensome, 1979 (Plate V, 18)

1979 *Sentusidinium myriatrichum* Fensome, p. 12–13, pl. 2, fig. 7; text-fig. 5A.

1989 *Pilosidinium myriatrichum* (Fensome, 1979) Courtinat, p. 191.

Remarks: *Sentusidinium myriatrichum* was first described from the Late Jurassic of East Greenland. It is subspheroidal with a distinctive dense covering of short, fine, simple hairs. The hair-like projections are basally bulbous and are so short that the cyst appears to have a granular ornament in plain view. Although similar to *Sentusidinium hirsutum*, *Sentusidinium myriatrichum* has much shorter less pronounced projections. We retain this species in *Sentusidinium*, since we consider *Pilosidinium* to be a taxonomic junior synonym of the former genus.

Sentusidinium perforoconum (Yun Hyesu, 1981) Islam, 1993 (Plate V, 19)

1981 *Cleistosphaeridium perforoconum* Yun Hyesu, p. 43, pl. 15, figs. 1–4.

1993 *Sentusidinium perforoconum* (Yun Hyesu, 1981) Islam, p. 88.

Remarks: *Sentusidinium perforoconum*, described from the Late Cretaceous of the USA (Yun Hyesu, 1981), has a spherical cyst body, with a microgranulate autophragm. The autophragm is covered with distinctive, prominent, conical to acuminate spines, 6–8 μm in length.

Sentusidinium pilosum (Ehrenberg, 1854) Sarjeant and Stover, 1978 (Plate V, 20)

1854 *Xanthidium pilosum* Ehrenberg, pl. 37, fig. 8, no. 4.

1937 *Hystrichosphaeridium pilosum* (Ehrenberg, 1854) Deflandre, 1937, p. 79.

1961 *Baltisphaeridium pilosum* (Ehrenberg, 1854) Sarjeant, 1961, p. 101.

1968 *Tenua pilosa* (Ehrenberg, 1854) Sarjeant, 1961, p. 231.

1978 *Sentusidinium pilosum* (Ehrenberg, 1854) Sarjeant and Stover, p. 50.

1980 *Batiacasphaera pilosa* (Ehrenberg, 1854) Dörhöfer and Davies, p. 40.

1989 *Barbatacysta pilosa* (Ehrenberg, 1854) Courtinat, p. 187.

Remarks: *Sentusidinium pilosum* is elongate-ovoidal with a dense covering of short, slender projections that have variable terminations (Erkmen and Sarjeant, 1980, pl. 1). As this species lacks a reticulate to rugulate ornament, we do not accept its transfer to *Batiacasphaera* by Dörhöfer and Davies (1980). Since we consider *Barbatacysta* to be a taxonomic junior synonym of *Sentusidinium*, we retain this species in the latter genus. *Sentusidinium pilosum* ranges from the Late Jurassic to the Early Cretaceous (Sarjeant, 1968).

Sentusidinium ringnesiorum (Manum and Cookson, 1964) comb. nov. (Plate VI, 1)

Basionym: *Canningia ringnesii* Manum and Cookson, 1964, p. 15, pl. 2, fig. 10.

1964 *Canningia ringnesii* Manum and Cookson, p. 15, pl. 2, fig. 10.

1968 *Chytroeisphaeridia pocockii* Sarjeant, p. 230, pl. 3, fig. 9.

1972 *Chytroeisphaeridia mantelli* Gitmez and Sarjeant, p. 186, pl. 1, figs. 3–4; pl. 12, fig. 3.

1972 *Meiourogonyaulax dicryptos* Gitmez and Sarjeant, p. 225–226, pl. 7, fig. 6; text fig. 22.

1975 *Batiacasphaera macrogranulata* Morgan, p. 162, pl. 2, fig. 3a–d.

1976 *Lithodinia dicrypta* (Gitmez and Sarjeant, 1972) Gocht, 1976, p. 334.

1976 *Membranosphaera granulata* Norvick, p. 79–80, pl. 11, fig. 9; pl. 12, fig. 3.

1978 *Kallosphaeridium*? *granulatum* (Norvick, 1976) Stover and Evitt, p. 59.

1979 *Lithodinia pocockii* (Sarjeant, 1968) Davey, p. 217.

1980 *Escharisphaeridia pocockii* (Sarjeant, 1968) Erkmen and Sarjeant, p. 62.

1980 *Batiacasphaera ringnesiorum* (Manum and Cookson, 1964) Dörhöfer and Davies, p. 40.

1980 *Chytroeisphaeridia ringnesiorum* (Manum and Cookson, 1964) Morgan, p. 19.

1980a *Membranosphaera norvickii* Burger, p. 73–74, pl. 26, figs. 7–8.

1980 *Chytroeisphaeridia rugosa* Courtinat in Courtinat and Gaillard, p. 15–16, pl. 1, fig. 12; pl. 2, fig. 1; text fig. 2d.
1980 *Chytroeisphaeridia granulata* Courtinat in Courtinat and Gaillard, p. 13–14, pl. 1, figs. 4, 6; text fig. 2b.
1981 *Kallosphaeridium norvickii* (Burger, 1980a) Lentin and Williams, p. 161.
1981 *Canningia dicrypta* (Gitmez and Sarjeant, 1972) Below, p. 31.
1983 *Escharisphaeridia rudis* Davies, p. 28, pl. 10, figs. 7, 10–18; text fig. 25.
1987 *Escharisphaeridia granulata* (Courtinat in Courtinat and Gaillard, 1980) Stover and Williams, 1987, p. 89.
1987 *Kallosphaeridium*? *ringnesiorum* (Manum and Cookson, 1964) Helby, p. 324–325.
1988 *Escharisphaeridia senegalensis* Jan du Chêne, p. 155, pl. 15, figs. 1–8.
1989 *Escharisphaeridia mantelli* (Gitmez and Sarjeant, 1972) Courtinat, 2006, p. 180.
1989 *Batiacasphaera norvickii* (Burger, 1980a) Lentin and Williams, p. 35.
1989 *Escharisphaeridia rugosa* (Courtinat in Courtinat and Gaillard, 1980) Courtinat, 2006, p. 181.
1989 *Escharisphaeridia gaillardii* Courtinat, p. 178–179, pl. 17, fig. 7; pl. 20, figs. 5, 8; pl. 21, fig. 10; pl. 22, fig. 13; pl. 23, figs. 2, 7–8; text fig. 78A.
1989 *Batiacasphaera henanensis* He et al., p. 38, pl. 7, fig. 10; name not validly published.
1990 *Batiacasphaera mica* Harding, p. 48, pl. 25, figs. 10–19 ex Harding in Williams et al., 1998, p. 67.
1991 *Batiacasphaera sparsa* He, p. 53–54, pl. 6, fig. 4.
1991 *Batiacasphaera tuberculata* He, p. 54, pl. 6, fig. 2.
1993 *Batiacasphaera xinjiangensis* Lentin and Williams, p. 57.
1993 *Escharisphaeridia dicrypta* (Gitmez and Sarjeant, 1972) Williams et al., 1993, p. 57.
1994 *Sentusidinium spatiosum* Dodekova, p. 33, pl. 5, figs. 6–8, 11.
1997 *Batiacasphaera granofoveolata* Pan Zhaoren in Jinli et al., p. 43, pl. 39, fig. 1; name not validly published, as there was no English or Latin description.
2005 *Batiacasphaera floralis* He et al., p. 67–68, pl. 16, figs. 8–12.
2006 *Batiacasphaera rugosa* (Courtinat in Courtinat and Gaillard, 1980) Courtinat, 2006, p. 211.
2009 *Batiacasphaera granofoveolata* Pan Zhaoren in Jinli et al., 1997, ex He et al., p. 649.
2009 *Batiacasphaera macropyla* He et al., p. 644, pl. 56, fig. 6.

Remarks: *Sentusidinium ringnesiorum* was first described, as *Canningia ringnesii*, from the Late Cretaceous of Arctic Canada by Manum and Cookson (1964). (The epithet is correctly rendered as "*ringnesiorum*", rather than "*ringnesii*", because the species was avowedly named for the Ringnes brothers, not for an individual.) This species has a subcircular outline and highly irregular granular ornamentation (Davies, 1983, fig. 25). Typically, the autophragm is relatively thick and robust. The species, and its synonyms, have been attributed to a total of nine genera. These are: *Batiacasphaera*; *Canningia*; *Chytroeisphaeridia*; *Escharisphaeridia*; *Kallosphaeridium*; *Lithodinia*; *Meiourogonyaulax*; *Membranosphaera*; and *Sentusidinium*. *Sentusidinium ringnesiorum* has proved to be the most taxonomically complex of this review because we consider 20 other species to be taxonomic junior synonyms. These are: *Batiacasphaera floralis*, *Batiacasphaera granofoveolata*, *Batiacasphaera henanensis*, *Batiacasphaera macrogranulata*, *Batiacasphaera macropyla*, *Batiacasphaera mica*, *Batiacasphaera norvickii*, *Batiacasphaera rugosa*, *Batiacasphaera sparsa*, *Batiacasphaera tuberculata*, *Batiacasphaera xinjiangensis*, *Escharisphaeridia dicrypta*, *Escharisphaeridia gaillardii*, *Escharisphaeridia granulata*, *Escharisphaeridia mantellii*, *Escharisphaeridia pocockii*, *Escharisphaeridia rudis*, *Escharisphaeridia senegalensis*, *Kallosphaeridium*? *granulatum* and *Sentusidinium spatiosum*. After reviewing the descriptions and illustrations of these species in detail, we consider that they cannot be consistently separated. *Sentusidinium ringnesiorum* belongs in the genus *Sentusidinium* since it lacks reticulate to rugulate ornament and an anterior intercalary plate, precluding its assignment to *Batiacasphaera* and *Kallosphaeridium* respectively. As circumscribed here *Sentusidinium ringnesiorum* has a stratigraphical range of Jurassic to Eocene (Fig. 3b–e), reflecting its simple morphology and probable polyphyly.

Sentusidinium sahii (Khanna and Singh, 1981) comb. nov. (Plate VI, 3)

Basionym: *Hexagonifera sahii* Khanna and Singh, 1981, p. 391–393, fig. 2, nos. 1–3; fig. 4, no. 4; text-figs. 4–5.
1981 *Hexagonifera sahii* Khanna and Singh, p. 391–393, fig. 2, nos. 1–3; fig. 4, no. 4; text-figs. 4–5.
1984 *Kallosphaeridium curiosum* Bujak, p. 188, pl. 2, figs. 17–20.
1985 *Batiacasphaera curiosa* (Bujak, 1984) Jan du Chêne et al., p. 15.
1991 *Sentusidinium minutum* He, p. 59, pl. 15, fig 4.
1993 *Batiacasphaera*? *sahii* (Khanna and Singh, 1981) Lentin and Williams, p. 56.

Remarks: *Sentusidinium sahii* was first described from the Eocene of the Simla Hills in northern India by Khanna and Singh (1981), as *Hexagonifera sahii*. It was transferred to *Batiacasphaera*? by Lentin and Williams (1993). This species is characterised by its subspherical to ovoidal central body, which is densely granular, and sparse, randomly distributed longer spines. The lack of a reticulate or rugulate autophragm means that *Batiacasphaera* is an inappropriate assignment, but the species falls within the circumscription of *Sentusidinium*, to which we transfer it. We consider the Eocene species *Batiacasphaera curiosa* from the North Pacific and *Sentusidinium minutum* from China to be morphologically indistinguishable from *Sentusidinium sahii* and hence to be taxonomic junior synonyms.

Sentusidinium separatum McIntyre and Brideaux, 1980 (Plate VI, 5–6)

1980 *Cleistosphaeridium separatum* McIntyre and Brideaux, p. 19–20, pl. 6, figs. 4–5, 7–8.
1981 *Sentusidinium separatum* (McIntyre and Brideaux, 1980) Lentin and Williams, p. 254.

Remarks: The Early Cretaceous (Valanginian) species *Sentusidinium separatum* is a small subspherical, proximochorate dinoflagellate cyst. Its distinguishing feature is the thin granulate autophragm, which is surmounted by a moderately dense covering of long (2–8 μm) spines, with closed, bifid or branched distal terminations.

Sentusidinium setulosum (Chenglong, 1999) comb. nov. (Plate VI, 7–8)

Basionym: *Batiacasphaera setulosa* Chenglong, 1999, p. 182, figs. 72–77, figs. 84–86.
1999b *Batiacasphaera setulosa* Chenglong, p. 182, figs. 72–77, figs. 84–86.
1999b *Batiacasphaera setulosa* var. *setulosa* (Autonym; see Chenglong, p. 182, figs. 72–77).
1999b *Batiacasphaera setulosa* var. *minima* Chenglong, p. 182, figs. 84–86.

Remarks: *Sentusidinium setulosum* was described from the Eocene of Taiwan by Chenglong (1999). It is a small to intermediate dinoflagellate cyst with a subspherical outline. The autophragm is covered in setose ornamentation, with elements 2–3 μm long. *Batiacasphaera setulosa* var. *minima* appears to be morphologically identical to *Sentusidinium setulosa* var. *setulosa* and hence we consider the two varieties synonymous. We transfer the species from *Batiacasphaera* to *Sentusidinium* because it lacks a reticulate or rugulate autophragm.

Sentusidinium sparsibarbatum Erkmen and Sarjeant, 1980 (Plate VI, 4)

1980 *Sentusidinium sparsibarbatum* Erkmen and Sarjeant, p. 54–56, pl. 2, figs. 2–8; pl. 6, fig. 9; text-fig. 4a–c.

1980 *Sentusidinium brevispinosa* Courtinat in Courtinat and Gaillard, p. 60, pl. 9, figs. 4, 7, 11; text-fig. 10e.
1989 *Barbatacysta brevispinosa* (Courtinat in Courtinat and Gaillard, 1980) Courtinat, p. 185.

Remarks: *Sentusidinium sparsibarbatum* is subspherical to elongate in outline and is characterised by its granular autophragm covered in short spines, with blunt, capitate or bifurcating distal terminations. The elongate morphotypes (e.g. Erkmen and Sarjeant, 1980, text-fig. 4b, pl. 2, figs. 2, 3, 6) are especially distinctive. We consider that the ornamentation common to *Sentusidinium sparsibarbatum* and *Sentusidinium brevispinosum* warrants treating the two species as synonyms. Both were described in the same year, with Erkmen and Sarjeant, 1980 appearing prior to Courtinat and Gaillard (1980). Hence the name *Sentusidinium sparsibarbatum* has priority. The stratigraphical range of *Sentusidinium sparsibarbatum* is Middle to Late Jurassic (Callovian–Oxfordian; Fig. 3e); the species has been recorded from Europe and Australia (Mantle, 2009).

Sentusidinium verrucosum (Sarjeant, 1968) Sarjeant and Stover, 1978 (Plate VI, 9)
1968 *Tenua verrucosa* Sarjeant, p. 232, pl. 1, fig. 17; pl. 2, figs. 3, 6.
1978 *Sentusidinium verrucosum* (Sarjeant, 1968) Sarjeant and Stover, p. 50.
1979 *Sentusidinium pelionense* Fensome, p. 13–15, pl. 1, figs. 5–9; text-fig. 5B.
1980 *Batiacasphaera verrucosa* (Sarjeant, 1968) Dörhöfer and Davies, p. 41.
1989 *Barbatacysta verrucosa* (Sarjeant, 1968) Courtinat, p. 187.
1989 *Barbatacysta pelionensis* (Fensome, 1979) Courtinat, p. 187.
1989 *Pilosidinium fensomei* Courtinat, p. 190–191, pl. 21, figs. 2–3, 5, 7; pl. 23, fig. 15.

Remarks: *Sentusidinium verrucosum* is a subspheroidal dinoflagellate cyst, characterised by its distinct irregular verrucae set on a granular autophragm. We consider it to be a taxonomic senior synonym of *Barbatacysta pelionensis* and *Pilosidinium fensomei*, both of which exhibit the same characteristics. *Sentusidinium verrucosum* should be retained in *Sentusidinium* as it lacks reticulate or rugulate ornament: its stratigraphical range is Middle to Late Jurassic (Bajocian–Oxfordian; Fig. 3e).

Sentusidinium villersense (Sarjeant, 1968) Sarjeant and Stover, 1978 (Plate VI, 10)
1968 *Tenua villerense* Sarjeant, p. 231–232, pl. 1, fig. 16; pl. 2, figs. 5–10.
1978 *Sentusidinium villersense* (Sarjeant, 1968) Sarjeant and Stover, p. 50.
1980 *Batiacasphaera villersensis* (Sarjeant, 1968) Dörhöfer and Davies, p. 41.

Remarks: *Sentusidinium villersense* was first recorded from the Jurassic (Callovian–Oxfordian) of France by Sarjeant (1968). It has a spherical outline and a granular autophragm surmounted by numerous distinguishing, well-spaced spines, with distally expanded terminations: at the antapex there is a short broad spine. We retain the species in *Sentusidinium* as it lacks a reticulate or rugulate autophragm.

Problematical species:

The following four species, which have been assigned to *Sentusidinium*, lack an unequivocal apical archaeopyle hence are deemed to be problematical taxa.

Sentusidinium? asymmetricum (Pocock, 1972) Jansonius, 1986 (Plate VI, 11)
1972 *Leiosphaeridia asymmetrica* Pocock, p. 107, pl. 26, figs. 29–30.
1986 *Sentusidinium asymmetricum* (Pocock, 1972) Jansonius, p. 219.
2004 *Pilosidinium asymmetricum* (Pocock, 1972) Courtinat in Fauconnier and Masure, p. 447.

Remarks: *Sentusidinium*? *asymmetricum* is predominantly subspherical in outline. However, it has a distinct lobe on one lateral side. The autophragm is covered in dense spines. We consider *Sentusidinium*? *asymmetricum* to be a problematical species due to the lack of evidence for an apical archaeopyle. Since we consider *Pilosidinium* to be a taxonomic junior synonym of *Sentusidinium*, we retain the species in the latter genus. *Sentusidinium*? *asymmetricum* was originally described from the Middle Jurassic of Alberta, Canada.

Sentusidinium? panshanensum (Jiabo, 1978) Islam, 1993 (Plate VI, 12)
1978 *Cleistosphaeridium panshanense* Jiabo, p. 63, pl. 22, figs. 1–6.
1989 *Sentusidinium densispinum* He Chegquan et al. in He et al., p. 67, pl. 17, figs. 1–3.
1989 *Sentusidinium shenxianense* He Chegquan et al. in He et al., p. 68, pl. 17, figs. 6–10; text-fig. 10.
1993 *Sentusidinium panshanense* (Jiabo, 1978) Islam, p. 88.
2004 *Sentusidinium*? *panshanense* (Jiabo, 1978) Islam, 1993. Courtinat in Fauconnier and Masure, p. 487.

Remarks: *Sentusidinium*? *panshanensum* was described from the Palaeogene of China by Jiabo (1978). It is small, subspherical and densely covered in tubiform spines. We consider two species, *Sentusidinium densispinum* and *Sentusidinium shenxianense*, to be taxonomic synonyms of *Sentusidinium*? *panshanensum*. The lack of evidence of an apical archaeopyle makes it a problematical species.

Sentusidinium? reticuloidum (Jiabo, 1978) comb. nov. (Plate VI, 13)
Basionym: *Baltisphaeridiium reticuloidum* Jiabo, 1978, p. 115–116, pl. 31, figs. 18–19.
1978 *Baltisphaeridiium reticuloidum* Jiabo, p. 115–116, pl. 31, figs. 18–19.
1978 *Filisphaeridium aspersum* Jiabo, p. 116, pl. 31, figs. 1–6; pl. 49, figs. 2–4.
1985 *Filisphaeridium reticuloidum* (Jiabo, 1978) Zhichen et al., 1985, p. 55–56.
1994 *Kallosphaeridium*? *reticuloidum* (Jiabo, 1978) Sarjeant and Stancliffe, p. 56.
1994 *Kallosphaeridium*? *aspersum* (Jiabo, 1978) Sarjeant and Stancliffe, p. 56.

Remarks: *Sentusidinium*? *reticuloidum* was described from the Oligocene of China (Jiabo, 1978). It is subspherical in outline and has a pronounced granular autophragm, surmounted by sparse, variable short projections. Due to the apparent lack of an anterior intercalary plate this species cannot be retained in *Kallosphaeridium* and therefore is transferred to *Sentusidinium*. However, the complete lack of evidence of an apical archaeopyle, makes it a problematical species. *Kallosphaeridium*? *aspersum*, which also does not have a discernible archaeopyle, is interpreted here as a taxonomic junior synonym of *Sentusidinium reticuloidum*.

Sentusidinium? spongiosum (Batten and Lister, 1988) comb. nov. (Plate VI, 14–16)
1988 *Kallosphaeridium*? *spongiosum* Batten and Lister, p. 344–345, fig. 4e–h.

Remarks: *Sentusidinium spongiosum* was described from Lower Cretaceous (Upper Hauterivian) freshwater strata from Surrey, southern England. It is no longer considered to be referable to *Kallosphaeridium* as there is no indication of an anterior intercalary plate. Therefore, we transfer it to *Sentusidinium* as a problematical species because there is no clear evidence of an apical archaeopyle, and the autophragm exhibits tabulation.

4. Phylogenetic affinities

Due to their simple morphology and limited tabulation details, the phylogenetic affinities of the four genera in the *Sentusidinium* complex are difficult to assess. The complex as a group is clearly polyphyletic, as too may be the genera *Sentusidinium* and *Batiacasphaera*. It is clear that all four genera belong to the order Gonyaulacales because of their apical archaeopyles (Fensome et al., 1993), but further assignment to family and subfamily is more difficult.

Table 3
Accepted and problematical species for *Sentusidinium*. * denotes the type species. Size guide S < 50 μm, I 50 > 100 μm, L > 100 μm (Evitt, 1978, p. 57).

Species name	Author(s)	Original holotype	Defining features	Size (S, I, L)	Original publication age	Location	Plate (herein)
Accepted species							
Sentusidinium agglutinatum	McIntyre and Brideaux, 1980	Plate 12, 7–9	Subspherical, with granulate autophragm, surrounded by a kalyptra.	I	Early Cretaceous	Mackenzie, Canada	Plate IV, 1–3
Sentusidinium aptiense	Burger, 1980a	Plate 23, 1	Elongate, with prominent hollow tubular spines.	S-I	Early Cretaceous	Western Australia	Plate IV, 5–7
Sentusidinium asymmetrum	Fenton et al., 1980	Plate 16, 3	Subspherical, with granulate to baculate ornamentation which is reduced towards the apex.	I	Middle Jurassic	Dorset, UK	Plate IV, 4
Sentusidinium baculatum	Dodekova, 1975	Plate 6, 1–3	Subspherical, with variable ornamentation. Irregular gemmae to baculae with sparse short spines either distally joined or closed.	I	Middle Jurassic	Northeastern Bulgaria	Plate IV, 9–11
Sentusidinium bellulum	Jiabo, 1978	Plate 23, 14–16	Subspherical, with psilate autophragm surmounted by gemmae.	S	Eocene	Bohai Coast, China	Plate IV, 8
Sentusidinium bifidum	Jiabo, 1978	Plate 22, 7–16	Subspherical, with granulate autophragm surmounted by tuberculae.	S-I	Late Eocene	China	Plate IV, 12
Sentusidinium callosum	Dodekova, 1994	Plate 4, 7	Subspherical, with psilate to finely scabrate autophragm.	I	Late Jurassic - Early Cretaceous	North Bulgaria	Plate IV, 13
Sentusidinium capillatum	Davey, 1975	Plate 2, 7	Subspherical, setose ornament with variable tips.	S-I	Late Cretaceous	Ghana	Plate IV, 14
Sentusidinium capitatum	Cookson and Eisenack, 1960	Plate 39, 9	Elongate, short dense spines with accuminate to capitate tips.	S-I	Late Jurassic	Australia	Plate IV, 15
Sentusidinium densicomatum	Maier, 1959	Plate 29, 7	Subspherical, with granulate autophragm, surmounted by long hair-like, acicular projections.	I-L	Middle Oligocene	Germany	Plate IV, 16
Sentusidinium echinatum	Gitmez and Sarjeant, 1972	Plate 1, 1	Subspherical, with echinate ornamentation.	S-I	Late Jurassic	Dorset, UK	Plate IV, 17
Sentusidinium eisenackii	Boltenhagen, 1977	Plate 5, 5a–b	Subspherical, with variable ornamentation, including hooks.	I	Late Cretaceous	Gabon	Plate IV, 18–19
Sentusidinium euteichum	Davey, 1969a, 1969b	Plate 3, 8	Subspherical, with a thick wall and densely granular autophragm.	S-I	Late Cretaceous	Calais, France	Plate IV, 20
Sentusidinium explanatum	Bujak in Bujak et al., 1980	Plate 13, 13–14	Subspherical, with psilate autophragm.	S-I	Early Cretaceous	Surat Basin, Australia	Plate V, 1
Sentusidinium extravermiculatum	Chenglong, 1999	Figures 87–89	Subspherical, with variable ornamentation, giving a spongy appearance.	S-I	Eocene	Taiwan	Plate V, 2–4
Sentusidinium fibrillosum	Backhouse, 1988	Plate 41, 4a–b	Subspherical, with fibrous ornamented autophragm, well defined cingulum. Rarely has an offset short antapical horn.	S	Early Cretaceous	South Perth, Australia	Plate V, 5–6
Sentusidinium granulosum	Cookson and Eisenack, 1974	Plate 28, 10	Elongate, small archeopyle, with granulate autophragm.	S	Cretaceous	Australia	Plate V, 7
Sentusidinium hirsutum	Stover, 1977	Plate 1, 1–2	Subspherical, with a covering of thin dense hairs.	S	Oligocene	Blake Plateau, Atlantic	Plate V, 9–10
Sentusidinium macbethiae	Mantle, 2009	Plate 8, 1	Subspherical, psilate to shagreenate autophragm with a prominent and visible inclusion body.	S-I	Middle Jurassic	Timor Sea, Australia	Plate V, 11–12
Sentusidinium microcystum	Bujak in Bujak et al., 1980	Plate 22, 2–5	Elongate, with a shagreenate autophragm surmounted by long spines with capitate or bifid tips.	S	Late Eocene	Isle of Wight, UK	Plate V, 13–14
Sentusidinium micropapillatum	Stover, 1977	Plate 1, 7	Subspherical, with a thin wall and scabrate to papillate autophragm.	S	Oligocene - Early Miocene	Blake Plateau, Atlantic	Plate V, 8
Sentusidinium millepiedii	Jain and Millepied, 1975	Plate 5, 80–81	Subspherical, with setose ornamentation.	S-I	Early Cretaceous	Senegal basin, Africa	Plate V, 15–16
Sentusidinium minus	Jiabo, 1978	Plate 23, 5–7	Subspherical, with a covering of sparse thin spines.	S	Palaeogene	Bohai Coast, China	Plate V, 17
Sentusidinium myriatrichum	Fensome, 1979	Plate 12, 7	Subspherical, with dense, short hairs covering the autophragm.	S-I	Late Jurassic	Langryggen, Eastern Greenland	Plate V, 18
Sentusidinium perforoconum	Yun Hyesu, 1981	Plate 15, 4	Subspherical, proximochorate cyst with distinctive conical to accuminate spines.	I	Late Cretaceous	USA	Plate V, 19
Sentusidinium pilosum	Ehrenberg, 1854	Plate 37, 8, no. 4	Elongate, very dense short processes with variable tips.	S-I	Late Jurassic - Early Cretaceous	Podgorze, Kraków, Poland	Plate V, 20
Sentusidinium ringnesiorum	Manum and Cookson, 1964	Plate 2, 10	Subspherical, with a pronounced granulate autophragm.	I-L	Late Cretaceous	Ellef Ringnes Island, Canada	Plate VI, 1
**Sentusidinium rioultii*	Sarjeant, 1968	Plate 1, 22; plate 2, 1	Subspherical, with a granular surface surmounted by well-spaced projections with variable tips.	S-I	Middle Jurassic	France	Plate VI, 2
Sentusidinium sahii	Khanna and Singh, 1981	Figure 2, no. 2	Subspherical, with granulate autophragm surmounted by sparse long spines with variable tips.	S-I	Early–Middle Eocene	Simla Hills, India	Plate VI, 3
Sentusidinium separatum	McIntyre and Brideaux, 1980	Plate 6, 4–5	Subspherical, proximochorate cyst, with a shagreenate autophragm surmounted by long hollow spines with closed, bifid and branched tips.	S-I	Early Cretaceous	Canada	Plate VI, 5–6
Sentusidinium setulosum	Chenglong, 1999	Figures 72–73	Subspherical, with a densely setose autophragm.	S-I	Eocene	Taiwan	Plate VI, 7–8

(continued on next page)

Table 3 (*continued*)

Species name	Author(s)	Original holotype	Defining features	Size (S, I, L)	Original publication age	Location	Plate (herein)
Sentusidinium sparsibarbatum	Erkmen and Sarjeant, 1980	Plate VI, 9, text- 4	Elongate, with an echinate and granulate autophragm.	S-I	Middle Jurassic	Dorset, UK	Plate VI, 4
Sentusidinium verrucosum	Sarjeant, 1968	Plate 1, 17; plate 2, 3–6	Subspherical, with dense irregular verrucate autophragm.	S-I	Middle - Late Jurassic	Normandy, France	Plate VI, 9
Sentusidinium villerense	Sarjeant, 1968	Plate 1, 16	Subspherical, with granulate autophragm surmounted by well-spaced spines with variable tips. Short broad spine at antapex.	I	Middle - Late Jurassic	France	Plate VI, 10
Problematical species							
Sentusidinium? asymmetricum	Pocock, 1972	Plate 26, 29	Subspherical, with setose autophragm and lateral projection. No proven apical archeopyle.	S	Middle Jurassic	Alberta, Canada	Plate VI, 11
Sentusidinium? panshanensum	Jiabo, 1978	Plate 22, 1–6	Subspherical, with long tubiform spines with variable tips. No proven apical archeopyle.	S	Palaeogene	Bohai Coast, China	Plate VI, 12
Sentusidinium? reticuloidum	Jiabo, 1978	Plate 31, 18–19	Subspherical, with granulate ornamentation. No proven apical archeopyle.	S	Oligocene	Bohai Coast, China	Plate VI, 13
Sentusidinium? spongiosum	Batten and Lister, 1988	Figures 4e–g	Subspherical, with tabulation and granulate ornamentation surmounted by short pilate structures. Problematical operculum.	S	Early Cretaceous	Sussex, UK	Plate VI, 14–16

Kallosphaeridium is distinctive in having an extra climactal plate (climactal plates are apical plus anterior intercalary plates). Fensome et al. (1993) placed *Kallosphaeridium* questionably in the subfamily Cribroperidinioideae of the family Gonyaulaceae because of the similarity of its tabulation to that of *Lingulodinium*, which is based on cyst-theca relationships (see Dodge, 1989, text-fig. 1I for a climactal tabulation pattern attributed to *Lingulodinium* that is very similar to that of *Kallosphaeridium*). However, *Kallosphaeridium* exhibits no direct evidence of a cribroperidinioid tabulation, which is characterised most definitively by dextral torsion, so we prefer to consider *Kallosphaeridium* as having uncertain subfamily affinity within the Gonyaulacaceae.

Pentafidia also shows a characteristic tabulation feature in the reported presence of five precingular plates. As noted above, it is possible that this number represents a misinterpretation, or perhaps reflects a fusion of two plates. However, if the number of precingulars is confirmed, the only other gonyaulacoid dinoflagellates with five precingular plates belong to the exclusively extant family Ceratocoryaceae (Fensome et al., 1993). The morphology of the Ceratocoryaceae is so distinctive that without further evidence to support such an affinity, considering *Pentafidia* to be a ceratocoryacean would be overly speculative. The Jurassic–Cretaceous genus *Atopodinium* was originally thought to have five precingular plates (Drugg, 1978), but this was later convincingly shown to be a misinterpretation due to partial suppression of parasutures (Masure, 1991). Perhaps it is best for now to consider *Pentafidia* as a member of the order Gonyaulacales of uncertain family assignment.

Similarly, the tabulation reflected by the archaeopyle outline of the type of *Batiacasphaera*, *Batiacasphaera compta*, is unclear, although some specimens of that species and some other species of the genus reflect a more conventional apical tabulation. Hence based on the type, and like Fensome et al. (1993), we retain *Batiacasphaera* as a member of the order Gonyaulacales of uncertain family assignment.

The conventional apical tabulation of *Sentusidinium*, as indicated by the archaeopyle margin, confirms its affinity with the family Gonyaulacaceae, although in the absence of knowledge of the hypocystal tabulation, the subfamilial assignment must remain uncertain. It is possible that more than one gonyaulacacean subfamily developed cysts with a relatively simple "*Sentusidinium*" morphology.

5. Conclusions

The Mesozoic–Cenozoic *Sentusidinium* complex is a polyphyletic group of gonyaulacacean dinoflagellate cysts with a relatively simple morphology. They are acavate and generally subspheroidal, have an apical archaeopyle and relatively low ornamentation. As a result of this detailed review, we consider that all the species with this morphology can be assigned to one of four genera: *Batiacasphaera*, *Kallosphaeridium*, *Pentafidia* and *Sentusidinium*. Through extensive synonymising of forms with very similar to identical morphologies, we have reduced the number of species from 134 to 71, and have eliminated infraspecific taxa.

Sentusidinium is the most diverse genus in the complex and has the longest stratigraphical range. The archaeopyle in *Sentusidinium* normally has a free operculum and generally exhibits accessory archaeopyle sutures between precingular plates. The 34 accepted species of this genus collectively range from the Jurassic to the Neogene (Miocene); no post-Miocene species are known. The majority of the Jurassic *Sentusidinium* species were originally described from Europe. By contrast, all but one of the Cretaceous species are from Africa, Australia and North America. Six of the nine Palaeogene taxa were described from Asia (Table 3). The oldest representatives of the genus globally are from the Late Toarcian of northern England (Riding, 1984), were originally called *Escharisphaeridia* sp., and are now attributable to *Sentusidinium ringnesiorum*. However, *Sentusidinium* is absent from the Toarcian of Australia (Riding and Helby, 2001). The oldest occurrence of the *Sentusidinium* complex in the southern hemisphere is that of *Kallosphaeridium*? *hypornatum* from the Bajocian of Australia (Mantle and Riding, 2012). The *Sentusidinium* species with the oldest type is *Sentusidinium asymmetrum*, from the latest Bajocian of southern England (Fenton et al., 1980).

Pentafidia is an unusual gonyaulacoid genus, in that it apparently only has five precingular plates. It comprises two species, both from the Jurassic-Cretaceous transition from Western Australia (Backhouse, 1988).

The 17 accepted species of *Batiacasphaera* have a reticulate to rugulate autophragm, and many lack deep accessory archaeopyle sutures. The stratigraphical range of *Batiacasphaera* is Early Cretaceous to Miocene (Table 1). Most Cretaceous species are from the former Gondwanan continents, whereas the Miocene species are predominately of North Atlantic affinity.

The principal characteristics of the six accepted species of *Kallosphaeridium* are a ventrally attached operculum, a five-plate archaeopyle, and distinct accessory archaeopyle sutures. All the six accepted species of this genus were originally described from Palaeogene strata around the North Atlantic (Table 2). Out of all twelve *Kallosphaeridium* species, only *Kallosphaeridium*? *circulare* and *Kallosphaeridium*? *coninckii* have been found beyond the North Atlantic in the Cretaceous strata of Australia.

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Appendix 2

Applied Petroleum Technology (UK) Ltd

Comments on Microscopy Data for Two Gulf of Mexico Wells

29 samples of isolated kerogen from interval 12630ft. MD to 22900ft. MD in the VK 117 well, and one of isolated kerogen from 9710ft. MD in the CH 265 well, both drilled in the Gulf of Mexico, were mounted in resin, polished, and analysed for vitrinite reflectivity. These analyses were augmented by observation of exinite in fluorescent near UV blue light.

Tabular presentation of the data is given in Table 1. Histograms of the VK 117 and CH 265 wells are given in Appendices 1 and 2 respectively. A plot of vitrinite reflectivity against depth (with a datum of 5000 MD at 'surface') is shown in Figure 1.

Equipment

Reflectivity analysis was carried out using a Zeiss Universal microscope fitted with an MPM 03 photometer tube, a Zeiss Epiplan – Neofluar 40X oil immersion objective and 10X eyepieces, to give a total visual magnification of 400X. The immersion oil used is Cargille Type A, n_d = 1.515 at 23°C.

Measurements were made using a halogen white light source filtered at an ICCP standard wavelength of 546nm (green). The measuring aperture is circular with a diameter of 1.6 micron. Voltage generated in the photometer during measuring is converted to reflectivity by comparison with standards of known reflectivity. Two of three standards are used; Spinel, with a Ro of 0.588%, Yttrium-Aluminium-Garnet with a Ro of 0.879% and Gadolinium-Gallium-Garnet with a Ro of 1.696%. The choice of standards used is dependent on the expected range of reflectivity of the samples being examined.

Procedures

Vials of isolated kerogen suspended in water were delivered to APT UK Ltd. for reflectance analysis. Preparation involved coating microscope slide cover slips with a release agent (PTFE), and then adding a small amount of the kerogen/water slurry to the cover slip. When dry, two or three drops of resin with added hardener are placed on the coverslip. A labelled, frosted petrographic slide was then inverted onto the coverslip, and the resin allowed to cure. Upon curing, the coverslip was removed, leaving the slide with a thin, very smooth layer of resin, which in turn was covered by a film of kerogen.

The slide was then polished on a rotating lap wheel using progressively finer polishes (3.0µ and 1.0µ suspensions, and lastly 0.05µ gamma-alumina polishing compound.

Preparation of the samples was complicated by the presence in most samples of a mixture polyvinyl alcohol and hydrochloric acid, which reacts upon drying to form a rubbery, elastic film that adheres poorly to the surface of the slide and in which much of the organic matter is trapped. As a result, much organic matter was lost during polishing, and polish quality suffered. Nonetheless, sufficient vitrinite was available in most samples to provide reliable data.

RESULTS

Well VK 117

The shallowest two samples, 12630ft. MD and 15870ft. MD, were nearly barren and contained no measureable vitrinite. Vitrinite reflectivity ranged from 1.23% Ro at 17100ft. MD (but 1.24% Ro at 16170ft. MD and 16590ft. MD) to 3.03% Ro at 22500ft. MD. This latter value is based only upon four measurements and should be treated cautiously, but the value falls close to the trend established by the majority of the data. The deepest sample with a robust data set is at 20890ft. MD, which has a mean reflectivity of 2.47% Ro derived from 34 measurements. The standard deviation of the sample, ~0.2%, is consistent with populations at similar reflectivity.

A reduction in reflectivity to 2.43% Ro for the largest population in the deepest sample (22900ft. MD) is highly anomalous and reflects probable downhole caving, an interpretation supported by significant caved palynomorphs recorded in the palynological data. Nine measurements ranging from 2.95% to 3.7% Ro give a mean reflectivity of 3.29% Ro, a value which is consistent with the overall trend and may represent *in situ* material. An interpretation based on such a small number of measurements, however, should be treated cautiously.

Samples at 20400ft. MD and below contained low reflecting lignite that was probably added to the mud system. Although this material dominated the organic matter in several of these samples, it did not present a problem in interpretation, as the difference in reflectivity between the contaminants and *in situ* vitrinite was so great. Where lignite was common, 10 measurements were taken from it as evidence of its occurrence.

No significant fluorescence was noted in the VK 117 samples, partly due to the high maturity of the interval, but also to strong green to yellow fluorescence arising from the polyvinyl alcohol, which would have masked any exinite fluorescence present.

The data indicate that the interval 16170ft. MD to 17970ft. MD lies at the boundary between the oil and gas windows; samples below this interval are entirely within the gas window. A plot of vitrinite reflectivity against depth is shown in Figure 1. Because of graphical limitations (our plotting routines cannot accept depths below 19000ft.) a datum of 5000ft. was used. Therefore, 5000ft. must be added to any depth cited on the plot to give the actual depth as measured from kelly bushing.

An upward extension of a line drawn through the data points indicates that the base value of vitrinite reflectivity (~0.2%) will be encountered at about 5000ft. MD. Therefore, the gradient seen from these data indicates that a higher thermal gradient was present during and shortly after the deposition of sediments below 17100ft. MD than is the case at the present time.

Well CH 265

The one analysed sample, 9710ft. MD, contained almost entirely amorphous organic matter (AOM). This material was cohesive, orange, and with orange to brown matrix fluorescence and bright yellow to green fluorescing inclusions. These characteristics suggest that the sample is immature for petroleum generation. Only one particle, of uncertain affinity, was found for measurement. The value of 0.44% Ro, if it is indeed from vitrinite, confirms the sample's immaturity; however, the value is based upon only one measurement and this interpretation should be treated cautiously.

Rick Harding;

Organic Petrologist.

RWH– 01/09/16

Well	Depth	Units	Sample type	Sample prep.	Vitrinite Reflectivity										Comments
					Indigenous				Other populations						
					No.	Ave. %Ro	Min %Ro	Max %Ro	Type	No.	Ave. %Ro	Min %Ro	Max %Ro		
VK117	12630	ft	DC	KC	-	-	-	-							Barren. Trace amounts of inertinite only.
VK117	15870	ft	DC	KC	-	-	-	-	C	1	0.33	0.33	0.33		Nearly barren.
									L	1	0.71	0.71	0.71		
VK117	16170	ft	DC	KC	40	1.24	1.04	1.43	R	15	1.57	1.46	1.73		Low recovery. Almost all structured organic matter is inertinite.
VK117	16470	ft	DC	KC	-	-	-	-							Resin peeled off slide. Analysis not possible.
VK117	16590	ft	DC	KC	31	1.24	1.12	1.37	L	9	1.00	0.93	1.07		Good vitrinite wisps and large occasional irregular particles are common, but inertinite predominates. Moderate to dark brown miospores.
									R	15	1.55	1.42	1.76		
VK117	16800	ft	DC	KC	-	-	-	-							Slide rendered upolishable due to PVA precipitate. Not analysed.
VK117	17100	ft	DC	KC	17	1.23	1.07	1.41	L	2	0.69	0.63	0.75		Very low recovery.
									R	28	1.82	1.50	2.44		
VK117	17370	ft	DC	KC	2	1.27	1.23	1.31	R	6	1.81	1.68	1.94		Nearly barren.
VK117	17670	ft	DC	KC	39	1.38	1.19	1.58	L	12	0.76	0.27	1.06		Occasional good wisps and blocks of vitrinite, but inertinite predominates. Low reflecting material a combination of cavings and drilling additive.
									R	4	1.75	1.67	1.82		

TABLE 1 Vitrinite reflectivity data

Well	Depth	Units	Sample type	Sample prep.	Vitrinite Reflectivity									Comments
					Indigenous				Other populations					
					No.	Ave. %Ro	Min %Ro	Max %Ro	Type	No.	Ave. %Ro	Min %Ro	Max %Ro	
VK117	17970	ft	DC	KC	20	1.40	1.17	1.64	L	3	0.94	0.83	1.05	Very low recovery.
									R	11	1.79	1.70	2.03	
VK117	18270	ft	DC	KC	40	1.68	1.42	1.95	L	5	1.25	1.17	1.36	Occasional good wisps and blocks of vitrinite, but inertinite predominates.
									R	10	2.13	1.99	2.34	
VK117	18570	ft	DC	KC	35	1.67	1.42	1.97	C	3	0.57	0.50	0.68	Occasional good wisps and blocks of vitrinite, but inertinite predominates.
									L	10	1.26	1.12	1.37	
									R	7	2.21	2.01	2.44	
VK117	18870	ft	DC	KC	7	1.85	1.58	2.15	C	8	0.74	0.45	1.24	Almost barren. Very poor sample. Wide range of reflectivities. Lower popualtions oxidised and clearly bireflective and vary from ~0.4-0.7% Ro.
									R	3	2.52	2.44	2.67	
VK117	19170	ft	DC	KC	-	-	-	-						Most resin peeled off slide. Analysis not possible.
VK117	19440	ft	DC	KC	49	2.24	1.80	2.62	R	6	3.06	2.82	3.40	Wispy to blocky, fairly large vitrinite fairly common. May be a key sample.
VK117	19770	ft	DC	KC	-	-	-	-						Resin peeled off slide. Analysis not possible.
VK117	19830	ft	DC	KC	42	2.55	2.20	2.93	R	15	3.34	3.02	3.91	Poor surface due to PVA contamination. Large particles but difficult to distinguish inertintie from vitrinte - reflectivities are similar.
VK117	19990	ft	DC	KC	43	2.11	2.20	2.93	R	12	2.69	2.50	3.15	Low recovery but small amounts of good blocky to wispy vitrinite present.

TABLE 1 Vitrinite reflectivity data

Well	Depth	Units	Sample type	Sample prep.	Vitrinite Reflectivity									Comments
					Indigenous				Other populations					
					No.	Ave. %Ro	Min %Ro	Max %Ro	Type	No.	Ave. %Ro	Min %Ro	Max %Ro	
VK117	20090	ft	DC	KC	48	2.30	1.84	2.77	R	7	3.14	2.86	3.45	PVA contamination; little organic matter remainig. Minor amounts of vitrinite and inertinite present.
VK117	20190	ft	DC	KC	28	1.91	1.64	2.18	R	27	2.41	2.21	2.76	Very low recovery, but minor amounts of good blocky vitrinite and some inertinte.
VK117	20400	ft	DC	KC	40	2.35	1.89	2.80	C	140	0.33	0.27	0.43	Sample mainly large lignite fragments from mud additive. Occasional large inertinite fragments with well-preserved cell structure. Vitrinite v. rare & ID uncertain.
VK117	20500	ft	DC	KC	29	2.00	1.65	2.33	C	10	0.2	0.37	0.25	Lignite common. Otherwise, little recovery.
									R	16	2.98	2.43	3.48	
VK117	20600	ft	DC	KC	38	2.03	1.58	2.38	C	10	0.28	0.19	0.39	Low recovery; small wispy vitrinite.
									R	7	2.63	2.47	2.88	
VK117	20700	ft	DC	KC	40	2.38	2.07	2.81	C	10	0.34	0.26	0.47	Some very large, coaly vitrinite particles present. Occasional lignite mud additive.
									R	5	3.18	2.90	3.48	
VK117	20800	ft	DC	KC	39	2.66	2.33	2.93	L	5	1.94	1.79	2.15	Vitrinite and some inertinite commonly embedded in PVA precipitate.
									R	11	3.34	2.96	3.91	
VK117	20890	ft	DC	KC	34	2.47	2.10	2.81	C	10	0.2	0.15	0.30	Vitrinite and some inertinite commonly embedded in PVA precipitate.
									R	11	3.19	2.91	3.55	
VK117	22300	ft	DC	KC	16	2.83	2.42	3.33	C	10	0.25	0.18	0.30	Poor slide. Little kerogen and abundant PVA precipitate. Minor amounts of vitrinite and inertinite.

TABLE 1 Vitrinite reflectivity data

Well	Depth	Units	Sample type	Sample prep.	Vitrinite Reflectivity									Comments
					Indigenous				Other populations					
					No.	Ave. %Ro	Min %Ro	Max %Ro	Type	No.	Ave. %Ro	Min %Ro	Max %Ro	
VK117	22500	ft	DC	KC	4	3.03	2.34	3.33	C	6	0.25	0.22	0.32	Almost no recovery. Some lignite from mud additive present.
									R	2	4.28	3.94	4.62	
VK117	22900	ft	DC	KC	9	3.29	2.95	3.70	C	10	0.24	0.19	0.27	Little kerogen but some inertinite and wispy to blocky vitrinite is present. Caved vitrinite appears to dominated the assemblage.
									C	34	2.43	2.04	2.85	
									R	2	4.1	4.06	4.13	
CH 265	9710	ft	DC	KC	1	0.44	0.44	0.44						100% orange, immature, fluorescing amorphous organic matter. One questionable particle found.

TABLE 1 Vitrinite reflectivity data

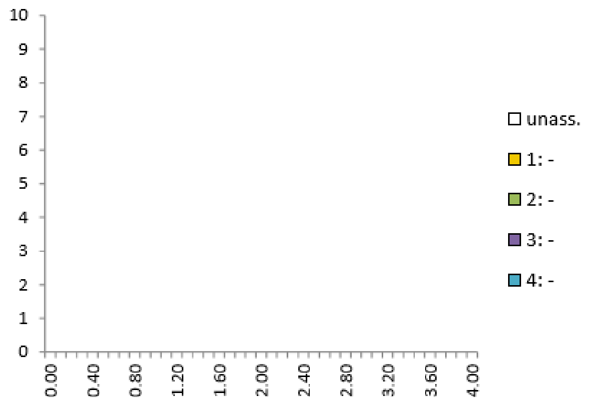
SAMPLE DATA
DEPTH/ORDER: 12630
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

STATISTICS
POPN 1 - n/a

POPN 2 - n/a

POPN 3 - n/a

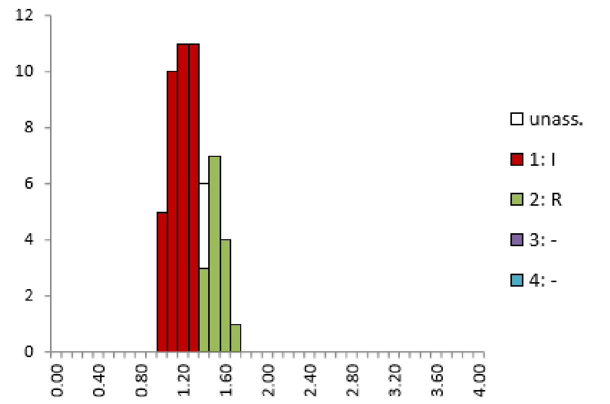
POPN 4 - n/a



SAMPLE DATA
DEPTH/ORDER: 16170
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

STATISTICS
POPN 1 - Indigenous
Mean value: 1.24
No. of values: 40
Range: 1.04 to 1.43
POPN 2 - Reworked
Mean value: 1.57
No. of values: 15
Range: 1.46 to 1.73
POPN 3 - n/a

POPN 4 - n/a

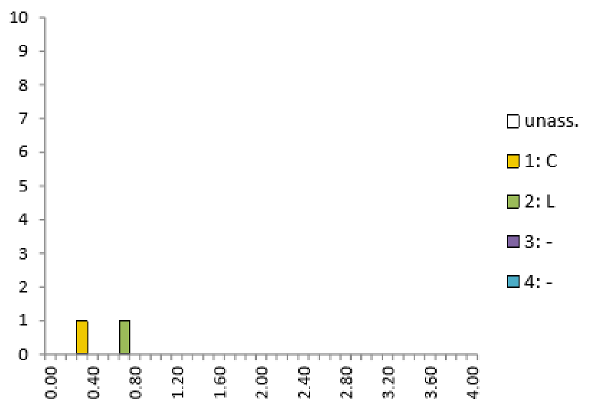


1.04	1.10	1.15	1.20	1.25	1.28	1.33	1.38	1.46	1.52	1.64
1.05	1.13	1.15	1.23	1.26	1.30	1.33	1.39	1.47	1.55	1.68
1.07	1.14	1.15	1.24	1.27	1.30	1.33	1.41	1.49	1.55	1.69
1.09	1.14	1.18	1.25	1.27	1.32	1.35	1.43	1.50	1.57	1.69
1.09	1.14	1.19	1.25	1.27	1.33	1.36	1.43	1.51	1.57	1.73

SAMPLE DATA
DEPTH/ORDER: 15870
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

STATISTICS
POPN 1 - Caved
Mean value: 0.33
No. of values: 1
Range: 0.33 to 0.33
POPN 2 - Low reflecting
Mean value: 0.71
No. of values: 1
Range: 0.71 to 0.71
POPN 3 - n/a

POPN 4 - n/a



0.33
0.71

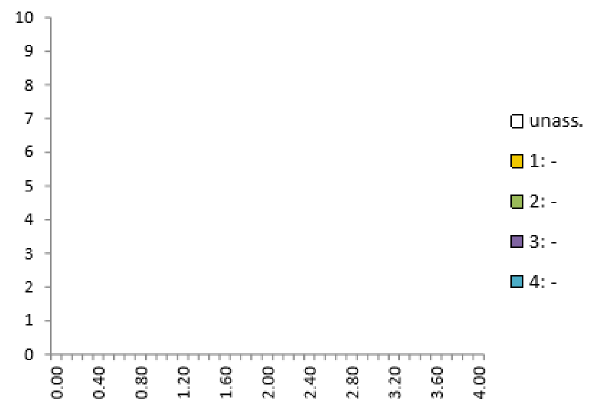
SAMPLE DATA
DEPTH/ORDER: 16470
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

STATISTICS
POPN 1 - n/a

POPN 2 - n/a

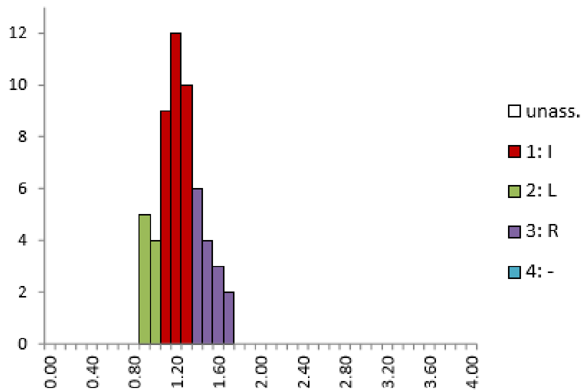
POPN 3 - n/a

POPN 4 - n/a



SAMPLE DATA
DEPTH/ORDER: 16590
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

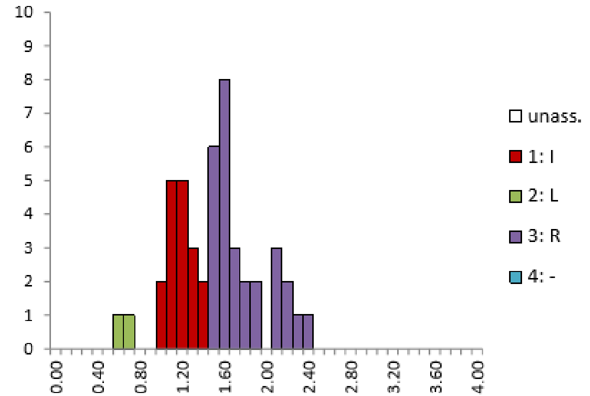
STATISTICS
POPN 1 - Indigenous
Mean value: 1.24
No. of values: 31
Range: 1.12 to 1.37
POPN 2 - Low reflecting
Mean value: 1.00
No. of values: 9
Range: 0.93 to 1.07
POPN 3 - Reworked
Mean value: 1.55
No. of values: 15
Range: 1.42 to 1.76
POPN 4 - n/a



0.93	1.01	1.12	1.17	1.20	1.24	1.30	1.34	1.42	1.48	1.63
0.94	1.03	1.12	1.17	1.22	1.24	1.30	1.35	1.42	1.51	1.64
0.95	1.06	1.12	1.19	1.22	1.25	1.31	1.36	1.42	1.52	1.65
0.98	1.07	1.15	1.20	1.22	1.26	1.33	1.36	1.45	1.55	1.71
0.99	1.12	1.17	1.20	1.23	1.29	1.33	1.37	1.46	1.58	1.76

SAMPLE DATA
DEPTH/ORDER: 17100
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

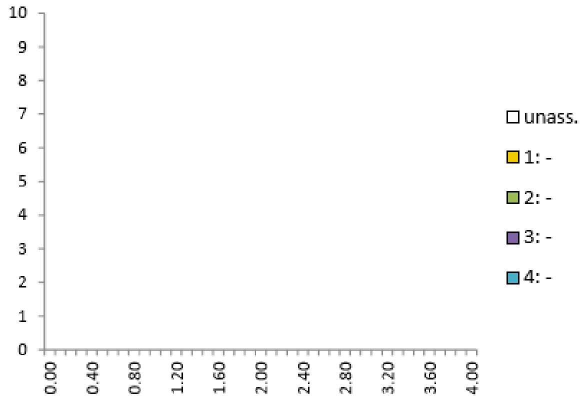
STATISTICS
POPN 1 - Indigenous
Mean value: 1.23
No. of values: 17
Range: 1.07 to 1.41
POPN 2 - Low reflecting
Mean value: 0.69
No. of values: 2
Range: 0.63 to 0.75
POPN 3 - Reworked
Mean value: 1.82
No. of values: 28
Range: 1.50 to 2.44
POPN 4 - n/a



0.63	1.11	1.20	1.36	1.53	1.60	1.65	1.73	2.12	2.36
0.75	1.12	1.24	1.39	1.55	1.62	1.66	1.82	2.14	2.44
1.07	1.17	1.25	1.41	1.57	1.62	1.68	1.84	2.16	
1.09	1.19	1.27	1.41	1.58	1.63	1.71	1.92	2.22	
1.11	1.20	1.32	1.50	1.59	1.64	1.72	1.99	2.23	

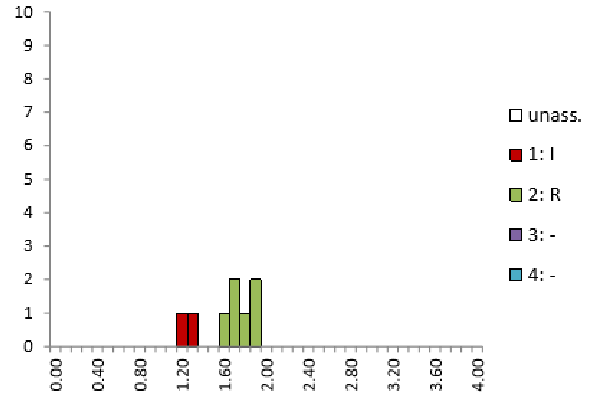
SAMPLE DATA
DEPTH/ORDER: 16800
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: 0
BLOCK No..: 0
APT-ID.: 0

STATISTICS
POPN 1 - n/a
POPN 2 - n/a
POPN 3 - n/a
POPN 4 - n/a



SAMPLE DATA
DEPTH/ORDER: 17370
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

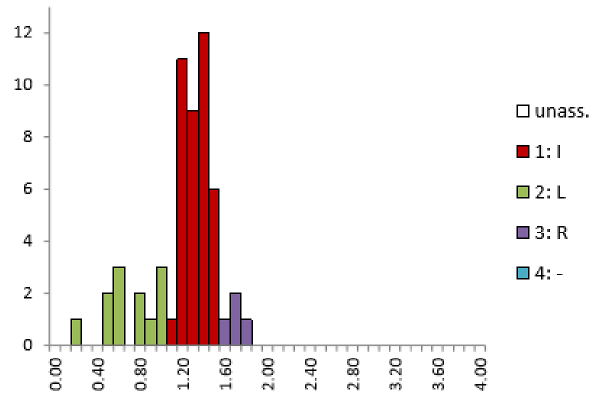
STATISTICS
POPN 1 - Indigenous (?)
Mean value: 1.27
No. of values: 2
Range: 1.23 to 1.31
POPN 2 - Reworked
Mean value: 1.81
No. of values: 6
Range: 1.68 to 1.94
POPN 3 - n/a
POPN 4 - n/a



1.23	1.83
1.31	1.92
1.68	1.94
1.74	
1.76	

SAMPLE DATA
DEPTH/ORDER: 17670
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

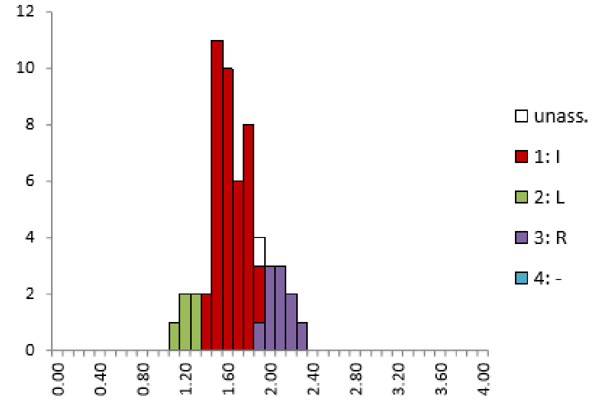
STATISTICS
POPN 1 - Indigenous
Mean value: 1.38
No. of values: 39
Range: 1.19 to 1.58
POPN 2 - Low reflecting
Mean value: 0.76
No. of values: 12
Range: 0.27 to 1.06
POPN 3 - Reworked
Mean value: 1.75
No. of values: 4
Range: 1.67 to 1.82
POPN 4 - n/a



0.27	0.67	1.02	1.24	1.28	1.34	1.36	1.42	1.47	1.50	1.58
0.50	0.87	1.06	1.25	1.28	1.34	1.39	1.42	1.47	1.51	1.67
0.58	0.88	1.19	1.26	1.29	1.35	1.39	1.43	1.47	1.54	1.75
0.61	0.99	1.20	1.26	1.29	1.35	1.40	1.43	1.49	1.56	1.77
0.66	1.01	1.23	1.27	1.34	1.35	1.41	1.46	1.49	1.58	1.82

SAMPLE DATA
DEPTH/ORDER: 18270
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

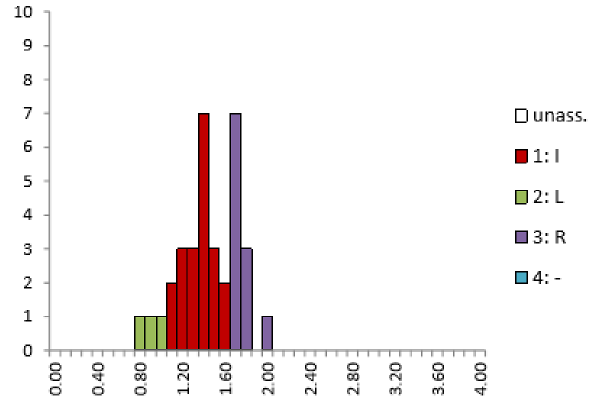
STATISTICS
POPN 1 - Indigenous
Mean value: 1.68
No. of values: 40
Range: 1.42 to 1.95
POPN 2 - Low reflecting
Mean value: 1.25
No. of values: 5
Range: 1.17 to 1.36
POPN 3 - Reworked
Mean value: 2.13
No. of values: 10
Range: 1.99 to 2.34
POPN 4 - n/a



1.17	1.42	1.55	1.58	1.61	1.67	1.73	1.82	1.86	1.99	2.13
1.20	1.45	1.55	1.58	1.63	1.68	1.74	1.82	1.87	2.00	2.14
1.24	1.50	1.56	1.59	1.63	1.68	1.74	1.83	1.91	2.03	2.25
1.30	1.53	1.56	1.60	1.65	1.71	1.76	1.84	1.92	2.06	2.29
1.36	1.53	1.58	1.60	1.66	1.71	1.81	1.86	1.95	2.11	2.34

SAMPLE DATA
DEPTH/ORDER: 17970
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

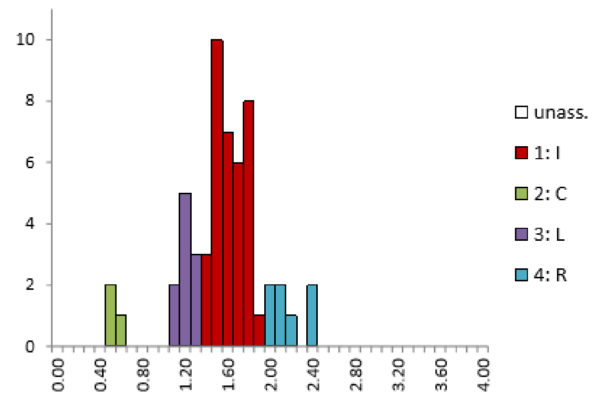
STATISTICS
POPN 1 - Indigenous
Mean value: 1.40
No. of values: 20
Range: 1.17 to 1.64
POPN 2 - Low reflecting
Mean value: 0.94
No. of values: 3
Range: 0.83 to 1.05
POPN 3 - Reworked
Mean value: 1.79
No. of values: 11
Range: 1.70 to 2.03
POPN 4 - n/a



0.83	1.20	1.37	1.45	1.57	1.71	1.81
0.95	1.24	1.40	1.46	1.64	1.71	1.86
1.05	1.26	1.41	1.46	1.64	1.77	1.88
1.17	1.34	1.42	1.51	1.70	1.78	2.03
1.19	1.36	1.44	1.53	1.71	1.78	

SAMPLE DATA
DEPTH/ORDER: 18570
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

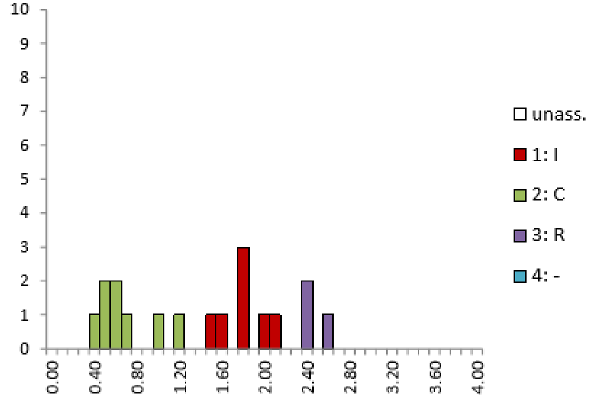
STATISTICS
POPN 1 - Indigenous
Mean value: 1.67
No. of values: 35
Range: 1.42 to 1.97
POPN 2 - Caved
Mean value: 0.57
No. of values: 3
Range: 0.50 to 0.68
POPN 3 - Low reflecting
Mean value: 1.26
No. of values: 10
Range: 1.12 to 1.37
POPN 4 - Reworked
Mean value: 2.21
No. of values: 7
Range: 2.01 to



0.50	1.21	1.30	1.48	1.53	1.57	1.68	1.74	1.81	1.87	2.15
0.52	1.22	1.35	1.51	1.54	1.60	1.68	1.75	1.84	1.89	2.16
0.68	1.23	1.37	1.52	1.55	1.60	1.68	1.75	1.84	1.97	2.21
1.12	1.27	1.42	1.52	1.56	1.62	1.70	1.79	1.84	2.01	2.42
1.19	1.29	1.48	1.53	1.56	1.67	1.71	1.80	1.85	2.07	2.44

SAMPLE DATA
DEPTH/ORDER: 18870
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

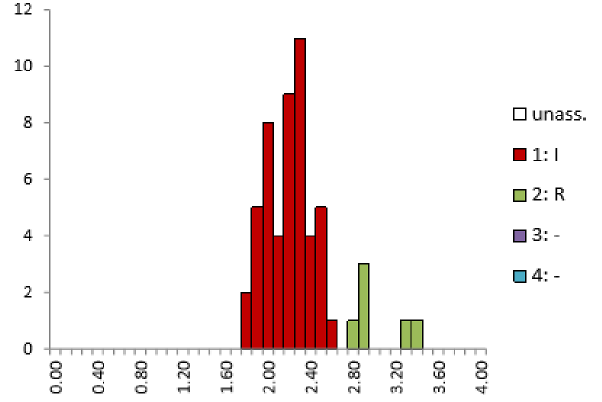
STATISTICS
POPN 1 - Indigenous
Mean value: 1.85
No. of values: 7
Range: 1.58 to 2.15
POPN 2 - Caved
Mean value: 0.74
No. of values: 8
Range: 0.45 to 1.24
POPN 3 - Reworked
Mean value: 2.52
No. of values: 3
Range: 2.44 to 2.67
POPN 4 - n/a



0.45	0.72	1.82	2.44
0.58	1.02	1.83	2.45
0.58	1.24	1.87	2.67
0.60	1.58	2.03	
0.69	1.65	2.15	

SAMPLE DATA
DEPTH/ORDER: 19440
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

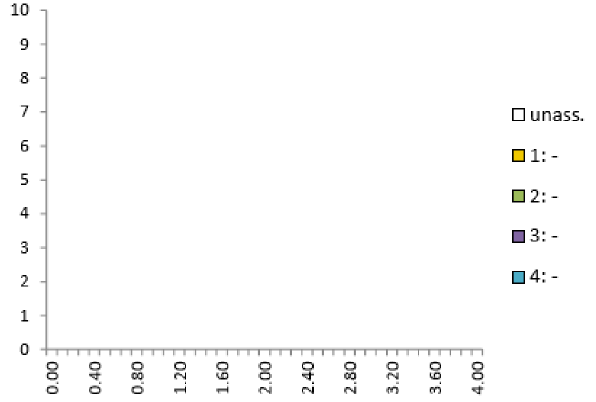
STATISTICS
POPN 1 - Indigenous
Mean value: 2.24
No. of values: 49
Range: 1.80 to 2.62
POPN 2 - Reworked
Mean value: 3.06
No. of values: 6
Range: 2.82 to 3.40
POPN 3 - n/a
POPN 4 - n/a



1.80	1.96	2.04	2.10	2.22	2.28	2.32	2.39	2.44	2.56	2.90
1.88	1.96	2.05	2.10	2.22	2.29	2.32	2.39	2.45	2.57	2.92
1.92	2.00	2.07	2.11	2.23	2.29	2.33	2.39	2.46	2.58	2.96
1.93	2.03	2.09	2.14	2.24	2.31	2.37	2.39	2.50	2.62	3.34
1.94	2.04	2.09	2.22	2.26	2.31	2.37	2.42	2.54	2.82	3.40

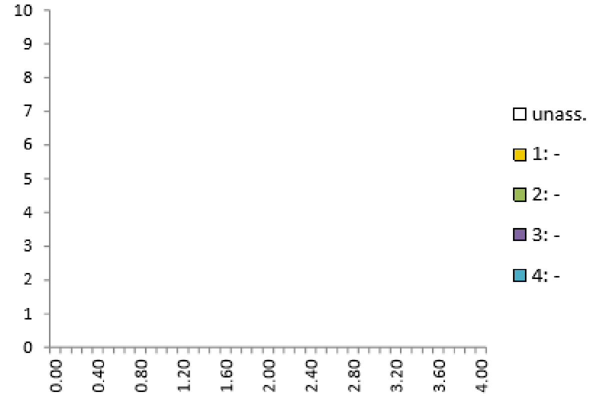
SAMPLE DATA
DEPTH/ORDER: 19170
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

STATISTICS
POPN 1 - n/a
POPN 2 - n/a
POPN 3 - n/a
POPN 4 - n/a



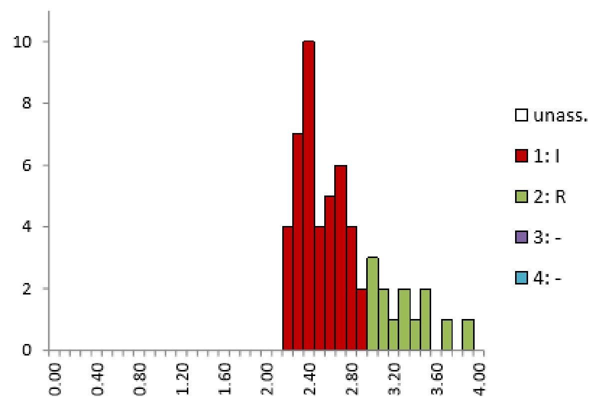
SAMPLE DATA
DEPTH/ORDER: 19770
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: 0
BLOCK No..: 0
APT-ID.: 0

STATISTICS
POPN 1 - n/a
POPN 2 - n/a
POPN 3 - n/a
POPN 4 - n/a



SAMPLE DATA
DEPTH/ORDER: 19830
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

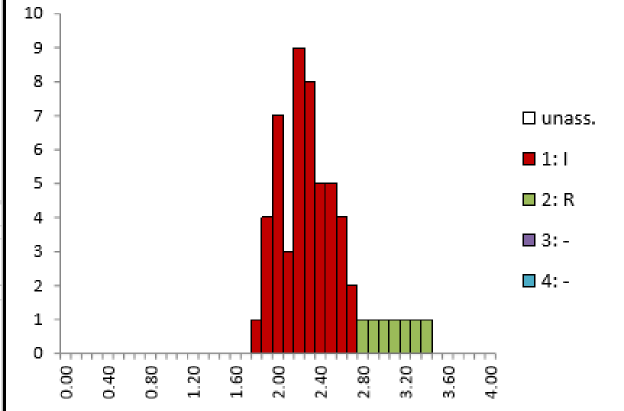
STATISTICS
POPN 1 - Indigenous
Mean value: 2.55
No. of values: 42
Range: 2.20 to 2.93
POPN 2 - Reworked
Mean value: 3.34
No. of values: 13
Range: 3.02 to 3.91
POPN 3 - n/a
POPN 4 - n/a



2.20	2.34	2.39	2.44	2.49	2.62	2.70	2.74	2.93	3.13	3.40
2.22	2.34	2.41	2.45	2.53	2.65	2.71	2.86	2.93	3.13	3.51
2.27	2.37	2.41	2.47	2.54	2.65	2.71	2.86	3.02	3.24	3.58
2.28	2.38	2.43	2.47	2.54	2.68	2.73	2.87	3.05	3.32	3.73
2.32	2.38	2.43	2.47	2.58	2.69	2.73	2.88	3.09	3.33	3.91

SAMPLE DATA
DEPTH/ORDER: 20090
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

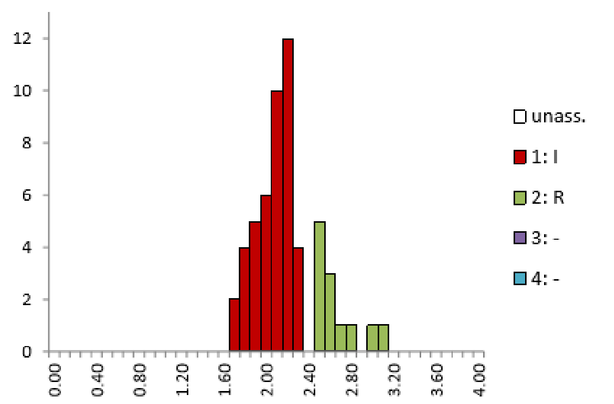
STATISTICS
POPN 1 - Indigenous
Mean value: 2.30
No. of values: 48
Range: 1.84 to 2.77
POPN 2 - Reworked
Mean value: 3.14
No. of values: 7
Range: 2.86 to 3.45
POPN 3 - n/a
POPN 4 - n/a



1.84	2.01	2.04	2.20	2.25	2.31	2.37	2.48	2.57	2.65	3.00
1.93	2.01	2.06	2.20	2.27	2.33	2.39	2.49	2.57	2.74	3.13
1.96	2.02	2.11	2.20	2.27	2.34	2.44	2.52	2.60	2.77	3.25
1.99	2.03	2.12	2.20	2.27	2.34	2.45	2.53	2.61	2.86	3.39
1.99	2.03	2.13	2.24	2.30	2.36	2.46	2.55	2.64	2.90	3.45

SAMPLE DATA
DEPTH/ORDER: 19990
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

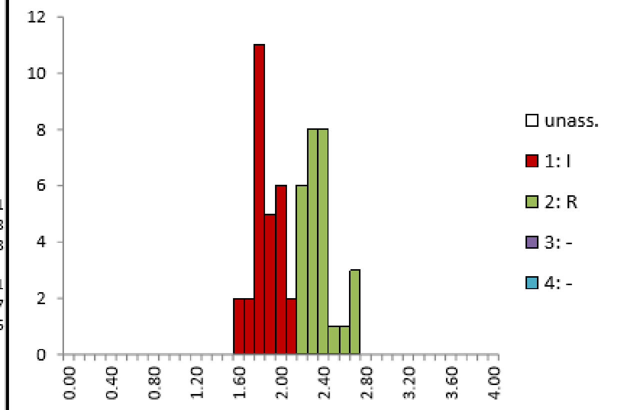
STATISTICS
POPN 1 - Indigenous
Mean value: 2.11
No. of values: 43
Range: 1.72 to 2.35
POPN 2 - Reworked
Mean value: 2.69
No. of values: 12
Range: 2.50 to 3.15
POPN 3 - n/a
POPN 4 - n/a



1.72	1.89	1.99	2.05	2.14	2.19	2.23	2.27	2.35	2.53	2.68
1.77	1.90	2.02	2.06	2.15	2.19	2.23	2.27	2.35	2.55	2.71
1.83	1.90	2.02	2.10	2.16	2.21	2.23	2.28	2.35	2.55	2.87
1.86	1.91	2.02	2.10	2.16	2.22	2.26	2.29	2.50	2.60	3.01
1.87	1.93	2.03	2.12	2.17	2.22	2.26	2.33	2.52	2.65	3.15

SAMPLE DATA
DEPTH/ORDER: 20190
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

STATISTICS
POPN 1 - Indigenous
Mean value: 1.91
No. of values: 28
Range: 1.64 to 2.18
POPN 2 - Reworked
Mean value: 2.41
No. of values: 27
Range: 2.21 to 2.76
POPN 3 - n/a
POPN 4 - n/a



1.64	1.81	1.86	1.90	2.02	2.09	2.25	2.31	2.37	2.42	2.52
1.67	1.81	1.86	1.92	2.03	2.13	2.26	2.31	2.39	2.43	2.68
1.70	1.82	1.87	1.93	2.04	2.18	2.26	2.34	2.40	2.44	2.70
1.77	1.83	1.87	1.95	2.06	2.21	2.29	2.34	2.40	2.45	2.73
1.80	1.85	1.89	1.99	2.07	2.24	2.30	2.36	2.41	2.48	2.76

SAMPLE DATA

DEPTH/ORDER: 20400
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

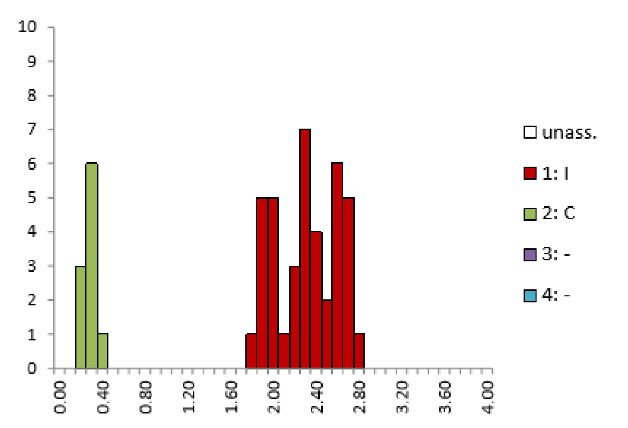
STATISTICS

POPN 1 - Indigenous
Mean value: 2.35
No. of values: 40
Range: 1.89 to 2.80

POPN 2 - Caved
Mean value: 0.33
No. of values: 10
Range: 0.27 to 0.43

POPN 3 - n/a

POPN 4 - n/a



0.27	0.33	1.89	1.96	2.05	2.30	2.36	2.45	2.65	2.72
0.27	0.33	1.90	2.00	2.18	2.32	2.37	2.50	2.65	2.75
0.29	0.34	1.91	2.02	2.27	2.33	2.40	2.51	2.66	2.75
0.32	0.35	1.95	2.03	2.27	2.33	2.44	2.60	2.67	2.78
0.32	0.43	1.95	2.03	2.28	2.35	2.45	2.63	2.71	2.80

SAMPLE DATA

DEPTH/ORDER: 20600
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

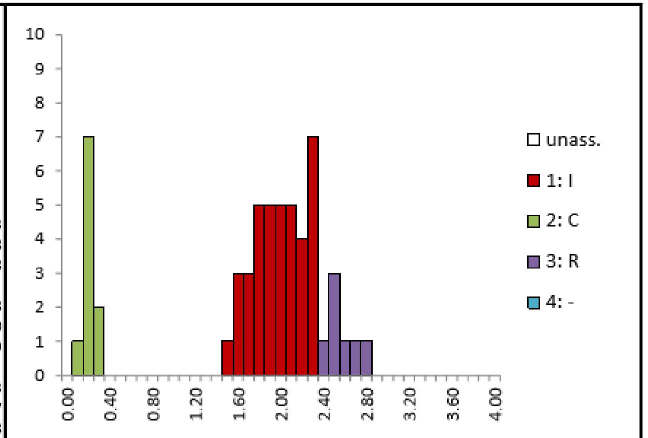
STATISTICS

POPN 1 - Indigenous
Mean value: 2.03
No. of values: 38
Range: 1.58 to 2.38

POPN 2 - Caved
Mean value: 0.28
No. of values: 10
Range: 0.19 to 0.39

POPN 3 - Reworked
Mean value: 2.63
No. of values: 7
Range: 2.47 to 2.88

POPN 4 - n/a



0.19	0.28	1.58	1.78	1.84	1.96	2.07	2.15	2.26	2.36	2.54
0.22	0.29	1.60	1.79	1.87	1.97	2.09	2.18	2.32	2.37	2.58
0.24	0.29	1.66	1.82	1.91	2.01	2.10	2.20	2.33	2.38	2.68
0.27	0.32	1.67	1.83	1.93	2.04	2.13	2.22	2.33	2.47	2.72
0.28	0.39	1.76	1.84	1.96	2.05	2.13	2.23	2.34	2.53	2.88

SAMPLE DATA

DEPTH/ORDER: 20500
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

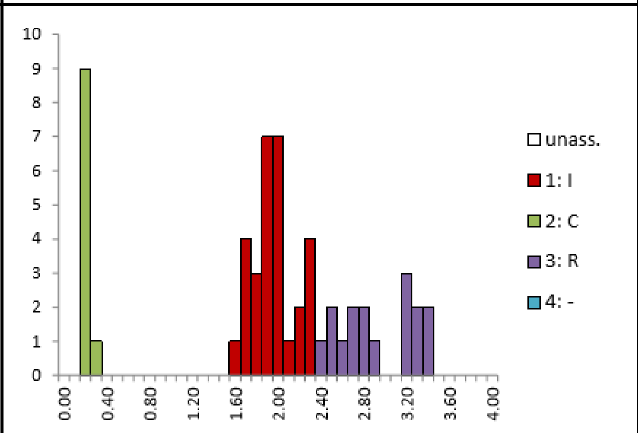
STATISTICS

POPN 1 - Indigenous
Mean value: 2.00
No. of values: 29
Range: 1.65 to 2.33

POPN 2 - Caved
Mean value: 0.25
No. of values: 10
Range: 0.20 to 0.37

POPN 3 - Reworked
Mean value: 2.98
No. of values: 16
Range: 2.43 to 3.48

POPN 4 - n/a



0.20	0.25	1.69	1.80	1.91	2.02	2.07	2.30	2.54	2.80	3.27
0.20	0.26	1.72	1.81	1.91	2.05	2.08	2.31	2.59	2.81	3.35
0.22	0.27	1.73	1.87	1.97	2.06	2.16	2.33	2.63	2.91	3.38
0.23	0.28	1.75	1.90	1.99	2.06	2.25	2.33	2.73	3.24	3.40
0.25	0.37	1.79	1.91	1.99	2.07	2.27	2.43	2.79	3.26	3.48

SAMPLE DATA

DEPTH/ORDER: 20700
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

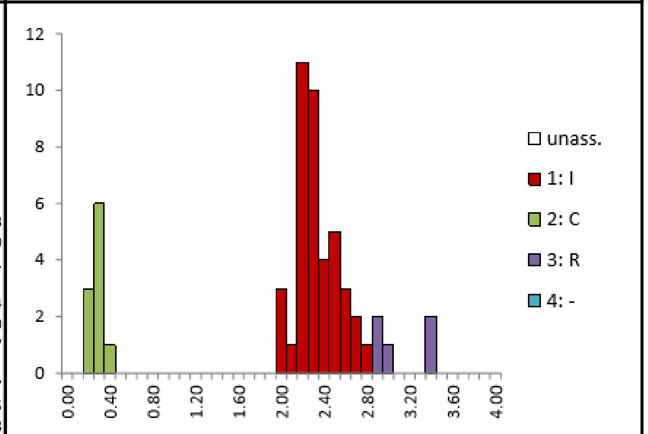
STATISTICS

POPN 1 - Indigenous
Mean value: 2.38
No. of values: 40
Range: 2.07 to 2.81

POPN 2 - Caved
Mean value: 0.34
No. of values: 10
Range: 0.26 to 0.47

POPN 3 - Reworked
Mean value: 3.17
No. of values: 5
Range: 2.90 to 3.48

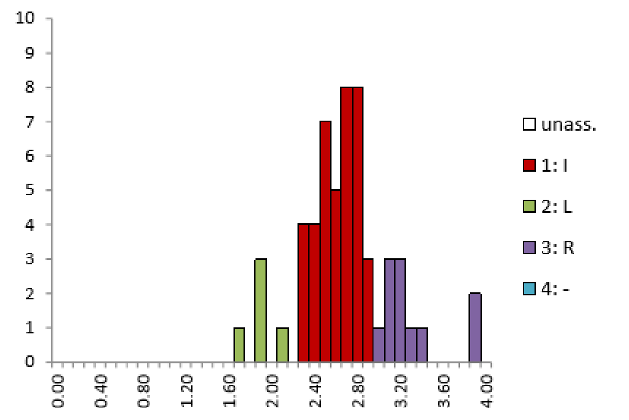
POPN 4 - n/a



0.26	0.35	2.07	2.20	2.25	2.30	2.33	2.40	2.53	2.62	2.90
0.29	0.35	2.08	2.21	2.25	2.32	2.36	2.42	2.56	2.69	2.96
0.29	0.36	2.08	2.22	2.27	2.32	2.37	2.43	2.56	2.73	3.06
0.30	0.38	2.18	2.22	2.28	2.32	2.39	2.44	2.56	2.74	3.47
0.32	0.47	2.20	2.24	2.29	2.33	2.39	2.51	2.61	2.81	3.48

SAMPLE DATA
DEPTH/ORDER: 20800
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

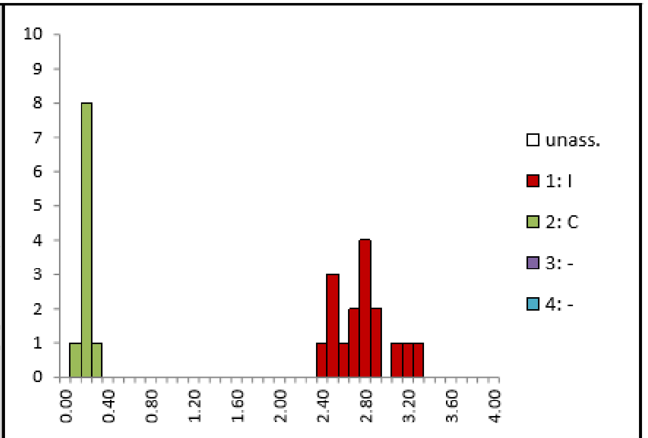
STATISTICS
POPN 1 - Indigenous
Mean value: 2.66
No. of values: 39
Range: 2.33 to 2.93
POPN 2 - Low reflecting
Mean value: 1.94
No. of values: 5
Range: 1.79 to 2.15
POPN 3 - Reworked
Mean value: 3.34
No. of values: 11
Range: 2.96 to 3.91
POPN 4 - n/a



1.79	2.33	2.46	2.54	2.63	2.70	2.78	2.82	2.88	3.11	3.26
1.90	2.34	2.48	2.54	2.63	2.72	2.78	2.83	2.90	3.13	3.34
1.90	2.36	2.48	2.54	2.66	2.73	2.79	2.84	2.93	3.17	3.46
1.97	2.37	2.50	2.57	2.69	2.73	2.80	2.86	2.93	3.21	3.90
2.15	2.46	2.52	2.58	2.69	2.76	2.81	2.86	3.05	3.25	3.91

SAMPLE DATA
DEPTH/ORDER: 22300
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

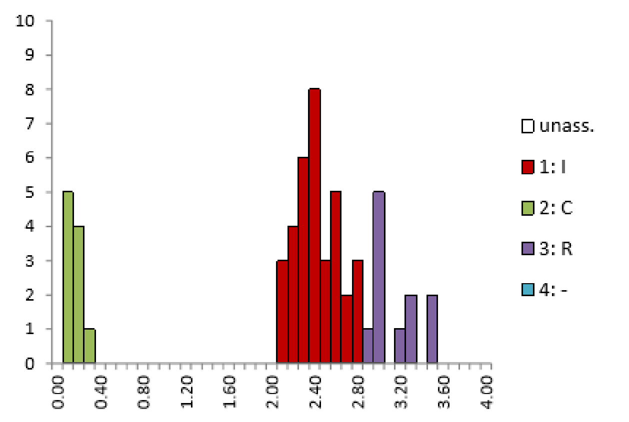
STATISTICS
POPN 1 - Indigenous
Mean value: 2.83
No. of values: 16
Range: 2.42 to 3.33
POPN 2 - Caved
Mean value: 0.25
No. of values: 10
Range: 0.18 to 0.30
POPN 3 - n/a
POPN 4 - n/a



0.18	0.25	2.42	2.70	2.86	3.33
0.22	0.26	2.53	2.78	2.96	
0.25	0.27	2.55	2.81	2.97	
0.25	0.28	2.58	2.82	3.19	
0.25	0.30	2.68	2.86	3.20	

SAMPLE DATA
DEPTH/ORDER: 20890
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

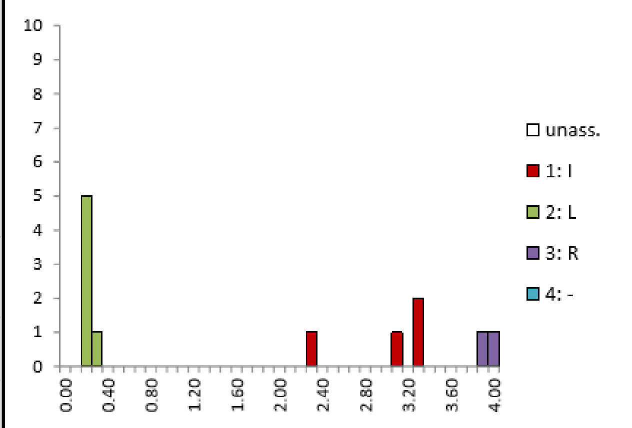
STATISTICS
POPN 1 - Indigenous
Mean value: 2.47
No. of values: 34
Range: 2.10 to 2.81
POPN 2 - Caved
Mean value: 0.20
No. of values: 10
Range: 0.15 to 0.30
POPN 3 - Reworked
Mean value: 3.19
No. of values: 11
Range: 2.91 to 3.55
POPN 4 - n/a



0.15	0.21	2.10	2.27	2.35	2.42	2.48	2.66	2.78	3.01	3.22
0.16	0.22	2.17	2.29	2.36	2.42	2.50	2.67	2.80	3.04	3.30
0.16	0.22	2.19	2.30	2.38	2.43	2.54	2.68	2.81	3.05	3.39
0.17	0.24	2.20	2.34	2.40	2.44	2.55	2.68	2.81	3.08	3.50
0.19	0.30	2.24	2.35	2.41	2.47	2.61	2.78	2.91	3.09	3.55

SAMPLE DATA
DEPTH/ORDER: 22500
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

STATISTICS
POPN 1 - Indigenous (?)
Mean value: 3.03
No. of values: 4
Range: 2.34 to 3.33
POPN 2 - Low reflecting
Mean value: 0.25
No. of values: 6
Range: 0.22 to 0.32
POPN 3 - Reworked
Mean value: 4.28
No. of values: 2
Range: 3.94 to 4.62
POPN 4 - n/a



0.22	0.32	3.94
0.22	2.34	4.62
0.22	3.14	
0.23	3.31	
0.28	3.33	

SAMPLE DATA

DEPTH/ORDER: 22900
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: 0
APT-ID.: 0

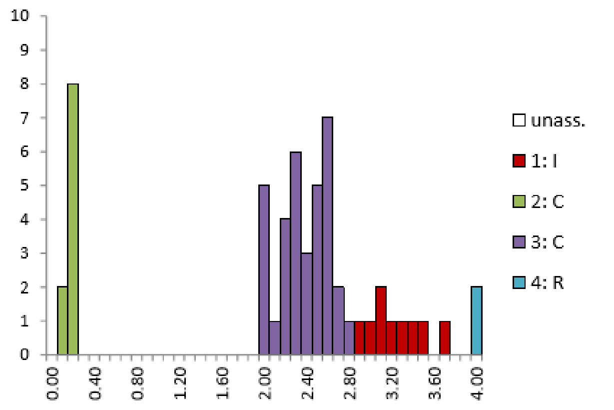
STATISTICS

POPN 1 - Indigenous (?)
Mean value: 3.29
No. of values: 9
Range: 2.95 to 3.70

POPN 2 - Caved
Mean value: 0.24
No. of values: 10
Range: 0.19 to 0.27

POPN 3 - Caved
Mean value: 2.43
No. of values: 34
Range: 2.04 to 2.85

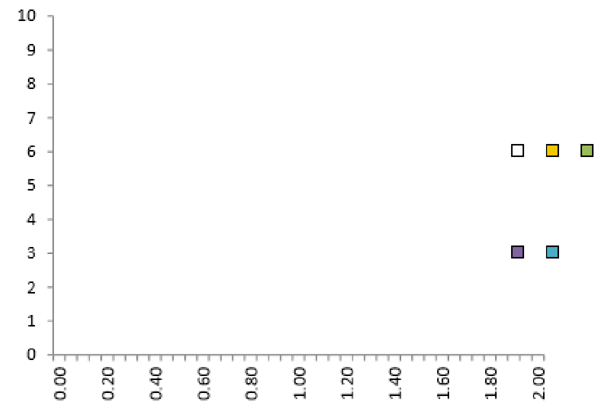
POPN 4 - Reworked
Mean value: 4.10
No. of values: 2
Range: 4.06 to 4.13



0.19	0.25	2.04	2.17	2.32	2.39	2.53	2.62	2.68	3.05	3.46
0.19	0.26	2.06	2.22	2.34	2.41	2.57	2.65	2.76	3.16	3.54
0.24	0.27	2.07	2.28	2.35	2.45	2.57	2.66	2.78	3.17	3.70
0.24	0.27	2.07	2.29	2.35	2.46	2.59	2.68	2.85	3.23	4.06
0.24	0.27	2.08	2.29	2.37	2.50	2.60	2.68	2.95	3.33	4.13

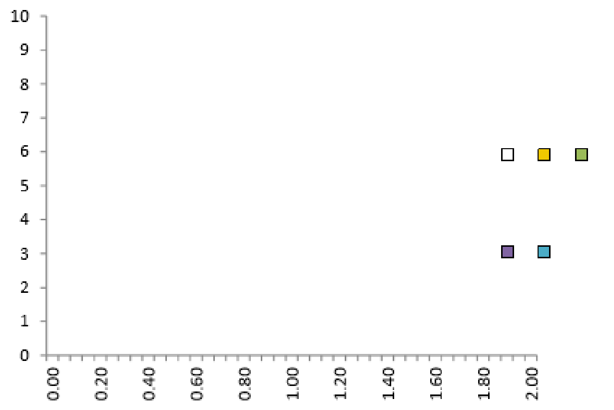
SAMPLE DATA

STATISTICS



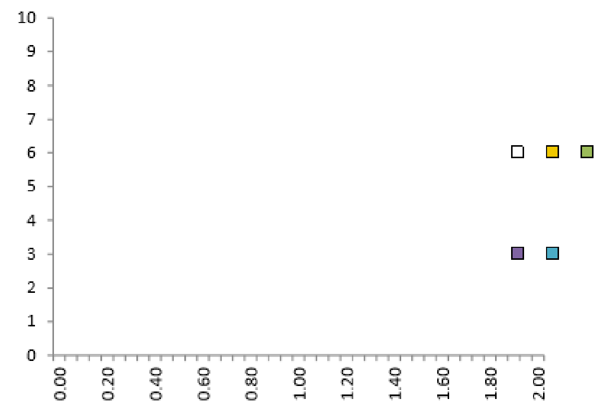
SAMPLE DATA

STATISTICS



SAMPLE DATA

STATISTICS



SAMPLE DATA

DEPTH/ORDER: 9710
SAMPLE-ID: 0
SAMPLE TYPE: DC
BLOCK TYPE.: Kerogen
BLOCK No..: n.a.
APT-ID.: n.a.

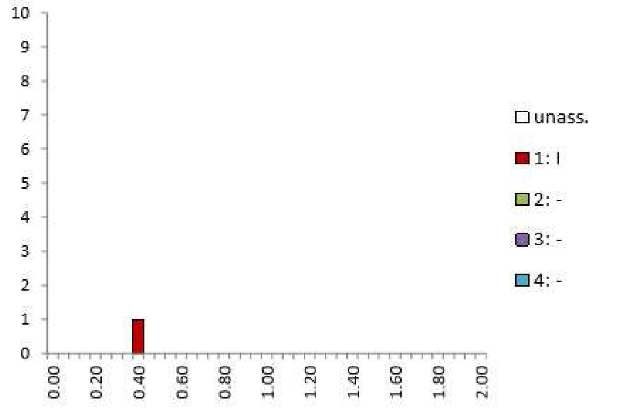
STATISTICS

POPN 1 - Indigenous
Mean value: 0.44
No. of values: 1
Range: 0.44 to 0.44

POPN 2 - n/a

POPN 3 - n/a

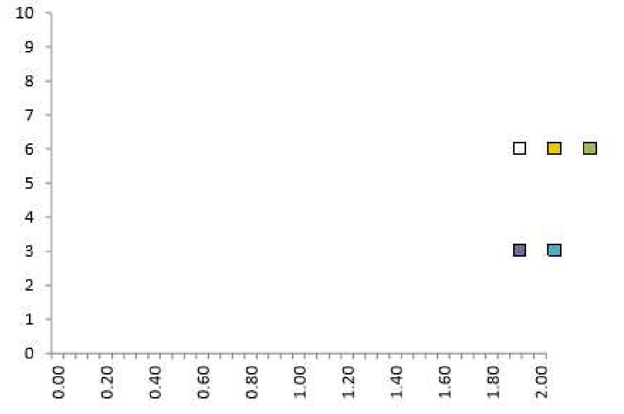
POPN 4 - n/a



0.44

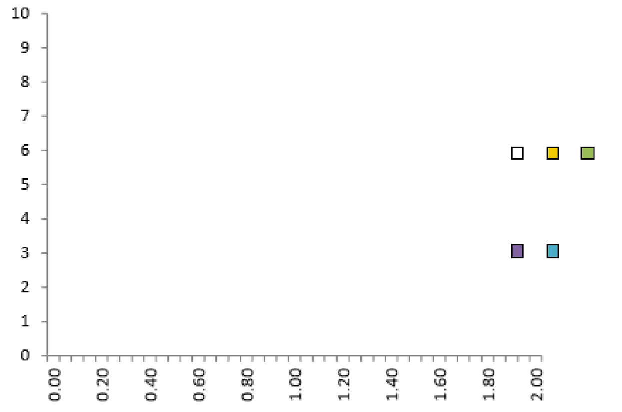
SAMPLE DATA

STATISTICS



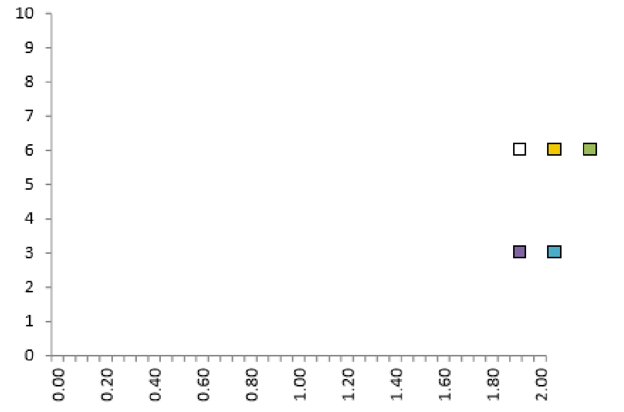
SAMPLE DATA

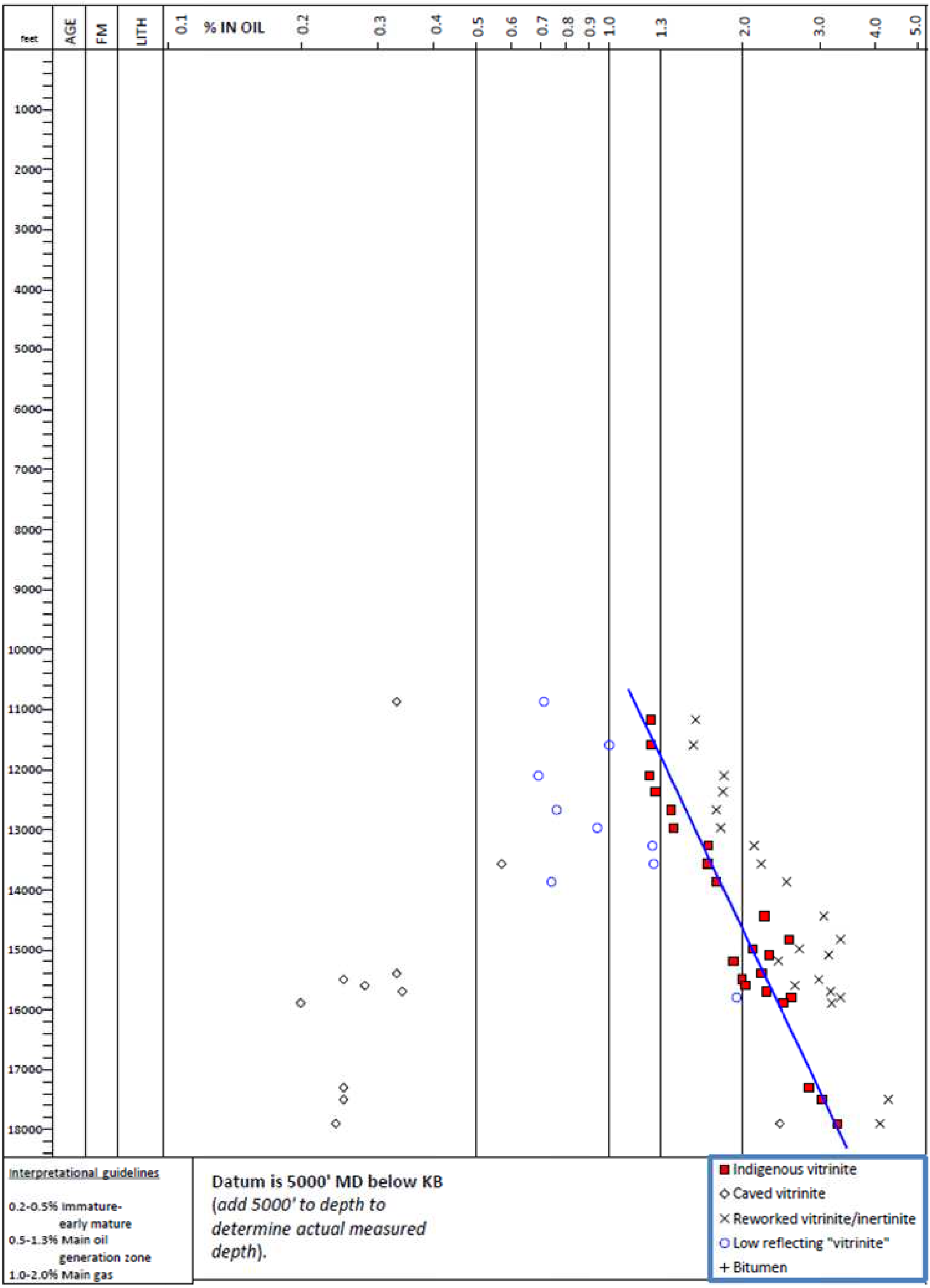
STATISTICS



SAMPLE DATA

STATISTICS




feet
AGE
FM
LITH
% IN OIL
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.3
2.0
3.0
4.0
5.0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
17000
18000
Interpretational guidelines
0.2-0.5% Immature-early mature
0.5-1.3% Main oil generation zone
1.0-2.0% Main gas
Datum is 5000' MD below KB (add 5000' to depth to determine actual measured depth).
Indigenous vitrinite
Caved vitrinite
Reworked vitrinite/inertinite
Low reflecting "vitrinite"
Bitumen