The Jurassic (Pliensbachian to Kimmeridgian) palynology of the Algarve Basin and the Carrapateira outlier, southern Portugal

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ABSTRACT

The palynology of the Jurassic (Upper Pliensbachian to Lower Kimmeridgian) fill of the Algarve Basin and the Carrapateira outlier, southern Portugal was investigated. Samples were collected from Armação Nova Bay, Mareta Beach, Cilheta Beach and the Carrapateira outlier. At Armação Nova Bay the Upper Pliensbachian-Lower Toarcian succession proved barren, or yielded sparse, non age-diagnostic palynomorphs. Dinoflagellate cysts are confined to the Upper Bajocian to Upper Callovian sedimentary rocks exposed at Mareta and Cilheta beaches and the Lower Kimmeridgian strata of the Carrapateira outlier. At Mareta Beach, the Upper Bajocian, Bathonian and Callovian produced relatively low to moderate diversity dinoflagellate cyst assemblages. Several key bioevents confirm the Bathonian and Callovian ages of the succession; no age-significant Late Bajocian bioevents were noted. The Upper Callovian of Cilheta Beach yielded moderately diverse dinoflagellate cyst associations dominated by *Ctenidodinium* spp. Key Late Callovian bioevents confirm the age of this succession. Many familiar marker forms known from northwest Europe were not encountered. No typically Arctic forms were recovered throughout the Upper Bajocian to Callovian of this part of the Algarve Basin. It is clear that there was no significant Late Bajocian to Late Callovian dinoflagellate cyst provincialism within southern and northern Europe and adjacent regions. The Carrapateira outlier yielded a moderately diverse Early Kimmeridgian dinoflagellate cyst flora. The Early Kimmeridgian age assessment based on corals and foraminifera is confirmed. *Amphorula* and *Histiophora* are present; these are typical of the Late Jurassic of the Tethyan Realm, and their presence is consistent with Late Jurassic provincialism within Europe. The relatively low diversity nature of these Late Bajocian to Lower Kimmeridgian dinoflagellate cyst floras is probably mainly due to the relatively deep water, partially enclosed depositional setting. The partially enclosed nature of this part of the Algarve Basin and the Carrapateira outlier seems to have prevented the free migration of dinoflagellates between southern Portugal and elsewhere in Europe.

Keywords: biostratigraphy; palynology; Jurassic; Algarve Basin; Carrapateira outlier; Portugal

1. Introduction

The Algarve Basin is an important Mesozoic depocentre in southern Portugal (Fig. 1). It is located south of the Palaeozoic-dominated “Serra Algarvia” and mainly comprises Jurassic and Lower Cretaceous limestones. This maritime region is locally known as the ‘Barrocal’ and the carbonate-dominated lithologies have given rise to gentle karst topography with west-east aligned fold axes and faults. The basin extends from Cape Saint Vincent in the west to the Guadiana River on the Portuguese-Spanish border in the east (Fig. 1). In the western part of the basin, the Upper Triassic, Jurassic and Lower Cretaceous succession is superbly exposed in sea cliffs between Cape Saint Vincent and Lagos. The Jurassic outcrops of the Carrapateira outlier, located around 20 km north of Sagres (Fig. 1), represent a northerly extension of the Algarve Basin.

This sedimentary basin was initiated by rifting associated with the opening of the North and Central Atlantic Ocean, following the breakup of Pangea. However, due to its location, the Algarve Basin was also influenced by the formation of the Neo-Tethys Ocean. The evidence for a Tethyan influence is largely from the dominance of sub-Mediterranean Late Pliensbachian to Tithonian ammonite faunas (Rocha, 1976). Typically boreal ammonites (*Amaltheidea*) did migrate southwards into the Algarve Basin during the Late Pliensbachian, however they never became dominant (Rocha, 1976). Furthermore, Late Sinemurian benthic foraminifera with Tethyan affinities represent further evidence that the Algarve Basin was part of the Tethyan Realm during the Early Jurassic (Azerêdo et al., 2003).

Short term compressional phases within the broad extensional framework occurred during the Jurassic in the Algarve Basin (Terrinha et al., 2002). These tectonic events may have at least partially isolated the basin thereby preventing the mixing of Tethyan and boreal faunas, especially during the Toarcian-Aalenian and the Callovian-Oxfordian intervals. The Algarve Basin thus straddled the Tethyan and boreal palaeogeographical realms, making it an extremely important depocentre in terms of the Jurassic biogeography in Western Europe.

Lateral facies changes across the Algarve Basin, allow its division into the Western (Sagres), the Budens-Lagoa, and the Eastern (Faro) subbasins (Manuppella et al., 1988; Fig. 1). These relatively small depocentres are separated by major regional faults which were probably active during deposition. Sedimentation in the Algarve Basin commenced with Upper Triassic continental red beds and evaporites which unconformably overlie Upper Palaeozoic strata (Palain, 1976). These Upper Triassic strata are overlain by Early Jurassic (Hettangian) volcanic rocks associated with the Central Atlantic Magmatic Province (CAMP). Following this important magmatic event, Sinemurian to Tithonian marine carbonate sedimentation became well-established across the Algarve basin. The dominant lithofacies are shallow water limestones and cycles of pelagic marls and limestones. The Lower Cretaceous is represented by a mixed clastic and carbonate succession, deposited in nearshore and terrestrial settings (Rey, 2006). During the Late Cretaceous, a major basin inversion event occurred, related to Alpine tectonism and the emplacement of the Late Cretaceous (Campanian, ca. 72 Ma) syenite of Monchique into Upper Palaeozoic strata (Terrinha et al., 2002; Miranda et al., 2009). Therefore, no Upper Cretaceous strata are present in the

Algarve Basin. Sedimentation resumed during the Miocene with bioclastic limestones which unconformably overlie the Jurassic and Lower Cretaceous succession.

Palynological studies of the Mesozoic of the Algarve Basin are largely on the Lower Cretaceous (e.g. Berthou and Leereveld, 1990; Heimhofer et al., 2003; 2007). There are only two published reports of Jurassic palynomorphs from the Algarve Basin. The first was Fechner (1989), on the Lower Jurassic salt diapir at Loulé; the second is a brief description of the Middle Jurassic palynofloras of Mareta Beach by Oliveira et al. (2009). The present contribution is a preliminary account of the Pliensbachian to Kimmeridgian palynology of the Algarve Basin near Sagres and in the Carrapateira outlier. Davies (1985), Mohr and Schmidt (1988), Smelror et al. (1991), Smelror (1993), Bucefalo Palliani and Riding (1999; 2003) and Oliveira et al. (2007) documented the Sinemurian to Kimmeridgian palynology of the Lusitanian Basin, west-central Portugal.

2. Geological background

The Sagres region is the reference area for the Mesozoic fill of the Western subbasin. Jurassic strata outcrop spectacularly in the cliffs between Cape Saint Vincent and Mareta Bay (Fig. 2). The Jurassic stratigraphy and palaeontology of the Sagres area was described by Choffat (1887) and Rocha (1976).

The Lower Jurassic is well-represented at Cape Saint Vincent and Armação Nova (Fig. 2). At Cape Saint Vincent, an extensive (>30 m) ?Sinemurian to Lower Pliensbachian carbonate-dominated succession is organic-lean, probably due to the intensely dolomitised nature of these beds. A well-exposed Lower Toarcian succession approximately 35 m thick occurs at Armação Nova Bay, 1 km northeast of Cape Saint Vincent (Fig. 2). The base consists of intensely dolomitised limestones, of probable Late Pliensbachian age, passing upwards to interbedded marls and bioclastic limestones (Fig. 3). The bases of the limestone beds exhibit normal grading, longitudinal scours and flute casts, and the tops are rich in *Zoophycos* traces. The scour casts and the bioclastic character of the limestone beds suggest that they represent turbidites, however evidence of bioturbation mitigates against this interpretation.

Middle Jurassic strata are well exposed at Mareta Bay (Figs. 2, 4). The base of the succession consists of coral bioherms with karstified tops. There are no marker fossils in the bioherms; however the karst cavities are filled and covered by Upper Bajocian bioclastic limestones and Middle Bathonian marls. This indicates that the karstification was pre-Late Bajocian, and that the bioherms are therefore of Aalenian to Early Bajocian age. At beach level there is a conglomerate which overlies the bioherms. This is dominated by limestone clasts and these include clasts of the bioherms. The conglomerate is coeval with the palaeokarstification event, and exhibits lateral thickness changes. Overlying the conglomerate is a ca. 8 m thick succession of Upper Bajocian limestones with *Zoophycos* (see Rocha, 1976). The youngest strata are a 120 m thick succession of grey marls that grade into marly limestones which have been affected by several slump events (Fig. 4). Ammonite faunas indicate a Callovian age (Rocha, 1976).

Following the deposition of the Callovian strata a tectonic event, observed throughout Iberia, folded the Middle Jurassic succession. This is observed at Cilheta Beach, where Upper Jurassic limestones rest unconformably on gently-folded Callovian marly limestones and marls (Figs. 2, 5). Above the unconformity is a highly fossiliferous matrix-supported conglomerate with ammonites indicative of the Middle Oxfordian Plicatilis Chronozone. This bed is overlain by 200 m of Upper Jurassic interbedded limestones, marls and dolomite (Fig. 5).

The Carrapateira outlier is located around 20 km north of Sagres, and preserves an Upper Triassic to Upper Jurassic succession which is closely genetically related to the fill of the Algarve Basin. The base of this succession outcrops at the northern part of Amado Beach and consists of Upper Triassic-Lower Jurassic red fluviatile sandstones and claystones that grade into limestones (Figs. 2, 6). These Lower and Middle Jurassic limestones are strongly dolomitised and have proved devoid of palynomorphs. However, the 50 m of Upper Jurassic interbedded limestones and marls at Três Angras is undolomitised (Ribeiro et al., 1987). Bioclastic limestones and conglomerates pass into interbedded marls and limestones (Fig. 6). The uppermost limestone beds are rich in macrofossils including well-preserved corals in life position. The macrofauna indicates an Early Kimmeridgian age (Ribeiro et al., 1987).

3. Material and methods

All the samples in this study were collected from outcrops at Armação Nova Bay, Mareta Beach, Cilheta Beach and the Carrapateira outlier (Figs. 2-6). They were prepared using standard palynological processing techniques involving acid digestion (Wood et al., 1996). The organic residue was sieved using a 15 µm mesh sieve and the palynomorph concentrates were mounted on slides using Entellan® resin. All sample materials, slides and figured specimens are housed in the collections of the LGM/LNEG (Portugese Geological Survey), S. Mamede Infesta, Portugal.

4. Palynology

Palynomorphs from Lower Jurassic (Upper Pliensbachian-Lower Toarcian), Middle Jurassic (Upper Bajocian, Bathonian and Callovian) and Upper Jurassic (Lower Kimmeridgian) strata from four localities in southwest Portugal were studied (Figs. 3-6). The assemblages recovered are described and interpreted in this section. Selected dinoflagellate cysts are illustrated in Plate 1. The author citations and references pertaining to the dinoflagellate cysts can be found in Appendices 1 and 2 and Fensome and Williams (2004) respectively.

4.1. Armação Nova Bay

Fourteen samples were collected from the Lower Jurassic outcrops at Armação Nova Bay, 1 km north east of Cape Saint Vincent (Fig. 3). Note that five samples (A9 through A13) were taken from the marly limestone bed at ca. 27 m. This succession is considered to be of Late Pliensbachian to Early Toarcian age (Rocha, 1976). These beds are devoid of palynomorphs due to their highly dolomitic nature and winnowing effects during deposition. The uppermost beds are less dolomitised and are correlated to the Tenuicostatum Chronozone (largely the Semicelatum Subchronozone) (Fig. 3). These samples (A6-A16) proved extremely palynologically sparse. Acanthomorph acritarchs

(*Micrhystridium* spp.) and miospores were recorded in extremely low proportions. The organic residues are dominated by resistant mineral grains and fragments of black wood. Dinoflagellate cysts proved absent, hence it is not possible to effect comparisons with the low diversity Late Pliensbachian assemblages recorded from the Lusitanian Basin by Oliveira et al. (2007).

4.2. Mareta Beach

The coastal cliff exposures at Mareta Beach, south of Sagres (Figs. 1, 2) represent an important reference section. A composite, sporadically fossiliferous succession of interbedded limestones and marls >140 m thick is exposed (Fig. 4). This section was assigned to the Late Bajocian to ?Late Oxfordian/Kimmeridgian by Choffat (1887) and Rocha (1976). Forty-nine samples were collected from this succession (Fig. 4, Table 1). The palynofloras were briefly described by Oliveira et al. (2009). This sample set is viewed as preliminary; more samples will be studied in future.

The palynomorph assemblages are outlined in Table 1. The residues which proved productive are relatively abundant and include moderately well-preserved palynomorphs and dark woody phytoclasts. Pollen and spores are consistently the dominant palynomorph group, with marine microplankton (i.e. acritarchs, dinoflagellate cysts, foraminiferal test linings and prasinophytes) being subordinate. The miospore assemblages are relatively consistent throughout this succession and include bisaccate pollen, *Callialasporites dampieri*, *Callialasporites turbatus, Callialasporites* spp., *Classopollis classoides***,** *Cyathidites* spp., *Ischyosporites variegatus*, *Leptolepidites* spp., *Perinopollenites elatoides* and *Sestrosporites pseudoalveolatus* (Table 1)**.**

4.2.1 Late Bajocian

Four samples were studied from the Late Bajocian. Samples M1 and M14 proved barren and virtually devoid of palynomorphs respectively. By contrast, samples M19 and M15 yielded workable assemblages (Table 1). Sample M19 proved richest in palynomorphs. Dinoflagellate cysts recognised include *Ctenidodinium cornigerum*, the

Ctenidodinium sellwoodii group, *Ctenidodinium* spp., *Korystocysta gochtii, Korystocysta pachyderma,* the *Meiourogonyaulax caytonensis* group, *Pareodinia ceratophora, Sentusidinium* spp., *Valensiella ovulum* and *Valensiella* spp. (Table 1). This low-diversity assemblage is dominated by forms with epicystal archaeopyles. No exclusively Bajocian markers such as *Cribroperidinium crispum, Endoscrinium asymmetricum* of Feist-Burkhardt and Wille (1992) and *Meiourogonyaulax valensii* were observed (Woollam and Riding, 1983; Feist-Burkhardt and Wille, 1992; Riding and Thomas, 1992; Feist-Burkhardt and Monteil, 1997). Furthermore, no taxa with Bathonian or younger range bases such as *Adnatosphaeridium caulleryi, Meiourogonyaulax reticulata* and *Sirmiodinium grossii* were recorded (Riding, 1987; Prauss, 1989; Feist-Burkhardt and Wille, 1992; Riding and Thomas, 1992). Hence the Late Bajocian dinoflagellate cyst assemblage from Mareta Beach cannot provide a refined age assessment; however, it is consistent with the Late Bajocian-Bathonian interval due to the presence of forms such as *Ctenidodinium cornigerum* and *Korystocysta pachyderma* (see Prauss, 1989, fig. 49; Riding and Thomas, 1992, fig. 2.10).

This association, despite the relatively low-diversity, is similar in taxonomic content to other Late Bajocian marine palynofloras from western Europe (e.g. Prauss, 1989; Feist-Burkhardt and Monteil, 1997). Unsurprisingly, no characteristic boreal taxa such as *Phallocysta thomasii* and *Valvaeodinium aquilonium* were observed. The latter taxa are presumably coldwater forms which are part of a characteristic assemblage restricted to northern Europe and the Arctic (Smelror, 1991; Smelror and Below, 1992).

4.2.2 Bathonian

Eighteen samples were studied from the Bathonian strata of Mareta Beach. Nine of these (M3, M4, M6, M7, M8, M9, M13, M10 and M21) produced relatively abundant palynofloras. The remainder proved either entirely barren or extremely sparse palynologically. The lowermost productive samples, M3 and M4 are from a prominent marl bed which overlies the prominent Upper Bajocian calcarenite. This marl was assigned to the Early Bathonian by Rocha (1976). The distribution of palynomorphs is illustrated in Table 1. Dinoflagellate cysts recorded include *Adnatosphaeridium caulleryi, Batiacasphaera* spp., *Ctenidodinium continuum, Ctenidodinium cornigerum,* the *Ctenidodinium sellwoodii* group, *Ctenidodinium* spp., *Ellipsoidictyum/Valensiella* group, *Epiplosphaera gochtii, Gonyaulacysta jurassica* subsp. *adecta, Korystocysta gochtii, Korystocysta pachyderma, Korystocysta* spp., the *Meiourogonyaulax caytonensis* group, *Meiourogonyaulax* spp., *Mendicodinium groenlandicum, Pareodinia ceratophora, Sentusidinium* spp., *Systematophora areolata, Tubotuberella dangeardii* and *Valensiella ovulum* (Table 1). Forms with epicystal archaeopyles are prominent in this moderately diverse assemblage. This is typical of the Bathonian Stage of Europe (Riding et al., 1985; 1991; 1999). More specifically, it is similar in nature to the Bathonian assemblages reported from the Lusitanian Basin, eastern central Portugal by Davies (1985, fig. 8) and Smelror et al. (1991, fig. 7). The presence of forms such as *Adnatosphaeridium caulleryi, Ctenidodinium cornigerum,* the *Ctenidodinium sellwoodii* group, *Ctenidodinium* spp., the *Ellipsoidictyum/Valensiella* group, *Gonyaulacysta jurassica* subsp. *adecta, Korystocysta* spp. and *Valensiella ovulum* is characteristic of the Bathonian Stage (e.g. Gocht, 1970; Sarjeant, 1976; Fenton et al., 1980; Taugourdeau-Lantz and Lachkar, 1984; Riding et al., 1985; Prauss, 1989; Riding and Thomas, 1992). Specifically, the range bases of *Adnatosphaeridium caulleryi, Gonyaulacysta jurassica* subsp. *adecta*, *Mendicodinium groenlandicum* and *Tubotuberella dangeardii* are intra-Early Bathonian (Riding et al., 1985; Prauss, 1989; Feist-Burkhardt and Wille, 1992). The range top of *Ctenidodinium cornigerum* is Late Bathonian (Riding and Thomas, 1992, fig. 2.10). Thus the Bathonian age of these samples from Mareta Beach is confirmed on dinoflagellate cyst evidence; however the biostratigraphical resolution is not at the substage level. However, no exclusively Bathonian markers such as *Jansonia manifesta* and *Meiourogonyaulax reticulata* were recovered (Riding et al., 1991; Riding and Thomas, 1992).

The presence of *Systematophora areolata* is interesting; this is the first report of this species from the Bathonian since that of Bujak and Williams (1977, fig. 2A) from easetern Canada. By far the majority of reports of this species, and related forms, record its range base as Early to Middle Oxfordian (e.g. Kunz, 1990; Riding and Thomas, 1997; Riding, 2005). However occasional reports of *Systematophora* are known from the Callovian (e.g. Huber et al., 1987; Prauss, 1989).

Ctenidodinium combazii is prominent in the Bathonian of southern England (Riding et al., 1985). This distinctive taxon is not widespread, and was not recorded from Mareta Beach. Riding et al. (1985) contended that the highly-ornamented

Ctenidodinium combazii preferred stable, open marine conditions and was not tolerant of environmental fluctuations and stresses. In contrast, less ornamented forms such as *Ctenidodinium sellwoodii* and *Korystocysta* spp. were geographically-widespread and consequently were more environmentally tolerant. *Ctenidodinium combazii* appears to have been restricted to the Bathonian of part of northwest Europe (England, Germany, France, The Netherlands). It has not been recorded from localities in the Tethyan region such as Iberia or Israel (Conway, 1978; 1990; Davies, 1983). Hence it is possible that the distribution of *Ctenidodinium combazii* was at least partially controlled by latitude. Smelror et al. (1991, fig. 7) reported this species from the Early Callovian (Herveyi [previously Macrocephalus] Chronozone) in the Lusitanian Basin, central Portugal.

As mentioned above, the Bathonian dinoflagellate cyst assemblage from Mareta Beach is similar to coeval floras from northwest Europe. The Bathonian was a time of significant provincialism in the Northern Hemisphere (Riding et al., 1999). Boreal forms such as *Evansia perireticulata, Lacrymodinium warrenii, Paragonyaulacysta* spp. and *Valvaeodinium thereseae* were unsurprisingly not recorded from the Algarve Basin. The latter taxa are presumed to be cold-loving/Arctic forms (Bailey and Partington, 1991; Smelror and Below, 1992).

4.2.3 Callovian

Twenty-seven samples were studied from the Callovian succession exposed at Mareta Beach. Thirteen of these proved entirely palynologically barren; the remaining 14 samples yielded palynofloras of variable productivity. The productive samples are overwhelmingly in the Lower and Middle Callovian; by contrast the Upper Callovian succession proved largely devoid of palynomorphs (Table 1). Samples M25, M27 and M28 are from a marl-dominated unit, which is considered to be Early Callovian in age, and was assigned to the Herveyi Chronozone by Rocha (1976). The interbedded limestones and marls above the stratigraphical break between 37 and 57 m were assigned to the Middle Callovian (Coronatum Chronozone) by Rocha (1976). The palynomorph distribution is illustrated in Table 1. The dinoflagellate cysts recorded include *Batiacasphaera* spp., *Chytroeisphaeridia chytroeides*, the *Ctenidodinium sellwoodii* group, *Ctenidodinium* spp., the *Ellipsoidictyum/Valensiella* group, *Epiplosphaera gochtii*, *Gonyaulacysta jurassica* subsp. *adecta*, *Gonyaulacysta* sp., *Impletosphaeridium* spp., *Korystocysta gochtii, Korystocysta* spp., the *Meiourogonyaulax caytonensis* group, *Meiourogonyaulax* spp., *Mendicodinium groenlandicum, Pareodinia ceratophora, Sentusidinium* spp., *Systematophora areolata, Systematophora penicillata, Systematophora* spp., *Tubotuberella dangeardii, Tubotuberella spp., Valensiella ovulum* and *Valensiella* spp. (Table 1). Of this association, the *Ctenidodinium sellwoodii* group is the most prominent.

This assemblage is of moderate diversity and is typical of the Callovian of Europe. The consistent presence of forms such as *Ctenidodinium continuum,* the *Ctenidodinium sellwoodii* group, *Gonyaulacysta jurassica* subsp. *adecta, Korystocysta gochtii,* the *Meiourogonyaulax caytonensis* group, *Meiourogonyaulax* spp., *Mendicodinium groenlandicum* and *Tubotuberella dangeardii* is characteristic of the Callovian Stage (e.g. Prauss, 1989; Riding and Thomas, 1997; Riding, 2005). Smelror et al. (1991, fig. 7) reported a similar flora with prominent *Ctenidodinium sellwoodii* from Cape Mondego in the Lusitanian Basin of central Portugal.

The Early Callovian (Herveyi Chronozone) samples M25, M26, M27 and M28 lack Early Callovian dinoflagellate cyst markers known from further north in Europe such as *Chytroeisphaeridia hyalina, Ctenidodinium combazii* and *Impletosphaeridium varispinosum.* Species of *Systematophora* are present; further north the inception of this genus is normally within the Oxfordian (see above). Likewise, ?*Leptodinium* sp. is present in sample M25; this genus is normally present in Oxfordian and younger strata (e.g. Riding and Thomas, 1992). *Liesbergia liesbergensis* was recovered from sample M27 (Table 1). This species is present from the Middle Callovian-Early Oxfordian interval (Berger, 1986; Riding and Thomas, 1997).

The occurrence of *Ctenidodinium ornatum* in the Middle Callovian sample M47 is potentially significant. This species is typical of the Middle-Upper Callovian of northwest Europe (Berger, 1986). *Endoscrinium asymmetricum* was recorded from sample M47 and questionably in M45 (Table 1). This species is typical of the Early-Middle Callovian interval (Riding, 1987; 2005; Riding and Thomas, 1997). The chorate taxon *Impletosphaeridium varispinosum* is confined to sample M48 (Table 1). This is the first report of this taxon from southern Europe. Elsewhere in northwest Europe, this species is confined to the Early Callovian (Riley and Fenton, 1982; Riding and Thomas, 1997; Riding, 2005). Sample M47 yielded small proportions of *Rhynchodiniopsis*?

regalis (Table 1). This distinctive form is typical of the Bajocian-Bathonian further north in Europe (e.g. Riding et al., 1985; Feist-Burkhardt and Wille, 1992). The only occurrence of the genus *Wanaea* in this study is the record of *Wanaea acollaris* in sample M45 (Table 1). This is entirely consistent with a Callovian age (Riding and Thomas, 1992). The only productive sample in the Upper Callovian, M32, produced a relatively low diversity flora similar to those from the underlying Middle Callovian (Table 1).

Callovian dinoflagellate cyst floras from further north in Europe are normally markedly higher in diversity than those recorded herein. The majority of Callovian biomarkers known in northwest Europe are apparently absent in the Algarve Basin. No unequivocal intra-Callovian markers were recovered from Mareta Beach. These include the many forms which typically have range bases in the Late Callovian such as *Scriniodinium crystallinum, Trichodinium scarburghensis* and *Wanaea thysanota* (see Riley and Fenton, 1982; Feist-Burkhardt and Wille, 1992; Riding and Thomas, 1992). Despite the lack of these biomarkers, the occurrences of *Ctenidodinium ornatum* (sample M47), *Endoscrinium asymmetricum* (M47), *Impletosphaeridium varispinosum* (M48) and *Wanaea acollaris* (M45) is broadly consistent with a Middle Callovian (Coronatum Chronozone) age.

The relatively low diversity nature of this dinoflagellate cyst flora was probably influenced by several factors. The Mareta Beach succession represented relatively deep water conditions, seaward of reef limestone facies within a highly enclosed basin. Rocha (1976) envisaged an offshore pelagic setting, possibly with stratified water and occasional upwelling within a restricted marine environment. The latter interpretation is not consistent with the palynofacies, which is not typical of highly organic-rich facies and the occurrence of benthic faunas (largely echinoderms, foraminifera, gastropods, ostracods and the ichnogenus *Zoophycos*). The relatively restricted nature of the marine waters at this locality probably prevented communication with many dinoflagellate cysts typical of further north in Europe which explains the low-diversity floras. Boreal taxa such as *Evansia dalei, Evansia perireticulata, Paragonyaulacysta calloviensis* and *Paragonyaulacysta retiphragmata* were not recorded from Mareta Beach. The latter taxa are cold-loving/Arctic forms (Smelror and Below, 1992; Riding et al., 1999).

4.3. Cilheta Beach

Cilheta lies 1 km west of Sagres, and the cliffs expose a sparsely fossiliferous, carbonate-dominated succession 41 m thick which has been assigned to the Late Callovian to the ?Late Oxfordian-Kimmeridgian interval by Rocha (1976) (Fig. 5). At sea level to 22 m, a unit of marly limestone with two thin (<1.0 m) marly interbeds is exposed. These beds were deemed to be of Late Callovian (Athleta Zone) age by Rocha (1976). Eleven samples were taken from this Upper Callovian unit (Fig. 5). The Upper Callovian is unconformably overlain by a thin (ca. 0.5 m) fossiliferous limestone of Middle Oxfordian (Plicatilis Chronozone) age (Fig. 5). This unconformity is markedly angular and extremely prominent (Choffat, 1887; Rocha, 1976, fig. 2.12). It represents a regional hiatus which can be traced throughout Iberia (Mouterde, 1971). The youngest unit at Cilheta Beach comprises approximately 20 m of dolomitised limestones of Late Oxfordian-Kimmeridgian age (Fig. 5).

The two marl beds in the Upper Callovian succession at Cilheta produced relatively abundant organic residues which are dominated by dinoflagellate cysts with subordinate pollen and spores. By contrast, the marly limestones largely proved palynologically barren (Fig. 5, Table 2). This section proved significantly more productive than the Upper Callovian samples studied from Mareta Beach (see above). The dinoflagellate cyst assemblages are moderately well-preserved, and are overwhelmingly dominated by *Ctenidodinium cornigerum,* the *Ctenidodinium sellwoodii* group, and intermediate morphotypes between these two forms. Other taxa which are consistently present include *Gonyaulacysta jurassica* subsp. *adecta,* indeterminate chorate cysts, *Korystocysta gochtii, Meiourogonyaulax* spp., *Pareodinia ceratophora, Sentusidinium* spp., *Surculosphaeridium*? *vestitum, Systematophora areolata* and *Tubotuberella dangeardii* (Table 2). The pollen-spore associations are relatively sparse, and are of low diversity. These include bisaccate pollen, *Callialasporites dampieri*, *Callialasporites* spp., *Classopollis classoides*, *Cyathidites* spp. and *Ischyosporites variegatus* (Table 2).

Late Callovian dinoflagellate cyst assemblages from further north in Europe are significantly higher in diversity, and typically not dominated by *Ctenidodinium* (e.g. Woollam, 1980; Prauss, 1989; Riding and Thomas, 1997). Representatives of the many taxa with Late Callovian range bases in northwest Europe such as *Trichodinium* *scarburghensis* are absent (see above). Furthermore, the acme of *Mendicodinium groenlandicum* so typical of the Late Callovian of northwest Europe (Woollam, 1980; Riding and Thomas, 1997) is not present in the Algarve Basin. Nevertheless, the dinoflagellate cyst associations from Cilheta Beach are indicative of a Callovian age. *Gonyaulacysta jurassica* subsp. *adecta, Korystocysta* spp., *Meiourogonyaulax caytonensis* and *Tubotuberella dangeardii* are highly characteristic of the Callovian Stage (Riding and Thomas, 1992; Riding, 2005). As at Mareta Beach, the majority of the well established northwest European Callovian biomarkers were not recorded at Cilheta Beach. However, the range tops of *Ctenidodinium continuum* and *Pareodinia prolongata* are present (Table 2); these bioevents are known to be Late Callovian (Riley and Fenton, 1982; Herngreen et al., 1984; Berger, 1986; Kunz, 1990). The inception of *Surculosphaeridium*? *vestitum,* which is present at Cilheta (Table 2), is intra-Callovian (Riding, 1987; Prauss, 1989; Feist-Burkhardt and Wille, 1992). Typically, the range base of *Surculosphaeridium*? *vestitum* is of Middle-Late Callovian age (Coronatum and Athleta chronozones) (Woollam, 1980; Riding, 2005). Hence, this occurrence supports the Late Callovian age of the unit sampled at Cilheta. As mentioned previously, the chorate genus *Systematophora,* which was recorded throughout at Cilheta (Table 2), is normally typical of the Late Jurassic.

The low diversity nature of the Late Callovian dinoflagellate cyst associations from Cilheta Beach is probably largely due to palaeogeographical factors. This succession was deposited in a partially enclosed, relatively deep water basin seaward of reef limestone facies. The palaeoenvironment was interpreted as restricted offshore pelagic, possibly with stratified waters and sporadic upwelling by Rocha (1976). However, the palynofacies and benthic faunas are not typical of an organic-rich depositional setting. The restricted nature of the Algarve Basin during the Callovian probably prevented full mixing of dinoflagellates with areas further to the north in Europe. This at least partially explains the low-diversity assemblages. Typically boreal genera which have latitudinally-controlled northerly distributions such as *Crussolia* and *Paragonyaulacysta* are not present in the Cilheta Beach section.

4.4. The Carrapateira outlier

The Carrapateira outlier is located north of the main Algarve Basin, west of Carrapateira village and consists of basic volcanics, dolomites, limestones, marls and sandstones of Late Triassic to Late Jurassic age. The most complete exposures in the Carrapateira outlier, are the spectacular coastal outcrops of Upper Jurassic carbonates which have been partially dolomitised (Ramalho and Ribeiro, 1985). An Early Kimmeridgian age for this section has been invoked based on corals (Choffat, 1887; Geyer, 1956; Rosendhal, 1985) and foraminifera (Ramalho and Ribeiro, 1985; Ribeiro et al., 1987).

The lowermost part of the succession at Carrapateira consists of approximately 150 m of intensely dolomitised limestones. By contrast, the uppermost strata comprise 50 m of interbedded limestones and marls (Fig. 6). Because dolomites are typically devoid of palynomorphs, only the undolomitised uppermost beds were sampled herein. Thirty-eight samples largely from the marls were studied; seven of these (C1-C7) are from a prominent marl bed between 18 and 36 m above the base of the section (Fig. 6).

The organic residues from Carrapateira are abundant in wood fragments and various plant phytoclasts. Moderately well-preserved palynomorphs are also present, pollen and spores being more abundant than marine microplankton. The palynomorphs, especially the dinoflagellate cysts, have been affected by pyrite. The most persistent dinoflagellate cysts are *Batiacasphaera* spp., the *Cribroperidinium globatum* group, *Ctenidodinium* spp., the *Ellipsoidictyum/Valensiella* group, *Gonyaulacysta jurassica* subsp. *jurassica,* indeterminate chorate cysts, *Mendicodinium groenlandicum, Sentusidinium* spp., *Systematophora areolata, Systematophora* spp. and *Tubotuberella dangeardii*. Other taxa include *Amphorula* sp., *Corculodinium inaffectum, Histiophora ornata, Hystrichosphaerina*? *orbifera, Korystocysta gochtii, Occisucysta balios, Pareodinia ceratophora, Rhynchodiniopsis* spp., *Scriniodinium inritibile, Systematophora penicillata* and *Valensiella ovulum* (Table 3). The pollen-spore associations are of low diversity and include bisaccate pollen, *Callialasporites* spp., *Classopollis classoides, Cyathidites* spp., *Ischyosporites variegatus, Leptolepidites* spp. and *Perinopollenites elatoides* (Table 3).

The dinoflagellate cyst associations from Carrapateira are indicative of an Early Kimmeridgian age by comparison to other records from northwest Europe. The occurrences of *Corculodinium inaffectum* (sample C29), *Gochteodinia* sp. (sample C35) and *Occisucysta balios* (sample C29) are all indicative of the Kimmeridgian Stage (Nøhr-Hansen, 1986; Riding, 1987; Riding and Thomas, 1988; Barron, 1989; Riding et al., 1999). Furthermore, species such as *Cribroperidinium globatum, Hystrichosphaerina*? *orbifera, Scriniodinium inritibile* and *Systematophora penicillata* are highly characteristic of the Kimmeridgian (Riding and Thomas, 1988). More specifically, the occurrences of *Gonyaulacysta jurassica* subsp. *jurassica* and *Tubotuberella dangeardii* throughout the productive part of the succession mean that this section is no younger than Early Kimmeridgian. The range tops of these forms are Early Kimmeridgian (Lam and Porter, 1977; Riding, 1987; Riding and Thomas, 1988; Barron, 1989; Jan du Chêne et al., 1999). *Tubotuberella dangeardii* is especially typical of the earliest Kimmeridgian (Baylei and Cymodoce chronozones) (Riding and Thomas, 1988). The occurrences of *Amphorula* sp. (sample C35), *Histiophora* spp. (samples C49, C50) and *Histiophora ornata* (sample C35) are also highly significant. *Amphorula* and *Histiophora* are both typical of the Kimmeridgian and Tithonian of the Tethyan Realm. *Amphorula* ranges from the latest Oxfordian to the Berriasian (Monteil, 1990, tables 4, 5). *Amphorula dodekovae* has been recorded from the Late Oxfordian to Middle Tithonian of the North Atlantic and Europe (Zotto et al., 1987; Brenner, 1988; Dodekova, 1992; Feist-Burkhardt and Wille, 1992); this taxon is especially characteristic of the Kimmeridgian Stage. Dürr (1987; 1988) reported prominent *Histiophora ornata* from the Early Kimmeridgian Mutabilis Chronozone of southern Germany. Dodekova (1992, p. 42) stated that this species ranges from the Middle Kimmeridgian to Early Tithonian of Bulgaria. Hence the presence of *Histiophora ornata* in sample C35 is indicative of the Early Kimmeridgian by comparison with the German records. The Early Kimmeridgian age of the succession at Carrapateira based on corals and foraminifera is therefore confirmed by dinoflagellate cysts, specifically the co-occurrences of *Histiophora ornata, Gonyaulacysta jurassica* subsp. *jurassica* and *Tubotuberella dangeardii*. It is possible that some reworking from the Callovian/Oxfordian may be present due to the occurrences of *Korystocysta* spp. (Riding, 2005) (Table 3).

Mohr and Schmidt (1988) reported a poorly-preserved, low diversity Late Oxfordian-Early Kimmeridgian dinoflagellate cyst flora from the Lusitanian Basin, central Portugal. This is dominated by proximate/proximochorate forms with apical archaeopyles, i.e. *Cassiculosphaeridia, Escharisphaeridia* and *Sentusidinium*.

Kimmeridgian dinoflagellate cyst assemblages from further north in Europe normally have markedly higher diversities (e.g. Ioannides et al., 1976; Dürr, 1988; Riding and Thomas, 1988) than these southern Portuguese floras. Closer to Portugal, van Erve et al. (1988) reported more diverse palynofloras from the Lower Kimmeridgian of eastern Spain. Some typically Early Kimmeridgian species such as *Endoscrinium luridum* and *Glossodinium dimorphum* were not observed at Carrapateira. The relatively low diversity nature of the Early Kimmeridgian dinoflagellate cyst floras from Carrapateira was probably largely controlled by palaeogeographical factors. The beds in the middle part of the succession were probably deposited in a relatively deep water, partially enclosed depocentre, whereas the lower and upper part of this section were deposited in shallow water settings represented by lagoon and reef carbonate facies. The partially enclosed nature of this part of the Algarve Basin during the Early Kimmeridgian appears to have prevented free mixing of the dinoflagellates with areas outwith southern Portugal. Typically boreal taxa which have latitudinally-controlled northerly distributions such as *Gonyaulacysta dualis* and *Paragonyaulacysta capillosa* (see Davies, 1983) are not present in the Carrapateira section.

5. Overview of the Jurassic palynofloras of the Algarve Basin and the Carrapateira outlier

Palynomorph assemblages from the Lower, Middle and Upper Jurassic (Upper Pliensbachian-Lower Kimmeridgian) succession from the Algarve Basin and the Carrapateira outlier, southern Portugal were studied. The Upper Pliensbachian to Lower Toarcian strata of Armação Nova Bay proved extremely sparse palynologically, no dinoflagellate cysts were encountered. Dinoflagellate cysts were confined to the Upper Bajocian to Upper Callovian sedimentary rocks exposed at Mareta and Cilheta beaches and the Lower Kimmeridgian strata of the Carrapateira outlier.

At Mareta Beach, the Upper Bajocian and Bathonian produced low/moderate diversity assemblages dominated by *Ctenidodinium* and *Korystocysta*. In the Upper Bajocian, no stratigraphical markers were recorded. By contrast, in the Bathonian, several key bioevents confirm the age of the succession. The chorate species *Systematophora areolata* was, unusually, recorded from the Bathonian. The absence of *Ctenidodinium combazii* may have been due to palaeoecological factors and/or latitudinal control. The productive Callovian samples from this locality are largely from the Lower and Middle Callovian succession. The *Ctenidodinium sellwoodii* group proved prominent. *Ctenidodinium ornatum, Endoscrinium asymmetricum, Impletosphaeridium varispinosum, Liesbergia liesbergensis* and *Wanaea acollaris* are present and these species confirm the Callovian age of these strata.

Two marl units in the Upper Callovian of Cilheta yielded relatively abundant dinoflagellate cysts which are dominated by *Ctenidodinium cornigerum* and the *Ctenidodinium sellwoodii* group. The diversity is markedly lower than typical Late Callovian associations from further north in Europe. The occurrences of taxa such as *Gonyaulacysta jurassica* subsp. *adecta* and *Meiourogonyaulax caytonensis,* together with some key Late Callovian bioevents, are characteristic of the Callovian Stage. To summarise, the Upper Bajocian to Callovian strata at the Mareta and Cilheta beaches produced low diversity dinoflagellate cyst assemblages; many familiar marker forms from northwest Europe were not encountered. Furthermore, no typically Tethyan forms, or any latitudinally-controlled northerly (Arctic) forms were recovered throughout this succession.

The Carrapateira outlier includes spectacular outcrops of partially dolomitised Upper Jurassic (Early Kimmeridgian) carbonates which have yielded dinoflagellate cyst floras. These are indicative of an Early Kimmeridgian age due to the occurrences of key taxa such as *Amphorula* sp., *Corculodinium inaffectum, Gonyaulacysta jurassica* subsp. *jurassica, Histiophora ornata, Hystrichosphaerina*? *orbifera, Occisucysta balios* and *Tubotuberella dangeardii.* This confirms the dating of Early Kimmeridgian based on corals and foraminifera. *Amphorula* and *Histiophora* are both typical of the Upper Jurassic of the Tethyan Realm; no Arctic/boreal forms were observed.

6. Conclusions

The dinoflagellate cyst assemblages from the Upper Bajocian, Bathonian and Callovian of Mareta and Cilheta beaches and the Lower Kimmeridgian of the Carrapateira outlier proved to be consistently significantly less diverse than coeval assemblages from northwest Europe. Many important, well-established marker forms were not encountered from southern Portugal. The relatively low diversity nature of these dinoflagellate cyst floras was probably largely due to palaeogeographical factors. The Upper Bajocian to Callovian successions at Mareta and Cilheta beaches, and the middle part of the Lower Kimmeridgian section of the Carrapateira outlier were deposited in relatively deep water, partially enclosed depositional settings.

During the Bajocian to Callovian, this part of the Algarve Basin was located seaward of reef limestone facies within this enclosed basin. The depocentre is thus interpreted as a restricted offshore pelagic setting. Rocha (1976) suggested that there were intervals within the Bajocian to Callovian when the waters became stratified with sporadic upwelling of bottom waters. The benthic faunas and the palynofacies do not, however, support the occurrence of organic-rich sediments. Hence the partially enclosed nature of this part of the Algarve Basin and the Carrapateira outlier during the Late Bajocian to the Early Kimmeridgian appears to have prevented the free migration of dinoflagellates (and other planktonic groups) between southern Portugal and elsewhere in Europe and surrounding areas. This, at least partially, explains the low diversity assemblages of marine microplankton. No typically northerly (Arctic) or Tethyan taxa were recovered throughout this succession. Callovian dinoflagellate cyst assemblages were relatively uniform throughout the Northern Hemisphere (Riding et al., 1999), hence the principal reason for the relatively restricted floras in this part of the Algarve Basin appears to have been the enclosed nature of the depocentre at this time.

Despite the relatively low diversity palynofloras recovered, this study has helped to establish that Late Bajocian to Late Callovian dinoflagellate cyst associations do not exhibit significant biotal provincialism between southern and northern Europe. Coeval floras from North Africa and the Middle East, to the south and east respectively of Portugal also appear to lie within this relatively extensive Northern Hemisphere floral province (e.g. Conway, 1978; 1990; Thusu and Vigran, 1985; Thusu et al., 1988; Wheeler and Sarjeant, 1990; El Beialy and Ibrahim, 1997; El Beialy et al., 2002; Ibrahim et al., 2002; 2003). By contrast, there is a clear distinction between European and Arctic assemblages, with significant numbers of typically high latitude Middle Jurassic taxa being confined to the boreal realm (Smelror and Below, 1992; Riding et al., 1999).

The Lower Kimmeridgian of the Carrapateira outlier also produced relatively low diversity dinoflagellate cyst assemblages. Unsurprisingly no boreal forms were observed; however some Tethyan elements such as *Amphorula* sp. and *Histiophora ornata* are present. The occurrence of typically Tethyan forms is consistent with significant provincialism between northern and southern Europe at this time (Riding and Ioannides, 1996; Abbink et al., 2001).

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Appendix 1

This Appendix lists all the palynomorph taxa below generic level which were recovered from the material studied herein with full author citations. The palynomorphs are listed alphabetically within their constituent groups. References to the dinoflagellate cyst author citations can be found in Fensome and Williams (2004).

Dinoflagellate cysts:

Adnatosphaeridium caulleryi (Deflandre 1939) Williams & Downie 1969

Chytroeisphaeridia chytroeides (Sarjeant 1962) Downie & Sarjeant 1965

Corculodinium inaffectum (Drugg 1978) Courtinat 2000

Cribroperidinium globatum (Gitmez & Sarjeant 1972) Helenes 1984

Ctenidodinium continuum Gocht 1970

Ctenidodinium cornigerum (Valensi 1953) Jan du Chêne et al. 1985

Ctenidodinium ornatum (Eisenack 1935) Deflandre 1939

Ctenidodinium sellwoodii (Sarjeant 1975) Stover & Evitt 1978

Dapsilidinium? *deflandrei* (Valensi 1947) Lentin & Williams 1981

Ellipsoidictyum cinctum Klement 1960

Endoscrinium asymmetricum Riding 1987

Epiplosphaera gochtii (Fensome 1979) Brenner 1988

Fromea tornatilis (Drugg 1978) Lentin & Williams 1981 [listed as an acritarch in Fensome and Williams (2004, appendix A)]

Gonyaulacysta jurassica (Deflandre 1939) Norris & Sarjeant 1965 subsp. *adecta* Sarjeant 1982

Gonyaulacysta jurassica (Deflandre 1939) Norris & Sarjeant 1965 subsp. *jurassica* (autonym)

Histiophora ornata Klement 1960

Hystrichosphaerina? *orbifera* (Klement 1960) Stover & Evitt 1978

Impletosphaeridium varispinosum (Sarjeant 1959) Islam 1993

Korystocysta gochtii (Sarjeant 1976) Woollam 1983

Korystocysta pachyderma (Deflandre 1939) Woollam 1983

Liesbergia liesbergensis Berger 1986

Meiourogonyaulax caytonensis (Sarjeant 1959) Sarjeant 1969

Mendicodinium groenlandicum (Pocock & Sarjeant 1972) Davey 1979

Occisucysta balios Gitmez 1970

Pareodinia ceratophora Deflandre 1947

Pareodinia halosa (Filatoff 1975) Prauss 1989

Pareodinia prolongata Sarjeant 1959

Rhynchodiniopsis? *regalis* (Gocht 1970) Jan du Chêne et al. 1985

Scriniodinium inritibile Riley in Fisher & Riley 1980

Surculosphaeridium? *vestitum* (Deflandre 1939) Davey et al. 1966

Systematophora areolata Klement 1960

Systematophora penicillata (Ehrenberg 1843 ex Ehrenberg 1854) Sarjeant 1980

Tubotuberella dangeardii (Sarjeant 1968) Stover & Evitt 1978

Valensiella ovulum (Deflandre 1947) Eisenack 1963

Wanaea acollaris Dodekova 1975

Pteridophyte spores:

Coronatispora valdensis (Couper 1958) Dettmann 1963

Ischyosporites variegatus (Couper 1958) Schulz 1967

Leptolepidites rotundus Tralau 1968

Sestrosporites pseudoalveolatus (Couper 1958) Dettmann 1963

Todisporites minor Couper 1958

Gymnospermous pollen:

Callialasporites dampieri (Balme 1957) Sukh Dev 1961

Callialasporites minus (Tralau 1968) Guy 1971

Callialasporites trilobatus (Balme 1957) Sukh Dev 1961

Callialasporites turbatus (Balme 1957) Schulz 1967

Classopollis classoides (Pflug 1953) Pocock & Jansonius 1961

Perinopollenites elatoides Couper 1958

Appendix 2

This Appendix alphabetically lists all the dinoflagellate cyst taxa below generic level mentioned in this contribution, but were not recovered from the material studied herein, with full author citations. References to the author citations can be found in Fensome and Williams (2004).

Amphorula dodekovae Zotto et al. 1987

Chytroeisphaeridia hyalina (Raynaud 1978) Lentin & Williams 1981

Cribroperidinium crispum (Wetzel 1967) Fenton 1981

Ctenidodinium combazii Dupin 1968

Endoscrinium luridum (Deflandre 1939) Gocht 1970

Evansia dalei (Smelror & Århus 1989) Below 1990

Evansia perireticulata (Århus et al. 1989) Lentin & Williams 1993

Glossodinium dimorphum Ioannides et al. 1976

Gonyaulacysta dualis (Brideaux & Fisher 1976) Stover & Evitt 1978

Jansonia manifesta Riding & Walton in Riding et al. 1991

Lacrymodinium warrenii Albert et al. 1986

Meiourogonyaulax reticulata Dodekova 1975

Meiourogonyaulax valensii Sarjeant 1966

Paragonyaulacysta calloviensis Johnson & Hills 1973

Paragonyaulacysta capillosa (Brideaux & Fisher 1976) Stover & Evitt 1978

Paragonyaulacysta retiphragmata Dörhöfer & Davies 1980

Phallocysta thomasii Smelror 1991

Scriniodinium crystallinum (Deflandre 1939) Klement 1960

Sirmiodinium grossii Alberti 1961

Trichodinium scarburghense (Sarjeant 1964) Williams et al. 1993

Valvaeodinium aquilonium (Dörhöfer & Davies 1980) Below 1987

Valvaeodinium thereseae Smelror 1991

Wanaea thysanota Woollam 1982

Figure captions

Fig. 1. The location and geology of the Algarve Basin and the Carrapateira outlier, illustrating the areas studied herein, and the geographical extents of the Western (Sagres), Budens-Lagoa and Eastern (Faro) subbasins (adapted from Manuppella, 1992).

Fig. 2. The left-hand panel depicts the geology of the Western (Sagres) Subbasin in the western part of the Algarve Basin including the locations of the successions studied at Armação Nova, Mareta Beach and Cilheta Beach (adapted from Manuppella and Perdigão, 1972). The geology of the Carrapateira outlier in the western part of the Algarve Basin is depicted in the right-hand panel (adapted from Feio et al., 1985).

Fig. 3. Lithological log of the Upper Pliensbachian and Lower Toarcian section at Armação Nova modified from Rocha (1976) with sample positions.

Fig. 4. Lithological log of the Bajocian to ?Upper Oxfordian/Kimmeridgian section at Mareta Beach with sample positions.

Fig. 5. Lithological log of the Upper Callovian to ?Upper Oxfordian/Kimmeridgian section at Cilheta Beach with sample positions (modified from Rocha, 1976). The key refers to Figs 3-6 inclusive.

Fig. 6. Lithological log of the Lower Kimmeridgian section from the Carrapateira outlier with sample positions.

Table captions

Table 1. The overall palynomorph assemblages in the Upper Bajocian to Upper Callovian of the Mareta Beach section. The circle symbols represent semiquantitative groupings. There are five sizes of circle symbols; the diameters of the circles are proportional to the relative abundances of the respective palynomorphs. Listing these from small to large they are: VR = very rare (<1%); R = rare (1-15%); P = present (15-50%); C = common (50-75%); Ab = abundant (>75%). A question mark (?) is indicative that the respective identifications are equivocal.

Table 2. The overall palynomorph assemblages in the Upper Callovian of the Cilheta Beach section. The circle symbols represent semiquantitative groupings. There are four sizes of circle symbols; the diameters of the circles are proportional to the relative abundances of the respective palynomorphs. Listing these from small to large they are: R = rare (1-15%); P = present (15-50%); C = common (50-75%); Ab = abundant (>75%). A question mark (?) is indicative that the respective identifications are equivocal.

Table 3. The overall palynomorph assemblages in the Lower Kimmeridgian of the Carrapateira outlier section. The circle symbols represent semiquantitative groupings. There are four sizes of circle symbols; the diameters of the circles are proportional to the relative abundances of the respective palynomorphs. Listing these from small to large they are: R = rare (1-15%); P = present (15-50%); C = common (50-75%); Ab = abundant (>75%). A question mark (?) is indicative that the respective identifications are equivocal.

Plate caption

Plate 1.

Selected dinoflagellate cysts from the Early Bathonian to the Middle Callovian (Coronatum Chronozone) of the Mareta Beach section, Algarve Basin and the Early Kimmeridgian of the Carrapateira outlier. All are specimens housed in the collections of the LGM/LNEG (Portugese Geological Survey), S. Mamede Infesta, Portugal. The sample, slide and England Finder coordinates are provided.

1. *Gonyaulacysta jurassica* (Deflandre 1939) Norris & Sarjeant 1965 subsp *adecta* Sarjeant 1982. Mareta Beach section, Lower Callovian (Herveyi Chronozone), sample M27, slide 1, N47.

2. *Gonyaulacysta jurassica* (Deflandre 1939) Norris & Sarjeant 1965 subsp. *jurassica* (autonym). Carrapateira outlier, Early Kimmeridgian, sample C47, slide 1, R12/4.

3. *Pareodinia ceratophora* Deflandre 1947. Mareta Beach section, Lower Callovian (Herveyi Chronozone), sample M28, slide 1, L38/2.

4. *Tubotuberella dangeardii* (Sarjeant 1968) Stover & Evitt 1978. Mareta Beach section, Middle Callovian (Coronatum Chronozone), sample M45, slide 1, P18.

5. *Ctenidodinium sellwoodii* (Sarjeant 1975) Stover & Evitt 1978. Mareta Beach section, Early Bathonian, sample M2, slide 2, W53.

6. *Ctenidodinium cornigerum* (Valensi 1947) Jan du Chêne et al. 1985. Mareta Beach section, Lower Callovian (Herveyi Chronozone), sample M25, slide 1, N3.

7. *Ctenidodinium* sp. Carrapateira outlier, Early Kimmeridgian, sample C12, slide 1, G34/4.

8. *Histiophora* cf. *ornata* Klement 1960. Carrapateira outlier, Early Kimmeridgian, sample C35, slide 1, R36.

9. *Korystocysta gochtii* (Sarjeant 1976) Woollam 1983. Mareta Beach section, Lower Callovian (Herveyi Chronozone), sample M28, slide 1, M63.

10. *Meiourogonyaulax caytonensis* (Sarjeant 1959) Sarjeant 1969. Mareta Beach section, Early Bathonian, sample M3, slide 1, O18/3.

11. *Mendicodinium groenlandicum* (Pocock & Sarjeant 1972) Davey 1979. Mareta Beach section, Lower Callovian (Herveyi Chronozone), sample M27, slide 2, Q30/1.

12. *Systematophora* cf. *areolata* Klement 1960. Carrapateira outlier, Early Kimmeridgian, sample C4, slide 1, U36.

13. *Valensiella* cf. *ovulum* (Deflandre 1947) Eisenack 1963. Mareta Beach section, Early Bathonian, sample M3, slide 2, V30/2.