Regional correlation of Jurassic/Cretaceous boundary strata based on the Tithonian to Valanginian dinoflagellate cyst biostratigraphy of the Volga Basin, western Russia

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ABSTRACT

Precise stratal correlation of Jurassic/Cretaceous boundary successions in the Boreal Province, including the western European and Russian regions, based on ammonite biostratigraphy remain significantly problematical due to widespread faunal provincialism. In order to help clarify this situation, the marine palynology of the Tithonian (uppermost Jurassic) and the Berriasian and Valanginian (Lower Cretaceous) strata exposed on the banks of the River Volga at Gorodishche and Kashpir, near Ul'yanovsk, has been studied in detail. Over 100 dinoflagellate cyst species were recovered, and their ranges used to compile a detailed Tithonian to Valanginian palynostratigraphy for the Volga Basin. First and last appearance datums of key dinoflagellate cyst taxa are used to define ages for unreliably dated strata in the Russian successions by comparison with the stratigraphical ranges of the same taxa calibrated to ammonite zones in Boreal northwest Europe. These dinoflagellate cyst bioevents include the range bases of *Gochteodinia villosa*, *Pseudoceratium brevicornutum, Pseudoceratium pelliferum*, *Spiniferites primaevus* and *Spiniferites ramosus*, and the range tops of *Egmontodinium polyplacophorum*, *Pseudoceratium brevicornutum* and *Senoniasphaera jurassica*. For example, the inception of *Gochteodinia villosa* indicates a correlation between the base of the Late Tithonian Epivirgatites nikitini Zone of the Volga Basin and that of the Galbanites kerberus Zone of northwest Europe. It is clear that dinoflagellate cysts have great potential for correlating between the northwest European and Russian Platform (and Siberian) ammonite zonations. Based on the successive range bases and tops of key taxa a new dinoflagellate cyst interval zonation scheme, consisting of five zones and seven subzones, has been defined for the Volga Basin. Graphic correlation of the dinoflagellate cyst range data indicate that part of the Mid Tithonian Zaraskaites zarajskensis Subzone is missing at Kashpir. However, the two successions were characterised by steady, coeval sedimentation up to the top of the Late Tithonian-Early Berriasian Craspedites nodiger Zone. There are some differences between Tithonian and Berriasian dinoflagellate cyst floras between the Volga Basin and northwest Europe, but these are relatively minor compared to the endemism displayed by molluscan faunas. Valanginian dinoflagellate cyst assemblages throughout the Northern Hemisphere, however, are significantly more similar. This scenario is also reflected globally, with the most significant floral differences being manifested between the Tithonian-Berriasian of the Southern Hemisphere and the rest of the world.

Keywords: Latest Jurassic; Early Cretaceous; dinoflagellate cysts; biostratigraphy; correlation; biozonation; western Russia.

1. Introduction

Global correlation of Jurassic/Cretaceous (J/K) boundary strata has always proved highly problematical due to intense and widespread faunal provincialism throughout the Northern Hemisphere (Hoedemaeker, 1991; Wimbledon, 2007; Wimbledon et al., in press). The J/K boundary strata of the Volga Basin in western Russia represent an important succession which is difficult to correlate with other areas. In order to mitigate this, Tithonian to Valanginian dinoflagellate cyst floras from important reference sections on the banks of the River Volga have been studied in detail. These are at Gorodishche, 25 km north of Ul'yanovsk, and at Kashpir, 140 km south of that town (Fig. 1).

Ammonites are the primary biostratigraphical indices for the Jurassic and Cretaceous (Callomon, 1995; Zeiss, 2003); however, other fossil groups have considerable and growing significance (Torrens, 1980). The profound endemism of latest Jurassic-earliest Cretaceous ammonite faunas has led to a complex stage terminology for the terminal Jurassic stage, including junior synonyms. Thus the stages Kimmeridgian, Portlandian, Purbeckian, Tithonian and Volgian have been variously applied from England/France to Poland (and Greenland), on the Russian Platform/Siberia (each with different ammonite zonations) and in the Submediterranean/Tethyan province (i.e. the Tethyan Realm) for the post-Oxfordian interval (Fig. 2). In 1990, the Tithonian was formally ratified as the terminal Jurassic stage by the International Commission on Stratigraphy, and this is used herein. This ratification has proved controversial because the Portlandian is a senior synonym of the Tithonian. Later, Cope (1993) proposed the Bolonian and the Portlandian as stages of a Tithonian Superstage. The Bolonian equates to the old Upper Kimmerigian Stage, i.e. the Upper Kimmeridge Clay Formation of northwest Europe, spanning the Pectinatites elegans to the Virgatopavlovia fittoni zones; it is not illustrated in Fig. 2. A Global Stratotype Section and Point and internal divisions for the Tithonian have not been finalised. Middle and Upper Berriasian units in the Boreal Realm have been assigned to the Ryazanian (Fig. 2), but the Berriasian Stage has always been considered to be the global standard and is therefore used in preference to the Ryazanian in this paper.

The most complete and best documented J/K boundary successions are in the Submediterranean/Tethyan province. Consequently the Tithonian-Berriasian ammonite zonation is the primary standard for the J/K boundary, although latterly it is rivalled by the calpionellid zonation (Remane, 1998). Recently, emphasis has been placed on the base of the M18r magnetrochron interval as a proxy for the lowermost Berriasian (Gradstein et al., 2004). The Tithonian and Berriasian stage nomenclature has been formally adopted by the Russian Interdepartmental Stratigraphical Committee and local stage names suppressed. However, dissident support remains for the view that the Volgian Stage should remain intact and that it must be, *a priori*, entirely Jurassic, even though it is clear that it spans the Tithonian and much of the Berriasian (Fig. 2; Zakharov and Rogov, 2008).

Correlations between the Submediterranean/Tethyan province and the northern Boreal region are somewhat tentative and remain uncertain by potentially as much as an entire ammonite zone. Hence the boundaries and ammonite zones of the Tithonian and Berriasian stages of the Tethyan Realm cannot be recognised precisely in Russia. However, recent palaeomagnetic research at Nordvik in Siberia by Houša et al. (2007) has shown that the base of the Berriasian, in marine and non-marine (i.e. Purbeck of Dorset) facies, can be approximately correlated with the Siberian equivalent of the Craspedites nodiger Zone of the Russian Platform. Thus magnetostratigraphy is proving to be a valuable tool for constraining biostratigraphical correlations and helping solve provincialism problems, but it cannot be effective in all areas due to diagenesis, incomplete sedimentary successions and weathering (Ogg et al., 1994).

The Portlandian (Brongniart, 1829; d'Orbigny 1842-51) was applied to supposed Portland and ?Purbeck formation equivalents in Russia (Pavlov, 1889). However a synonym, the Volgian, was proposed by Nikitin (1881). The base of the Volgian (the Subplanites klimovi Zone) is approximately equivalent to the base of the Tithonian (Gerasimov and Mikhailov, 1966). Stratigraphical breaks, indicated by phosphatites, pebble beds and winnowed horizons, within the Volgian are geographically widespread. Despite this, the term Volgian has been used extensively in the high northern latitudes outside onshore Britain, for example in the North Sea Basin (e.g. Richards et al., 1993). The Boreal or Sub-boreal nature of Oxfordian to Early Kimmeridgian and late Early Cretaceous ammonite faunas of the Russian Platform has ensured that correlation between this area and northwest Europe is now relatively well documented (Krymholts et al., 1988; Hantzpergue et al., 1998; Hoedemaeker, 1999). However, significant problems remain in the uppermost Jurassic and lowermost Cretaceous parts of these successions. Correlation of the well-known northwest European J/K boundary successions with those of the Russian Platform has proved problematical due to the geographical isolation of the Russian Platform from Kimmeridgian to Early Berriasian times, and the resultant profoundly endemic ammonite faunas (Gerasimov and Mikhailov, 1966; Casey, 1967; 1968; 1973; Wimbledon and Cope, 1978; Cope, 1978; Wimbledon, 1984; Zakharov et al., 1997; Abbink et al., 2001; Rogov and Zakharov, 2008). These problems are even more acute when attempting to correlate the Russian and Tethyan ammonite zonations (Geyssant, 1997). Moreover alternative stratigraphically significant microfossils such as calcareous nannofossils and calpionellids, extensively employed as precise biomarkers around the J/K boundary in the Tethyan Realm, are rare or absent in Russia. In summary, there is never likely to be a universally-accepted ammonite-based scheme that can accommodate the Lower Tithonian to Lower Berriasian of the Russian Platform, all other areas of the Boreal Realm and the Tethyan Realm. Several alternative schemes have been presented, for example Kusnetsova (1978), Lord et al. (1987), Krymholts et al. (1988), Hoedemaeker (1991; 1999) and Hantzpergue et al. (1998).

This study uses dinoflagellate cysts to help to resolve the aforementioned correlation problems. Motile planktonic dinoflagellates, and hence their cysts, have very wide geographical distributions (e.g. Taylor and Pollingher, 1987). Dinoflagellate cysts are thus potentially much less provincial than many other macrofossil and microfossil taxa (Riding et al., 2010; 2011). A palynological investigation has been undertaken of the Tithonian to Valanginian sections on the banks of the River Volga in order to develop an integrated biostratigraphical correlation between the Russian Platform and northwest Europe. This paper reviews the Gorodishche and Kashpir sections, presents a detailed description of the dinoflagellate cyst ranges, and compares these data to those from other localities in the Russian Platform, Siberia and northwest Europe. The principal dinoflagellate cyst bioevents are discussed, thereby helping to clarify the correlation of the ammonite zonal schemes for the Russian Platform with those of northwest Europe, and a dinoflagellate cyst interval biozonation for the Russian Platform is proposed. All ammonite zones and subzones cited herein are used in the sense of biozones. The zonal index taxa are written in Roman script, and the initial letters of the words "zones" and "subzones" are capitalised. Hence the index species of the Dorsoplanites panderi Zone is *Dorsoplanites panderi* d'Orbigny.

The ammonite zonation of the Lower Tithonian to Lower Berriasian at Gorodishche was outlined by Gerasimov and Mikhailov (1966), Mikhailov (1966), Gerasimov (1969) and Mitta (1993a,b; 1994), whereas that of the reference section at Kashpir was described by Pavlov (1886), Gerasimov (1969), Mesezhnikov (1977) and Blom et al. (1984). Correlations between the Russian and English Tithonian-Early Berriasian ammonite schemes differ markedly (Lord et al., 1987). These include the schemes of Kuznetsova (1978), Sasanova and Sasanov (1979), Wimbledon (1984), Lord et al. (1987), Krymholts et al., (1988), Hoedemaeker (1991), Hantzpergue et al. (1998) and Rogov and Zakharov (2009). Lord et al. (1987) synthesised the data of Casey (1967; 1973), Cope (1967; 1978), Wimbledon and Cope (1978) and Cox and Gallois (1981). Correlations between Europe and the Volga Basin are presented as Fig. 3.

Lord et al. (1987) correlated the Epivirgatites nikitini Zone of the Volga Basin and the Progalbanites albani Zone of northwest Europe as a result of the possible recognition of two specimens of *Epivirgatites nikitini* from the Progalbanites albani Zone by Cope (1978). However, the correlation by Krymholts et al. (1988) of the Zaraiskites zarajskensis Subzone with the Progalbanites albani Zone followed the suggestion by Arkell (1956) that the ammonite genera *Progalbanites* and *Zaraiskites* were synonymous. More recently, however, the base of the Epivirgatites nikitini Zone was deemed to be coincident with the top of the Progalbanites albani Zone (e.g. Hantzpergue et al., 1998) despite Krymholts et al. (1988) having placed the base of the Epivirgatites nikitini Zone within the Galbanites okusensis Zone (Fig. 3). Ongoing studies by one of us (WAPW) have revealed no conspecific relationships between the Mid-Late Tithonian (= Portlandian) ammonites of England, France and Greenland (Progalbanites albani-Titanites anguiformis zones) and the supposedly coeval faunas from the Volga Basin. The most recent studies on the successions at Gorodishche and Kashpir (i.e. Ruffell et al., 2002; Gröke et al., 2003; Kessels et al., 2003) all adopted the ammonite zonal correlations of Hantzpergue et al. (1998). These papers illustrated sedimentary logs for the successions; despite no formal descriptions being provided, they correlate reasonably well with the logs of Hantzpergue et al. (1998) and herein (Fig. 4).

2. Previous research on the Tithonian to Valanginian successions at Gorodishche and Kashpir

This section is an overview of previous research on the Tithonian to Valanginian successions of Gorodishche and Kashpir including their ammonite biostratigraphy and palynology. These studies are compared with the high-resolution lithological logs and ammonite data which have been compiled herein.

2.1. Gorodishche

The Tithonian and Lower Berriasian succession at Gorodishche was first described by Pavlov (1886). It was subsequently redescribed by Sasanov (1951), Mesezhnikov (1977), Blom et al. (1984), Hantzpergue et al. (1998), Ruffell et al. (2002) and Zakharov et al. (2006). A lithological log of this section is illustrated in Figs. 4 and 5. Correlation of the log of the Gorodishche succession prepared by Mesezhnikov in Blom et al. (1984) with the log herein is illustrated in Fig. 5. The former log is of relatively lower resolution. Only the major lithological units were recognised, and it included vague bed thicknesses and somewhat basic sedimentological descriptions (Blom et al., 1984). Equating the lithostratigraphy of the two logs is thus problematical. However, several tie points can be identified on the basis of key lithologies, and verified using ammonite evidence.

Bed 11 of Blom et al. (1984) correlates with beds 1-13 herein (Fig. 5). Blom et al. (1984, p.71, 121) described the black units in Bed 11 as “pyroschist” in the key, and “bituminous, shaley dark gray brown clay (combustible shale)” in the bed descriptions. These probably equate with the laminated siltstone horizons recognised herein. The laminated lithology was described as “lime clay” by Blom et al. (1984, p. 71), and corresponds to the calcareous mudstone units (beds 1, 2, 4 and 6) herein. The substantial thickness of lenticular siltstones present in the uppermost part of the Zaraiskites zarajskensis Subzone is not represented in either the log or the sedimentological descriptions of Blom et al. (1984).

Beds 12 and 14 of Blom et al. (1984, p.121) were described as “phosphorite conglomerates”, and clearly equate with our beds 14 and 16 (Fig. 5). Beds 15-18 of the Russian workers were all described as grey calcareous sandstones with glauconite, but were subdivided on the basis of ammonites rather than sedimentology. This faunal information thus provides a simple means of equating this interval with our beds 17 and 18; the tie-points are indicated in Fig. 5. Bed 19 of Blom et al. (1984) corresponds, by default, to the phosphorite horizon, since the adjacent units can be confidently matched. However, the description of bed 19 of Blom et al. (1984, p. 122), i.e. “sandstone, conglomerate-like yellowish-grey, ferruginated, with numerous pebbles from underlying sandstone” contrasts with the findings herein. This may suggest lateral variation within this unit, but this was not observed in the field. Bed 20 of Blom et al. (1984, p.121) was described as “clay....with numerous gypsum crystals”, and equates to our bed 20.

At Gorodishche, Lord et al. (1987) previously described the dinoflagellate cyst biostratigraphy of eight samples from the Upper Kimmeridgian (Aulacostephanus eudoxus Zone) to the lowermost Middle Tithonian (Zaraskaites zarajskensis Subzone). Only the uppermost of these eight samples, from bed 11 of Mesezhnikov (1977), overlaps with the interval examined here. The log of Lord et al. (1987) was taken from Mesezhnikov (1977), and is correlated with our log in Fig. 5. Lord et al. (1987) used the ammonite zonation of Kuznetsova (1978), and gave a log that apparently shows a generalised representation of bed 11, because it depicts many more “bituminous shale” horizons than were indicated by Blom et al. (1984). Lord et al. (1987) did not establish a dinoflagellate cyst zonation.

Hogg (1994) analysed 28 samples from the Upper Kimmeridgian to Upper Tithonian-Lower Berriasian (the Aulacostephanus eudoxus Zone to the Craspedites nodiger Zone). The log of Hogg (1994) was based on data provided by VNIGRI, Saint Petersburg, and is correlated with other logs in Fig. 5. Hogg (1994) also did not erect a dinoflagellate cyst zonation and the dinoflagellate cyst range/abundance charts were not discussed in detail. Correlation of the Russian and English ammonite successions followed that of Lord et al. (1987).

Riding et al. (1999) provided the most detailed account of the dinoflagellate cyst biostratigraphy of the Gorodishche succession, as part of a dinoflagellate cyst zonation for the Bathonian to Berriasian of the Russian Platform. Twenty-four samples spanning the Upper Kimmeridgian to Upper Tithonian-Lower Berriasian (Aulacostephanus eudoxus Zone to Craspedites nodiger Zone) were examined, and each was linked to a bed number of Blom et al. (1984). Precise comparison of the samples of Riding et al.

(1999) with the present work is problematical but, in general terms, the uppermost ten samples (samples RP56 to RP47) overlap with the interval studied here.

Riboulleau et al. (2003, p. 180) studied the palynology of the Tithonian-Lower Berriasian from the Gorodishche section as part of a geochemical and sedimentological study, but did not provide any taxonomic details.

2.2. Kashpir

The Tithonian to Valanginian succession at Kashpir was described by Pavlov (1886), Gerasimov (1969) and Blom et al. (1984). Lithological logs of the section are illustrated in Figs. 4 and 6. A correlation of the logs of Mesezhnikov in Blom et al. (1984) and Lord et al. (1987) with the log herein is illustrated in Fig. 6. There are several key lithologies which are useful markers in matching the earlier logs and the more detailed present results. Bed 6 (a “bituminous shale”) of Blom et al. (1984) correlates with our bed 2 (a laminated siltstone). Similarly the coarse-grained beds in the Virgatites virgatus Zone and Epivirgatites nikitini Zone are represented by beds 9-12 of Blom et al. (1984); these correspond to beds 4-9 herein. Bed 18, a bituminous shale horizon, herein corresponds to bed 20 of Blom et al. (1984) which is a “bituminous....combustible shale”, and beds 21-24 herein are beds 22-26 of Blom et al. (1984) on the basis of sedimentological descriptions. Bed 24 herein, the questionably Valanginian sandstone with phosphatic concretions, correlates with bed 26 of Blom et al. (1984, p.124) which was described as “conglomerate...wax-red, consists of abundant phosphorite pebbles.” The mica-rich siltstones (beds 27-30) of the current investigation were not included in the log of Blom et al. (1984).

The marine palynology of this sucession was briefly considered by Lord et al. (1987), who studied two samples from the Middle Tithonian (Zaraskaites zarajskensis Subzone) (beds 5 and 7 of Blom et al., 1984). More recently, Riding et al. (1999) analysed nine samples from the Middle Tithonian (Zaraskaites zarajskensis Subzone) to the Upper Berriasian (Riasanites rjasanensis/Surites spasskensis Zone). The uppermost five samples of Riding et al. (1999) (i.e. samples RP75 to RP71) correspond to the interval examined by us.

3. The Middle Tithonian to Lower Valanginian dinoflagellate cyst biostratigraphy of the Gorodishche and Kashpir successions

The dinoflagellate cyst assemblages from Gorodishche and Kashpir are rich; over 300 forms were identified from the 70 samples studied (Smith, 1999; Fig. 4; Tables 1, 2). These are all listed, with author citations where appropriate, in Appendix 1. The 70 samples are listed in Appendix 2. Tables 1 and 2 comprise the ranges and relative abundance data for all dinoflagellate cysts recorded herein. The ranges of morphotypes with stratigraphically restricted occurrences are illustrated in Figs. 7-10. Selected forms are illustrated in Plates I and II. Many of the taxa recovered have also been found in coeval sections from other Boreal regions.

The majority of the samples yielded abundant and diverse dinoflagellate cysts. Numerous taxa range across the entire interval examined. These comprise *Ambonosphaera*? *staffinensis*, *Cassiculosphaeridia magna*, *Cassiculosphaeridia reticulata*, *Chlamydophorella nyei*, *Chytroeisphaeridia chytroeides*, *Circulodinium distinctum*, *Dapsilidinium multispinosum*, *Dingodinium cerviculum, Dingodinium tuberosum*, *Gonyaulacysta* spp., *Hystrichodinium pulchrum*, *Leptodinium subtile*, *Pareodinia ceratophora*, *Prolixosphaeridium parvispinum, Sentusidinium rioultii, Sirmiodinium grossii*, *Stephanelytron membranoideum*, *Tanyosphaeridium isocalamum, Tanyosphaeridium magneticum, Tenua hystrix, Valensiella ovulum, Wallodinium cylindricum, Wallodinium krutzschii* and *Wrevittia* spp. (Tables 1, 2). Four taxa, *Cribroperidinium magnificum, Cribroperidinium undoryensis, Meiourogonyaulax distincta* and *Thalassiphora*? *robusta* are apparently indigenous to the Volga Basin (Smith and Harding, 2004). The dinoflagellate cyst nomenclature of Fensome and Williams (2004) is used throughout, and all author citations of the taxa discussed can be found in this index. Further information on the informal morphotypes referred to (e.g. *Cribroperidinium* sp. 1) can be found in Smith (1999). All samples, slides and figured specimens are housed in the collections of the School of Ocean and Earth Sciences, University of Southampton, Southampton Oceanography Centre, Southampton, United Kingdom.

3.1. Middle Tithonian (the Zaraskaites zarajskensis Subzone of the Dorsoplanites panderi Zone)

This account refers mainly to the Gorodishche succession, where 20 samples were collected. Only two samples were collected from the Zaraskaites zarajskensis Subzone at Kasphir (Fig. 4). *Dingodinium tuberosum* is the most abundant form in this subzone where it ranges from 10-36%. Other taxa which are relatively prominent include *Chytroeisphaeridia chytroeides, Cometodinium whitei*, *Kleithriasphaeridium* *fasciatum, Sirmiodinium grossii, Systematophora daveyi* and *Trichodinium* sp. 1. *Glossodinium dimorphum*, *Gochteodinia tuberculata* and *Thalassiphora*? *robusta* are restricted to the Zaraskaites zarajskensis Subzone in both sections (Tables 1, 2).

The last appearance datum (LAD) or range top of *Glossodinium dimorphum* occurs stratigraphically closer to the base of the Virgatites virgatus Zone at Kashpir than at Gorodishche (Figs. 7, 9). This may indicate a short stratigraphical gap beneath the base of the Virgatites virgatus Zone at Kashpir. *Cribroperidinium magnificum* and *Trichodinium* sp. 1, both of which have LADs in this Subzone at Gorodishche, have relatively extended ranges at Kashpir with LADs at the top of the Craspedites subditus and the top of the Kachpurites fulgens zones respectively. *Cribroperidinium erymnoseptatum* and *Cribroperidinium* sp. 6 have LADs close to the base of the Zaraskaites zarajskensis Subzone at Gorodishche, but do not occur at Kashpir (Figs. 7, 9). This is consistent with the contention that samples were only taken from the upper part of this subzone at Kashpir. These two forms may thus serve to separate the upper and lower parts of this subzone, although more material needs to be examined from stratigraphically lower in this subzone at Kashpir in order to verify this. The LAD of consistent abundant (i.e. 10-36 %) *Dingodinium tuberosum* is coincident with the top of the Zaraskaites zarajskensis Subzone in both successions (Tables 1, 2).

Generally, taxa with FADs in the Zaraskaites zarajskensis Subzone at Gorodishche also have coeval range bases at Kashpir. There are two notable exceptions, firstly *Kleithriasphaeridium corrugatum* which first appears in the Craspedites subditus Zone at Kashpir. The second is *Senoniasphaera jurassica*, which appears near the top of the Zaraskaites zarajskensis Subzone at Gorodishche, but not until the Kachpurites fulgens Zone at Kashpir (Figs. 7, 9, 10).

3.2. Middle to Upper Tithonian (Virgatites virgatus and Epivirgatites nikitini zones)

This summary is taken entirely from Gorodishche; no samples from the Virgatites virgatus and Epivirgatites nikitini zones were collected from Kashpir (Fig. 4). Stratigraphically restricted taxa which consistently occur throughout the Middle and Upper Tithonian succession at Gorodishche include *Cometodinium whitei*, *Hystrichosphaeridium petilum*, *Kleithriasphaeridium fasciatum*, *Lithodinia* sp. 1, *Prolixosphaeridium parvispinum*, *Systematophora daveyi*, *Tehamadinium* sp. 1, *Trichodinium* cf. *T. ciliatum*, and *Tubotuberella apatela*. In addition, *Cribroperidinium* sp. 1 and *Tenua hystrix* appear consistently within the upper part of this interval (Tables 1, 2).

Because these zones were not sampled at Kashpir, no direct comparisons can be made. However, several of the taxa with LADs in this interval at Gorodishche occur in younger deposits at Kashpir. *Dichadogonyaulax*? *chondra*, which has its LAD at Gorodishche at the base of the Virgatites virgatus Zone is last found in the Craspedites subditus Zone at Kashpir. *Hystrichosphaeridium petilum* and *Tehamadinium sousense*, which both have LADs in the *Virgatites virgatus* Zone at Gorodishche, both extend into the Kachpurites fulgens Zone at Kashpir. *Stiphrosphaeridium dictyophorum* and *Tenua hystrix*, both of which have LADs in the Virgatites virgatus and Epivirgatites nikitini zones at Gorodishche respectively, appear last in the Middle to Upper Berriasian at Kashpir. *Tehamadinium* sp. 1, which has its LAD in the Epivirgatites nikitini Zone at Gorodishche, last appears at Kashpir within the Craspedites nodiger Zone. Additionally, *Egmontodinium polyplacophorum* first appears in the Virgatites virgatus Zone at Gorodishche, but has a younger FAD at Kashpir, within the Craspedites subditus Zone (Figs. 7, 8, 9; Tables 1, 2).

3.3. Upper Tithonian to Lower Berriasian (Kachpurites fulgens to Craspedites nodiger zones)

Stratigraphically restricted dinoflagellate cysts which occur consistently and range through the Upper Tithonian to Lower Berriasian succession at Gorodishche include *Achomosphaera neptuni*, *Cribroperidinium* spp., *Egmontodinium toryna*, *Endoscrinium granulatum*, *Gochteodinia villosa*, *Gonyaulacysta dentata*, *Kleithriasphaeridium corrugatum*, *Kleithriasphaeridium eoinodes*, *Kleithriasphaeridium fasciatum*, *Kleithriasphaeridium porosispinum*, *Lithodinia* sp. 1, *Perisseiasphaeridium ingegerdiae*, *Prolixosphaeridium parvispinum*, *Senoniasphaera jurassica*, *Sentusidinium* aff. *S. ?fibrillospinosum*, *Sentusidinium* sp. 3, *Sirmiodinium grossii*, *Stanfordella exsanguia*, *Stephanelytron membranoideum*, *Stiphrosphaeridium dictyophorum*, *Systematophora daveyi*, *Tehamadinium daveyi*, *Trichodinium* cf. *T. ciliatum*, *Tubotuberella apatela*, *Valensiella ovula* and *Wrevittia* spp. (Tables 1, 2).

Tehamadinium daveyi has its FAD in the Kachpurites fulgens Zone in both sections. Other taxa with FADs in this zone at Kashpir include *Endoscrinium granulatum* and *Scriniodinium inritibile.* These datums both occur in the Zaraskaites zarajskensis Subzone at Gorodishche. *Cribroperidinium nuciforme*, which has its LAD in the Kachpurites fulgens Zone at Gorodishche, last appears in the Middle–Upper Berriasian at Kashpir (Figs. 7-10; Tables 1, 2).

Circulodinium compta and *Stiphrosphaeridium anthophorum* have FADs in the Craspedites subditus Zone of both sections although the latter appears later, at the top of this zone in Kashpir. Furthermore, *Sentusidinium rioultii* also first appears in the Craspedites subditus Zone at Kashpir; at Gorodishche, however, this species has its FAD in the Virgatites virgatus Zone. *Leptodinium subtile* has its LAD in the Craspedites subditus Zone at both localities. *Cometodinium whitei* also last occurs in the Craspedites subditus Zone at Gorodishche but ranges slightly higher, to the base of the Craspedites nodiger Zone, at Kashpir (Figs, 7-10; Tables 1, 2).

Tenua cf. *T. hystrix* is the only taxon to have its FAD in the Craspedites nodiger Zone at Gorodishche, but was first recorded stratigraphically higher, from Middle to Upper Berriasian strata, at Kashpir. At Gorodishche, the only notable taxon with its LAD in the Craspedites nodiger Zone is *Circulodinium copei*. The extent of this taxon at Gorodishche contrasts markedly to that at Kashpir, where its FAD is within the Middle–Upper Berriasian. At Kashpir, *Gonyaulacysta dentata* and *Senoniasphaera jurassica* have LADs in the Craspedites nodiger Zone. However, at Gorodishche these taxa both have last occurrences in the unzoned phosphorite at the Jurassic/Cretaceous boundary (Figs, 7-10; Tables 1, 2).

3.4. The Jurassic/Cretaceous boundary

The Jurassic/Cretaceous boundary is markedly different in the two successions, with most of the Berriasian being entirely absent at Gorodishche (Fig. 2). Here the boundary is marked by a phosphorite horizon (sample U33) with dinoflagellate cyst assemblages dominated by long-ranging taxa such as *Chytroeisphaeridia chytroeides*, *Hystrichodinium pulchrum* and an abundance of the "*Cleistosphaeridium aciculum*" taxon group. Among the taxa with ranges extending above and below this horizon, *Circulodinium compta*, *Kleithriasphaeridium* spp., *Sirmiodinium grossii*, *Stephanelytron membranoidium*, *Trichodinium ciliatum* and *Wrevittia* spp. are relatively prominent (Table 1). At Kashpir, the Jurassic/Cretaceous boundary lies within a bituminous shale horizon (sample K10), which is barren of identifiable dinoflagellate cysts (Table 2).

3.5. Middle to Upper Berriasian (unzoned to the Surites tzikwinianus Zone)

Much of the Middle and Upper Berriasian is absent at Gorodishche, hence no meaningful comparison with Kashpir can be made. However, *Exochosphaeridium* *phragmites*, *Muderongia endovata*, *Pseudoceratium pelliferum* and *Sentusidinium* sp. 4 first appear in the Middle to Upper Berriasian of Kashpir, and have FADs in the base of the overlying ?Valanginian mica-rich facies at Gorodishche (Fig. 10, Tables 1, 2).

The dinoflagellate cyst assemblages of the unzoned Middle to Upper Berriasian succession at Kashpir contain relatively prominent *Dingodinium tuberosum, Chytroeisphaeridia chytroeides*, *Circulodinium compta*, *Hystrichodinium pulchrum*, *Sentusidinium* spp., *Tenua* cf. *T. hystrix* and *Trichodinium* cf. *T. ciliatum*. Important taxa that consistently occur throughout the overlying Upper Beriasian Riasanites rjasanensis/Surites spasskensis zones-Surites tzikwinianus Zone at Kashpir are similar to the marine palynofloras from the Jurassic/Cretaceous boundary beds and the Middle Berriasian (Table 2).

3.6. Valanginian

There is no ammonite zonation for the post-Berriasian Lower Cretaceous strata of the two sections studied, somewhat hampering the accurate comparison of the two sets of dinoflagellate cyst data. In the Kashpir section the base of this unzoned sucession is represented by bed 24, a sandstone horizon which includes phosphatic concretions (Fig. 4). This bed has yielded an extremely well-preserved dinoflagellate cyst assemblage (Smith and Harding, 2004). The biostratigraphical evidence from dinoflagellate cysts strongly suggests that the entire Valanginian succession is part of the same genetic unit and hence all these strata (bed 20 at Gorodishche and beds 24-31 at Kashpir) belong to the same stage.

Biostratigraphically significant dinoflagellate cysts which consistently occur in this interval include *Achomosphaera neptuni, Cassiculosphaeridia reticulata*, *Chlamydophorella nyei*, *Circulodinium compta, Cometodinium habibii*, *Dapsilidinium multispinosum*, *Dingodinium tuberosum*, *Impletosphaeridium lumectum, Oligosphaeridium complex*, *Phoberocysta neocomica*, *Pseudoceratium pelliferum, Scriniodinium campanula*, *Sentusidinium* sp. and *Spiniferites ramosus* (Figs. 7-10; Tables 1, 2).

Spiniferites ramosus and *Wallodinium cylindricum* have FADs in the lowermost sample (K17) of the unzoned Early Cretaceous interval at Kashpir, with *Impletosphaeridium lumectum*, *Spiniferites primaevus* and *Warrenia*? *brevispinosa* having FADs somewhat higher, in samples K18 and K19. At Gorodishche the situation is similar with *Impletosphaeridium lumectum*, *Spiniferites ramosus* and *Warrenia*? *brevispinosa* having FADs in sample U34 at the base of the mica-rich siltstone facies.

The succession of the FADs of *Cometodinium habibii* and *Gardodinium* sp. 1, overlain by the FAD of *Phoberocysta tabulata* is present in both sections. Other taxa characteristic of this interval in both sections include *Batioladinium radiculatum*, *Meiourogonyaulax bulloidea* and *Systematophora* sp. 1. Neither *Cymososphaeridium validum*, which appears in the uppermost part of the interval sampled at Gorodishche, nor *Nelchinopsis kostromiensis* (which first appears immediately above the base of the unzoned interval in that section) were encountered at Kashpir (Figs. 8, 10; Tables 1, 2).

4. Comparison of this study with other investigations from the Volga Basin

Lord et al. (1987) studied the Tithonian of the Volga Basin, overlapping with the scope of the present investigation in coverage of the Zaraskaites zarajskensis Subzone of the Dorsoplanites panderi Zone. At Gorodishche these authors noted an interval of significant palynofloral change between beds 8 and 11 of Mesezhnikov (1977; 1984), with seven new forms appearing in the upper bed. Bed 11 correlates with beds 1-13 herein, although Lord et al. (1987) only collected one sample from this interval. The assemblage recovered by Lord et al. (1987) proved similar to that encountered here, if slightly less diverse. Important elements such as *Chytroeisphaeridia chytroeides*, *Glossodinium dimorphum*, *Pareodinia ceratophora*, *Systematophora daveyi* (as *Emmetrocysta sarjeantii* (Gitmez 1970) Stover & Evitt 1978) and *Tubotuberella apatela* are common to both studies. Lord et al. (1987) recorded *Millioudodinium sarjeantii* (Vozzhennikova 1967) Stover & Evitt 1978 *sphaericum* (autonym) as first appearing in Bed 11 at Gorodishche and Bed 7 of Mesezhnikov (1977) (i.e. below the current interval studied) at Kashpir. *Millioudodinium sarjeantii sphaericum* of Lord et al. (1987, fig. 10.1, 10.2) is termed *Cribroperidinium erymnoseptatum* herein. This species was recorded in the lower part of the Zaraskaites zarajskensis Subzone in this study (Fig. 7).

Hogg (1994) studied the dinoflagellate cyst assemblages from 28 samples of Late Kimmeridgian to Early-Mid Berriasian age, of which the upper eight overlap with the interval considered herein. The assemblages recovered by Hogg (1994) were not discussed in detail; they are of similar composition to those in the present study. *Cribroperidinium erymnoseptatum* was recorded by Hogg (1994) from a single sample in the Zaraskaites zarajskensis Subzone, possibly comparable to Bed 8 herein. This horizon may thus be stratigraphically above the FAD of this taxon indicated here. *Gochteodinia villosa* was recorded by Hogg (1994) only from the Kachpurites fulgens

Zone, and similarly *Kleithriasphaeridium porosispinum* and *Stephanelytron membranoidium* were only recorded in the Kachpurites fulgens and Craspedites subditus zones. The majority of other stratigraphically useful taxa encountered herein were recorded by Hogg (1994) in similar stratigraphical positions.

The dinoflagellate cyst floras recorded by Riding et al. (1999) from the Tithonian to Middle Berriasian of the Russian Platform are broadly comparable to those observed here, although of somewhat lower diversity, particularly in the Virgatites virgatus and Epivirgatites nikitini zones. However, there are some significant differences between the two studies. *Cribroperidinium globatum* (Gitmez & Sarjeant 1972) Helenes 1984 (considered to be 'prominent' through this interval by Riding et al., 1999), *Dichadogonyaulax*? *pannea* (Norris 1965) Sarjeant 1969*, Scriniodinium dictyotum* Cookson & Eisenack 1960 and *Tubotuberella rhombiformis* Vozzhennikova 1967 were not encountered in the present study. *Tubotuberella rhombiformis* has not always been consistently distinguished from *Tubotuberella apatela* in the literature, and the present authors deem the stratigraphical value of this species to be questionable. Herein, all specimens of the *Tubotuberella apatela-rhombiformis* plexus which lack tabulation, or have weakly-expressed cingular ridges restricted to the lateral areas were assigned to *Tubotuberella apatela.* No specimens with well-developed tabulation typical of *Tubotuberella rhombiformis* were encountered herein. Several common taxa in the Tithonian to Middle Berriasian material examined herein were not discussed by Riding et al. (1999). These include *Cribroperidinium erymnoseptatum* (from the Zaraskaites zarajskensis Subzone), *Perisseiasphaeridium ingegerdiae* (which is common in the Epivirgatites nikitini to Craspedites subditus zones), and *Tehamadinium* and *Tenua* (both common in the Middle Tithonian to Middle Berriasian).

The palynofloras from the Middle-Upper Berriasian strata at Kashpir described by Riding et al. (1999) contrast markedly with those herein in terms of diversity and preservation. Riding et al. (1999) examined a single sample from this level, noting the most common elements of the flora to be *Cribroperidinium* spp., *Circulodinium distinctum* (Deflandre & Cookson 1955) Jansonius 1986, with additional *Cassiculosphaeridia* spp. In the present study *Chlamydophorella nyei*, *Dingodinium* spp., *Hystrichodinium* spp. and *Sentusidinium* sp. 4, were all found to be common in this interval at Kashpir (Table 2). Other Middle to Upper Berriasian material studied by Riding et al. (1999) from the Oka Basin appears to bear closer resemblance to the assemblages studied herein. In particular, they encountered abundant *Circulodinium compta*, which Riding et al. (1999) noted is also common in the Middle to Upper Berriasian of northwest Europe.

Riding et al. (1999) considered *Muderongia endovata* (as *Muderongia simplex* Alberti 1961) and *Phoberocysta neocomica* to be indicative of the uppermost Berriasian. The taxon previously referred to as *Muderongia simplex* is now considered to be *Muderongia endovata* (see Riding et al., 2000). Some specimens of *Muderongia endovata* in the present study differ slightly from the species *sensu stricto.* This is because the periphragm is more closely fitting around the endocyst, the endocyst is less angular than described by Riding et al. (2000), and the lateral horns occasionally display the 'bent' terminations of Monteil (1991). This material is assigned to *Muderongia endovata* despite these minor morphological variations; it differs from *Muderongia tomaszowensis* in consistently having joined antapical horns (Type ATP II) instead of one axial horn (Type ATP I of Monteil, 1991). The FAD of *Muderongia endovata* herein is slightly older that this datum (as *Muderongia simplex*) noted by Riding et al. (1999). In this study, *Muderongia endovata* was first encountered at Kashpir in the unzoned Middle-Upper Berriasian (Fig. 10).

Species of *Cassiculosphaeridia* from the Volga Basin were not distinguished by Riding et al. (1999). These authors commented that although their *Cassiculosphaeridia* spp. are reminiscent of the earliest Cretaceous, their samples lacked reliable Middle-Upper Berriasian marker species. Numerous species of *Cassiculosphaeridia,* and the similar genus *Valensiella* were also encountered from the Middle-Upper Berriasian of Kashpir herein. *Cassiculosphaeridia pygmaeus* was confined to the Middle-Upper Berriasian of Kashpir, and thus may be of local stratigraphical significance in the Russian Platform (Fig. 10; Table 2).

5. Comparison of key Tithonian-Valanginian dinoflagellate cyst ranges, principally from northwest Europe and Russia, with those from Gorodishche and Kashpir

There are many published latest Jurassic to earliest Cretaceous dinoflagellate cyst range data from northwest Europe (e.g. Riding and Thomas, 1992; Riding and Ioannides, 1996; Poulsen and Riding, 2003 and references therein). However, comparatively few of these studies describe dinoflagellate cyst occurrences from successions that are directly calibrated to the standard ammonite zones. This makes accurate wider stratigraphical correlations difficult. For example although Herngreen et al. (2000; 2003), Andsbjerg and Dybkjaer (2003) and Ineson et al. (2003) discussed Tithonian to Valanginian dinoflagellate cyst zonations of Denmark and the Netherlands, correlation to the standard ammonite zones is indirect. The ammonite zone boundaries in these studies were based on earlier ammonite-calibrated dinoflagellate cyst zonations (K. Dybkjaer and G.F.W. Herngreen, personal communications, 2004). Nevertheless, there are several studies that have compared the dinoflagellate cyst biohorizons of northwest Europe with the Boreal standard ammonite zones throughout the Early Tithonian to Hauterivian. Several of these are mentioned below; the most recent is Poulsen and Riding (2003) for the Jurassic of Subboreal northwest Europe.

In this section, the ranges of the biostratigraphically significant Tithonian to Valanginian dinoflagellate cyst marker taxa recovered from Gorodishche and Kashpir are compared with ranges from other regions, principally northwest Europe and elsewhere in Russia (Figs. 11, 12). Where possible these data are used to help correlate the various Eurasian ammonite zonal schemes, or to date the Volga Basin strata which lack ammonite control.

5.1. Mid to Late Tithonian (pars) (Dorsoplanites panderi to Epivirgatites nikitini zones)

Most of the dinoflagellate cysts in the Mid Tithonian Zaraskaites zarajskensis Subzone of the Volga Basin range into older strata (Lord et al., 1987; Hogg, 1994; Riding et al., 1999). These include *Egmontodinium toryna*, *Glossodinium dimorphum*, *Hystrichodinium pulchrum*, *Hystrichosphaeridium petilum*, *Leptodinium subtile*, *Rhynchodiniopsis martonense*, *Scriniodinium inritibile*, *Senoniasphaera jurassica*, *Sirmiodinium grossii, Systematophora daveyi*, *Tenua hystrix* and *Tubotuberella apatela*. All of these taxa are known from the Kimmeridgian and Tithonian of northwest Europe and Siberia (Woollam and Riding, 1983; Heilmann-Clausen, 1987; Poulsen, 1992; 1994; 1996; Riding and Thomas, 1992; Bailey et al., 1997; Duxbury et al., 1999; Poulsen and Riding, 2003; Ilyina et al., 2005).

Consistent records of *Amphorula expirata* first appear in the Mid Tithonian Pavlovia rotunda Zone of northwest Europe (Barron, 1989). This species has its FAD in the Mid Tithonian Dorsoplanites panderi Zone at both Gorodishche and Kashpir (Figs. 7, 9); this bioevent is within the Zaraskaites zarajskensis Subzone at Gorodische. This Mid Tithonian datum hence is apparently coeval and thus is of extensive correlative significance (Figs. 4, 11).

Cribroperidinium erymnoseptatum was recorded at Gorodishche from the lower part of the Mid Tithonian Zaraskaites zarajskensis Subzone (Fig. 7). This species is therefore likely to range below the interval examined, because it was recorded from the Kimmeridgian of the North Sea area (Bailey, 1993). *Cribroperidinium erymnoseptatum* is associated with diverse palynofloras including the *Circulodinium distinctum* group, *Glossodinum dimorphum*, *Pareodinia ceratophora*, *Perisseiasphaeridium pannosum* and *Scriniodinium inritibile* (Tables 1, 2). Thus the occurrences and ranges of these taxa are similar in northwest Europe and the Volga Basin.

The FAD of *Gochteodinia villosa*, which was deemed to be the 'most significant bioevent in the Portlandian' by Stover et al. (1996, p.662), was recorded at the base of the Late Tithonian Paracraspedites oppressus Zone by Davey (1979), Woollam and Riding (1983), Riding (1984) and Riding and Thomas (1992). However, *Gochteodinia villosa* was reported from the base of the older Late Tithonian Galbanites kerberus Zone by Davey (1982), Heilmann-Clausen (1987) and Poulsen (1996), and from the Late Tithonian Galbanites okusensis Zone by Duxbury et al. (1999). The concensus thus is that this datum lies within the Galbanites kerberus to Paracraspedites oppressus zone interval. This bioevent was not discussed in relation to the Volga Basin by Riding et al. (1999), but this datum was given at the base of the Late Tithonian Kachpurites fulgens Zone in the Oka Basin. Herein, the oldest unequivocal specimens of *Gochteodinia villosa* were recorded from the lower part of the Late Tithonian Epivirgatites nikitini Zone at Gorodishche (Figs. 8, 11). This bioevent hence indicates a correlation of the Epivirgatites nikitini Zone of the Volga Basin with the Galbanites kerberus Zone of northwest Europe.

Rhynchodiniopsis martonense was recorded from the Mid Tithonian Zaraskaites zarajskensis Subzone and the lowermost part of the Virgatites virgatus Zone at Gorodishche (Fig. 7), and in the Zaraskaites zarajskensis Subzone by Riding et al. (1999, fig. 22). Bailey et al. (1997) described this species from the Mid Tithonian Pectinatites hudlestoni to Pectinatites pectinatus zones of northern England. Thus in the Volga Basin the stratigraphical distribution of this species is similar, perhaps ranging into slightly younger strata than in northwest Europe.

The range of *Athigmatocysta glabra* in the Volga Basin is significantly older than previously thought. It was recorded herein from the Mid Tithonian to latest Berriasian at Kashpir (Table 2). However in northwest Europe this taxon characterises the latest Berriasian to Hauterivian-Barremian interval (Duxbury, 1977; Davey, 1982).

The range top of *Glossodinium dimorphum* is within the Late Tithonian Titanites anguiformis Zone in northwest Europe (Riding and Thomas, 1992), although LADs of this taxon have been recorded within the Mid to Late Tithonian Virgatopavlovia fittoni, Progalbanites albani, Galbanites okusensis and Paracraspedites oppressus zones (Raynaud, 1978; Fisher and Riley, 1980; Haq et al., 1987; Heilmann-Clausen, 1987; Poulsen, 1996; Duxbury et al., 1999). Comparing the present study with that of Riding et al. (1999), it is clear that the LAD of *Glossodinium dimorphum* occurs at the top of the Mid Tithonian Zaraskaites zarajskensis Subzone across the Russian Platform (Figs. 7, 11), which is hence significantly older than this bioevent in northwest Europe.

Isthmocystis distincta has its range base at or near the base of the Late Tithonian Galbanites kerberus Zone in northwest Europe (Heilmann-Clausen, 1987; Riding and Thomas, 1992; Duxbury et al., 1999). Herein the FAD of this taxon was recorded from the middle of the Mid to Late Tithonian Virgatites virgatus Zone at Gorodishche (Fig. 8); this datum lies within the Late Tithonian Kachpurites fulgens Zone at Kashpir (Fig. 10). This means that the FAD of *Isthmocystis distincta* is slightly older older in the Volga Basin than in northwest Europe, but it is a regional biomarker for the Mid to Late Tithonian in the Northern Hemisphere (Fig. 11).

Scriniodinium pharo has its FAD at the base of the Mid Tithonian Progalbanites albani Zone (Davey, 1982; Riding and Thomas, 1992; Poulsen, 1996). However, the FAD of consistent/common occurrences are within the earliest Berriasian Subcraspedites preplicomphalus Zone (Woollam and Riding, 1983; Duxbury et al., 1999). *Scriniodinium pharo* was reported from the uppermost Tithonian-Mid Berriasian of northeast Siberia by Nikitenko et al. (2008). This species was encountered near the base of the Mid Tithonian Zaraskaites zarajskensis Subzone in the present study (Figs. 7, 9), which is broadly consistent with the record in northwest Europe (Fig. 11). This indicates that the FAD of *Scriniodinium pharo* is slightly older in the Volga Basin than in northwest Europe.

The range base of *Egmontodinium polyplacophorum* in northwest Europe is within the Early Tithonian Pectinatites elegans Zone (Woollam and Riding, 1983; Riding and Thomas, 1992; Poulsen, 1996). Other studies such as Riding and Thomas (1988) and Barron (1989) placed the FAD of consistent records of this species somewhat younger, within the Mid Tithonian. *Egmontodinium polyplacophorum* is rare in the Volga Basin, having its FAD in the Mid-Late Tithonian Virgatites virgatus Zone at Gorodishche (Fig. 8). By contrast, it first appears at Kashpir in the Late Tithonian Craspedites subditus Zone (Table 2). Due to the rarity of this species, further work may reveal older specimens from the Volga Basin, however the present study suggests that this range base is younger in Russia than in northwest Europe.

Kleithriasphaeridium porosispinum, which has its FAD in the Mid Tithonian Pectinatites pectinatus Zone in northwest Europe (Davey, 1982), was not noted below the Mid Tithonian, specifically the latest part of the Pavlovia pavlovi Subzone (of the Dorsoplanites panderi Zone) by Riding et al. (1999, fig. 26). These authors encountered "significant numbers" of *Kleithriasphaeridium porosispinum* in the Mid Tithonian Zaraskaites zarajskensis Subzone of the Dorsoplanites panderi Zone. This taxon was not encountered below the Mid-Late Tithonian Virgatites virgatus Zone at Gorodishche herein (Figs. 8, 11). Therefore this bioevent appears to be younger in Russia than in northwest Europe.

The LAD of *Leptodinium subtile* has been variously placed between the top of the Progalbanites albani Zone (Woollam and Riding, 1983; Riding and Thomas, 1992) and the top of the Galbanites okusensis Zone (Davey, 1982) close to the Mid-Late Tithonian transition of northwest Europe. Riding et al. (1999) noted the last occurrence of this species from the top of the Mid Tithonian Zaraskaites zarajskensis Subzone at Gorodishche, and they suggested that this datum may have stratigraphical significance in the Russian Platform. By contrast, Lord et al. (1987) recorded the LAD of *Leptodinium subtile* significantly older, within the Early Tithonian Ilowaiskya klimovi Zone at Gorodishche. Herein this taxon was recorded in the Late Tithonian to Mid Berriasian, up to the Craspedites subditus Zone at both localities studied (Figs. 7, 9), although it is extremely rare above the Mid-Late Tithonian Virgatites virgatus Zone (Tables 1, 2). Thus *Leptodinium subtile* may range into slightly younger strata in the Volga Basin than has previously been recorded in northwest Europe (Fig. 11).

Scriniodinium inritibile has its LAD in northwest Europe in the Mid-Late Tithonian between the top of the Progalbanites albani Zone (Woollam and Riding, 1983; Riding and Thomas, 1988; 1992; Poulsen, 1996), and the top of the Galbanites okusensis Zone (Davey, 1982). Riding et al. (1999) noted the LAD of this taxon at the top of the Mid Tithonian Zaraskaites zarajskensis Subzone in the Russian Platform. However, *Scriniodinium inritibile* was recovered in small proportions herein from stratigraphically higher, within the Upper Tithonian to Middle Berriasian succession (in the Kachpurites fulgens Zone at Gorodishche and the Craspedites nodiger Zone at Kashpir) (Figs. 7, 9, 11). Thus *Scriniodinium inritibile* ranges into younger strata in the Volga Basin than in northwest Europe (Fig. 11).

The FAD of *Senoniasphaera jurassica* is within the Mid Tithonian Zaraskaites zarajskensis Subzone at Gorodishche (Figs. 7, 11). This range base was also reported from the Mid-Late Tithonian of northeast Siberia by Nikitenko et al. (2008, fig. 5). In northwest Europe, the range base of significant numbers of this distinctive species is within the earliest Mid Tithonian Pectinatites pectinatus Zone (Riding and Thomas, 1988, fig. 3). Hence this bioevent appears to be slightly younger in the Volga Basin.

Riding et al. (1999, fig. 26) noted the LAD of *Perisseiasphaeridium pannosum* at the top of the Late Tithonian Epivirgatites nikitini Zone in the Russian Platform. These authors commented that the range top of this species and that of the closely related taxon *Oligosphaeridium patulum* are thus younger than their earliest Mid

Tithonian LADs (Pavlovia pallasioides and Pectinatites pectinatus zones respectively) in England (Riding and Thomas, 1988). In Riding et al. (1999), *Oligosphaeridium patulum* was recorded only from the base of the Mid Tithonian Zaraskaites zarajskensis Subzone, whilst *Perisseiasphaeridium pannosum* was equally rare, and not recorded above this subzone. Ilyina et al. (2005, fig. 8) reported *Oligosphaeridium patulum* from the Mid and Late Tithonian of western Siberia. These taxa were both not encountered herein.

Riding et al. (1999) stated that the LAD of *Prolixosphaeridium parvispinum* is of stratigraphical significance in the Russian Platform at the top of the Late Tithonian Epivirgatites nikitini Zone. Herein *Prolixosphaeridium parvispinum* exhibits significant variations in the number and morphology of the processes. Specimens close to the holotype were recorded from the lower part of the Lower Cretaceous mica-rich siltstones in both sections herein (Tables 1, 2). Since these morphological variations appear to be gradational, all the specimens in this study were assigned to *Prolixosphaeridium parvispinum*. Thus the Late Tithonian Epivirgatites nikitini Zone LAD of Riding et al. (1999) appears not to be a reliable biomarker.

The Mid-Late Tithonian occurrences of *Apteodinium spinosum, Avellodinium falsificum, Cassiculosphaeridia magna, Cassiculosphaeridia reticulata, Chlamydophorella nyei*, *Cometodinium whitei, Dapsilidinium multispinosum,* ?*Downiesphaeridium*? *aciculare, Exiguisphaera phragma*, *Kleithriasphaeridium corrugatum*, *Kleithriasphaeridium eoinodes, Kleithriasphaeridium fasciatum, Oligosphaeridium pulcherrimum, Stanfordella exsanguia, Stanfordella fastigiata, Stiphrosphaeridium dictyophorum, Tanyosphaeridium magneticum* and *Tehamadinium sousense* are recorded from significantly older strata in the Volga Basin than in reports from other Northern Hemisphere localities (e.g. Davey, 1974; Duxbury, 1977; 1979; Davies, 1983).

Similarly, the Mid-Late Tithonian and younger records of *Chytroeisphaeridia cerastes, Chytroeisphaeridia chytroeides, Circulodinium copei, Cribroperidinium nuciforme, Dichadogonyaulax*? *chondra*, *Gochteodinia tuberculata*, *Gonyaulacysta dentata* and *Perisseiasphaeridium ingegerdiae* from the Volga Basin (Tables 1, 2) are also anomalously young when compared to records from elsewhere in the Northern Hemisphere (Drugg, 1978; Raynaud, 1978; Nøhr-Hansen, 1986; Riding and Thomas, 1988; Below, 1990; Bailey, 1993; Poulsen, 1996; Bailey et al., 1997). The disparity in the Callovian-Oxfordian stratigraphical ranges of *Chytroeisphaeridia cerastes, Cribroperidinium nuciforme* and *Gonyaulacysta dentata* (see Deflandre, 1938; Riding, 1987; Riding and Thomas, 1997) between northwest Europe and the Volga Basin means that the reports of these species from Gorodishche and Kashpir (Tables 1, 2) probably represent reworking.

5.2. Late Tithonian (pars) to Early Berriasian (Kachpurites fulgens to Craspedites nodiger zones)

The Upper Tithonian and Lower Berriasian successions at Gorodishche and Kashpir produced abundant and diverse marine palynofloras (Tables 1, 2). There are relatively few stratigraphically significant dinoflagellate cyst bioevents in this interval in northwest Europe (e.g. Riding and Thomas, 1992, fig. 2.14).

The range top of *Egmontodinium polyplacophorum* in northwest Europe is within the Late Tithonian Paracraspedites oppressus Zone (Davey, 1979; 1982; Woollam and Riding, 1983; Partington et al., 1993; Duxbury et al., 1999). However, this bioevent was subsequently revised to within the Subcraspedites preplicomphalus Zone of the Early Berriasian by Abbink et al. (2001, fig. 11). The Paracraspedites oppressus to Subcraspedites preplicomphalus Zone interval is equivalent to the Tithonian-Berriasian transition of the Russian Platform (Figs. 1, 3). *Egmontodinium polyplacophorum* was recorded from both sections herein. Its LAD is in the Craspedites nodiger Zone at Kashpir (Fig. 10); at Gorodishche, this species ranges from the Mid-Late Tithonian Virgatites virgatus Zone to the Late Tithonian Kachpurites fulgens Zone (Fig. 8). Hence, this important bioevent at Kashpir represents evidence for the correlation of the Subcraspedites preplicomphalus Zone of northwest Europe with the Craspedites nodiger Zone of the Volga Basin (Figs. 1, 3, 11).

The LAD of *Senoniasphaera jurassica* is within the Early Berriasian in the Volga Basin (Figs. 7, 9, 11). This bioevent in northwest Europe is somewhat equivocal (Poulsen and Riding, 1992, p. 29, 30). Several authors placed it within the Progalbanites albani Zone of the Mid Tithonian (Raynaud, 1978; Davey, 1979; Woollam and Riding, 1983). Subsequently, this bioevent was assigned to within the Galbanites kerberus and Titanites anguiformis zones, i.e. stratigraphically younger in the Late Tithonian (Wimbledon and Hunt, 1983; Poulsen and Riding, 1992; Riding and Thomas, 1992; Poulsen, 1996; Duxbury et al., 1999). However, more recently Hunt (2004, fig. 3) reported *Senoniasphaera jurassica* from the Subcraspedites preplicomphalus Zone close to the Tithonian-Berriasian transition. Interestingly, Abbink et al. (2001) did not record *Senoniasphaera jurassica* from the Subcraspedites preplicomphalus Zone in the North Sea, hence it appears to be relatively rare in the latest Tithonian-Early Berriasian of northwest Europe. In the Russian Platform, the LAD of *Senoniasphaera jurassica* was encountered by Riding et al. (1999) within the Craspedites nodiger Zone, and these authors suggested that this bioevent is a reliable marker for the Mid Tithonian to Early Berriasian in the Volga Basin. This is consistent with this bioevent recorded herein from Gorodishche and Kashpir (Figs 7, 9). Consequently, its reliability as a marker in the Russian Platform is confirmed. Despite the aforementioned lack of concensus on the precise LAD of *Senoniasphaera jurassica,* and its relative scarcity in the Late Tithonian and Early Berriasian in northwest Europe, this bioevent appears to be broadly coeval throughout the Northern Hemisphere based on the record of Hunt (2004). This provides strong evidence for the correlation of the Craspedites nodiger Zone with the Subcraspedites preplicomphalus Zone (Figs. 1, 3, 11). Nikitenko et al. (2008, fig. 5) reported sporadic occurrences of *Senoniasphaera jurassica* from the Mid-Late Berriasian of northeast Siberia. These isolated occurrences may represent reworking; this species is known to be somewhat prone to stratigraphical recycling (Poulsen and Riding, 1992, fig. 2).

Circulodinium compta has its FAD close to the base of the Craspedites subditus Zone in both sections (Figs. 8, 10). This datum is consistent with northwest Europe, where the range base of this species is typically in the Late Tithonian (Davey, 1982; Heilmann-Clausen, 1987; Abbink et al., 2001). The occurrence of *Ellipsoidictyum cinctum* in the Late Tithonian (Craspedites subditus Zone) of Kashpir (Table 2) is consistent with the Mid-Late Jurassic range of this taxon (Riding et al., 1985; Barron, 1989; Riding, 2005). Similarly, the range base of *Hystrichodinium voigtii* was observed in the Late Tithonian (Kachpurites fulgens Zone) of Kashpir (Table 2). This bioevent was reported from the Mid and Late Tithonian of Denmark by Davey (1982), hence this datum can help to recognise this interval.

Tehamadinium daveyi ranges from the Late Tithonian Kachpurites fulgens Zone to the Late Berriasian of the Volga Basin (Figs. 8, 10). This taxon has been recorded from the Mid-Late Berriasian and Valanginian in northwest Europe (Jan du Chêne et al., 1986, fig. 8). Costa and Davey (1992) reported the FAD of this species from the latest Berriasian (Peregrinoceras albidum Zone). Hence the Late Tithonian occurrences from Gorodishche and Kashpir are the oldest records known.

The LAD of *Scriniodinium inritibile* lies in the latest Tithonian-Early Berriasian at Gorodishche and Kashpir (Figs. 7, 9). By contrast, this bioevent in northwest Europe is of Mid Tithonian age (Virgatopavlovia fittoni and Progalbanites albani zones) (Fisher and Riley, 1980; Riding and Thomas, 1992; Riding and Fensome, 2002; Poulsen and Riding, 2003). Similarly, *Stiphrosphaeridium anthophorum* first occurs in the Late Tithonian (Craspedites subditus Zone) of the Volga Basin (Tables 1, 2); however, this species has a Mid Tithonian range base in Europe (Heilmann-Clausen, 1987). *Systematophora areolata* was recorded at Kashpir from the Late Tithonian (Craspedites subditus Zone) to the Late Berriasian (Table 2). In northwest Europe, this distinctive chorate species ranges from the Oxfordian to the Late Tithonian (Raynaud, 1978; Riding, 1987), hence the reports from Kashpir are significantly younger.

The Early Berriasian and younger records of *Gonyaulacysta eisenackii, Kalyptea diceras* and *Kleithriasphaeridium telaspinosum* from Kashpir (Table 2) are also anomalously young when compared to records from elsewhere (Cookson and Eisenack, 1960; Fisher and Riley, 1980; Poulsen, 1996). The disparity in the Callovian-Oxfordian range of *Gonyaulacysta eisenackii* (see Riding, 1987; Riding and Thomas, 1997) between northwest Europe and the Volga Basin means that the reports of this species from Kashpir (Table 2) probably represent reworking. By contrast, the occurrences of *Gonyaulacysta speciosa* in the Early Berriasian of the Volga Basin (Tables 1, 2) are anomalously old compared to the Early Barremian records of this taxon in western Europe (Harding, 1990).

5.3. Late Berriasian (Riasanites rjasanensis/Surites spasskensis and Surites tzikwinianus zones)

Upper Berriasian strata are best developed at Kashpir, and this succession has yielded abundant and diverse marine palynofloras (Tables 1, 2).

The LAD of *Amphorula expirata* is within the Mid to Late Berriasian at Kashpir (Table 2); this is consistent with the Late Berriasian (Hectoroceras kochi Zone) range top in northwest Europe (Abbink et al., 2001). The FAD of *Batioladinium*? *gochtii* occurs at the base of the Late Berriasian Riasanites rjasanensis/Surites spasskensis zones at Kashpir (Fig. 10). Iosifova (1996) also reported the range base of this species in the lower part of the Riasanites rjasanensis/Surites spasskensis zones of the Moscow Basin. Thus this datum appears to be a reliable marker for the Late Berriasian throughout western Russia. The range of *Batioladinium radiculatum* is from the Late Berriasian (Riasanites rjasanensis/Surites spasskensis zones) to the Valanginian at Gorodishche and Kashpir (Figs. 8, 10). This is broadly consistent with Davey (1982), Poulsen (1996) and Duxbury et al. (1999) who reported the FAD of this species from the Mid-Late Berriasian. The range base of *Cribroperidinium volkovae* is in the upper part of the Riasanites rjasanensis/Surites spasskensis zones (Iosifova, 1996). *Cribroperidinium* cf. *C. volkovae* herein differs slightly from *Cribroperidinium volkovae sensu stricto* in having intratabular tuberculae and numerous penitabular features (Smith, 1999). The FAD of *Cribroperidinium* cf. *C. volkovae* at Kashpir is within the Surites tzikwinianus Zone (Fig. 10). The range bases of *Cribroperidinium volkovae* and *Cribroperidinium* cf. *C. volkovae* are thus broadly similar across the Russian Platform, and are reliable markers for the latest Berriasian in this area. The range of *Lagenorhytis delicatula* is latest Berriasian/earliest Valanginian (Peregrinoceras albidum and Paratollia zones) to earliest Hauterivian (Endemoceras ambylgonium Zone) in northwest Europe (Duxbury, 1977; 2001; Davey, 1982; Costa and Davey, 1992). At Kashpir, the range of rare *Lagenorhytis delicatula* is within the Valanginian mica-rich siltstones (Fig. 10). Hence this distinctive species appears to be a reliable Valanginian marker throughout the Northern Hemisphere.

The range bases of *Muderongia endovata*, *Phoberocysta neocomica*, *Phoberocysta tabulata*, *Pseudoceratium brevicornutum* and *Pseudoceratium pelliferum* are all within the latest Berriasian (Surites stenomphalus and Peregrinoceras albidum zones) of northwest Europe (e.g. Duxbury, 1977; Davey, 1979; Woollam and Riding, 1983; Heilmann-Clausen, 1987; Costa and Davey, 1992; Poulsen and Riding, 2003). Because of their close morphological resemblance to the extant motile dinoflagellate genus *Ceratium*, these have been termed ‘pseudoceratioid’ cysts (Wall and Evitt, 1975; Woollam and Riding, 1983, p. 14). Riding et al. (1999, fig. 31) recorded the FADs of *Muderongia endovata* and *Phoberocysta neocomica* within the Riasanites rjasanensis/Surites spasskensis zones, and *Pseudoceratium pelliferum* at the top of the Surites tzikwinianus Zone in the Russian Platform. Herein, the FAD of *Muderongia endovata* at Kashpir is at the top of the unzoned Middle-Upper Berriasian succession (Table 2), hence is slightly stratigraphically older than in northwest Europe. Furthermore, the inceptions of *Phoberocysta neocomica* and *Pseudoceratium pelliferum* are in the upper part of the Late Berriasian Surites tzikwinianus Zone, and the FAD of *Phoberocysta tabulata* is stratigraphically younger (Figs. 8, 10). The FAD of *Phoberocysta neocomica* herein is therefore slightly later than noted by Riding et al. (1999). The FAD of *Phoberocysta tabulata* apparently occurs in the Valanginian of the Volga Basin (Fig. 12), i.e. stratigraphically younger than in northwest Europe. However, the range bases of ‘pseudoceratioid’ cysts such as *Phoberocysta neocomica* and *Pseudoceratium pelliferum* are reliable markers for the Late Berriasian throughout northwest Europe and the Russian Platform (Fig. 12).

The range of *Pseudoceratium brevicornutum* is latest Berriasian (Peregrinoceras albidum Zone) to Early Valanginian (Polyptychites Zone) (Heilmann-Clausen (1987; Herngreen et al., 2000; Davey, 2001). Late Valanginian and Early Hauterivian records were interpreted as reworking by Herngreen et al. (2000, p. 50). This species was recorded herein from the Late Berriasian (Surites tzikwinianus Zone) to within the earliest Valanginian at Kashpir (Figs. 10, 12). This means that the range base of *Pseudoceratium brevicornutum* at Kashpir in the Volga Basin is a reliable tie-point between the Surites tzikwinianus Zone and the Peregrinoceras albidum Zone. The LAD of this form at the base of the mica-rich siltstones at Kashpir is consistent with a Valanginian age; this bioevent indicates a correlation with the Paratollia and Polyptychites zones of northwest Europe.

In northwest Europe, *Systematophora daveyi* ranges from the Kimmeridgian to the Late Berriasian (Hectoroceras kochi Zone) (Davey, 1982; Riding and Thomas, 1988; Abbink et al., 2001; Poulsen and Riding, 2003). In the Volga Basin, the LAD of *Systematophora daveyi* is within the unzoned Middle-Upper Berriasian succession (Figs. 7, 9), thus this datum is comparable in both regions. *Systematophora palmula* is confined to the Mid-Late Berriasian (samples K13-K16) at Kashpir (Fig. 10). In northwest Europe, this species is typical of the latest Berriasian and Early Valanginian (Surites stenomphalus to Polyptychites zones) (Davey, 1982; Costa and Davey, 1992; Duxbury, 2001). However, Heilmann-Clausen (1987) reported *Systematophora palmula* from the Late Berriasian (Hectoroceras kochi Zone), hence this taxon appears to be a reliable marker for the Mid-Late Berriasian in the Northern Hemisphere.

The FAD of *Achomosphaera neptuni* was recorded from the Mid Tithonian to Mid Berriasian at Gorodishche and Kashpir respectively (Figs. 7, 9). By contrast, the range base of *Achomosphaera neptuni* is a reliable marker for the latest Berriasian (Peregrinoceras albidum Zone) in northwest Europe (Davey, 1979; Heilmann-Clausen, 1987; Costa and Davey, 1992; Duxbury et al., 1999). Riding et al. (1999, fig. 23) recorded a single, questionable specimen of *Achomosphaera*? sp. from the unzoned Middle-Upper Berriasian succession at Kashpir. The specimens assigned to *Achomosphaera neptuni* in this study from the Mid Tithonian to Mid Berriasian have thinner cyst walls than are typical for this species. Unequivocal specimens of *Achomosphaera neptuni* were encountered herein from within the unzoned Middle Berriasian succession into the Valanginian. The Mid-Late Tithonian occurrences from Gorodishche hence represent the oldest known examples of *Achomosphaera*. Therefore the FAD of *Achomosphaera neptuni* (*sensu lato*) in the Mid-Late Tithonian in the Volga Basin is significantly earlier than in northwest Europe.

The range of *Wallodinium anglicum* at Kashpir is Late Berriasian (Surites spasskensis Zone) to Valanginian (Table 2). This is not consistent with the significantly younger Late Albian-Early Cenomanian range reported by Cookson and Hughes (1964).

Previous reports of *Tehamadinium evittii* are Kimmeridgian-Early Berriasian (Dodekova, 1969; Jan du Chêne et al., 1986). This species was recorded in small numbers from the Late Berriasian (Surites spasskensis Zone) to Valanginian at Kashpir (Table 2), hence these occurrences represent an extension of the range of this taxon into the Valanginian. Similarly, the Mid-Late Berriasian to Valanginian occurrences of *Cribroperidinium venustum, Endoscrinium granulatum* and *Lithodinia arcanitabulata* (Tables 1, 2) are also anomalously young compared to the Mid Oxfordian-Early Tithonian, Tithonian and Late Oxfordian-Early Kimmeridgian ranges respectively of these species in Europe (Klement, 1960; Raynaud, 1978; Brenner, 1988; Feist Burkhardt and Wille, 1992; Poulsen, 1996).

The FAD of rare *Wallodinium luna* is within the Surites spasskensis Zone of Kashpir (Table 2); this is consistent with its Berriasian range base in Australia (Morgan, 1980). Similarly, *Cassiculosphaeridia pygmaeus* may be a good biomarker. The range of this species in Australia is Berriasian (Stevens, 1987), and it is present in the Mid-Late Berriasian and Valanginian at Kashpir (Table 2). *Apteodinium spongiosum* is present in the Late Berriasian to Valanginian at Kashpir (Table 2). This species was reported from the Valanginian of arctic Canada by McIntyre and Brideaux (1980), hence may be a reliable long-range marker for the earliest Cretaceous.

5.4. Valanginian (unzoned)

Sandstones and siltstones of Valanginian age are present at Kashpir and Gorodishche; these beds are significantly thicker at Kashpir (Fig. 4). These successions have produced abundant and diverse dinoflagellate cyst associations (Tables 1, 2).

The cosmopolitan species *Egmontodinium toryna* was recorded from the Mid and Late Tithonian to the Early Cretaceous of Gorodishche and Kashpir (Figs. 7, 9). At Kashpir, the LAD of this taxon is in Bed 29, within the Valanginian mica-rich siltstones. The range top of *Egmontodinium toryna* is within the earliest Valanginian Paratollia Zone in northwest Europe (Duxbury, 1977; 2001; Davey, 1979; Heilmann-Clausen, 1987; Costa and Davey, 1992). This bioevent is thus considered to be a key marker for the earliest Valanginian in Europe and Russia.

The LAD of *Gochteodinia villosa* was noted by Riding et al. (1999, figs. 24, 26, 31) within the Late Berriasian Riasanites rjasanensis/Surites spasskensis zones in the Russian Platform. However in this study, this datum was recorded in the earliest Valanginian at Kashpir (Fig. 9). In northwest Europe, the range top of *Gochteodinia villosa* is highly characteristic of the Berriasian/Valanginian transition (Peregrinoceras albidum and Paratollia zones) (Davey, 1982; Heilmann-Clausen, 1987; Costa and Davey, 1992). Therefore, this datum is a reliable regional marker in the Northern Hemisphere for the Berriasian/Valanginian boundary.

Scriniodinium campanula has its FAD in the Valanginian of the Volga Basin (Figs. 8, 10). The range base of this species has been recorded from the latest Berriasian in northwest Europe (Riding and Fensome, 2002, fig. 2). Hence this bioevent is of widespread biostratigraphical significance for the Berriasian-Valanginian transition. The large and distinctive species *Scriniodinium pharo* is present in the Mid and Late Tithonian to Valanginian of both Gorodishche and Kashpir. The LAD is in the lower part of the Valanginian mica-rich siltstones in both sections (Figs. 8, 10, Tables 1, 2). The range top of this taxon is well-established, and lies within the Early Valanginian Paratollia Zone in northwest Europe (Duxbury, 1977; 2001; Davey, 1982; Woollam and Riding, 1983; Heilmann-Clausen, 1987; Costa and Davey, 1992). This datum is therefore considered to be a reliable regional marker for the earliest Valanginian throughout the Northern Hemisphere.

Spiniferites primaevus is confined to the Valanginian at Gorodishche and Kashpir (Figs. 8, 10, 12; Tables 1, 2). In northwest Europe, the FAD of this species lies within the Early Valanginian, in the earliest Paratollia Zone (Duxbury, 1977; Heilmann-Clausen, 1987; Costa and Davey, 1992). This means that the range base of this species has widespread correlative significance for the Early Valanginian in the Northern Hemisphere. The FAD of *Spiniferites ramosus* was noted herein from the earliest Valanginian. This is the base of the mica-rich siltstone (Bed 20) at Gorodishche, and within the phosphatic concretion-bearing siltstone unit (Bed 24) at Kashpir (Figs. 8, 10, 12). The range base of this distinctive and important species is within the Paratollia Zone of the Early Valanginian in northwest Europe (Davey, 1979; 1982; Heilmann-Clausen, 1987; Costa and Davey, 1992). It hence is clear that this bioevent has widespread correlative significance. *Tanyosphaeridium magneticum* was reported from the Valanginian of the Arctic by Davies (1983), hence the records in the Volga Basin (Tables 1, 2) are broadly consistent with this range.

The FADs of *Cymososphaeridium validum*, *Nelchinopsis kostromiensis* and *Oligosphaeridium complex,* and the LADs of *Kleithriasphaeridium porosispinum* and *Tubotuberella apatela* are of Early Valanginian age in northwest Europe (Davey, 1979; 1982; Heilmann-Clausen, 1987; Costa and Davey, 1992; Duxbury, 2001). In the Volga Basin, these datums are present in the Valanginian mica-rich siltstones (Figs. 7-10). These data confirm the utility of these bioevents as regional biomarkers for the Early Valanginian of northwest Europe and the Russian Platform.

Several taxa recorded from the Early Cretaceous of the Volga Basin herein are typical of this interval in western Europe. Some of these forms have ranges which extend stratigraphically younger than the Valanginian in Europe. These include *Achomosphaera neptuni*, *Aprobolocysta trycheria*, *Cymososphaeridium validum*, *Kleithriasphaeridium corrugatum*, *Kleithriasphaeridium eoinodes*, *Isthmocystis distincta*, *Nelchinopsis kostromiensis*, *Phoberocysta neocomica*, *Phoberocysta tabulata*, *Pseudoceratium pelliferum*, *Spiniferites ramosus* and *Trichodinium ciliatum* (Figs. 7-10; Tables 1, 2). Others, such as *Exochosphaeridium phragmites,* are characteristic of younger intervals within the Early Cretaceous of northwest Europe (Davey, 1982; Costa and Davey, 1992).

Aprobolocysta galeata was recorded in the Valanginian of Gorodishche (Table 1). This species was originally reported from the Valanginian to earliest Hauterivian of Western Australia (Backhouse, 1987), hence may be a reliable long-range index taxon. *Meiourogonyaulax bulloidea* is another typically Australian species present in the Volga Basin (Tables 1, 2). Its range in the Southern Hemisphere is Early-Mid Tithonian to earliest Valanginian (Riding and Helby, 2001), hence the range top may be a reliable marker for the Valanginian.

The range of rare *Batioladinium jaegeri* at Gorodishche is Valanginian (Table 2). This is inconsistent with the significantly younger latest Hauterivian to Cenomanian range in northwest Europe (Duxbury, 1977; Costa and Davey, 1992). The Valanginian mica-rich siltstones at Gorodishche and Kashpir yield several taxa noted by Iosifova (1996) from the Hauterivian of Tchernaya Retchka in the Moscow Basin. These include *Batioladinium*? *gochtii*, *Cribroperidinium* cf. *C. volkovae, Sentusidinium* sp. 4, *Spiniferites* sp. 2 and *Warrenia*? *brevispinosa* (Figs. 8, 10). Iosifova (1996) did not report any typical marker species for the Late Valanginian-Hauterivian of northwest Europe from the Moscow region.

By contrast, the Valanginian occurrences of *Dingodinium tuberosum, Gochteodinia mutabilis*, *Gonyaulacysta pectinigera*, *Impletosphaeridium lumectum* and *Mendicodinium reticulatum* from Gorodishche and Kashpir (Tables 1, 2) are significantly younger when compared to their records from northwest Europe (Sarjeant, 1960; Morgenroth, 1970; Fisher and Riley, 1980; Woollam and Riding, 1983; Riding et al., 1985). The particularly large disparity in the Late Pliensbachian range of *Mendicodinium reticulatum* (see Morgenroth, 1970) between northwest Europe and the Volga Basin records means that the occurrences of this species from Kashpir (Table 2) may represent reworking.

5.5. Important Tithonian to Valanginian dinoflagellate cyst bioevents in the Volga Basin and their correlation to ammonite zones

Six dinoflagellate cyst events were identified as prime markers for stratal correlations between the Tithonian to Valanginian successions in the Volga Basin and northwest Europe. These key bioevents provide strong evidence for establishing equivalencies between the ammonite zones in both these regions. These are:

- The FAD of *Gochteodinia villosa*. This bioevent occurs at the base of the Late Tithonian Epivirgatites nikitini Zone in the Volga Basin (Fig. 11). It has been reported from the base of the Late Tithonian Galbanites okusensis, Galbanites kerberus and Paracraspedites oppressus zones in northwest Europe. This important datum strongly indicates a correlation of the bases of the Late Tithonian Epivirgatites nikitini Zone and the Galbanites kerberus Zone, and hence that the Mid-Late Tithonian ammonite zonal correlations of Krymholts et al. (1988) are more accurate than those of Hantzpergue et al. (1998) (Fig. 3).

- The LAD of *Egmontodinium polyplacophorum.* This biomarker is within the Late Tithonian-Early Berriasian Craspedites nodiger Zone at Kashpir. In northwest Europe, this range top lies within the earliest Berriasian Subcraspedites preplicomphalus Zone (Abbink et al., 2001). This biomarker at Kashpir thus supports the correlation of the Subcraspedites preplicomphalus Zone of northwest Europe with the Craspedites nodiger Zone of the Volga Basin (Fig. 3).

- The LAD of *Senoniasphaera jurassica.* This bioevent was noted in the Late Tithonian-Early Berriasian Craspedites nodiger Zone by Riding et al. (1999, fig. 26) and at both Gorodishche and Kashpir herein (Fig. 9). This bioevent is characteristic of the earliest Berriasian Subcraspedites preplicomphalus Zone in northwest Europe (Hunt, 2004). This datum in the Volga Basin is thus consistent with the correlation of the Subcraspedites preplicomphalus Zone of northwest Europe with the Craspedites nodiger Zone of the Volga Basin (Fig. 3).

- The FAD of *Pseudoceratium pelliferum.* This study and Riding et al. (1999) established this datum within the upper part of the Late Berriasian Surites tzikwinianus Zone of the Volga Basin (Fig. 10). In northwest Europe, this datum occurs at the base of the latest Berriasian Peregrinoceras albidum Zone (e.g. Davey, 1979; Heilmann-Clausen, 1987; Poulsen, 1996). Thus this important bioevent provides additional evidence for the correlation of the upper part of the Surites tzikwinianus Zone with the Peregrinoceras albidum Zone (Fig. 3).

- The entire range of *Pseudoceratium brevicornutum*. The range base and range top of *Pseudoceratium brevicornutum* are excellent biomarkers for the latest Berriasian to Early Valanginian of the Northern Hemisphere respectively. In the Volga Basin, this species ranges from the upper part of the Late Berriasian Surites tzikwinianus Zone to immediately above the base of the unzoned Valanginian strata (Fig. 12). In northwest Europe, this species is present in the Peregrinoceras albidum to Polyptychites Zone interval (e.g. Heilmann-Clausen, 1987). Thus the range base of this taxon confirms the equivalence of the upper part of the Surites tzikwinianus Zone with the Peregrinoceras albidum Zone.

- The FADs of *Spiniferites primaevus* and *Spiniferites ramosus*. These datums occur at the base of the unzoned Valanginian strata in the Volga Basin (Fig. 12), and from within the earliest Valanginian Paratollia Zone in northwest Europe (e.g. Duxbury, 1977; Davey, 1979). These markers thus support the Early Valanginian age for these horizons at Gorodishche and Kashpir. Other biomarkers for the Early Valanginian of the Volga Basin include the LADs of *Scriniodinium pharo* and *Tubotuberella apatela*, and the FAD of *Oligosphaeridium complex*.

Three dinoflagellate cyst bioevents have been identified herein that appear to be useful for stratal correlation across the Volga Basin and the wider Russian Platform. These are:

- The LAD of *Glossodinium dimorphum*. This datum marks the top of the Mid Tithonian Zaraskaites zarajskensis Subzone in the Russian Platform based on Riding et al. (1999, figs. 26, 31) and herein (Fig. 7).

- The FAD of *Batioladinium*? *gochtii*. This range base occurs at the base of the Late Berriasian Riasanites rjasanensis/Surites spasskensis Zone in the Volga and Moscow Basins (Fig. 10 and Iosifova, 1996 respectively). Hence this bioevent is a reliable index for the base of the Late Berriasian in western Russia.

- The FAD of *Cribroperidinium* cf. *C. volkovae*. This datum of this form occurs within the Late Berriasian Surites tzikwinianus Zone at Kashpir in the Volga Basin (Fig. 10). The range base of *Cribroperidinium volkovae sensu stricto* is known from the upper part of the Late Berriasian Riasanites rjasanensis/Surites spasskensis Zone in the Moscow Basin (Iosifova, 1996). This datum is closely correlative in both areas, and is thus a useful marker for the Late Berriasian of western Russia.

6. The ages of the non ammonite-bearing strata at Gorodishche and Kashpir

In this section, the ages of five intervals at Gorodishche and Kashpir which have not yielded ammonites are discussed based on dinoflagellate cyst stratigraphy.

6.1. The age of Bed 19 at Gorodishche

Bed 19 at Gorodishche is a phosphorite unit which was assigned to the Valanginian by Blom et al. (1984). One sample, number U33, was taken from this unit (Fig. 4), which yielded a diverse dinoflagellate cyst assemblage (Table 1). Many long-ranging taxa such as *Chlamydophorella nyei*, *Sirmiodinium grossii* and *Tubotuberella apatela* are present. Some forms which are somewhat reminiscent of the Early Cretaceous such as *Cassiculosphaeridia reticulata, Kleithriasphaeridium corrugatum*, *Stanfordella fastigiata* and *Tehamadinium daveyi* were observed. However, no unequivocal Berriasian/Valanginian markers are present in Bed 19. The most stratigraphically diagnostic taxon in sample U33 is *Senoniasphaera jurassica*. The range top of this species is indicative of the earliest Berriasian Subcraspedites preplicomphalus Zone in northwest Europe (Hunt, 2004), which equates to the Craspedites nodiger Zone of the Volga Basin. The occurrence of *Dingodinium tuberosum* in this sample is consistent with a latest Tithonian-Early Berriasian age (Woollam and Riding, 1983). Furthermore, the lack of any significant change in the flora of Bed 19 compared to horizons sampled immediately below it strongly suggests that sample U33 belongs to the Craspedites nodiger Zone (Table 1).

6.2. The age of beds 18 to 22 at Kashpir

These strata are presumed to belong to the Mid-Late Berriasian Garniericeras subclypeiforme-Hectoroceras kochi zone interval of the Russian Platform, although whether this includes a hiatus in the Volga Basin is not known. The LADs of *Amphorula expirata* and *Systematophora daveyi* occur in samples K13 and K11 respectively (Table 2). These datums are characteristic of the Late Berriasian Hectoroceras kochi Zone (e.g. Davey, 1982; Abbink et al., 2001). Furthermore, the FAD of *Systematophora palmula* is in sample K13 (Table 2). This range base is known to be within the Hectoroceras kochi Zone (Heilman-Clausen, 1987). One apparently anomalous occurrence is the FAD of *Muderongia endovata* in sample K13 (Table 2). This bioevent is normally characteristic of the latest Berriasian (e.g. Duxbury, 1977; Davey, 1979), hence the Mid-Late Berriasian age of of K13 is arguably somewhat questionable. Other taxa such as *Cassiculosphaeridia reticulata*, *Stiphrosphaeridium dictyophorum* and *Tehamadinium daveyi* are consistent with a Mid-Late Berriasian age.

6.3. The age of Bed 24 at Kashpir

The phosphatic concretion-bearing Bed 24, and the overlying strata, at Kashpir were assigned to the Hauterivian by Blom et al. (1984). However no characteristically Hauterivian dinoflagellate cyst taxa such as *Aprobolocysta eilema* Duxbury 1977, *Canningia duxburyi* Harding 1990 or *Oligosphaeridium abaculum* Davey 1979 were found from sample K17, which was taken from this unit (Fig. 4).

The occurrences of *Circulodinium compta*, *Pseudoceratium brevicornutum*, *Scriniodinium pharo*, *Spiniferites ramosus* and *Tubotuberella apatela* (Fig. 10; Table 2), in the absence of any reliable Late Valanginian or Hauterivian markers, indicates that Bed 24 at Kashpir is of Early Valanginian age. The range tops of *Circulodinium compta*, *Pseudoceratium brevicornutum*, *Scriniodinium pharo* and *Tubotuberella apatela* and the range base of *Spiniferites ramosus* are all within the earliest Valanginian Paratollia Zone (e.g. Davey, 1982; Heilman-Clausen, 1987; Costa and Davey, 1992). Sample K17 represents the range base of *Spiniferites ramosus* and the range top of *Tubotuberella apatela* at Kashpir (Fig. 10; Table 2), which provides especially compelling biostratigraphcal evidence. Further evidence for an earliest Valanginian age is that sample K17 lies within the range of *Egmontodinium toryna* at Kashpir (Fig. 10; Table 2). The range of *Egmontodinium toryna* is Mid-Late Tithonian to earliest Valanginian (Duxbury, 1977; Riding and Thomas, 1988). The occurrences of forms in sample K17 with latest Berriasian range bases such as *Muderongia endovata,* *Pseudoceratium pelliferum* and *Scriniodinium campanula* (Fig. 10; Table 2) are consistent with this earliest Valanginian age assessment.

In summary, Bed 24 is attributed to the lower part of the Paratollia Zone of northwest Europe. Using the correlation scheme of Hoedemaeker (1991), the Paratollia Zone correlates with the Pseudogarnieria undulatoplicatilis Zone of the Russian Platform.

6.4. The age of Bed 20 at Gorodishche and beds 27 to 30 at Kashpir

Samples U34 to U40 inclusive were collected from Bed 20 at Gorodishche, and samples K19 to K30 inclusive were taken from beds 27 to 30 at Kashpir (Appendix 2). These mica-rich siltstone beds represent the youngest intervals studied herein (Fig. 4), and have yielded relatively abundant and diverse dinoflagellate cyst associations (Tables 1, 2).

Bed 20 at Gorodishche yielded several key dinoflagellate cysts which are indicative of an earliest Valanginian age. The cooccurences of *Circulodinium compta, Cymososphaeridium validum, Oligosphaeridium complex, Scriniodinium pharo, Spiniferites primaevus* and *Spiniferites ramosus* is indicative of the the Paratollia Zone. Similarly, beds 27 to 30 at Kashpir also yielded taxa characteristic of the earliest Valanginian Paratollia Zone. These are *Circulodinium compta*, *Egmontodinium toryna*, *Lagenorhytis delicatula, Oligosphaeridium complex, Scriniodinium pharo, Spiniferites primaevus* and *Spiniferites ramosus* (see Duxbury, 1977; 2001; Davey, 1979; 1982; Heilmann-Clausen, 1987; Costa and Davey, 1992). At both localities, the presence of taxa such as *Achomosphaera neptuni, Exiguisphaera phragma, Meiourogonyaulax bulloidea, Muderongia endovata, Phoberocysta neocomica, Phoberocysta tabulata, Pseudoceratium pelliferum* and *Scriniodinium campanula* is entirely consistent with the Early Valanginian; no Late Valanginian or Hauterivian markers were observed (Figs. 7-10; Tables 1, 2).

To conclude, these micaceous siltstones are correlated to the Paratollia Zone of northwest Europe; according to Hoedemaeker (1991), this zone is equivalent to the Pseudogarnieria undulatoplicatilis Zone of the Russian Platform.

7. The Tithonian to Early Valanginian dinoflagellate cyst zonation of the Volga Basin

Five dinoflagellate cyst zones are erected for the Tithonian to Early Valanginian of the Volga Basin herein, two of which are further divided into seven subzones. These are defined below and illustrated in Fig. 13. All the zones and subzones are interval zones of Salvador (1994). The zone and subzone boundaries are defined on first or last occurrences of selected taxa. Existing zonal index taxa and other important marker taxa known from northwest Europe were used where possible. First appearances were chosen in preference to last occurrences, due to the potential significance of reworking in condensed sections such as Gorodishche and Kashpir. First appearance datums (FADs) or range bases which have similar stratigraphical positions across the Russian Platform or in northwest Europe are used to augment and extend the dinoflagellate cyst zonation proposed by Riding et al. (1999). The biozonation proposed here for the Volga Basin is the most detailed hitherto, although its regional applicability has yet to be tested. The key datums in the proposed zonation is compared with those in Riding et al. (1999) for the Russian Platform, and other schemes of biozones for northwest Europe (Figs. 11, 12).

7.1. The Glossodinium dimorphum *(Gdi) Zone*

Definition. The interval from the LAD of *Subtilisphaera*? *inaffecta* (Drugg 1978) Bujak and Davies 1983 (see Riding et al., 1999, figs. 26, 31), to the LAD of *Glossodinium dimorphum* and the FAD of *Perisseiasphaeridium ingegerdiae* (Figs. 11, 13).
Age. Late Jurassic, Early to Mid Tithonian (Ilowaiskya sokolovi, Ilowaiskya pseudoscythica and Dorsoplanites panderi zones).
Reference section. Gorodishche.
Typical dinoflagellate cyst assemblages. The lower part of the Gdi Zone is characterised by abundant *Batiacasphaera* spp., *Dingodinium* spp., *Downiesphaeridium/Impletosphaeridium* spp. and *Systematophora daveyi,* with common *Chytroeisphaeridia chytroeides*, *Circulodinium* spp., *Kleithriasphaeridium fasciatum* and *Pareodinia* spp. Forms which are sporadically present are *Cometodinium whitei*, *Cribroperidinium* spp., *Lithodinia* sp. 1, *Prolixosphaeridium parvispinum*, *Sentusidinium* sp. 3, *Sirmiodinium grossii* and *Tehamadinium* sp. 1. Rare, but characteristic floral elements include *Gochteodinia tuberculata*, *Glossodinium dimorphum*, *Rhynchodiniopsis martonense*, *Tehamadinium sousense* and *Thalassiphora*? sp. Additionally, *Cribroperidinium erymnoseptatum* and *Trichodinium* sp. 1 are rare but typical of the lower part of the zone (Figs. 7-10, Tables 1, 2).

Remarks. The *Glossodinium dimorphum* Zone broadly follows the definition of Riding et al. (1999, p. 68, 69), but the upper boundary is additionally defined by the FAD of *Perisseiasphaeridium ingegerdiae*. The base of the *Glossodinium dimorphum* Zone (RPJ15) Zone of Riding et al. (1999) extends stratigraphically below the base of the Zaraskaites zarajskensis Subzone, and hence below the base of the interval studied herein. Therefore the lowermost marker of this zone, the LAD of *Subtilisphaera*? *inaffecta,* was not observed in this study, but follows Riding et al. (1999, fig. 31). Herein the LAD of *Glossodinium dimorphum* occurs below the top of the Zaraskaites zarajskensis Subzone at Gorodishche, and at the top of this subzone at Kashpir (Figs. 7, 9). The absence of the lenticular-bedded facies at the top of this subzone at Kashpir suggests the presence of a short stratigraphical gap at this level, which may be responsible for this minor incoherence (Fig. 4). For this reason, the upper limit of the zone is defined by the LAD of *Glossodinium dimorphum* and the FAD of *Perisseiasphaeridium ingegerdiae*, which occurs at the base of the Virgatites virgatus Zone at Gorodishche (Fig. 8).

The definition of the upper boundary of the *Glossodinium dimorphum* Zone is slightly emended herein, but the interval is as originally defined by Riding et al. (1999) for the entire Russian Platform. The zone corresponds to the Pectinatites wheatleyensis to Virgatopavlovia fittoni zones of the standard Boreal ammonite scheme (Fig. 11). The LAD of *Glossodinium dimorphum* in the Russian Platform is apparently significantly stratigraphically lower than in northwest Europe, where the range top is reported within the Titanites anguiformis Zone (Davey, 1979; Woollam and Riding, 1983). However, Raynaud (1978) and Fisher and Riley (1980) recorded this bioevent within the Progalbanites albani Zone, i.e. virtually coeval with the Russian Platform. No equivalent interval has been recorded in the Arctic provinces of the Boreal Realm.

7.2. The Perisseiasphaeridium ingegerdiae *(Pin) Zone*

Definition. The interval from the LAD of *Glossodinium dimorphum* and the FAD of *Perisseiasphaeridium ingegerdiae*, to the FAD of *Gochteodinia villosa* (Figs. 11, 13).
Age. Late Jurassic, Mid to Late Tithonian (Virgatites virgatus Zone).
Reference section. Gorodishche.
Typical dinoflagellate cyst assemblages. This interval is characterised by abundant *Systematophora daveyi* and common *Chlamydophorella nyei, Circulodinium* spp., *Cribroperidinium* spp., *Tenua hystrix* and *Trichodinium* cf. *T. ciliatum*. *Dingodinium* spp., *Kleithriasphaeridium fasciatum* and *Sirmiodinium grossii* are sporadically

significant (Figs. 7-10, Tables 1, 2). The *Perisseiasphaeridium ingegerdiae* Zone is distinguished from the underlying *Glossodinium dimorphum* Zone by the relatively low abundances of *Batiacasphaera* spp. and *Dingodinium* spp., and by the increased abundance of *Chlamydophorella nyei* and *Trichodinium* cf. *T. ciliatum*, together with the presence of *Achomosphaera neptuni*, *Impletosphaeridium* sp. 1 and *Perisseiasphaeridium ingegerdiae*. It is distinguishable from the overlying Gvi Zone by the absence of *Gochteodinia villosa* (Figs. 7-10, Tables 1, 2).

Remarks. The *Perisseiasphaeridium ingegerdiae* Zone is intercalated between the *Glossodinium dimorphum* and *Gochteodinia villosa* zones, and is hence comparable to the *Senoniasphaera jurassica* Zone of Riding et al. (1999, p. 69). The latter zone was not used herein as *Senoniasphaera jurassica* was not recovered from the Virgatites virgatus Zone (Figs. 7-10, Tables 1, 2). *Perisseiasphaeridium ingegerdiae* was not recorded by Riding et al. (1999). Poulsen (1996) stated that *Perisseiasphaeridium ingegerdiae* ranges from the Aulacostephanus mutabilis to Aulacostephanus autissiodorensis zones in Denmark. Nøhr-Hansen (1986) recorded this species from the Aulacostephanus mutabilis and Aulacostephanus eudoxus zones. In the Volga Basin, however, the range extends into the Valanginian at Gorodishche; it is unequivocally present in the Late Berriasian Surites tzikwinianus Zone (Fig. 9). Thus the FAD of *Perisseiasphaeridium ingegerdiae* may be of local significance in the Volga Basin, and its range appears to be markedly different to that in northwest Europe.

7.3. The Gochteodinia villosa *(Gvi) Zone*

Definition. The interval between the FAD of *Gochteodinia villosa,* and the FADs of *Cribroperidinium* cf. *C. volkovae* and *Pseudoceratium pelliferum* (Figs. 11-13).

Age. Late Jurassic, Late Tithonian (Epivirgatites nikitini Zone) to Early Cretaceous, Late Berriasian (lower part of the Surites tzikwinianus Zone).

Reference sections. Gorodishche and Kashpir.

Typical dinoflagellate cyst assemblages. This interval is characterised by abundant *Systematophora daveyi* with common *Batiacasphaera* spp., ?*Downiesphaeridium*? *aciculare*, *Gochteodinia villosa*, *Perisseiasphaeridium ingegerdiae*, *Tehamadinium daveyi* and *Trichodinium* cf. *T. ciliatum*. Also sporadically significant are *Dingodinium tuberosum*, *Hystrichodinium pulchrum*, *Impletosphaeridium* sp. 1, *Kleithriasphaeridium porosispinum* and *Stephanelytron membranoidium*. The Early Cretaceous assemblages contain abundant to common *Batiacasphaera* spp., *Chytroeisphaeridia chytroeides,* *Circulodinium compta*, *Dingodinium tuberosum* and *Hystrichodinium pulchrum*. *Tenua* cf. *T. hystrix* is sporadically important (Figs. 7-10, Tables 1, 2).

Remarks. This zone is broadly equivalent to the *Pareodinia dasyforma* Zone of Davey (1979, p. 66) for northwest Europe except that the upper limit is additionally defined by the FAD of *Cribroperidinium* cf. *C. volkovae*. It is not possible to locate the upper limit of this zone with accuracy in this study because only one sample was taken from the top of the Surites tzikwinianus Zone at Kashpir (Fig. 3). This top of the zone is hence tentatively placed within the Surites tzikwinianus Zone, between samples K15 (uppermost Riasanites rjasanensis/Surites spasskensis Zone) and K16 (uppermost Surites tzikwinianus Zone).

The Gvi zone as defined herein differs from the *Gochteodinia villosa* Zone of Riding et al. (1999, fig. 31) in that the first appearance of the index, and thus the base of the interval, is within the Epivirgatites nikitini Zone at Gorodishche (Fig. 8). This is stratigraphically lower than previously recorded (Fig. 11). In northwest Europe, the base of the *Gochteodinia villosa* Zone is normally taken as at the base of the Paracraspedites oppressus Zone (Davey, 1979; Woollam and Riding, 1983; Riding and Thomas, 1992, Poulsen and Riding, 2003). Other studies have reported *Gochteodinia villosa* from the underlying Galbanites okusensis and Galbanites kerberus zones (e.g. Davey, 1982; Heilmann-Clausen, 1987). Therefore the regional FAD of *Gochteodinia villosa* supports the correlation of the base of the Epivirgatites nikitini Zone of the Volga Basin with the Galbanites okusensis Zone of northwest Europe of Krymholts et al. (1988) (Fig. 3).

The upper limit of the zone herein is slightly higher than that of Riding et al. (1999) since the range base of *Pseudoceratium pelliferum* was recorded in the upper part of the Surites tzikwinianus Zone at Gorodishche (Fig. 10). However this may not reflect the true FAD due to a sampling gap (see above). The FAD of *Pseudoceratium pelliferum* in the Volga Basin thus correlates well with this bioevent in northwest Europe at the base of the Peregrinoceras albidum Zone (e.g. Davey, 1979, Woollam and Riding, 1983; Heilmann-Clausen, 1987). Other authors have placed this range base within the underlying Surites stenomphalus Zone (Costa and Davey, 1992; Duxbury et al., 1999). Both these bioevents are consistent with the correlation of the Surites tzikwinianus Zone of the Russian Platform with the Surites stenomphalus and Peregrinoceras albidum zones of the Boreal standard (Krymholts et al., 1988) (Fig. 3).

Subzones. The *Gochteodinia villosa* Zone is subdivided into four interval subzones. These are based on dinoflagellate cyst data of local and regional stratigraphical importance in the Russian Platform, but they are not comparable to the subdivisions of this zone in northwest Europe.

Subzone a

Definition. The interval from the FAD of *Gochteodinia villosa* to the FAD of *Circulodinium compta* (Figs. 11, 13).

Age. Late Jurassic, Late Tithonian (Epivirgatites nikitini and Kachpurites fulgens zones).

Reference section. Gorodishche.

Subzone b

Definition. The interval from the FAD of *Circulodinium compta,* to the FADs of *Cassiculosphaeridia pygmaeus* and *Muderongia endovata* (Figs. 11-13).

Age. Late Jurassic, Late Tithonian (Craspedites subditus Zone) to Early Cretaceous, Mid-Late Berriasian, within the earliest part of the Berriasian unzoned interval. The latter is equivalent to the Mid to Late Berriasian interval (Garniericeras subclypeiforme-Hectoroceras kochi zones) of the Russian Platform, and the Mid to Late Berriasian Praetollia (Runctonia) runctoni and Hectoroceras kochi zones of the Boreal standard.

Reference section. Kashpir.

Subzone c

Definition. The interval from the FADs of *Cassiculosphaeridia pygmaeus* and *Muderongia endovata*, to the FAD of *Batioladinium*? *gochtii* (Figs. 12, 13).

Age. Early Cretaceous, Mid to Late Berriasian, the Berriasian unzoned interval to earliest Late Berriasian, the lowermost part of the Riasanites rjasanensis/Surites spasskensis Zone.

Reference section. Kashpir.

Subzone d

Definition. The interval from the FAD of *Batioladinium*? *gochtii,* to the FADs of *Cribroperidinium* cf. *C. volkovae* and *Pseudoceratium pelliferum* (Figs. 12, 13).

Age. Early Cretaceous, Late Berriasian, the lowermost part of the Riasanites rjasanensis/Surites spasskensis Zone to the lower part of the Surites tzikwinianus Zone).

Reference section. Kashpir.

Remarks. Subzones c and d can be distinguished from subzones a and b by the increased abundances of *Achomosphaera neptuni*, *Circulodinium compta*, *Sentusidinium* sp. 4 and *Tenua* cf. *T. hystrix*, and by the absence of *Systematophora daveyi*. The FADs of *Batioladinium*? *gochtii* and *Muderongia endovata* are comparable to bioevents noted by Iosifova (1996) from the Moscow Basin, and are therefore of regional stratigraphical significance in the Russian Platform. The FADs of *Cassiculosphaeridia pygmaeus* and *Circulodinium compta* are at different levels in other parts of the Russian Platform, and hence are of local stratigraphical significance in the Volga Basin.

7.4. The Pseudoceratium pelliferum *(Ppe) Zone*

Definition. The interval from the FADs of *Cribroperidinium* cf. *C. volkovae* and *Pseudoceratium pelliferum,* to the FAD of *Spiniferites ramosus* and the LAD of *Gochteodinia villosa* (Figs. 12, 13).

Age. Early Cretaceous, Late Berriasian (upper part of the Surites tzikwinianus Zone).

Reference section. Kashpir.

Typical dinoflagellate cyst assemblages. The single horizon examined from the Ppe Zone, sample K16, contains abundant *Dingodinium* spp., and common *Chlamydophorella nyei*, *Chytroeisphaeridia chytroeides*, *Circulodinium compta*, ?*Downiesphaeridium*? *aciculare*, *Impletosphaeridium* sp. 1, *Kleithriasphaeridium corrugatum* and *Sentusidinium* sp. 4. Rare, but stratigraphically important forms are *Cribroperidinium* cf. *C. volkovae*, *Phoberocysta neocomica*, *Pseudoceratium brevicornutum* and *Pseudoceratium pelliferum* (Figs. 7-10, Tables 1, 2).

Remarks. The Ppe Zone herein corresponds to the upper part of the unnamed zone (RPK1) of Riding et al. (1999, p. 70). RPK1 is the interval from the LAD of *Gochteodinia villosa* to the FAD of *Pseudoceratium pelliferum*. The base of the Ppe Zone as defined herein correlates with the base of the *Pseudoceratium pelliferum* Zone in northwest Europe (e.g. Davey, 1979; Woollam and Riding, 1983). The FAD of *Pseudoceratium pelliferum* is an important bioevent providing independent evidence for the correlation of the Russian Surites tzikwinianus Zone with the Surites stenomphalus and Peregrinoceras albidum zones of the Boreal standard. Davey (1979; 1982) placed the FAD of *Spiniferites ramosus* within the Paratollia Zone, and thus positioned the top of the *Pseudoceratium pelliferum* Zone at this level. This important FAD also allows correlation between the earliest Valanginian of northwest Europe and the Russian Platform.

7.5. The Spiniferites ramosus *(Sra) Zone*

Definition. The interval from the FAD of *Spiniferites ramosus* and the LAD of *Gochteodinia villosa*, to the top of the interval studied (Figs. 12, 13).

Age. Early Cretaceous, Early Valanginian.

Reference sections. Gorodishche and Kashpir for the Early Valanginian, and various sections in northwest Europe described by Davey (1979) for the Late Valanginian.

Typical dinoflagellate cyst assemblages. *Achomosphaera neptuni*, *Chlamydophorella nyei*, *Circulodinium compta*, *Dapsilidinium multispinosum*, *Dingodinium* spp., *Impletosphaeridium lumectum*, *Impletosphaeridium* sp. 1, *Kleithriasphaeridium corrugatum*, *Sentusidinium* sp. 4 and *Stephanelytron membranoidium* are common to abundant. Sporadically significant forms include *Cassiculosphaeridia reticulata*, *Chytroeisphaeridia chytroeides*, *Circulodinium* spp., *Cometodinium habibii*, ?*Downiesphaeridium*? *aciculare*, *Nelchinopsis kostromiensis*, *Oligosphaeridium complex*, *Phoberocysta neocomica*, *Spiniferites ramosus*, *Spiniferites* sp. 2, *Tenua* cf. *T. hystrix* and *Warrenia*? *brevispinosa*. Other rare but stratigraphically important elements are *Cymososphaeridium validum*, *Exochosphaeridium phragmites*, *Meiourogonyaulax bulloidea*, *Phoberocysta tabulata*, *Spiniferites primaevus* and *Wallodinium cylindricum* (Figs. 7-10, Tables 1, 2).

Remarks. The *Spiniferites ramosus* Zone is directly comparable to this biozone in northwest Europe (Davey, 1979; 1982). No taxa characteristic of the Late Valanginian to Hauterivian of northwest Europe were encountered in this study. There is hence no evidence for the *Spiniferites ramosus* Zone herein to range into the Hauterivian.

Subzones. The Sra Zone is subdivided into three interval subzones.

Subzone a

Definition. The interval from the FAD of *Spiniferites ramosus* and the LAD of *Gochteodinia villosa,* to the FADs of *Oligosphaeridium complex*, *Spiniferites primaevus* and *Warrenia*? *brevispinosa* (Figs. 12, 13).

Age. Early Cretaceous, earliest part of the Valanginian unzoned interval, possibly equivalent to the Pseudogarnieria undulatoplicatilis Zone of the Russian Platform and the early part of the Paratollia Zone of the Boreal standard.

Reference section. Kashpir.

Remarks. This subzone comprises Bed 24, a phosphatic concretion-bearing sandstone, at Kashpir. An extremely well-preserved palynoflora with three-dimensional preservation was recovered from this bed, including taxa apparently confined to it (Smith and Harding, 2004); these include *Meiourogonyaulax distincta*.

Subzone b

Definition. The interval from the FADs of *Oligosphaeridium complex*, *Spiniferites primaevus* and *Warrenia*? *brevispinosa*, to the FAD of *Phoberocysta tabulata* (Figs. 12, 13).

Age. Early Cretaceous, middle part of the Early Valanginian unzoned interval, possibly equivalent to the Temnoptychites hoplitoides Zone of the Russian Platform and the upper part of the Paratollia Zone of the Boreal standard.

Reference sections. Gorodishche and Kashpir.

Subzone c

Definition. The interval from the FAD of *Phoberocysta tabulata* to the top of the interval studied (Figs. 12, 13).

Age. Early Cretaceous, upper part of the Early Valanginian unzoned interval, possibly equivalent to the Polyptychites michalskii Zone of the Russian Platform and the Polyptychites Zone of the Boreal standard, to the top of the interval studied.

Reference sections. Gorodishche and Kashpir.

Remarks. The FAD of *Phoberocysta tabulata* in northwest Europe is latest Berriasian (Heilmann-Clausen, 1987; Costa and Davey, 1992), hence this FAD in the Volga Basin is of local stratigraphical significance. The top of this subzone cannot be defined herein.

8. Graphic correlation

Graphic correlation of the ammonite zone boundaries and the dinoflagellate cyst distributions in the Gorodishche and Kashpir successions is equivocal, perhaps partly due to the low dinoflagellate cyst sample densities in certain of the beds (Fig. 14). However, the dinoflagellate cyst data indicate that significant levels of Middle Tithonian (Zaraskaites zarajskensis Subzone) strata are missing at Kashpir, probably due to erosional truncation at the base of Bed 4. There are no discontinuities suggested by the dinoflagellate cyst data through the sedimentologically complex Middle-Upper Tithonian (Virgatites virgatus and Epivirgatites nikitini zones) succession, but this may be an artefact of sample density, because the FADs of several taxa in sample K3 at Kashpir indicates hiatuses. The two successions demonstrate steady, coeval sedimentation up to the top of the Upper Tithonian-Lower Berriasian (Craspedites nodiger Zone) sequence (Fig. 14). The dinoflagellate cyst data indicate that the phosphoritic Bed 19 at Gorodishche may represent a significantly condensed horizon equivalent to the Upper Berriasian (Riasanites rjasanensis/Surites spasskensis-Surites tzikwinianus zones) succession as developed at Kashpir. However resolution of this question may be acheived by denser sampling through the phosphorite at Gorodishche and in the coeval succession at Kashpir.

9. Provincialism of Tithonian to Valanginian dinoflagellate cyst assemblages with emphasis on the Volga Basin

The vast majority of the dinoflagellate cyst taxa recovered from the Tithonian to Valanginian successions at Gorodishche and Kashpir are characteristic of northwest Europe. This study has clearly demonstrated the overall similarities between these regions both in terms of the relative proportions of taxa and their biostratigraphy. Some stratigraphical differences were perceived (see above), and several minor provincial differences were noted. In this section, the Tithonian to Valanginian dinoflagellate cyst assemblages from Gorodishche and Kashpir are compared to coeval floras from northwest Europe and elsewhere.

9.1. Comparison of Tithonian and Berriasian marine palynofloras of the Volga Basin and northwest Europe

Generally, the Tithonian and Berriasian marine palynofloras of the Volga Basin and northwest Europe are substantially similar both in terms of stratigraphical ranges, taxonomical spectra and relative proportions. For example *Circulodinium compta, Cribroperidinium* spp., *Dingodinium* spp., *Gochteodinia villosa*, *Hystrichodinium pulchrum*, *Senoniasphaera jurassica*, *Sentusidinium* spp., *Sirmiodinium grossii*, *Systematophora daveyi*, *Systematophora* spp. and *Tubotuberella apatela* are prominent in the Tithonian and Berriasian of both the Volga Basin and northwest Europe (Tables 1, 2; Davey, 1982; Riding and Thomas, 1988; Riding et al., 1999, fig. 26; Abbink et al, 2001, figs 10, 11). This means that dinoflagellates had relatively wide geographical distributions during this interval of profound provincialism among macrofaunas (e.g. Hoedemaeker, 1991; Wimbledon, 2007). Moreover, it confirms that dinoflagellate cysts are extremely important biomarkers over extensive geographical areas, and that they can help to resolve correlation problems where other fossil groups are affected by endemism (Riding et al., 2010; 2011).

Dinoflagellate cyst species typical of the Tithonian and Berriasian of northwest Europe which were not recorded in the Volga Basin include *Cribroperidinium*? *gigas* (Raynaud 1978) Helenes 1984, *Dichadogonyaulax culmula* (Norris 1965) Loeblich Jr. & Loeblich III 1968, *Dichadogonyaulax*? *pannea* (Norris 1965) Sarjeant 1969, *Dingodinium*? *spinosum* (Duxbury 1977) Davey 1979, *Gochteodinia virgula* Davey 1982, *Hystrichodinium voigtii* (Alberti 1961) Davey 1974, *Mendicodinium groenlandicum* (Pocock & Sarjeant 1972) Davey 1979, *Muderongia simplex* Alberti 1961 (i.e. *Muderongia* sp. A of Davey, 1979), *Pareodinia halosa* (Filatoff 1975) Prauss 1989 and *Rotosphaeropsis thule* (Davey 1982) Riding & Davey 1989. The absence of *Rotosphaeropsis thule* in the Volga Basin is perhaps the most marked difference. This species is a persistent Tithonian-Berriasian element in northwest Europe (Davey, 1979; Riding, 1984; Costa and Davey, 1992). *Rotosphaeropsis thule* is especially common in the latest Tithonian to Late Berriasian interval (Riding and Davey, 1989). Similarly, *Glossodinium dimorphum* is far more common in the Tithonian of northwest Europe than it is in the Volga Basin (Riding and Thomas, 1988, fig. 3). By contrast, species of *Kleithriasphaeridium* appear to be more diverse and common in the Tithonian of the Volga region than in northwest Europe (Tables 1, 2; Riding and Thomas, 1988). Likewise, there are relatively few dinoflagellate cyst taxa in this interval which are endemic within the Volga Basin (Smith and Harding, 2004).

9.2. Comparison of Valanginian marine palynofloras of the Volga Basin and northwest Europe

Dinoflagellate cysts from the Valanginian (and younger Cretaceous stages) across the Russian Platform and northwest Europe are significantly more cosmopolitan than their Tithonian and Berriasian counterparts; this reflects more widespread marine connections at this time. Forms such as *Achomosphaera neptuni, Aprobolocysta trycheria*, *Batioladinium* spp., *Cassiculosphaeridia magna, Cassiculosphaeridia reticulata, Chlamydophorella nyei, Cribroperidinium* spp., *Cymososphaeridium validum, Dingodinium* spp., *Exiguisphaera phragma*, *Exochosphaeridium phragmites*, *Hystrichodinium* spp., *Isthmocystis distincta, Kleithriasphaeridium* spp., *Lagenorhytis delicatula, Muderongia simplex, Nelchinopsis kostromiensis, Oligosphaeridium complex, Phoberocysta neocomica, Phoberocysta tabulata, Pseudoceratium brevicornutum*, *Pseudoceratium pelliferum, Scriniodinium campanula, Scriniodinium pharo, Spiniferites primaevus, Spiniferites ramosus, Stanfordella exsanguia, Tanyosphaeridium* spp., *Trichodinium ciliatum* and *Wallodinium* spp. are present in both areas (e.g. Davey, 1979; 1982; Heilmann-Clausen, 1987). The ranges and relative proportions are also substantially similar. Species typical of the Valanginian of northwest Europe which were not recorded in the Volga Basin include *Cantulodinium speciosum* Alberti 1961, *Ctenidodinium elgantulum* Millioud 1969, *Discorsia nannus* (Davey 1974) Duxbury 1977, *Heslertonia heslertonensis* (Neale & Sarjeant 1962) Sarjeant 1966, *Hystrichosphaerina schindewolfii* Alberti 1961, *Nematosphaeropsis scala* Duxbury 1977 and *Systematophora palmula* Davey 1982. Despite the apparent absence of the latter species in the Valanginian of the Volga Basin, there are no major floral differences with assemblages of this age from northwest Europe.

9.3. *Comparison of Tithonian to Valanginian marine palynofloras of other regions and the Volga Basin/northwest Europe*

In this subsection, Tithonian to Valanginian marine palynofloras from southern Europe, the Arctic, the North Atlantic and the Southern Hemisphere are briefly described, and the differences between these and coeval associations from the Volga Basin and northwest Europe highlighted. Dinoflagellate cyst assemblages from this interval in North Africa and surrounding regions are substantially similar to their equivalents from western Russia and northwest Europe (e.g. Thusu and Vigran, 1985; Thusu et al., 1988; Ibrahim and El-Beialy, 1995; Baioumi, 2002).

During the Tithonian and Berriasian, biotic provincialism was at its maximum. Despite this, species such as *Pareodinia ceratophora, Scriniodinium crystallinum, Sirmiodinium grossii* and *Tubotuberella apatela* are present worldwide during this interval. Valanginian dinoflagellate cyst associations globally include significantly less endemic taxa.

9.3.1. Southern Europe

The Tithonian to Valanginian dinoflagellate cyst record of southeast France, southeast Spain and western Switzerland was studied by Jardiné et al. (1984), Leereveld (1989; 1997), Monteil (1992a,b; 1993) and Hoedemaeker and Leereveld, 1995). Although some species in the latter area are present throughout the Northern Hemisphere, the Tithonian and Berriasian associations from this part of southern Europe are significantly different to coeval floras from northwest Europe and the Russian Platform, with many endemic forms present. Clearly, this is a reflection of the profound provincialism of biotas at this time. By contrast, dinoflagellate cysts of the

Valanginian (and younger stages) across Europe and the Russian Platform are much more cosmopolitan, reflecting relatively widespread open marine settings at this time.

This situation is best illustrated by Monteil (1992b) and Leereveld (1997). These authors recorded several endemic species from the Mid Tithonian to Late Berriasian interval of southeast France and southeast Spain. These taxa include *Amphorula metaelliptica* Dodekova 1969, *Biorbifera johnewingii* Habib 1972, *Cirrusphaera dissimilis* Monteil 1992, *Cometodinium habibii* Monteil 1991, *Diacanthum hollisteri* Habib 1972, *Dichadogonyaulax bensonii* Monteil 1992, *Foucheria modesta* Monteil 1992, *Lanterna bulgarica* Dodekova 1969, *Prolixosphaeridium basifurcatum* Dodekova 1969*, Protobatioladinium lunare* Monteil 1992, *Pyxidinopsis challengerensis* Habib 1976 and *Warrenia californica* Monteil 1992 (see Monteil, 1992b, table 1; Leereveld, 1997, figs. 2, 3). None of these species were recorded in the Volga Basin. Mid Tithonian to Late Berriasian taxa which are present throughout Europe and western Russia include *Achomosphaera neptuni, Pseudoceratium pelliferum, Spiniferites ramosus, Systematophora areolota, Tubotuberella apatela* and *Wallodinium cylindricum* (see Monteil, 1992b, table 1; Leereveld, 1997, figs. 2, 3). By contrast, the Valanginian of southeast France and southeast Spain is dominated by forms which are present in the Volga Basin and north and south Europe. These include *Cassiculosphaeridia magna*, *Hystrichodinium pulchrum, Kleithriasphaeridium corrugatum*, *Kleithriasphaeridium fasciatum, Nelchinopsis kostromiensis*, *Oligosphaeridium complex* and *Spiniferites primaevus* (see Jardiné et al., 1984, fig. 6.16; Monteil, 1992b, table 1; Leereveld, 1997, figs. 2, 3). Endemic subtropical forms such as *Amphorula metaelliptica, Biorbifera johnewingii, Druggidium apicopaucicum* Habib 1973, *Druggidium deflandrei* (Millioud 1969) Habib 1973 and *Foucheria modesta* are present but they are relatively minor components (Monteil, 1992b, table 1; Leereveld, 1997, figs. 2, 3). The partitioning of Tethyan/Atlantic taxa such as *Biorbifera johnewingii* from more Arctic/Boreal forms such as Gochteodinia spp. was illustrated by Leereveld (1989, fig. 2).

Dodekova (1994) described Tithonian dinoflagellate cysts from northern Bulgaria. According to this author, the majority of the taxa recognised are typical of northwest Europe and the Russian Platform (Dodekova, 1994, fig. 2). These are hence more similar to the Volga Basin floras than the coeval material from southeast France and Switzerland. Dodekova (1994), however, recorded several species which are typical of the northwest part of Tethys. These include *Amphorula dodekovae* Zotto et al. 1987*, Amphorula metaelliptica*, *Amphorula*? *monteilii* Dodekova 1974, *Atlantodinium jurassicum* Zotto et al. 1987*, Biorbifera johnewingii, Lanterna bulgarica* Dodekova

1969, *Lanterna sportula* Dodekova 1969 and *Meiourogonyaulax bejui* Zotto et al. 1987 (see Dodekova, 1994, fig. 2).

9.3.2. The Arctic region

Davies (1983) reported relatively low diversity floras dominated by endemic forms from the Tithonian and Berriasian of the Canadian Arctic. Relatively few taxa are present in the Volga Basin and northwest Europe. These typically high latitude species include *Paragonyaulacysta*? *borealis* (Brideaux & Fisher 1976) Stover & Evitt 1978, *Paragonyaulacysta capillosa* (Brideaux & Fisher 1976) Stover & Evitt 1978 and *Tetrachacysta spinosigibberosa* (Brideaux & Fisher 1976) Backhouse 1988. In the Valanginian (the *Tanyosphaeridium magneticum* Oppel-Zone of Davies, 1983), there is a significant increase in diversity. The base of this biozone, is characterised by significant numbers of inceptions including several typically European taxa such as *Heslertonia heslertonensis*, *Nelchinopsis kostromiensis* and *Odontochitina operculata* (Wetzel 1933) Deflandre & Cookson 1955 (see Davies, 1983, fig. 4). This confirms that widespread marine connections became reestablished, following Tithonian-Berriasian restricted depocentres, in the Valanginian. Other studies on the Arctic region which report characteristically high latitude taxa in the latest Jurassic-earliest Cretaceous include Brideaux and Fisher (1976), Håkansson et al. (1981), Smelror et al. (1998), Lebedeva and Nikitenko (1999) and Smelror and Dypvik (2005).

9.3.3. The North Atlantic

The Tithonian to Valanginian succession from offshore eastern U.S.A. in the North Atlantic was studied by Habib (1972; 1973; 1975) and Habib and Drugg (1983; 1987). These assemblages, from offshore Florida to New Jersey, are extremely reminiscent of coeval floras from southeast France, southeast Spain and western Switzerland (see above). Relatively low numbers of dinoflagellate cyst species in this interval in the North Atlantic are common to the Russian Platform and northwest Europe, particularly in the Tithonian and Berriasian. Characteristic species of the North Atlantic region include *Amphorula metaelliptica, Biorbifera johnewingii, Druggidium apicopaucicum*, *Druggidium deflandrei*, *Druggidium rhabdoreticulatum* Habib 1973, *Histiophora* sp. and *Pyxidinopsis challengerensis* (see Habib, 1975, fig. 3; Habib and Drugg, 1987, fig. 2). These associations are typically southern European/western Tethyan and constitute a provincial flora which is centered on the early North Atlantic and adjacent areas (Smith and Briden, 1977, maps 8, 9). This phytoprovince is relatively widespread; van Helden (1986) recorded *Amphorula metaelliptica* from offshore Newfoundland. The relatively geographically isolated nature of the North Atlantic at this time may have prevented the free passive dispersal of, for example, *Druggidium* spp. However, latitudinal and/or climatic controls may also have controlled the distribution of these apparently highly geographically restricted taxa. *Biorbifera johnewingii* has also been reported from the Berriasian and Valanginian of California (Habib and Warren, 1973).

9.3.4. The Southern Hemisphere

The Tithonian dinoflagellate cyst floras of the Northwest Shelf of Australia, New Zealand, Papua New Guinea and the Antarctic Peninsula are profoundly different to their counterparts from Europe and western Russia. These Southern Hemisphere floras were described by Davey (1987), Helby et al. (1987; 1988), Riding et al. (1992), Snape (1992), Bint and Marshall (1994), Riding and Helby (2001) and Riding et al. (2010). The Austral floras are overwhelmingly dominated by endemic forms, however small proportions of cosmopolitan taxa such as *Imbatodinium kondratjevii*, *Nannoceratopsis pellucida*, *Sirmiodinium grossii* and *Tubotuberella apatela* are present (Snape, 1992, fig. 2; Bint and Marshall, 1994, fig. 4). The intensity of this provincialism was slightly lessened in the Berriasian and Valanginian. Typically Australasian Tithonian species such as *Broomea simplex* Cookson & Eisenack 1958, *Nummus similis* (Cookson & Eisenack 1960) Burger 1980 and *Omatia montgomeryi* Cookson & Eisenack 1958 are also present in the Tithonian of northeast India (Garg et al., 2003). This is similar to the Tithonian of Kenya, East Africa where Jiang et al. (1992) reported Austral species such as *Broomea ramosa* Cookson & Eisenack 1958, *Carnarvonodinium morganii* Parker 1988, *Komewuia glabra* Cookson & Eisenack 1960 and *Mombasadinium parvelatum* (Jiang in Jiang et al. 1992) Riding & Helby 2001. Similarly, Schrank (2005) recorded several typically Australian species, for example *Endoscrinium attadalense* (Cookson & Eisenack 1958) Riding & Fensome 2003 from the Tithonian of Tanzania, East Africa. By contrast, Tithonian dinoflagellate cyst associations from Argentina are low in diversity and appear to lack any of the typically Australasian endemic elements (Quattrocchio and Sarjeant, 1992, fig. 6). This is despite the Tethys circumglobal current (TCC), which flowed westwards in the tropics during the Mesozoic. Hence the TCC could have potentially dispersed planktonic organisms from eastern to western Tethys at this time. However, north-south currents tend to be relatively weak during greenhouse conditions (Bush, 1997). This factor may have prevented the passive dispersal of dinoflagellate cysts from Gondwana northwards into Eurasia (Riding et al., 2011). Similarly, the latest Jurassic-earliest Cretaceous interval;

of China is not, apparently, characterised by typically Australasian taxa (e.g. He and Zhu, 2003; Zhu and He, 2007).

9.3.5. Synthesis

Based on an analysis of global reports of Tithonian and Berriasian marine palynofloras, it is clear that significant endemism operated during this interval. The most significant differences are between Australasia and elsewhere in the world. This provincialism is interpretated as being largely due largely to geographical isolation (Riding et al., 2010; 2011). Specifically, latitudinal and/or palaeotemperature barriers probably prevented passive dispersal of dinoflagellate cysts from Australasia to Eurasia northwards across Tethys. Similar palaeoclimatic interfaces, together with geographical barriers apparently prevented the mixing of dinoflagellate cyst floras from the Volga Basin and northwest Europe, with their counterparts in the Arctic and southern Europe. The North Atlantic region was somewhat geographically isolated at this time (Smith and Briden, 1977, map 9), and this factor may have at least partially controlled prevented the relatively restricted distributions of forms such as *Druggidium* spp.

Therefore, it appears that the extents of the various phytoplanktonic provinces were controlled by several factors during the Tithonian and Berriasian. By contrast, Valanginian dinoflagellate cyst associations include more cosmopolitan taxa than their Tithonian and Berriasian counterparts. This indicates the re-establishment of open marine connections at this time.

10. Conclusions

Correlation of Jurassic/Cretaceous boundary successions between the Volga Basin, and northwest and southern Europe based on ammonite biostratigraphy is hampered by intense and widespread molluscan provincialism. The dinoflagellate cyst biostratigraphy of the Tithonian to Valanginian successions at Gorodishche and Kashpir in the Volga Basin, western Russia have been investigated in detail in order to attempt to help with these longstanding correlation problems.

Both the Gorodishche and Kashpir sections produced abundant, diverse and well-preserved dinoflagellate cyst floras which were used to construct a detailed Tithonian to Valanginian palynostratigraphy applicable to western Russia. The stratigraphical ranges of all dinoflagellate cyst taxa recognised have been assessed and the key datums used to effect correlations to the northwest European Boreal ammonite biostratigraphy. The most important bioevents include the inceptions of *Gochteodinia villosa*, *Pseudoceratium* spp. and *Spiniferites* spp., and the apparent extinctions of *Egmontodinium polyplacophorum*, *Pseudoceratium brevicornutum* and *Senoniasphaera jurassica*. Examples of these are the range tops of *Egmontodinium polyplacophorum* and *Senoniasphaera jurassica* which are in the Late Tithonian-Early Berriasian Craspedites nodiger Zone at Gorodishche and Kashpir. These bioevents support the correlation of the Craspedites nodiger Zone with the Subcraspedites preplicomphalus Zone of northwest Europe. The range base of *Spiniferites* spp. at the base of the unzoned Valanginian strata in the Volga Basin is consistent with an earliest Valanginian age. Other datums confirm this earliest Valanginian age assessment, and other dinoflagellate cyst bioevents established in northwest Europe have allowed the dating of the Middle-Upper Berriasian strata from the Volga River sections which are devoid of ammonites. Thus it is evident that dinoflagellate cysts have substantial potential for the correlation of the northwest European and Russian Platform ammonite biozonations, thereby refining the work of authors such as Krymholts et al. (1988) and Hantzpergue et al. (1998). Selected important dinoflagellate cyst bioevents were used to construct a Tithonian to Valanginian dinoflagellate cyst zonation comprising five interval zones and seven interval subzones and which is applicable to the Volga Basin. This palynozonation markedly refines the biozonal scheme of Riding et al. (1999) for the Russian Platform. Moreover this new zonal scheme is partially comparable to the dinoflagellate cyst zonation for northwest Europe of Riding and Thomas (1992), despite some minor apparent differences in the ranges of several taxa.

Graphic correlation of the ammonite zonal boundaries using the dinoflagellate cyst data has provided some interesting conclusions. It appears that a significant part of the Middle Tithonian (Zaraskaites zarajskensis Subzone) succession is missing at Kashpir, probably due to erosional truncation. There are apparently no discontinuities indicated by the dinoflagellate cyst data in the Middle-Upper Tithonian (Virgatites virgatus and Epivirgatites nikitini zones) sequence. The two successions were characterised by steady, coeval sedimentation up to the top of the Upper Tithonian-Lower Berriasian (Craspedites nodiger Zone) (Fig. 14).

The majority of the Tithonian to Valanginian dinoflagellate cyst taxa from Gorodishche and Kashpir are present in northwest Europe. The marked endemism which affected molluscan populations, especially in the Tithonian-Berriasian interval, was not manifested in the marine phytoplankton. Some apparent differences in taxonomical spectra and stratigraphical ranges were observed. For example the prominent Early Tithonian to Mid-Late Berriasian species *Rotosphaeropsis thule* was not recorded in the Volga Basin, despite being prominent in the North Sea and surrounding regions. However, the floras in both areas are substantially similar, offering the potential for robust correlations to be made. The Tithonian to Berriasian interval exhibits most differences. By contrast, however, Valanginian dinoflagellate cyst assemblages throughout the Northern Hemisphere, however, are markedly more similar. These associations are relatively diverse and include many geographically widespread markers such as *Lagenorhytis delicatula, Nelchinopsis kostromiensis, Oligosphaeridium complex* and *Spiniferites* spp.

Tithonian to Valanginian dinoflagellate cyst associations are, however, demonstrably provincial at the global scale. Cosmopolitan taxa in the Tithonian to Berriasian interval are relatively rare, especially in the Arctic and the the Southern Hemisphere. Jurassic-Cretaceous boundary beds in southern Europe and the North Atlantic region include significant proportions of taxa which are present in northwest Europe and the Volga Basin. However the former areas are typified by several apparently provincial forms such as species of *Amphorula, Druggidium, Lanterna* and *Warrenia*. As mentioned above, the Tithonian to Valanginian of the Arctic region is typified by endemic high latitude taxa such as *Paragonyaulacysta* spp. The Tithonian of Australasia and the Antarctic Peninsula is dominated by endemic taxa, and some of these forms have been reported from East Africa and India. This provincialism was most likely to have been due to a number of factors including the absence of open marine connections, interruptions in shelfal seas, lithofacies control, nutrient levels, ocean currents, salinity, seasonality, temperature and water stratification.

This study has significantly advanced the understanding of the Tithonian to Valanginian dinoflagellate cyst biostratigraphy of the important outcrop sections at Gorodishche and Kashpir, and how this can advance stratal correlations, particularly with northwest Europe. Future studies on the Jurassic-Cretaceous boundary strata of the Volga Basin could include the more detailed study of beds not extensively sampled here, detailed taxonomic assessments of forms here placed in open nomenclature and work on the dinoflagellate cyst concentrations.

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References

Abbink, O.A., Callomon, J.H., Riding, J.B., Williams, P.D.B., Wolfard, A., 2001. Biostratigraphy of Jurassic-Cretaceous boundary strata in the Terschelling Basin, The Netherlands. Proceedings of the Yorkshire Geological Society 53, 275-302.

Andsbjerg, J., Dybkjaer, K., 2003. Sequence stratigraphy of the Jurassic of the Danish Central Graben. In: Ineson, J.R., Surlyk, F. (Eds.), The Jurassic of Denmark and Greenland. Geological Survey of Denmark Bulletin 1, 265-300.

Arkell, W.J., 1956. The Jurassic geology of the world. Oliver and Boyd Limited, Edinburgh, 806 pp.

Backhouse, J., 1987. Microplankton zonation of ther Lower Cretaceous Warnbro Group, Perth Basin, Western Australia. Memoir of the Association of Australasian Palaeontologists 4, 204-226.

Bailey, D.A., 1993. Selected *Cribroperidinium* species (Dinophyceae) from the Kimmeridgian and Volgian of northwest Europe. Journal of Micropalaeontology 12, 219-226.

Bailey, D.A., Milner, P., Varney, T., 1997. Some dinoflagellate cysts from the Kimmeridge Clay in North Yorkshire and Dorset, UK. Proceedings of the Yorkshire Geological Society 51, 235-243.

Baioumi, A.E.A., 2002. Late Jurassic – Early Cretaceous palynomorphs from El Mazar – 1 well, North Sinai, Egypt. Egyptian Journal of Palaeontology 2, 385-397.

Barron, H.F., 1989. Dinoflagellate cyst biostratigraphy and palaeoenvironments of the Upper Jurassic (Kimmeridgian to basal Portlandian) of the Helmsdale region, east Sutherland, Scotland. In: Batten, D.J., Keen, M.C. (Eds.), Northwest European micropalaeontology and palynology. British Micropalaeontological Society Series. Ellis Horwood Limited, Chichester, UK, 193-213.

Below, R., 1990. Evolution und Systematik von Dinoflagellaten-Zysten aus der Ordnung Peridiniales. III. Familie Pareodiniaceae. Palaeontographica Abteilung B 220, 1-96.

Bint, A.N., Marshall, N.G., 1994. High resolution palynostratigraphy of the Tithonian Angel Formation in the Wanaea and Cossack oil fields, Dampier sub-basin. In: Purcell, P.G., Purcell, R.R. (Eds.), The Sedimentary Basins of Western Australia. Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth 1994, 543-554.

Blom, G.I., Kuznetsova, K.I., Mesezhnikov, M.S., 1984. Cretaceous boundary beds in the Middle Volga River area and Ryasan District. Guide to Excursion 060. In: Blom, G.I., Breslav, S.L., Gerasimov, P.A., Golivkin, N.I., Demchenko, D.M., Dmitriev, V.P., Zolotariov, G.S., Kononov, N.D., Korobeinikov, V.N., Kuznetsova, K.I., Kuzmenko, Y.T., Lazarenko, M.T., Lifits, Y.G., Mesezhnikov, M.S., Orlov, V. (Eds.), 27th International Geological Congress, USSR. Central Regions of the European part of the RSFSR; Moscow syncline, Voronezh and Volgo-Ural anticlines. Guidebook for excursions 059, 060, 066. Moscow, 71-72, 113-124.

Brenner, W., 1988. Dinoflagellaten aus dem Unteren Malm (Oberer Jura) von Süddeutschland; Morphologie, Okologie, Stratigraphie. Tübinger Mikropaläontologische Mitteilungen 6, 115 p.

Brideaux, W.W., Fisher, M.J., 1976. Upper Jurassic-Lower Cretaceous dinoflagellate assemblages from Arctic Canada. Geological Survey of Canada Bulletin 259, 53 pp.

Brongniart, A., 1829. Tableau des terrains qui composent l’écorce du globe ou essai sur la structure de la partie connue de la terre. Paris and Strasbourg 435 pp.

Bush, A.B.G., 1997. Numerical simulation of the Cretaceous Tethys circumglobal current. Science 275, 807-810.

Callomon, J.H., 1995. Time from fossils: S.S. Buckman and Jurassic high-resolution geochronology. In: Le Bas, M.J. (Ed.), Milestones in Geology. Geological Society Memoir (London) 16, 127-150.

Casey, R., 1967. The position of the Middle Volgian in the English Jurassic. Proceedings of the Geological Society of London 1640, 128-133.

Casey, R., 1968. The type section of the Volgian stage (Upper Jurassic) at Gorodishche, near Ulyanovsk, U.S.S.R. Proceedings of the Geological Society of London 1648, 74-75.

Casey, R., 1973. The ammonite succession at the Jurassic-Cretaceous boundary in eastern England. In: Casey, R., Rawson, P.F. (Eds.), The Boreal Lower Cretaceous. Geological Journal Special Issue 5, 193-266.

Cookson, I.C., Eisenack, A., 1960. Upper Mesozoic microplankton from Australia and New Guinea. Palaeontology 2, 243-261.

Cookson, I.C., Hughes, N.F., 1964. Microplankton from the Cambridge Greensand (mid-Cretaceous). Palaeontology 7, 37-59.

Cope, J.C.W., 1967. The ammonite faunas and stratigraphy of the lower part of the Upper Kimmeridge Clay of Dorset. Bulletin of the British Museum (Natural History), Geology 15, 1-79.

Cope, J.C.W., 1978. The ammonite faunas and stratigraphy of the upper part of the Upper Kimmeridge Clay of Dorset. Palaeontology 21, 469-533.

Cope, J.C.W., 1993. The Bolonian Stage: an old answer to an old problem. Newsletters on Stratigraphy 28, 151-156.

Costa, L.I., Davey, R.J., 1992. Dinoflagellate cysts of the Cretaceous System. In: Powell, A.J. (Ed.), A stratigraphic index of dinoflagellate cysts. Chapman and Hall, London, 99-153.

Cox, B.M., Gallois, R.W., 1981. The stratigraphy of the Kimmeridge Clay of the Dorset type area and its correlation with some other Kimmeridge sequences. Institute of Geological Sciences Report 80/4, 44 pp.

Davies, E.H., 1983. The dinoflagellate Oppel-zonation of the Jurassic-Lower Cretaceous sequence in the Sverdrup Basin, arctic Canada. Geological Survey of Canada Bulletin 359, 59 p.

Davey, R.J., 1974. Dinoflagellate cysts from the Barremian of the Speeton Clay, England. Birbal Sahni Institute of Palaeobotany, Special Publication 3, 41-75.

Davey, R.J., 1979. The stratigraphic distribution of dinoflagellate cysts in the Portlandian (latest Jurassic) to Barremian (Early Cretaceous) of northwest Europe. American Association of Stratigraphic Palynologists Contributions Series 5B, 48-81.

Davey, R.J., 1982. Dinocyst stratigraphy of the latest Jurassic to Early Cretaceous of the Haldager No. 1 borehole, Denmark. Danmarks Geologiske Undersøgelse Serie B 6, 57 pp.

Davey, R.J., 1987. Palynological zonation of the Lower Cretaceous, Upper and uppermost Middle Jurassic in the northwestern Papuan Basin of Papua New Guinea. Geological Survey of Papua New Guinea Memoir 13, 77 pp.

Davey, R.J., 2001. A summary of the palynology of the lower Hauterivian (Lower Cretaceous) from Speeton, east England. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen 219, 83-93.

Deflandre, G., 1938. Microplancton des mers Jurassiques conservé dans les marnes de Villers-sur-Mer (Calvados). Étude liminaire et considérations générales. Travaux de la Station Zoologique de Wimereux 13, 147-200.

Dodekova, L., 1969. Dinoflagellés et acritarches du Tithonique aux environs de Pleven, Bulgarie centrale du Nord. Bulgarian Academy of Sciences – Committee of Geology. Bulletin of the Geological Institute – Series Paleontology 18, 13-24.

Dodekova, L., 1994. Dinoflagellate cysts from the Bathonian-Tithonian (Jurassic) of North Bulgaria. III. Tithonian dinoflagellate cysts. Geologica Balcanica 24, 11-46.

d'Orbigny, A., 1842-51. Description zoologique et géologique de tous les animaux mollusques et rayonnés fossiles de France comprenant leur application à la reconnaissance des couches. Terrains oolitiques ou Jurassiques, Volume I, Céphalopodes, Paléontologie Française. Editions Masson, Paris, 642 pp.

Drugg, W.S., 1978. Some Jurassic dinoflagellate cysts from England, France and Germany. Palaeontographica Abteilung B 168, 61-79.

Duxbury, S., 1977. A palynostratigraphy of the Berriasian to Barremian of the Speeton Clay of Speeton, England. Palaeontographica Abteilung B 160, 17-67.

Duxbury, S., 1979. Three new genera of dinoflagellate cysts from the Speeton Clay (Early Cretaceous) of Speeton, England. Micropaleontology 25, 198-205.

Duxbury, S., 2001. A palynological zonation scheme for the Lower Cretaceous – United Kingdom Sector, Central North Sea. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen 219, 95-137.

Duxbury, S., Kadolsky, D., Johansen, S., 1999. Sequence stratigraphic subdivision of the Humber Group in the Outer Moray Firth area (UKCS, North Sea). In: Jones, R.W., Simmons, M.D. (Eds.), Biostratigraphy in Production and Development Geology. Geological Society, London, Special Publications 152, 23-54.

Feist Burkhardt, S., Wille, W., 1992. Jurassic palynology in southwest Germany - state of the art. Cahiers de Micropaléontologie N.S. 7, 141-156.

Fensome, R.A., Williams, G.L., 2004. The Lentin and Williams index of fossil dinoflagellates 2004 edition. American Association of Stratigraphic Palynologists Contributions Series 42, 909 pp.

Fisher, M.J., Riley, L.A., 1980. The stratigraphic distribution of dinoflagellate cysts at the boreal Jurassic-Cretaceous boundary. Fourth International Palynological Conference, Lucknow (1976-1977) Proceedings 2, 313-329.

Garg, R., Khowaja-Ateequzzaman, Krishna, J., Jain, K.P., 2003. Biostratigraphic potential of dinoflagellate cysts recovered from the Late Jurassic ammonites of the Tethys Himalaya, India. Journal of the Palaeontological Society of India 48, 41-58.

Gerasimov, P.A., 1969. The upper substage of the Volgian Stage of the central part of the Russian Platform: a palaeontological, stratigraphical and lithological study. Nauk Publishers, Moscow, 144 pp.

Gerasimov, P.A., Michailov, N.P., 1966. Volgian Stage and the geostratigraphical for the upper series of the Jurassic System. Izvestia Akademie Nauk SSSR Series Geology 1977/7, 14-33.

Geyssant, J.R., 1997. Tithonien. In: Cariou, E., Hantzpergue, P. (Eds.), Biostratigraphie du Jurassique ouest-européen et méditerranéen: zonations parallèles et distribution des invertébrés et microfossiles. Bulletin du Centre Recherches Elf Exploration Production Mémoire 17, 97-102.

Gradstein, F.M., Ogg, J.G., Smith, A.G. (eds.), 2004. A geologic time scale 2004. Cambridge University Press, 589 pp.

Gröke, D.R., Price, G.D., Ruffell, A.H., Mutterlose, J., Baraboshkin, E., 2003. Isotopic evidence for Late Jurassic-Early Cretaceous climate change. Palaeogeography, Palaeoclimatology, Palaeoecology 202, 97-118.

Habib, D., 1972. Dinoflagellate stratigraphy Leg 11, Deep Sea Drilling Project. Initial Reports of the Deep Sea Drilling Project 11, 367-425.

Habib, D., 1973. Taxonomy, morphology, and suggested phylogeny of the dinoflagellate genus *Druggidium*. Geoscience and Man 7, 47-55.

Habib, D., 1975. Neocomian dinoflagellate zonation in the western North Atlantic. Micropaleontology 21, 373-392.

Habib, D., Warren, J.S., 1973. Dinoflagellates near the Cretaceous Jurassic boundary. Nature 241, 217-218.

Habib, D., Drugg, W.S., 1983. Dinoflagellate age of Middle Jurassic-Early Cretaceous sediments in the Blake-Bahama Basin. Initial Reports of the Deep Sea Drilling Project 76, 623-638.

Habib, D., Drugg, W.S., 1987. Palynology of Sites 603 and 605, Leg 93, Deep Sea Drilling Project. Initial Reports of the Deep Sea Drilling Project 93, 751-775.

Håkansson, E., Birkelund, T., Piasecki, S., Zakharov, V., 1981. Jurassic-Cretaceous boundary strata of the extreme Arctic (Peary Land, North Greenland). Bulletin of the Geological Society of Denmark 30, 11-42.

Hantzpergue, P., Baudin, F., Mitta, A., Olferiev, A., Zacharov, V.A., 1998. The Upper Jurassic of the Volga Basin: ammonite biostratigraphy and occurrence of organic-carbon rich facies. Correlations between Boreal-subboreal and submediterranean provinces. In: Crasquin-Soleau, S., Barrier, É. (Eds.), Peritethys Memoir 4: Epicratonic Basins of Peri-Tethyan Platforms. Mémoires du Museum national d'Histoire naturelle 179, 9-33.

Haq, B.U., Hardenbol, J., Vail, P.R., 1987. Chronology of fluctuating sea levels since the Triassic. Science 235, 1156-1167.

Harding, I.C., 1990. A dinocyst calibration of the European Boreal Barremian Palaeontographica Abteilung B 218, 61-79.

He Cheng-Quan, Zhu You-Hua, 2003. Dinoflagellate assemblage from the uppermost part of the Dongrong Formation with discussion on Jurassic-Cretaceous boundary in Suibin area, northeastern Heilongjiang province, NE China. Acta Palaeontologica Sinica 43, 328-345.

Heilmann-Clausen, C., 1987. Lower Cretaceous dinoflagellate biostratigraphy in the Danish Central Trough. Danmarks Geologiske Undersøgelse Serie A 17, 89 pp.

Helby, R., Morgan, R., Partridge, A.D., 1987. A palynological zonation of the Australian Mesozoic. Memoir of the Association of Australasian Palaeontologists 4, 1-94.

Helby, R., Wilson, G.J., Grant-Mackie, J.A., 1988. A preliminary biostratigraphic study of Middle to Late Jurassic dinoflagellate assemblages from Kawhia, New Zealand. Memoir of the Association of Australasian Palaeontologists 5, 125-166.

Herngreen, G.F.W., Kerstholt, S.J., Munsterman, D.K., 2000. Callovian-Ryazanian (‘Upper Jurassic’) palynostratigraphy of the Central North Sea Graben and Vlieland Basin, the Netherlands. Mededelingen Nederlands Institut voor Toegepaste Geowetenschappen TNO 63, 99 pp.

Herngreen, G.F.W., Kouwe, W.F.P., Wong, T.E., 2003. The Jurassic of the Netherlands. In: Ineson, J.R., Surlyk, F. (Eds.), The Jurassic of Denmark and Greenland. Geological Survey of Denmark Bulletin 1, 217-229.

Hoedemaeker, P.J., 1991. Tethyan-Boreal correlations and the Jurassic-Cretaceous boundary. Newsletters in Stratigraphy 25, 37-60.

Hoedemaeker, P.J., 1999. A Tethyan-Boreal correlation of pre-Aptian Cretaceous strata: correlating the uncorrelatables. Geologica Carpathica 50, 101-124.

Hoedemaeker, P.J., Leereveld, H., 1995. Biostratigraphy and sequence stratigraphy of the Berriasian-lowest Aptian (Lower Cretaceous) of the Río Argos succession, Caravace, SE Spain. Cretaceous Research 16, 195-230.

Hogg, N.M., 1994. A research study into the Boreal Late Jurassic: Direct calibration of palynostratigraphy to ammonite zones of the type Volgian of the Russian Platform. Report for Shell UK Exploration and Production. University College London, 54 pp. (unpublished).

Houša, V., Pruner, P., Zakharov, V., Kostak, M., Chadima, M., Rogov, M., Šlechta, S., Mazuch, M., 2007. Boreal-tethyan correlation of the Jurassic-Cretaceous boundary interval by magneto- and biostratigraphy. Stratigraphy and Geological Correlation 15, 297-309.

Hunt, C.O., 2004. Palynostratigraphy of the classic Portland and Purbeck sequences of Dorset, southern England, and the correlation of Jurassic-Cretaceous boundary beds in the Tethyan and Boreal realms. In: Beaudoin, A.B., Head, M.J. (Eds.), The palynology and micropalaeontology of boundaries. Geological Society, London, Special Publications 230, 175-186.

Ibrahim, M.I.A., El-Beialy, S.Y., 1995. Kimmeridgian-Barremian palynostratigraphy of the Malha-1 well, North Sinai, Egypt. Bulletin des Sciences Géologiques 48, 187-209.

Ilyina, V.I., Nikitenko, B.L., Glinskikh, L.A., 2005. Foraminifera and dinoflagellate cyst zonation and stratigraphy of the Callovian to Volgian reference section in the Tyumenskaya superdeep well (West Siberia, Russia). In: Powell, A.J., Riding, J.B. (Eds.), Recent Developments in Applied Biostratigraphy. The Micropalaeontological Society, Special Publications. The Geological Society, London, 109-144.

Ineson, J.R., Bojesen-Koefoed, J.A., Dybkjaer, K., Nielsen, L.H., 2003. Volgian-Ryazanian ‘hot shales’ of the Bo Member (Farsund Formation) in the Danish Central Graben, North Sea: stratigraphy, facies and geochemistry. In: Ineson, J.R., Surlyk, F. (Eds.), The Jurassic of Denmark and Greenland. Geological Survey of Denmark Bulletin 1, 403-436.

Iosifova, E.K., 1996. Dinoflagellate cysts from Tchernaya Retchka (Ryazanian-Aptian, Lower Cretaceous) of the Moscow Basin, Russia. Review of Palaeobotany and Palynology 91, 187-240.

Jan du Chêne, R., Becheler, I., Helenes, J., Masure, E., 1986. Les genres *Diacanthum, Exiguisphaera, Occisucysta* et *Tehamadinium* gen. nov. (kystes fossiles de dinoflagellés). Cahiers de Micropaléontologie Nouvelle Serie 1, 5-37.

Jardiné, S., Raynaud, J.-F., de Reneville, P., 1984. Dinoflagellés, spores et pollens. In: Debrand-Passard, S., Courbaveux, S., Lienhardt, M.-J. (Eds.), Synthèse Geologique du Sud-Est de la France. Mémoires du BRGM 125, 300-303.

Jiang, Q., Mungai, M.W., Downie, C., Neves, R., 1992. Late Jurassic dinoflagellate assemblages of the Mto Panga Quarry, Mombassa, Kenya. Review of Palaeobotany and Palynology 74, 77-100.

Kessels, K., Mutterlose, J., Ruffell, A.H., 2003. Calcareous nannofossils from late Jurassic sediments of the Volga Basin (Russian Platform): evidence for productivity-controlled black shale deposition. Geologisches Rundschau 92, 743-757.

Klement, K., 1960. Dinoflagellaten und Hystrichosphaerideen aus dem unteren und mittleren Malm Südwestdeutschlands. Palaeontographica Abteilung A 114, 1-104.

Krymholts, G.Y., Mesezhnikov, M.S., Westermann, G.E.G., 1988. The Jurassic ammonite zones of the Soviet Union. Geological Society of America Special Paper 223, 116 pp.

Kuznetsova, K.I., 1978. Correlation of zonal subdivisions in stratotypes of the Volgian and Kimmeridgian stages. Bulletin of the Academy of Sciences of the USSR 21, 24-36.

Lebedeva, N.K., Nikitenko, B.L., 1999. Dinoflagellate cysts and microforaminifera of the Lower Cretaceous Yatria River section, Subarctic Ural, NW Siberia (eastern Russia). Grana 38, 134-143.

Leereveld, H., 1989. Dinoflagellate cyst zonation for the western Tethyan Lower Cretaceous. Stuifmail 7, 45-60.

Leereveld, H., 1997. Upper Tithonian-Valanginian (Upper Jurassic-Lower Cretaceous) dinoflagellate cyst stratigraphy of the western Mediterranean. Cretaceous Research 18, 385-420.

Lord, A.R., Cooper, M.K.E., Corbett, P.W.M., Fuller, N.G., Rawson, P.F., Rees, A.J.J., 1987. Microbiostratigraphy of the Volgian Stage (Upper Jurassic), Volga River, USSR. Neues Jahrbuch für Geologie und Paläontologie Monatshefte 10, 577-605.

McIntyre, D.J., Brideaux, W.W. 1980. Valanginian miospore and microplankton assemblages from the northern Richardson Mountains, District of Mackenzie, Canada. Geological Survey of Canada Bulletin, 320, 57 p.

Mesezhnikov, M.S., 1977. Jurassic/Cretaceous boundary beds in the middle Volga area. Ministry of Geology of the USSR, VNIGRI, Leningrad, 33 pp.

Mesezhnikov, M.S., 1984. The Kimmeridgian and Volgian stages of the Northern U.S.S.R. Nedra Publishers, Leningrad, 224 pp.

Mihailov, N.P., 1966. Boreal Jurassic ammonites (Dorsoplanitidae) and zonal subdivision of the Volgian Stage. Trudy Geologicheskogo Instituta, Akademiya Nauk SSSR (Leningrad) 151, 116 pp.

Mitta, V.V., 1993a. Ammonites and zonal stratigraphy of the Middle Volgian deposits of Central Russia. Geoprognoz, Kyiv 132 pp.

Mitta, V.V., 1993b. On the systematics of the Middle Volgian Virgatitidae (Ammonoidea) of Central Russia. Paleontological Journal 4, 41-48.

Mitta, V.V., 1994. On the systematics of the Middle Volgian Dorsoplanitidae (Ammonoidea) of Central Russia. Paleontological Journal 1, 27-37.

Monteil, E., 1991. Morphology and systematics of the Ceratioid Group: A new morphographic approach. Revision and emendation of the genus *Muderongia* Cookson & Eisenack 1958. Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine 15, 461-505.

Monteil, E., 1992a. Quelque nouvelles especes-index de kystes de dinoflagelles (Tithonique-Valanginien) du sud-est de la France et de l'Ouest de la Suisse. Revue de Paleobiologie 11, 273-297.

Monteil, E., 1992b. Kystes de dinoflagelles index (Tithonique-Valanginien) du sud-est de la France. Proposition d'une nouvelle zonation palynologique. Revue de Paleobiologie 11, 299-306.

Monteil, E., 1993. Dinoflagellate cyst biozonation of the Tithonian and Berriasian of south-east France. Correlation with the sequence stratigraphy. Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine 17, 249-273.

Morgan, R., 1980. Palynostratigraphy of the Australian Early and Middle Cretacous. Memoirs of the Geological Survey of New South Wales, Palaeontology 18, 153 pp.

Morgenroth, P., 1970. Dinoflagellate cysts from the Lias Delta of Lühnde/Germany. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen 136, 345-359.

Nikitenko, B.L., Pestchevitskaya, E.B., Lebedeva, N.K., Ilyina, V.I., 2008. Micropalaeontological and palynological analyses across the Jurassic-Cretaceous boundary on Nordvik Peninsula, Northeast Siberia. Newsletters on Stratigraphy 42, 181-222.

Nikitin, S.N., 1881. Jurassic formations between Rogbinsk, Mologa, and Myshkin: Materials on the Geology of Russia. Mineralogical Society Special Publication 10, 194.

Nøhr-Hansen, H., 1986. Dinocyst stratigraphy of the Lower Kimmeridge Clay, Westbury, Wiltshire, England. Bulletin of the Geological Society of Denmark 35, 31-51.

Ogg, J.G., Hassenyager, R.W., Wimbledon, W.A., 1994. Jurassic-Cretaceous boundary: Portlandian-Purbeck magnetostratigraphy and possible correlation to the Tethyan faunal realm. In: Cariou, E., Hantzpergue, P. (Eds.), 3rd International Symposium on Jurassic Stratigraphy (Poitiers 1991). Geobios Mémoire Spéciale, 17, 519-527.

Partington, M.A., Copestake, P., Mitchener, B.C., Underhill, J.R., 1993. Biostratigraphic calibration of genetic stratigraphic sequences in the Jurassic-lowermost Cretaceous (Hettangian to Ryazanian) of the North Sea and adjacent areas. In: Parker, J.R. (Ed.), Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference. The Geological Society, London, 371-386.

Pavlov, A.P., 1886. Les Ammonites de la Zone à *Aspidoceras acanthicum* de l’Est de la Russie. Mémoires de la Comité Géologique (Saint Petersburg) 2/3, 91 pp.

Pavlov, A.P., 1889. Études sur les couches jurassiques et crétacées de la Russie. I. Jurassique superieur et crétacé inférieur de la Russie et de l’Angleterre. Bulletin de la Société de Naturelles du Moscou, Nouvelle Série 1, 61-127.

Poulsen, N.E., 1992. Jurassic dinoflagellate cyst biostratigraphy of the Danish Subbasin in relation to sequences in England and Poland: a preliminary review. Review of Palaeobotany and Palynology 75, 33-52.

Poulsen, N.E., 1994. Dinoflagellate cyst biostratigraphy of Rhaetian-Ryazanian (Uppermost Triassic-Lowermost Cretaceous) deposits from the Danish subbasin. Geobios 17, 409-414.

Poulsen, N.E., 1996. Dinoflagellate cysts from marine Jurassic deposits of Denmark and Poland. American Association of Stratigraphic Palynologists Contributions Series 31, 227 pp.

Poulsen, N.E., Riding, J.B., 1992. A revision of the Late Jurassic dinoflagellate cysts *Ambonosphaera? staffinensis* (Gitmez 1970) comb. nov., and *Senoniasphaera jurassica* (Gitmez & Sarjeant 1972) Lentin & Williams 1976. Palynology 16, 25-34.

Poulsen, N.E., Riding, J.B., 2003. The Jurassic dinoflagellate cyst zonation of Subboreal Northwestern Europe. In: Ineson, J.R., Surlyk, F. (Eds.), The Jurassic of Denmark and Greenland. Geological Survey of Denmark Bulletin 1, 115-144.

Quattrocchio, M.E., Sarjeant, W.A.S., 1992. Dinoflagellate cysts and acritarchs from the Middle and Upper Jurassic of the Neuquén Basin, Argentina. Revista Española de Micropaleontología 24, 67-118.

Raynaud, J.F., 1978. Principaux dinoflagellés caractéristiques du Jurassique Supérieur d'Europe du Nord. Palinologia número extraordinario 1, 387-405.

Remane, J., 1998. Calpionellids. In: Hardenbol, J., Thierry, J., Farley, M.B., Jacquin, T., de Graciansky, P.-C., Vail, P.R., Mesozoic and Cenozoic Sequence Chronostratigraphic Framework of European Basins. In: de Graciansky, P.-C., Hardenbol, J., Jacquin, T., Vail, P.R. (Eds.), Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. SEPM (Society for Sedimentary Geology) Special Publication No. 60, 773-774, charts 5 and 7.

Riboulleau, A., Baudin, F., Deconinck, J.-F., Derenne, S., Largeau, C., Tribovillard, N., 2003. Depositional conditions and organic matter preservation pathways in an epicontinental environment: the Upper Jurassic Kashpir Oil Shales (Volga Basin, Russia). Palaeogeography, Palaeoclimatology, Palaeoecology 197, 171-197.

Richards, P.C., Lott, G.K., Johnson, H., Knox, R.W.O'B., Riding, J.B., 1993. Jurassic of the Central and Northern North Sea. In: Knox, R.W.O'B., Cordey, W.G. (Eds.), Lithostratigraphic nomenclature of the UK North Sea. British Geological Survey, Nottingham, 224 pp.

Riding, J.B., 1984. Dinoflagellate range top biostratigraphy of the uppermost Triassic to lowermost Cretaceous of northwest Europe. Palynology 8, 195-210.

Riding, J.B., 1987. Dinoflagellate cyst stratigraphy of the Nettleton Bottom Borehole (Jurassic: Hettangian to Kimmeridgian), Lincolnshire, England. Proceedings of the Yorkshire Geological Society 46, 231-266.

Riding, J.B., 2005. Middle and Upper Jurassic (Callovian to Kimmeridgian) palynology of the onshore Moray Firth Basin, northeast Scotland. Palynology 29, 87-142.

Riding, J.B., Thomas, J.E., 1988. Dinoflagellate cyst stratigraphy of the Kimmeridge Clay (Upper Jurassic) from the Dorset coast, southern England. Palynology 12, 65-88.

Riding, J.B., Davey, R.J., 1989. *Rotosphaeropsis thula* (Davey 1982) comb. nov., emend.: a dinoflagellate cyst from the Upper Jurassic-Lower Cretaceous of England. Journal of Micropalaeontology 8, 109-112.

Riding, J.B., Thomas, J.E., 1992. Dinoflagellate cysts of the Jurassic System. In: Powell, A.J. (Ed.), A stratigraphic index of dinoflagellate cysts. Chapman and Hall, London, 7-97.

Riding, J.B., Ioannides, N.S., 1996. A review of Jurassic dinoflagellate cyst biostratigraphy and global provincialism. Bulletin de la Société Géologique de France 167, 3-14.

Riding, J.B., Thomas, J.E., 1997. Marine palynomorphs from the Staffin Bay and Staffin Shale formations (Middle-Upper Jurassic) of the Trotternish Peninsula, NW Skye. Scottish Journal of Geology 33, 59-74.

Riding, J.B., and Helby, R., 2001. Marine microplankton from the Late Jurassic (Tithonian) of the north-west Australian region. Memoir of the Association of Australasian Palaeontologists 24, 177-220.

Riding, J.B., Fensome, R.A., 2002. A review of *Scriniodinium* Klement 1957, *Endoscrinium* (Klement 1960) Vozzhennikova 1967 and related dinoflagellate cyst taxa. Palynology 26, 5-33.

Riding, J.B., Penn, I.E., Woollam, R., 1985. Dinoflagellate cysts from the type area of the Bathonian stage (Middle Jurassic; southwest England). Review of Palaeobotany and Palynology 45, 149-169.

Riding, J.B., Keating, J.M., Snape, M.G., Newham, S., Pirrie, D., 1992. Preliminary Jurassic and Cretaceous dinoflagellate cyst stratigraphy of the James Ross Island area, Antarctic Peninsula. Newsletters on Stratigraphy 26, 19-39.

Riding, J.B., Fedorova, V.A., Ilyina, V.I., 1999. Jurassic and lowermost Cretaceous dinoflagellate cyst biostratigraphy of the Russian Platform and northern Siberia, Russia. American Association of Stratigraphic Palynologists Contributions Series 36, 183 pp.

Riding, J.B., Poulsen, N.E., Bailey, D.A., 2000. A taxonomic study of the dinoflagellate cyst *Muderongia simplex* Alberti 1961 and related species. Palynology 24, 21-35.

Riding, J.B., Mantle, D.J., Backhouse, J., 2010. A review of the chronostratigraphical ages of Middle Triassic to Late Jurassic dinoflagellate cyst biozones of the North West Shelf of Australia. Review of Palaeobotany and Palynology 162, 543-575.

Riding, J.B., Quattrocchio, M.E., Martínez, M.A., 2011. Mid Jurassic (Late Callovian) dinoflagellate cysts from the Lotena Formation of the Neuquén Basin, Argentina and their palaeogeographical significance. Review of Palaeobotany and Palynology 163, 227-236.

Rogov, M., Zakharov, V., 2009. Ammonite- and bivalve-based biostratigraphy and Panboreal correlation of the Volgian Stage. Science in China Series D: Earth Sciences 52, 1890-1909.

Ruffell, A.H., Price, G.D., Mutterlose, J., Kessels, K., Baraboshkin, E., Gröke, D.R., 2002. Palaeoclimate indicators (clay minerals, calcareous nannofossils, stable isotopes) compared from two successions in the late Jurassic of the Volga Basin (SE Russia). Geological Journal 37, 17-33.

Salvador, A., 1994. International stratigraphic guide. International Union of Geological Sciences and Geological Society of America Inc., Boulder. 214 pp.

Sarjeant, W.A.S., 1960. New hystrichospheres from the Upper Jurassic of Dorset. Geological Magazine 97, 137-144.

Sasanov, N.T., 1951. On some little known ammonites of the lower Cretaceous. Bulletin Moskva Obč Ispyt Prir 26(5), 57-63.

Sasanova, J.G., Sasanov, N.T., 1979. The Jurassic-Cretaceous boundary in the East European Platform. In: Wiedmann, J. (Ed.), Aspekte der Keride Europas. IUGS Series A 6 (Stuttgart), 487-496.

Schrank, E., 2005. Dinoflagellate cysts and associated aquatic palynomorphs from the Tendaguru Beds (Upper Jurassic-Lower Cretaceous) of southeast Tanzania. Palynology 29, 49-85.

Smelror, M., Dypvik, H., 2005. Marine microplankton biostratigraphy of the Volgian-Ryazanian boundary strata, western Barents Shelf. Norges Geologiske Undersøkelse Bulletin 443, 61-69.

Smelror, M., Mørk, A., Monteil, E., Rutledge, D., Leereveld, H., 1998. The Klippfisk Formation - a new lithostratigraphic unit of lower Cretaceous platform carbonates on the Western Barents Shelf. Polar Research 17, 181-202.

Smith, A.G., Briden, J.C., 1977. Mesozoic and Cenozoic paleocontinental maps. Cambridge University Press, 63 pp.

Smith, G.A., 1999. Palynology of the Jurassic/Cretaceous Boundary Interval in the Volga Basin of Russia. Unpublished PhD thesis, University of Bristol, UK, 461 pp.

Smith, G.A., Harding, I.C., 2004. New dinoflagellate cyst species from Upper Jurassic to Lower Cretaceous sediments of the Volgian lectostratotype sections at Gorodishche and Kashpir, Volga Basin, Russia. Review of Palaeobotany and Palynology 128, 335-379.

Snape, M.G., 1992. Dinoflagellate cysts from an allochthonous block of Nordenskjöld Formation (Upper Jurassic), north-west James Ross Island. Antarctic Science 4, 267-278.

Stevens, J., 1987. Some Early Cretaceous dinoflagellates from the *Cassiculosphaeridia delicata* Zone on the Exmouth Plateau, Western Australia. Memoir of the Association of Australasian Palaeontologists 4, 185-197.

Stover, L.E., Brinkhuis, H., Damassa, S.P., de Verteuil, L., Helby, R.J., Monteil, E., Partridge, A.D., Powell, A.J., Riding, J.B., Smelror, M., Williams, G.L., 1996. Chapter 19. Mesozic-Tertiary dinoflagellates, acritarchs and prasinophytes. In: Jansonius, J., McGregor, D.C. (Eds.), Palynology: principles and applications. American Association of Stratigraphic Palynologists Foundation 2, 641-750.

Taylor, F.R.J., Pollingher, U., 1987. Chapter 11. Ecology of dinoflagellates. In: Taylor, F.R.J. (Ed.), The biology of dinoflagellates. Botanical Monographs 21, Blackwell Scientific Publications, Oxford, 398-529.

Thusu, B., Vigran, J.O., 1985. Middle - Late Jurassic (Late Bathonian - Tithonian) palynomorphs. In: Thusu, B., Owens, B. (Eds.), Palynostratigraphy of north-east Libya. Journal of Micropalaeontology 4(1), 113-130.

Thusu, B., van der Eem, J.G.L.A., El-Mehdawi, A., Bu-Argoub, F., 1988. Jurassic - Early Cretaceous palynostratigraphy in northeast Libya. In: El-Arnauti, A., Owens, B., Thusu, B. (Eds.), Subsurface Palynostratigraphy of northeast Libya. Garyounis University Publications, Benghazi, Libya, 171-213.

Torrens, H.S., 1980. 3. Means of correlation of Jurassic rocks. In: Cope, J.C.W., Getty, T.A., Howarth, M.K., Morton, N., Torrens, H.S. A correlation of Jurassic rocks in the

British Isles. Part One: Introduction and Lower Jurassic. Geological Society of London, Special Report 14, 4-16.

van Helden, B.G.T., 1986. Dinoflagellate cysts at the Jurassic-Cretaceous boundary, offshore Newfoundland, Canada. Palynology 10, 181-199.

Wall, D., Evitt, W.R., 1975. A comparison of the modern genus *Ceratium* Schrank, 1793, with certain Cretaceous marine dinoflagellates. Micropaleontology 21, 14-44.

Wimbledon, W.A., 1984. The Portlandian, the terminal Jurassic Stage in the Boreal Realm. 7th International Symposium on Jurassic Stratigraphy, Erlangen, 534-549.

Wimbledon, W.A.P., 2007. The Jurassic-Cretaceous boundary: an age-old correlative enigma. Episodes 31, 423-428.

Wimbledon, W.A., Cope, J.C.W., 1978. The ammonite faunas of the English Portland Beds and the zones of the Portlandian Stage. Journal of the Geological Society of London 135, 183-190.

Wimbledon, W.A., Hunt, C.O., 1983. The Portland-Purbeck junction (Portlandian-Berriasian) in the Weald, and correlation of latest Jurassic-early Cretaceous rocks in southern England. Geological Magazine 120, 267-280.

Wimbledon, W.A.P., Casellato, C.E., Reháková, D., Bulot, L., Gardin, S.,Verreussel, R.M.C.H., Munsterman, D.K., Hunt, C.O., in press. Fixing a basal Berriasian and J-K boundary – perhaps there is some light at the end of the tunnel? Rivista Italiana di Paleontologia e Stratigraphia.

Woollam, R., Riding, J.B., 1983. Dinoflagellate cyst zonation of the English Jurassic. Institute of Geological Sciences Report 83, 42 pp.

Zakharov, V.A., Rogov, M.A., 2008. Let the Volgian stage stay in the Jurassic. Russian Geology and Geophysics 49, 408-412.

Zacharov, V.A., Bogomolov, Y.I., Ilyina, V.I., 1997. Boreal Zonal Standard and biostratigraphy of the Siberian Mesozoic. Geology i geophysica 38, 927-956.

Zakharov, V., Rogov, M., Kisilev, D., 2006. The Volgian Stage and Jurassic/Cretaceous boundary in the Panboreal Superrealm. 7th International Congress on the Jurassic System, September 6-18, 2006, Kraków, Poland. Volumina Jurassica V, 224-226 (abstract).

Zeiss, A., 2003. The Upper Jurassic of Europe: its subdivision and correlation. In: Ineson, J.R., Surlyk, F. (Eds.), The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin 1, 75-114.

Zhu Youhua, He Chengquan, 2007. Middle Jurassic to Early Cretaceous dinoflagellate assemblage zones in eastern Heilongjiang Province, northeast China. Cretaceous Research 28, 327-332.

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Fig. 1. The locations of the sections sampled at Gorodishche and Kashpir near Ul'yanovsk in the Volga Basin, western Russia. a – regional map of western Russia and surrounding regions. b – the location of the section at Gorodishche on the west bank of the River Volga, to the south of Undory. c – the location of the section at Kashpir on the west bank of the River Volga, to the to the south of Stroetyel. The stippled areas in b and c represent the River Volga.

Fig. 2. Latest Jurassic (Tithonian) to Early Cretaceous (Valanginian) standard Tethyan stage nomenclature adjacent to the Jurassic/Cretaceous boundary. The British/French and Russian Platform (Boreal) stages and the regional ammonite zones are plotted against the standard.

Fig. 3. Correlation of the Late Jurassic to earliest Cretaceous ammonite zonation for eastern England with the ammonite zonation for the Volga Basin. The scheme of Hanzpergue et al. (1998) is the Volga Basin zonation used herein.

Fig. 4. The numbers and positions of the samples in this study on the summary lithological logs of the Middle Tithonian to Valanginian successions at Gorodishche

(samples U1-U40) and Kashpir (K1-K30). The logs were produced by Giles A. Smith and Vladimir Efimov.

Fig. 5. Correlation of the lithological logs for the Middle Tithonian to Valanginian succession at Gorodishche. 1 – the log of Lord et al. (1987) after Mesezhnikov (1977). 2 – the log of Hogg (1994) based on data supplied by VNIGRI, Saint Petersburg. 3 – the log of Mesezhnikov in Blom et al. (1984). 4 – the present study; the log was produced by Giles A. Smith and Vladimir Efimov. The correlation lines are based on lithological criteria and the ammonite zone boundaries indicated in Lord et al. (1987), Hogg (1994) and Mesezhnikov in Blom et al. (1984).

Fig. 6. Correlation of the lithological logs for the Middle Tithonian to Valanginian succession at Kashpir. 1 – the log of Lord et al. (1987). 2 – the log of Mesezhnikov in Blom et al. (1984). 3 – the present study; the log was produced by Giles A. Smith and Vladimir Efimov. The correlation lines are based on lithological criteria and the ammonite zone boundaries indicated in Lord et al. (1987) and Mesezhnikov in Blom et al. (1984).

Fig. 7. The ranges of selected stratigraphically-significant dinoflagellate cysts from the Middle Tithonian to Lower Valanginian succession of Gorodishche (1 of 2).

Fig. 8. The ranges of selected stratigraphically-significant dinoflagellate cysts from the Middle Tithonian to Lower Valanginian succession of Gorodishche (2 of 2).

Fig. 9. The ranges of selected stratigraphically-significant dinoflagellate cysts from the Middle Tithonian to Lower Valanginian succession of Kashpir (1 of 2).

Fig. 10. The ranges of selected stratigraphically-significant dinoflagellate cysts from the Middle Tithonian to Lower Valanginian succession of Kashpir (2 of 2).

Fig. 11. A comparison of biostratigraphically significant dinoflagellate cyst first and last appearance datums in the Tithonian (latest Jurassic) to Early Berriasian of the Volga Basin and Western Europe.

Fig. 12. A comparison of biostratigraphically significant dinoflagellate cyst first and last appearance datums in the Mid-Late Berriasian to Valanginian/Hauterivian (Early Cretaceous) of the Volga Basin and Western Europe.

Fig. 13. The dinoflagellate cyst biozonation proposed herein with the defining biostratigraphically significant dinoflagellate cyst bioevents. The biozonation herein is compared with those of Riding et al. (1999) for the Russian Platform and by other authors for northwest Europe.

Fig. 14. Graphic correlation. **Need a caption from ICH. We need to explain the significance of the circles, squares and crosses**

Table 1. The stratigraphical distribution and relative abundance data of dinoflagellate cysts from the Middle Tithonian to Valanginian of the Gorodishche section. The numbers represent actual numbers of specimens counted. Forms recorded outside of the formal count are indicated by an “X”.

Table 2. The stratigraphical distribution and relative abundance data of dinoflagellate cysts from the Middle Tithonian to Valanginian of the Kashpir section. The numbers represent actual numbers of specimens counted. Forms recorded outside of the formal count are indicated by an “X”. * = Upper Jurassic/Lower Cretaceous. ** = Upper Tithonian/Lower Berriasian.

Plate I

Transmitted light photomicrographs of selected dinoflagellate cysts from the Middle-Upper Tithonian, Upper Tithonian and Valanginian strata of Gorodishche and Kashpir. The sample number, slide number and England Finder (EF) coordinates are quoted for all specimens.

1, 2. *Achomosphaera neptuni* (Eisenack 1958) Davey & Williams 1966. Valanginian (unzoned) of Kashpir. Sample/slide K17-0/300-2, EF R43/0. Dorsal and ventral focus respectively.

3. *Batioladinium*? *gochtii* (Alberti 1961) Lentin & Wiliams 1977. Valanginian (unzoned) of Kashpir. Sample/slide K17, EF E41/3. Oblique lateral focus.

4, 10. *Scrinodinium pharo* (Duxbury 1977) Davey 1982. Valanginian (unzoned) of Kashpir. Sample/slide K17-0/300-2, EF K41/4. Dorsal and ventral focus respectively.

5. *Egmontodinium polyplacophorum* Gitmez & Sarjeant 1972. Upper Tithonian (Craspedites subditus Zone) of Kashpir. Sample/slide K8, EF G24/4. Lateral focus.

6, 11. *Cribroperidinium* cf. *C. volkovae* Iosifova 1996. Valanginian (unzoned) of Kashpir. Sample/slide K17-0/300, EF J35/3. Ventral and dorsal focus respectively.

7. *Gochteodinia villosa* (Vozzhennikova 1967) Norris 1978. Upper Tithonian (Craspedites subditus Zone) of Kashpir. Sample/slide K8, EF P53/0. Left lateral focus.

8. *Senoniasphaera jurassica* (Gitmez & Sarjeant 1972) Lentin & Wiliams 1976. Upper Tithonian (Craspedites subditus Zone) of Kashpir. Sample/slide K8, EF H39/0. Dorsal focus.

9. *Spiniferites ramosus* (Ehrenberg 1838) Mantell 1854. Valanginian (unzoned) of Kashpir. Sample/slide K17-0/300-2, EF J44/0. Ventral-lateral focus.

12. *Oligosphaeridium complex* (White 1842) Davey & Williams 1966. Valanginian (unzoned) of Kashpir. Sample/slide K27, EF J34/3. Ventral focus.

13, 14. *Tehamadinium daveyi* Jan du Chêne et al. 1986. Upper Tithonian (Craspedites subditus Zone) of Kashpir. Sample/slide K8-2, EF O31/0. Ventral and dorsal focus respectively.

15, 19. *Isthmocystis distincta* Duxbury 1979. Valanginian (unzoned) of Kashpir. Sample/slide K17-0/300-3, EF E34/2. Ventral focus on epitract and dorsal focus on hypotract respectively.

16. *Tubotuberella* cf. *apatela* (Cookson & Eisenack 1960) Ioannides et al. 1976. Middle-Upper Tithonian (Virgatites virgatus Zone) of Gorodishche. Sample/slide U23-2, EF N29/0. Ventral focus.

17, 18. *Kleithriasphaeridium eoinodes* (Eisenack 1958) Davey 1974. Valanginian (unzoned) of Kashpir. Sample/slide K17-0/300-2, EFM62/3. Ventral and dorsal focus respectively.

Plate II

Scanning electron photomicrographs of selected dinoflagellate cysts from the Upper Tithonian and Valanginian strata of Kashpir. The sample number, SEM stub number and the grid square coordinates are quoted for all specimens.

1. *Gochteodinia villosa* (Vozzhennikova 1967) Norris 1978. Upper Tithonian (Craspedites subditus Zone) of Kashpir. Sample K8, SEM stub 9, grid square 2/II. Dorsal view.

2. *Gochteodinia villosa* (Vozzhennikova 1967) Norris 1978. Upper Tithonian (Craspedites subditus Zone) of Kashpir. Sample K8, SEM stub 9, grid square 4/II. Dorsal view, note that one opercular plate has been lost, and another remains lodged within the archaeopyle.

3. *Isthmocystis distincta* Duxbury 1979. Valanginian (unzoned) of Kashpir. Sample K21, SEM stub 11, grid square 4/I. Ventral view.

4. *Senoniasphaera jurassica* (Gitmez & Sarjeant 1972) Lentin & Williams 1976. Upper Tithonian (Craspedites subditus Zone) of Kashpir. Sample K8, SEM stub 9, grid square 3/III. Dorsal focus.

5. *Phoberocysta tabulata* Raynaud 1978. Valanginian (unzoned) of Kashpir. Sample K24, SEM stub 8, grid square 3/IV. Ventral view.

6. *Scrinodinium pharo* (Duxbury 1977) Davey 1982. Valanginian (unzoned) of Kashpir. Sample K17, SEM stub 3, grid square 2/II. Ventral view, note the large sulcal claustrum.

7. *Amphorula expirata* (Davey 1982) Courtinat 1989. Upper Tithonian (Craspedites subditus Zone) of Kashpir. Sample K8, SEM stub 9, grid square 3/IV. Oblique lateral view.

8. *Hystrichodinium pulchrum* Deflandre 1935 (variety 1). Valanginian (unzoned) of Kashpir. Sample K21, SEM stub 11, grid square 2/II. Ventral view.

9. *Cribroperidinium* cf. *C. volkovae* Iosifova 1996. Valanginian (unzoned) of Kashpir. Sample K17, SEM stub 4, grid square 1/III. Dorsal view, note intratabular tuberculae.

10. *Pseudoceratium brevicornutum* Herngreen et al. 2000. Valanginian (unzoned) of Kashpir. Sample K17, SEM stub 4, grid square 3/I. Ventral view.

11. *Tehamadinium daveyi* Jan du Chêne et al. 1986. Upper Tithonian (Craspedites subditus Zone) of Kashpir. Sample K8, SEM stub 9, grid square 3/III. Dorsal view.

Appendix 1.

An alphabetical listing of all validly described dinoflagellate cyst species recorded in this study with full author citations. References to the dinoflagellate cyst author citations can be found in Fensome and Williams (2004).

Achomosphaera neptuni (Eisenack 1958) Davey & Williams 1966

2648 *Ambonosphaera*? *staffinensis* (Gitmez 1970) Poulsen & Riding 1992

2649 *Amphorula expirata* (Davey 1982) Courtinat 1989

2650 *Aprobolocysta galeata* Backhouse 1987

2651 *Aprobolocysta trycheria* Pourtoy 1988

2652 *Apteodinium spinosum* Jain & Millepied 1975

2653 *Apteodinium spongiosum* McIntyre & Brideaux 1980

2654 *Athigmatocysta glabra* Duxbury 1977

2655 *Avellodinium falsificum* Duxbury 1977

2656 *Batioladinium*? *gochtii* (Alberti 1961) Lentin & Williams 1977

2657 *Batioladinium jaegeri* (Alberti 1961) Brideaux 1975

2658 *Batioladinium radiculatum* Davey 1982

2659 *Cassiculosphaeridia magna* Davey 1974

2660 *Cassiculosphaeridia pygmaeus* Stevens 1987

2661 *Cassiculosphaeridia reticulata* Davey 1969

2662 *Chlamydophorella nyei* Cookson & Eisenack 1958

2663 *Chytroeisphaeridia cerastes* Davey 1979

2664 *Chytroeisphaeridia chytroeides* (Sarjeant 1962) Downie & Sarjeant 1965

2665 *Circulodinium compta* (Davey 1982) Helby 1987

2666 *Circulodinium copei* Bailey et al. 1997

2667 *Circulodinium distinctum* (Deflandre & Cookson 1955) Jansonius 1986

2668 *Cometodinium habibii* Monteil 1991

2669 *Cometodinium whitei* (Deflandre & Courteville 1939) Stover & Evitt 1978

2670 *Cribroperidinium erymnoseptatum* Bailey 1993

2671 *Cribroperidinium magnificum* Smith & Harding 2004

2672 *Cribroperidinium nuciforme* (Deflandre 1939 ex Sarjeant 1962) Courtinat 1989

2673 *Cribroperidinium undoryensis* Smith & Harding 2004

2674 *Cribroperidinium venustum* (Klement 1960) Poulsen 1996

2675 *Cribroperidinium* cf. *C. volkovae* Iosifova 1996

2676 *Cymososphaeridium validum* Davey 1982

2677 *Dapsilidinium multispinosum* (Davey 1974) Bujak et al. 1980

2678 *Dichadogonyaulax*? *chondra* (Drugg 1978) Courtinat 1989

2679 *Dingodinium cerviculum* Cookson & Eisenack 1958

2680 *Dingodinium jurassicum* Cookson & Eisenack 1958

2681 *Dingodinium tuberosum* (Gitmez 1970) Fisher & Riley 1980

2682 ?*Downiesphaeridium*? *aciculare* (Davey 1969) Islam 1993

2683 *Egmontodinium toryna* (Cookson & Eisenack 1960) Davey 1979

2684 *Egmontodinium polyplacophorum* Gitmez & Sarjeant 1972

2685 *Ellipsoidictyum cinctum* Klement 1960

2686 *Endoscrinium granulatum* (Raynaud 1978) Lentin & Williams 1981

2687 *Exochosphaeridium phragmites* Davey et al. 1966

2688 *Exiguisphaera phragma* Duxbury 1977

2689 *Glossodinium dimorphum* Ioannides et al. 1977

2690 *Gochteodinia mutabilis* (Riley in Fisher & Riley 1980) Fisher & Riley 1982

2691 *Gochteodinia tuberculata* Below 1990

2692 *Gochteodinia villosa* (Vozzhennikova 1967) Norris 1978

2693 *Gonyaulacysta* cf. *G. centriconnata* Riding 1983

2694 *Gonyaulacysta dentata* (Raynaud 1978) Lentin & Vozzhennikova 1990

2695 *Gonyaulacysta eisenackii* (Deflandre 1938) Górka 1965

2696 *Gonyaulacysta pectinigera* (Gocht 1970) Fensome 1979

2697 *Gonyaulacysta speciosa* Harding 1990

2698 *Hystrichodinium pulchrum* Deflandre 1935

2699 *Hystrichodinium voigtii* (Alberti 1961) Davey 1974

2700 *Hystrichosphaeridium petilum* Gitmez 1970

2701 *Impletosphaeridium lumectum* (Sarjeant 1960) Islam 1993

2702 *Isthmocystis distincta* Duxbury 1979

2703 *Kalyptea diceras* Cookson & Eisenack 1960

2704 *Kleithriasphaeridium corrugatum* Davey 1974

2705 *Kleithriasphaeridium eoinodes* (Eisenack 1958) Davey 1974

2706 *Kleithriasphaeridium fasciatum* (Davey & Williams 1966) Davey 1974

2707 *Kleithriasphaeridium porosispinum* Davey 1982

2708 *Kleithriasphaeridium telaspinosum* (Fisher & Riley 1980) Lentin & Williams 1981

2709 *Lagenorhytis delicatula* (Duxbury 1977) Duxbury 1979

2710 *Leptodinium subtile* Klement 1960

2711 *Lithodinia arcanitabulata* Brenner 1988

2712 *Meiourogonyaulax bulloidea* (Cookson & Eisenack 1960) Sarjeant 1969

2713 *Meiourogonyaulax distincta* Smith & Harding 2004

2714 *Mendicodinium reticulatum* Morgenroth 1970

2715 *Muderongia endovata* Riding et al. 2001

2716 *Nelchinopsis kostromiensis* (Vozzhennikova 1967) Wiggins 1972

2717 *Oligosphaeridium complex* (White 1842) Davey & Williams 1966

2718 *Oligosphaeridium pulcherrimum* (Deflandre & Cookson 1955) Davey & Williams 1966

2719 *Pareodinia ceratophora* Deflandre 1947

2720 *Perisseiasphaeridium ingegerdiae* Nøhr-Hansen 1986

2721 *Phoberocysta neocomica* (Gocht 1957) Millioud 1969

2722 *Phoberocysta tabulata* Raynaud 1978

2723 *Prolixosphaeridium parvispinum* (Deflandre 1937) Davey et al. 1969

2724 *Pseudoceratium brevicornutum* Herngreen et al. 2000

2725 *Pseudoceratium pelliferum* Gocht 1957

2726 *Rhynchodiniopsis martonense* Bailey et al. 1997

2727 *Scriniodinium campanula* Gocht 1959

2728 *Scriniodinium inritibile* Riley in Fisher & Riley 1980

2729 *Scriniodinium pharo* (Duxbury 1977) Davey 1982

2730 *Senoniasphaera jurassica* (Gitmez & Sarjeant 1972) Lentin & Williams 1976

2731 *Sentusidinium* aff. *S. ?fibrillosum* Backhouse 1988

2732 *Sentusidinium rioultii* (Sarjeant 1968) Sarjeant & Stover 1978

2733 *Sirmiodinium grossii* Alberti 1961

2734 *Spiniferites primaevus* (Duxbury 1977) Monteil 1991

2735 *Spiniferites ramosus* (Ehrenberg 1838) Mantell 1858

2736 *Stanfordella exsanguia* (Duxbury 1977) Helenes & Lucas-Clark 1997

2737 *Stanfordella fastigiata* (Duxbury 1977) Helenes & Lucas Clarke 1997

2738 *Stephanelytron membranoideum* (Vozzhennikova 1967) Courtinat 1999

2739 *Stiphrosphaeridium anthophorum* (Cookson & Eisenack 1958) Lentin & Williams 1985

2740 *Stiphrosphaeridium dictyophorum* (Cookson & Eisenack 1958) Lentin & Williams 1985

2741 *Systematophora areolata* Klement 1960

2742 *Systematophora daveyi* Riding & Thomas 1988

2743 *Systematophora palmula* Davey 1982

2744 *Tanyosphaeridium isocalamum* (Deflandre & Cookson 1955) Davey & Williams 1969

2745 *Tanyosphaeridium magneticum* Davies 1983

2746 *Tehamadinium daveyi* Jan du Chêne et al. 1986

2747 *Tehamadinium evittii* (Dodekova 1969) Jan du Chêne et al. 1986

2748 *Tehamadinium sousense* (Below 1981) Jan du Chêne et al. 1986

2749 *Tenua hystrix* Eisenack 1958

2750 *Thalassiphora*? *robusta* Smith & Harding 2004

2751 *Trichodinium ciliatum* (Gocht 1970) Eisenack & Klement 1964

2752 *Tubotuberella apatela* (Cookson & Eisenack 1960) Ioannides et al. 1977

2753 *Valensiella ovulum* (Deflandre 1947) Eisenack 1963

2754 *Wallodinium anglicum* (Cookson & Hughes 1964) Lentin & Williams 1973

2755 *Wallodinium cylindricum* (Habib 1970) Duxbury 1983

Wallodinium krutzschii (Alberti 1961) Habib 1972
Wallodinium luna (Cookson & Eisenack 1960) Lentin & Williams 1973
Warrenia? *brevispinosa* (Iosifova 1992) Iosifova 1996
Wrevittia cf. *W. helicoidea* (Eisenack & Cookson 1960) Helenes & Lucas-Clark 1997

Appendix 2.

Sample details – a listing of the 70 samples collected from the sections at Gorodishche (sample numbers prefixed “U”) and Kashpir (sample numbers prefixed “K”), giving the bed number, Stage/Substage and the ammonite zone where appropriate.

I Gorodishche:

Sample No.	**Bed No.**	**Stage/Substage**	**Ammonite Zone/Subzone**
U40	20	Valanginian	unzoned
U39	20	Valanginian	unzoned
U38	20	Valanginian	unzoned
U37	20	Valanginian	unzoned
U36	20	Valanginian	unzoned
U35	20	Valanginian	unzoned
U34	20	Valanginian	unzoned
U33	19	Upper Tith./Lower Berr.	Craspedites nodiger
U32	18	Upper Tith./Lower Berr.	Craspedites nodiger
U31	18	Upper Tith./Lower Berr.	Craspedites nodiger
U30	18	Upper Tithonian	Craspedites subditus
U29	18	Upper Tithonian	Craspedites subditus
U28	18	Upper Tithonian	Kachpurites fulgens
U27	18	Upper Tithonian	Kachpurites fulgens
U26	17	Upper Tithonian	Epivirgatites nikitini
U25	17	Upper Tithonian	Epivirgatites nikitini
U24	16	Middle/Upper Tithonian	Virgatites virgatus
U23	15	Middle/Upper Tithonian	Virgatites virgatus
U22	14	Middle/Upper Tithonian	Virgatites virgatus
U21	14	Middle/Upper Tithonian	Virgatites virgatus
U20	13	Middle Tithonian	D. panderi-Z. zarajskensis
U19	12	Middle Tithonian	D. panderi-Z. zarajskensis

U18	10	Middle Tithonian	D. panderi-Z. zarajskensis
U17	10	Middle Tithonian	D. panderi-Z. zarajskensis
U16	9	Middle Tithonian	D. panderi-Z. zarajskensis
U15	9	Middle Tithonian	D. panderi-Z. zarajskensis
U14	8	Middle Tithonian	D. panderi-Z. zarajskensis
U13	7	Middle Tithonian	D. panderi-Z. zarajskensis
U12	7	Middle Tithonian	D. panderi-Z. zarajskensis
U11	6	Middle Tithonian	D. panderi-Z. zarajskensis
U10	6	Middle Tithonian	D. panderi-Z. zarajskensis
U9	6	Middle Tithonian	D. panderi-Z. zarajskensis
U8	5	Middle Tithonian	D. panderi-Z. zarajskensis
U7	5	Middle Tithonian	D. panderi-Z. zarajskensis
U6	4	Middle Tithonian	D. panderi-Z. zarajskensis
U5	4	Middle Tithonian	D. panderi-Z. zarajskensis
U4	3	Middle Tithonian	D. panderi-Z. zarajskensis
U3	2	Middle Tithonian	D. panderi-Z. zarajskensis
U2	2	Middle Tithonian	D. panderi-Z. zarajskensis
U1	1	Middle Tithonian	D. panderi-Z. zarajskensis

II Kashpir:

Sample No.	**Bed No.**	**Stage/Substage**	**Ammonite Zone**
K30	30	Valanginian	unzoned
K29	30	Valanginian	unzoned
K28	30	Valanginian	unzoned
K27	29	Valanginian	unzoned
K26	29	Valanginian	unzoned
K25	29	Valanginian	unzoned
K24	29	Valanginian	unzoned
K23	28	Valanginian	unzoned
K22	27	Valanginian	unzoned
K21	27	Valanginian	unzoned
K20	27	Valanginian	unzoned
K19	27	Valanginian	unzoned
K18	26	Valanginian	unzoned
K17	24	Valanginian	unzoned

2828	K16	23	Upper Berriasian	Surites tzikwinianus
2829	K15	23	Upper Berriasian	Surites spasskensis
2830	K14	23	Upper Berriasian	Surites spasskensis
2831	K13	21	Middle/Upper Berriasian	unzoned
2832	K12	19	Middle/Upper Berriasian	unzoned
2833	K11	19	Middle/Upper Berriasian	unzoned
2834	K10	18	Middle/Upper Berriasian	unzoned
2835	K9	17	Upper Tith./Lower Berr.	Craspedites nodiger
2836	K8	14	Upper Tithonian	Craspedites subditus
2837	K7	14	Upper Tithonian	Craspedites subditus
2838	K6	13	Upper Tithonian	Craspedites subditus
2839	K5	13	Upper Tithonian	Craspedites subditus
2840	K4	11	Upper Tithonian	Kachpurites fulgens
2841	K3	11	Upper Tithonian	Kachpurites fulgens
2842	K2	3	Middle Tithonian	Dorsoplanites panderi
2843	K1	2	Middle Tithonian	Dorsoplanites panderi