Dinoflagellate cyst biostratigraphy of the Patasar Shale Member (Upper Jurassic) of the Wagad Uplift, Kachchh, Gujarat, western India

James B. Riding [a*], Rahul Garg [b], Jyotsana Rai [b]

[a] *British Geological Survey, Environmental Science Centre, Keyworth, Nottingham NG12 5GG, UK*
[b] *Birbal Sahni Institute of Palaeosciences, 53 University Road, Lucknow 226 007, India*

**Corresponding author*. Tel.: +44 115 9363447
E-mail address: jbri@bgs.ac.uk (J.B. Riding)

ABSTRACT

Two samples were analysed from the lowermost Patasar Shale Member of the Patasar Tank section on the western margin of the Wagad Uplift in the Kachchh Basin of Gujarat, western India. One of the samples produced an abundant, diverse and well-preserved palynobiota. The other sample produced a significantly sparser association, but of similar character. The overall assemblage is dominated by relatively long-ranging Jurassic gymnospermous pollen grains, but also includes dinoflagellate cysts of definite Gondwanan affinity. The dinoflagellate cysts are confidently correlated to the Australian *Dingodinium swanense* Interval Zone, which is of Kimmeridgian (Late Jurassic) age. This indicates that the Australasian Jurassic dinoflagellate cyst biostratigraphical scheme can be applied in western India, and probably throughout the Indian subcontinent. Due to evidence from ammonites and calcareous nannofossils in the Patasar Shale Member, allied with other biostratigraphical evidence from New Zealand and Papua New Guinea, the age of the *Dingodinium swanense* Interval Zone is reinterpreted as being of Early Kimmeridgian age. The *Dingodinium swanense* Interval Zone was previously assigned to the Early to Late Kimmeridgian. Its refinement and revision to an older age is entirely consistent with recent reassessments of these dinoflagellate cyst biozones.

Keywords: biostratigraphy; dinoflagellate cysts; Late Jurassic; pollen and spores; provincialism; Gujarat, western India

1. Introduction

In this study we develop an integrated biostratigraphy of the Patasar Shale Member in the Wagad Uplift which is part of the Great Rann of Kachchh (or Kachchh Basin) of Gujarat, western India (Fig. 1). The Patasar Shale Member is of Late Jurassic age, and is thought to be close to the Oxfordian–Kimmeridgian transition based on its macrofaunas (Fig. 2; Pandey et al. 2012). The present work is based on a study of the palynology of two samples from the lowermost Patasar Shale Member, with emphasis on marine palynomorphs. The resultant data are integrated with existing interpretations based on ammonites and calcareous nannofossils in order to achieve a comprehensive and refined biostratigraphical framework for these regionally important strata. It was anticipated that the Patasar Shale Member would yield palynobiotas of Gondwanan (Australasian) affinity. However little is known regarding the palaeobiogeographical relationships of Jurassic dinoflagellate cysts from the Indian subcontinent. The north-central part of Gondwana once occupied by India is a key area for understanding regional correlations and shelfal marine connections within the Gondwanan supercontinent.

2. Regional geological background

The Wagad Uplift of Gujarat, western India, forms part of the Great Rann of Kachchh (or Kachchh Basin). It is a pericratonic depocentre formed after continental rifting between Africa and India during the Late Triassic (Biswas, 1982; 1991; 2005). It contains an extensive Mesozoic succession comprising Upper Triassic terrestrially derived strata, Lower to Upper Jurassic (Pliensbachian–Tithonian) marine sedimentary rocks and Lower Cretaceous (Berriasian–Albian) marine to paralic beds. Most of the Jurassic strata, and some of the Lower Cretaceous intervals, are richly fossiliferous, the faunas including key zonal ammonites. Bordering the Kachchh region to the southwest is the Arabian Sea, and to the northeast the salt marshes of the Great Rann of Kachchh (Fig. 1). The Deccan Traps occupy the southern part of the Kachchh region, and domal structures with a west–east trending Mesozoic outcrop belt are present in the northern part. The Wagad Uplift lies in the east of the Kachchh Basin; it is an elongate anticlinal dome with

Jurassic rocks of Callovian to Kimmeridgian age in its core (Fig. 1; Biswas, 1977). The various uplifts and domes, including the area known as Kachchh Mainland, form ‘islands’ separated by plains covered in blown sand (Fig. 1).

3. The geology of the Wagad Uplift

The Wagad Uplift is situated in the easternmost part of the Kachchh Basin (Fig. 1; Biswas and Deshpande, 1970). A high angle fault with east-west strike separates the Wagad uplift in the north from southern Kachchh. Extensive exposures of Middle Jurassic (Callovian) to Lower Cretaceous strata are present in the Wagad Uplift (Biswas, 1971; Deshpande, 1972; Deshpande and Merh, 1980). While the Oxfordian to Kimmeridgian succession is strongly condensed, with stratigraphical gaps, in Kachchh (Fig. 2; Alberti et al., 2013), the Wagad Uplift preserves a relatively continuous Oxfordian–Kimmeridgian succession of shallow-water sedimentary rocks. It is therefore ideally suited for the present integrated biostratigraphcal study (Fig. 2).

The first Mesozoic lithostratigraphical framework of the Wagad Uplift succession was by Deshpande (1972). This reconnaissance research was followed by, for example, Biswas (1977), Pandey et al. (2012) and Fürsich et al. (2013). Lithostratigraphically, the Callovian to Kimmeridgian sedimentary rocks have been placed into the Washtawa, Kanthkot and Gamdau formations (Fig. 2). The uppermost Washtawa Formation is the Kanthkot Ammonite Bed of the Nara Shale Member. Overlying the Washtawa Formation is the Kanthkot Formation, which is subdivided into three members; the Patasar Shale Member is the lowermost of these units. The Gamdau Formation is undivided (Fig. 2; Fürsich et al., 2013).

The Patasar Shale Member, is the subject of this work. It comprises the lowermost part of the Kanthkot Member of the lower Wagad Sandstone of Biswas (1977) and conformably overlies the Kanthkot Ammonite Bed. The latter is richly fossiliferous and forms the uppermost part of the Nara Shale Member of the Washtawa Formation. The Kanthkot Ammonite Bed is considered to be coeval with the Dhosa Conglomerate Bed, an ammonite-rich condensed horizon which is present throughout the Kachchh Mainland (Fig. 2).

The ammonite biostratigraphy of the Washtawa, Kanthkot and Gamdau formations has been significantly refined in recent decades (e.g. Krishna et al., 1995; 1998; 2009a,b,c; Some and Bardhan, 2005; Pandey et al., 2012; 2013a,b). By contrast, data on calcareous nannofossils and dinoflagellate cysts from the Jurassic of the Kachchh Basin are relatively sparse (Krishna et al., 1983; Jain et al., 1984; 1986; Kumar, 1986a,b,c; Rai, 2003; Saxena and Jafar, 2008; Rai et al., 2015).

A single specimen of the ammonite genus *Erymnoceras* from an ooidal ferruginous marl band, presumed to be within the Nara Shale Member of the Washtawa Formation, was assigned to the Middle Callovian by Some and Bardhan (2005). This horizon is within the lower part of the Nara Shale Member, underlying the Kanthkot Ammonite Bed (Fig. 2). Furthermore, a single, poorly preserved fragment of an ammonite assigned to *Perisphinctes* (*Dichotomoceras*) cf. *besairiei* was reported by Pandey et al. (2012) from the lowermost Patasar Shale Member. As a result of the discovery of this biostratigraphically significant form, this part of the unit has been tentatively dated as Late Oxfordian (Bifurcatus Zone, Grossouvrei Subzone).

4. Material and methods

The two samples from the Patasar Shale Member described in this study, PTS 1A and PTS 1, were collected from the lowermost part of the scarp section exposed near Patasar Tank (i.e. reservoir), c. 2 km east of Kanthkot village at N 23º 29' 48.4'', E 70º 28' 01.7'' (Fig. 1; Table 1). This section is a relatively monotonous shale succession (Rai et al., 2015, fig. 3D). Of the 13 samples collected from this unit, only the lowermost two have yielded well-preserved palynomorphs (Tables 1, 2). Sample PTS 1A is 15 cm stratigraphically below PTS 1. One of the overlying eleven samples (PT6) yielded very rare and poorly preserved dinoflagellate cysts, which are consistently indeterminate. Samples from the remaining ten horizons proved barren of palynomorphs (Table 1). The generally poor recovery of palynomorphs throughout most of this succession may is probably due to the effects of long-term weathering in a subtropical climate.

The samples were all processed using standard palynological techniques (Wood et al. 1996) at the Birbal Sahni Institute of Palaeosciences (BSIP). After demineralisation using hydrochloric acid and hydrofluoric acid, the neutralised residue was macerated for several minutes with dilute nitric acid and then washed using distilled water onto a 15 μm sieve. The concentrated residue was then mixed with polyvinyl alcohol and mounted onto microscope slides using Canada Balsam as a mounting medium. Study and photography was carried out with a Olympus BH2 photomicroscope. The samples, prepared residues, microscope slides (BSIP numbers 15629–

15638) and figured specimens are all curated in the BSIP collections housed at 53 University Road, Lucknow 226 007, India.

5. Palynology

The present study documents the dinoflagellate cyst assemblages from the lowermost part of the Patasar Shale Member at its type section at Patasar Tank. This association is compared with calcareous nannofossil assemblages in samples from the overlying beds (Table 1; Rai et al., 2015, fig 3D). The ammonite, calcareous nannofossil and dinoflagellate cyst data from various horizons in the Wagad Uplift are integrated to provide greater and more precise biostratigraphical resolution. The dinoflagellate cysts are of Australasian affinity, and the present study has provided a more refined age for the *Dingodinium swanense* Interval Zone of Helby et al. (1987).

The two samples studied from the lower Patasar Shale Member of the Patasar Tank section (PTS 1A and PTS 1) yielded well-preserved palynomorph assemblages. However, sample PTS 1 proved markedly more abundant and diverse than PTS 1A (Table 2). Both samples are dominated by terrestrially derived forms, dominantly gymnospermous pollen. These mainly comprise *Araucariacites* spp., *Callialasporites dampieri, Callialasporites turbatus* and undifferentiated bisaccate pollen, with lesser proportions of *Classopollis* spp., *Perinopollenites elatoides* and indeterminate forms. Pteridophyte spores are extremely rare, but are represented by occasional smooth forms assigned to *Cyathidites* (Table 2).

Dinoflagellate cysts are subordinate in proportions to pollen and spores, however, they are much more diverse. In sample PTS 1, the assemblage is dominated by *Dingodinium jurassicum,* together with significant proportions of *Gonyaulacysta jurassica* subsp. *jurassica,* indeterminate forms, *Pareodinia* spp. (including *Pareodinia halosa*), *Scriniodinium dictyotum, Sentusidinium* spp. and *Stiphrosphaeridium* spp. Also present are *Acanthaulax* sp., *Apteodinium* sp., *Chlamydophorella wallala, Chlamydophorella* spp., *Egmontodinium polyplacophorum, Endoscrinium luridum, Glossodinium dimorphum, Hadriana cinctum,* indeterminate chorate forms, *Indodinium khariense, Leptodinium eumorphum, Mendicodinium granulatum, Perisseiasphaeridium*? sp., *Prolixosphaeridium parvispinum, Rhynchodiniopsis cladophora, Rigaudella aemula, Scriniodinium crystallinum, Scriniodinium inritibile, Trichodinium* sp. and

Tubotuberella apatela. The miscellaneous microplankton consist largely of foraminiferal test linings and very rare scolecodonts; no acritarchs were recorded (Table 2).

The kerogen macerals are dominated by palynomorphs (sample PTS 1) and plant fragments (sample PTS 1A). Wood is consistently present in significant proportions, and amorphous organic material is extremely sparse (Table 2). The dominance of gymnospermous pollen with relatively diverse dinoflagellate cysts and abundant plant tissue and wood is consistent with deposition in an open marine, offshore shelfal environment.

Despite the disparity in diversity, the overall similarity of the palynobiotas in the two samples confirm the field evidence that they are from the same genetic sedimentary unit (Table 2; Rai et al., 2015, fig. 3D). The palynomorph associations recorded in the two samples are fully documented in Table 2, and selected dinoflagellate cyst specimens are illustrated in Plates I and II. The dinoflagellate cysts recorded in this study, at and below the species level and with their author citations, are listed in Appendix 1.

6. Palynomorph biostratigraphy

Because the pollen assemblages are dominated by arauracarian forms, including *Callialasporites dampieri*, the material studied is referable to the *Callialasporites dampieri* Superzone of Helby et al. (1987) of Hettangian to Kimmeridgian age. The relatively sparse occurrences of *Classopollis* spp. and *Perinopollenites elatoides* support this assertion (Helby et al., 1987, fig. 13). The low-diversity association, especially of pteridophyte spores, prevents a more refined biostratigraphical breakdown based on terrestrially derived palynomorphs.

The two dinoflagellate cyst associations are typical of the Late Jurassic of Gondwana. Forms such as *Dingodinium jurassicum, Leptodinium eumorphum, Rigaudella aemula, Scriniodinium crystallinum* and *Stiphrosphaeridium anthophorum/dictyophorum* are characteristic of the Oxfordian to Tithonian of Australasia (Helby et al., 1987; Davey, 1988). *Egmontodinium polyplacophorum* and *Scriniodinium inritibile* have not been previously reported from the Gondwanan Realm. In Europe these species are typical of the Tithonian and Middle Oxfordian to Tithonian respectively (Woollam and Riding, 1983; Riding, 1984). Somewhat unusually, the typically Late Jurassic dinoflagellate cysts *Gonyaulacysta ceratophora* and *Nannoceratopsis pellucida* were not encountered.

The key marker dinoflagellate cysts are *Chlamydophorella wallala, Gonyaulacysta jurassica* subsp. *jurassica, Hadriana cinctum, Indodinium khariense, Rhynchodiniopsis cladophora* and *Stiphrosphaeridium dictyophorum.* These indicate a correlation to the *Dingodinium swanense* Interval Zone of Helby et al. (1987), which was deemed to be of Early to Late Kimmeridgian age by Riding et al. (2010). The range tops of *Gonyaulacysta jurassica* subsp. *jurassica* and *Rhynchodiniopsis cladophora* are of Middle Kimmeridgian age in Australia (Riding et al., 2010). However, Davey (1988) reported the youngest consistent occurrence of *Gonyaulacysta jurassica* subsp. *jurassica* as Late Kimmeridgian in Papua New Guinea. The inceptions of *Hadriana cinctum* and *Stiphrosphaeridium dictyophorum* in Australia are also within the Middle Kimmeridgian (Riding and Helby, 2001a; Riding et al., 2010). The summary range chart of Riding et al. (2010, fig. 12) indicates a minor intra-Kimmeridgian stratigraphical gap between the apparent extinctions of *Gonyaulacysta jurassica* subsp. *jurassica* and *Rhynchodiniopsis cladophora,* and the range bases of *Hadriana cinctum* and *Stiphrosphaeridium dictyophorum*, but this hiatus is not considered to be biostratigraphically significant. To summarise, the virtually overlapping ranges of *Gonyaulacysta jurassica* subsp. *jurassica* and *Rhynchodiniopsis cladophora,* with *Hadriana cinctum* and *Stiphrosphaeridium dictyophorum* is indicative of a Middle Kimmeridgian age by comparison with Australian assemblages.

The occurrences of *Chlamydophorella wallala* and *Indodinium khariense* are entirely consistent with this age assessment. The presence of *Chlamydophorella wallala* means that the samples are no younger than latest Kimmeridgian; the range top of this species coincides with the Kimmeridgian–Tithonian transition in Australia (Riding et al. 2010). The range of *Indodinium khariense* is Middle Oxfordian to earliest Tithonian (Helby et al., 1988; Riding and Helby, 2001a; Riding et al., 2010). Furthermore, the absence of the distinctive genus *Wanaea* indicates that the samples are younger than Early Kimmeridgian (Riding and Helby, 2001b; Riding et al., 2010). The lack of species such as *Herendeenia pisciformis, Komewuia glabra and Omatia montgomeryi* preclude a Tithonian age (Riding et al., 2010).

The occurrence of *Glossodinium dimorphum* in this material is interesting. In Australia and Papua New Guinea, this distinctive species ranges from the Callovian to the Middle Oxfordian (Helby et al., 1987; Davey, 1988; Riding et al., 2010). By contrast in Africa and Europe, it is present from the Middle Oxfordian to the Tithonian, and is especially prominent in the Kimmeridgian (Woollam and Riding, 1983; Msaky, 2011). *Dingodinium jurassicum* is the dominant taxon, but the samples are not assigned to the Middle Tithonian *Dingodinium jurassicum* Oppel Zone of Helby et al. (1987) because of the presence of key markers such as *Hadriana cinctum* and *Indodinium khariense.*

7. Integrated biostratigraphy

The biostratigraphy of the Wagad Uplift in the Kachchh Basin, summarised in Fig. 3, was discussed in detail by Rai et al. (2015). The Washatwa Formation of Oxfordian age underlies the Kanthkot Formation, which spans the latest Oxfordian to Kimmeridgian, according to ammonite biostratigraphy (Fig. 2). The Nara Shale Member is the youngest unit of the Washatwa Formation, and the uppermost unit is the Kanthkot Ammonite Bed. The two samples analysed in the present study are from the Patasar Shale Member, the lowermost member of the Kanthkot Formation (Fig. 2; Table 1).

The integrated biostratigraphy of the Nara Shale and Patasar Shale members is illustrated in Figs. 3 and 4. Calcareous nannofossils indicative of the Early and Middle Oxfordian have been recorded from the Nara Shale Member, below the Kanthkot Ammonite Bed (Rai et al., 2015). The Kanthkot Ammonite Bed is comprised of ferruginous, sandy strata with occasional shales that have yielded relatively abundant ammonites indicative of the Middle to Late Oxfordian (Pandey et al., 2012) and calcareous nannofossils characterisic of the Middle Oxfordian (Rai et al., 2015). Therefore it appears entirely probable that the entire Nara Shale Member is Middle Oxfordian in age (Fig. 4).

In the overlying lowermost part of the Patasar Shale Member, a single, poorly-preserved Late Oxfordian ammonite has been recovered (Pandey et al., 2012). Rai et al. (2015) reported a mixed assemblage of Middle–Late Oxfordian and Early Kimmeridgian calcareous nannofossils from the Patasar Shale Member immediately above the two samples studied here. These authors commented that the Middle and Late Oxfordian markers were probably reworked, and thus the calcareous nannofossil assemblages are Early Kimmeridgian in age. Samples PTS 1A and PTS 1 studied here have produced a Middle Kimmeridgian age based on correlations with Australian assemblages (section 6). These unequivocally Kimmeridgian dinoflagellate cysts significantly strengthen the case that the Oxfordian calcareous nannofossils in the Patasar Shale Member are reworked.

Thus, the lowermost part of the Patasar Shale Member appears to be Late Oxfordian, based on a single, fragmentary ammonite (Fig. 4). Above this, the part of the Patasar Shale Member sampled for microfossils is of Early–Middle Kimmeridgian age. However, Middle Kimmeridgian dinoflagellate cysts appear to underlie Early Kimmeridgian calcareous nannofossils.

In order to rationalise the apparently incoherent calcareous nannofossil and dinoflagellate cyst evidence in the Patasar Shale Member, the age of the *Dingodinium swanense* Interval Zone of Helby et al. (1987) must be reexamined. This zone was assigned to the Kimmeridgian and the Early to Late Kimmeridgian by Helby et al. (1987, p. 29; 2004) and Riding et al. (2010, p. 567) respectively. However, the latter authors stated that the evidence for this correlation was equivocal, and that the zone could possibly be as old as Late Oxfordian (Davey, 1988; 1999; Francis and Westermann, 1993). The *Dingodinium swanense* Interval Zone dinoflagellate cyst associations described herein are clearly intercalated between a Late Oxfordian ammonite and Early Kimmeridgian calcareous nannofossils. This is, thus far, the best and most direct control on the age of the *Dingodinium swanense* Interval Zone. Due to the ammonite in the lowermost Patasar Shale Member, the *Dingodinium swanense* Interval Zone cannot be older than Late Oxfordian (Fig. 4). Likewise, it apparently cannot be younger than Early Kimmeridgian due to the calcareous nannofossils stratigraphically above the two samples examined herein. Hence, due to the other independent evidence of an Early Kimmeridgian age for this zone based on radiolaria (Aita and Grant-Mackie, 1992), molluscs (Francis and Westermann, 1993) and calcareous nannofossils (Rai et al., 2015), the *Dingodinium swanense* Interval Zone is herein interpreted to be of Early Kimmeridgian age (Fig. 4). This reinterpretation of the age of an Australasian Jurassic dinoflagellate cyst zone such that it is older than it was first envisaged is a consistent theme. It appears that many of these dinoflagellate cyst zones originally established by Helby et al. (1987) are significantly older than was originally thought (Riding, 2003; Riding et al., 2010; Mantle and Riding, 2012). This biostratigraphical synthesis is summarised in Figs. 3 and 4.

8. The palaeogeographical affinity of the dinoflagellate cyst assemblage

The pollen and spore associations encountered comprise cosmopolitan forms, but the dinoflagellate cyst assemblage recovered is distinctly Gondwanan in affinity. The dominant species, *Dingodinium jurassicum*, was endemic to Gondwana. Furthermore, species such as *Chlamydophorella wallala, Hadriana cinctum, Indodinium khariense* and *Leptodinium eumorphum* were also confined to Australasia. Many of the species observed, such as *Glossodinium dimorphum*, *Rigaudella aemula, Scriniodinium crystallinum* and *Tubotuberella apatela*, are cosmopolitan (Woollam and Riding, 1983; Helby et al., 1987). Due to the Austral nature of the associations reported here from the Kachchh Basin, it seems that dinoflagellate cyst zonation schemes established in Australia and Papua New Guinea such as those by Helby et al. (1987), Davey (1988; 1999) and Riding et al. (2010) are applicable in western India and probably the entire Indian subcontinent. These schemes appear to have utility throughout Gondwana with the exception of South America. Research on the Jurassic marine palynology of the Neuquén Basin, Argentina, has indicated that the extreme west of Gondwana is characterised by associations with far more affinity to the northern hemisphere (e.g. Hedlund and Beju 1976; Harris, 1977; Quattrocchio and Volkheimer, 1990; Quattrocchio and Sarjeant, 1992; Quattrocchio et al., 2007; Riding et al. 2011).

9. Conclusions

One of two samples (PTS 1) from the lowermost Patasar Shale Member of the Patasar Tank section in the Kachchh Basin, western India yielded an abundant, moderately diverse and well-preserved palynobiota including a dinoflagellate cyst association of Gondwanan affinity. By contrast, the other sample examined (PTS 1A) produced a relatively poorly preserved and markedly less diverse assemblage. However, both the samples studied are clearly referable to the *Dingodinium swanense* Interval Zone of Australia, which is of Kimmeridgian age. This study indicates that Australasian dinoflagellate cyst biozonations can be applied in western India and, by extension, probably throughout the Indian subcontinent. Due to evidence from ammonites and calcareous nannofossils in the Patasar Shale Member outlined by Rai et al. (2015), together with other key evidence from Gondwana, the age of the *Dingodinium swanense* Interval Zone of Australia is reinterpreted herein as being Early Kimmeridgian in age (Fig. 4). This biozone was previously assigned to the Early to Late Kimmeridgian and this reassessment to an older age follows a familiar recent trend (e.g. Riding et al., 2010).

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Appendix 1

The palynomorphs recorded and mentioned herein, at and below the species level, are listed in this appendix with their respective author citations. They are listed alphabetically in two groupings, dinoflagellate cysts, and pollen and spores. The Plate and photograph numbers of the taxa which are figured herein are provided where appropriate. The references pertaining to the dinoflagellate cysts can be found in Fensome and Williams (2004).

Dinoflagellate cysts:

Chlamydophorella wallala Cookson & Eisenack 1960
Dingodinium jurassicum Cookson & Eisenack 1958
Dingodinium swanense Stover & Helby 1987
Egmontodinium polyplacophorum Gitmez & Sarjeant 1972
Endoscrinium luridum (Deflandre 1938) Gocht 1970
Glossodinium dimorphum Ioannides et al. 1977 (Plate II/1)
Gonyaulacysta ceratophora (Cookson & Eisenack 1960) Riding 2005
Gonyaulacysta jurassica (Deflandre 1938) Norris & Sarjeant 1965 subsp. *jurassica* (autonym) (Plate I/1, 2)
Hadriana cinctum Riding & Helby 2001
Herendeenia pisciformis (Cookson & Eisenack 1958) Wiggins 1969
Indodinium khariense Kumar 1986
Komewuia glabra Cookson & Eisenack 1960

Leptodinium eumorphum (Cookson & Eisenack 1960) Sarjeant in Davey et al. 1969
Mendicodinium granulatum Kumar 1986 (Plate I/11, 12)
Nannoceratopsis pellucida Deflandre 1938
Omatia montgomeryi Cookson & Eisenack 1958
Pareodinia halosa (Filatoff 1975) Prauss 1989
Prolixosphaeridium parvispinum (Deflandre 1937) Davey et al. 1969
Rhynchodiniopsis cladophora (Deflandre 1938) Below 1981
Rigaudella aemula (Deflandre 1938) Below 1982
Scriniodinium crystallinum (Deflandre 1938) Klement 1960
Scriniodinium dictyotum Cookson & Eisenack 1960
Scriniodinium inritibile Riley in Fisher & Riley 1980
Stiphrosphaeridium anthophorum (Cookson & Eisenack 1958) Lentin & Williams 1985
Stiphrosphaeridium dictyophorum (Cookson & Eisenack 1958) Lentin & Williams 1985
Tubotuberella apatela (Cookson & Eisenack 1960) Ioannides et al. 1977

Pollen and spores:
Callialasporites dampieri (Balme 1957) Sukh Dev 1966
Calllialasporites turbatus (Balme 1957) Schulz 1967
Perinopollenites elatoides Couper 1958

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Display material captions:

Fig. 1. A geological map of the Kachchh Basin of western India (b - top) with an inset map of India in the top left (a), and a schematic map of the Wagad Uplift, adapted from Deshpande and Mehr (1980) (c – below).

Fig. 2. Lithostratigraphy and ammonite biostratigraphy of the Upper Jurassic (Oxfordian and Kimmeridgian) strata of the Kachchh Basin, western India (adapted from Pandey et al., 2012).

Fig. 3. The integrated biostratigraphy of the uppermost Washtawa Formation and the lowermost Kanthkot Formation in the western part of the Wagad Anticline, Kachchh Basin, western India. The references quoted in this diagram which are not quoted in the text are as follows:

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Fig. 4. The stratigraphical occurrences of the key marker ammonites, calcareous nannofossils and dinoflagellate cysts in the Nara Shale Member, Kanthkot Ammonite Bed and Patasar Shale Member near Kanthkot, Wagad Anticline, Kachchh Basin, western India.

Table 1. The 13 micropalaeontology (calcareous nannofossil and palynomorph) samples collected from the Patasar Shale Member at the Patasar Tank section near Kanthkot, in the central west part of the Wagad Uplift, western India (N 23º 29’ 48.4’’, E 70º 28’ 01.7’’; see Fig.

1; Rai et al., 2015, fig 3D). The distances from the base of the exposure (in metres) are given, and the productivity of the samples indicated by an X. An ellipsis (…) indicates that the respective microfossil group was not recorded in that sample.

Table 2. The quantitative occurrences of palynomorphs and kerogen macerals in samples PTS 1A and PTS 1 from the Patasar Shale Member of the Patasar Tank section of the Wagad Anticline. The data are arranged into three major palynomorph groups, and the four principal kerogen macerals are listed as approximate percentages. The data are presented as actual counted specimens and percentages of the overall palynobiota for each sample. An 'X' indicates where a palynomorph or a kerogen maceral is present in the respective sample, but was not encountered in the count. An ellipsis (…) indicates that the respective palynomorph was not recorded in that sample.

Plate I. Selected dinoflagellate cysts from sample PTS 1 in the lower part of the Patasar Shale Member (Kanthkot Formation) of the Patasar Tank section in the western part of the Wagad Anticline, near Kanthkot, western India. The scale bars all indicate 20 µm, and the locations of the specimens on the BSIP slides are indicated by England Finder coordinates.

1, 2. *Gonyaulacysta jurassica* (Deflandre 1938) Norris & Sarjeant 1965 subsp. *jurassica* (autonym). 1 - BSIP slide number 15633, Q37/1; 2 - BSIP slide number 15635, O32/3.

3. *Tubotuberella apatela* (Cookson & Eisenack 1960) Ioannides et al. 1977, BSIP slide number 15633, J70/2.

4. *Egmontodinium polyplacophorum* Gitmez & Sarjeant 1972, BSIP slide number 15629, X60/1.

5. *Endoscrinium luridum* (Deflandre 1938) Gocht 1970, BSIP slide number 15636, Q51.

6. *Pareodinia halosa* (Filatoff 1975) Prauss 1989, BSIP slide number 15629, Q61/3.

7, 8. *Scriniodinium dictyotum* Cookson & Eisenack 1960. 7 - BSIP slide number 15636, T52; 8 - BSIP slide number 15636, V36.

9. *Indodinium khariense* Kumar 1986, BSIP slide number 15635, Q55.

10. *Chlamydophorella wallala* Cookson & Eisenack 1960, BSIP slide number 15630, E53/2.

11, 12. *Mendicodinium granulatum* Kumar 1986. 11 - BSIP slide number 15630, H58; 12 - BSIP slide number 15635, E54.

Plate II. Selected dinoflagellate cysts from sample PTS 1 in the lower part of the Patasar Shale Member (Kanthkot Formation) of the Patasar Tank section in the western part of the Wagad Anticline, near Kanthkot, western India. The scale bars all indicate 20 μm, and the locations of the specimens on the BSIP slides are indicated by England Finder coordinates.

1. *Glossodinium dimorphum* Ioannides et al. 1977, BSIP slide number 15635, J67/1.

2, 3. *Leptodinium eumorphum* (Cookson & Eisenack 1960) Sarjeant in Davey et al. 1969. 2 - BSIP slide number 15630, T68; 3 - BSIP slide number 15633, S55/2.

4. *Rhynchodiniopsis cladophora* (Deflandre 1938) Below 1981, BSIP slide number 15633, L47/4.

5, 6. *Dingodinium jurassicum* Cookson & Eisenack 1958. 5 - BSIP slide number 15634, M53; 6 - BSIP slide number 15636, Z39.

7. *Prolixosphaeridium parvispinum* (Deflandre 1937) Davey et al. 1969, BSIP slide number 15632, O57/3.

8, 9. *Stiphrosphaeridium anthophorum* (Cookson & Eisenack 1958) Lentin & Williams 1985. 8 - BSIP slide number 15638, W53/1; 9 - BSIP slide number 15634, Y61/1.

10, 11. *Hadriana cinctum* Riding & Helby 2001. 10 - BSIP slide number 15637, R58; 11 - BSIP slide number 15638, S44.

12. *Rigaudella aemula* (Deflandre 1938) Below 1982, BSIP slide number 15631, N40/4.