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Uppermost Jurassic and lowermost Cretaceous dinocyst successions of Siberia, the Subarctic Urals and Russian Platform and their interregional correlation

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Abstract: Uppermost Jurassic and lowermost Cretaceous dinocyst successions calibrated against ammonite and foraminiferal zones were studied in five sections from North Siberia, the Subarctic Urals and the Russian Platform. Together with analysis of published palynological material on additional contemporaneous sections from the Russian Platform, our research provides a reliable regional correlation. The obtained biostratigraphic results are compared to palynological data from different regions of Europe, America, Australia and Antarctica using the method of first/last appearances of selected key species and evolutionary trends of dinocyst floras. Four correlative levels are defined in the middle parts of the Volgian and Berriasian and near their tops providing interregional correlation of dinocyst successions. These levels range within 1–1.5 ammonite zones as the first/last appearances of some key species have minor stratigraphic shifts in different sections that may be related to migration processes or to a different understanding of the stratigraphic position of ammonite zones.

Key words: Upper Jurassic, Lower Cretaceous, Russia, bioevents, interregional correlation, dinoflagellate cysts.

Introduction

Organic walled dinoflagellate cysts (further dinocysts) were recently used for biostratigraphic studies of the Mesozoic in many regions. However, dinocyst zones are usually based on the local taxonomic changes of microphytoplankton assemblages that invoke a lot of difficulties in interregional correlations and age determination. To avoid these problems, palynologists apply the first and last appearances (FADs/LADs) of the selected species, and this approach is widely adopted in palynological practice. Nevertheless the composition of key species groups is often determined by regional palynostratigraphic needs that reflect regional peculiarities of the dinocyst successions. Uppermost Jurassic and the lowermost Cretaceous is an even more confused situation, when the isolation of Boreal basins caused high endemism of Boreal and Tethyan biotas. It makes long distance correlations very problematic, even through ecotone regions of the Russian Platform, Crimea and NW Europe.

In spite of high regional differences of dinocyst assemblages and key species, the general development of dinocyst floras apparently has to go on similar stages reflected by major evolutionary tendencies and global climatic and geological trends. Thus, a combined approach, including both the method of selected key species providing the definition of several marker levels, and the study of evolutionary stages of the dinocyst, can provide important information for correlation of dinocyst successions in distant regions. We used this approach for our palynostratigraphical investigation of the uppermost Jurassic and the lowermost Cretaceous of Siberia, the Urals and Russian Platform and this methodology allows us to compare our biostratigraphic results using palynological data from different regions of Europe, America, Australia and Antarctica.

Material and geological setting

Palynological material comes from five sections: Nordvik section (Laptev Sea coast), Severo-Vologochanskaya 18 well (Yenisei River mouth), Zapadno-Purpeiskaya 710 well (NW Siberia), Yatriya River section (Subarctic Urals), Kashpir section (middle reaches of the Volga River) (Fig. 1). An almost continuous succession of Oxfordian to the Hauterivian age deposits, containing diverse ammonites, bivalves, belemnites, foraminifers and palynomorphs, is exposed in several outcrops on the Nordvik Peninsula (Saks et al. 1963; Basov et al. 1970; Zakharov et al. 1983; Nikitenko et al. 2008). The Volgian and the Berriasian are represented by grey claystone and siltstone of the Paksa Formation which were deposited in the central part of the paleobasin. There are no stratigraphic gaps across the Jurassic-Cretaceous (J/K) boundary, which is located (Fig. 2): 1) at the base of the *Chetaites sibiricus* Zone (base of the Boreal Berriasian) calibrated against the *Berriasella jacobi* Zone by Saks et al. (1963), Basov et al. (1970), Zakharov et al. (1983) on the basis of paleontological data; 2) at the base of the *Craspedites okensis* (base of the Upper Volgian) calibrated against the *Berriasella jacobi* Zone by Sey & Kalacheva (1999) on the basis of paleontological data; 3) in the middle of *Craspedites taimyrensis* Zone (upper part of the Upper Volgian) calibrated against *Calpionella* Zone by Houša et al. (2007) on the basis of faunistic and paleomagnetic data (Chron M19n corresponds to the *Craspedites taimyrensis* Zone).

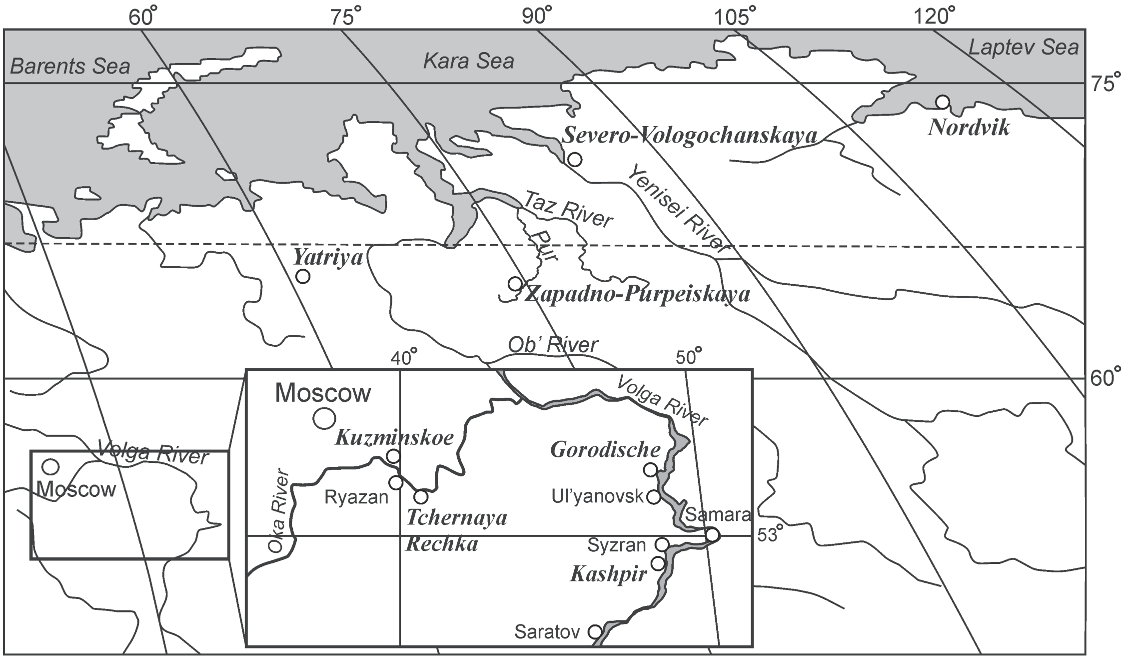

Fig. 1. Locations of analysed sections.

The Upper Berriasian was also studied in the Severo-Vologochanskaya 18 well, where it is represented by silty claystone of the Nizgnaya Kheta Formation. The Formation is characterized by diverse foraminifers and palynomorphs (Pestchevitskaya & Khafaeva 2008).

In the Zapadno-Purpeiskaya 710 well, the Volgian–Berriasian part of the section consists of clayey-siliciclastic rocks of the Bazhenovo Formation. Core material is studied from the Middle–Upper Volgian and Middle–lowermost Upper Berriasian. This stratigraphic subdivision is based on bivalves, ammonites and palynomorphs (Beisel et al. 2002).

A well-studied section of marine Upper Volgian–Lower Cretaceous deposits with diverse ammonites, belemnites, bivalves and palynomorphs is also exposed on the eastern slope of the Subarctic Ural Mountains (Golbert et al. 1972; Fedorova et al. 1993; Beizel et al. 1997; Lebedeva & Nikitenko 1998, 1999). The Upper Volgian and the Lower Berriasian are represented by grey sandy siltstone and silty claystone of the Fedorov and Khorasoim Formations respectively. The J/K boundary is located at the top of the *Chetaites chetae* Zone on the basis of ammonites (Golbert et al. 1972; Lebedeva & Nikitenko 1999) (Fig. 2). There is a hiatus in the Lower Berriasian including the *Chetaites sibiricus* Zone.

In the Kashpir section, the Ryazanian and the Volgian are represented by sandstone and siltstone of the Zhigulyovo and the Undory Formations comprising a bench of organic-reached claystone in its uppermost Volgian part (Gerasimov 1969; Mesezhnikov 1993a,b; Olferiev 1997). A stratigraphic gap at the base of the Zhigulyovo Formation includes the lower part of the Ryazanian and the very uppermost part of the Upper Volgian. The J/K boundary is located (Fig. 3): 1) at the top of the *Craspedites nodiger* Zone (Gerasimov 1969; Casey et al. 1977; Mesezhnikov 1993a; Olferiev 1997) on the basis of paleontological data and by Molostovsky & Eryomin (2008) on the basis of paleomagnetic data (Chron M19n corresponds to the *Craspedites nodiger* Zone); 2) at the base of the *Kachpurites fulgens* Zone (base of the Upper Volgian) by Hantzpergue et al. (1998) on the basis of ammonites. Published palynological data on the Lower and Middle Volgian of the Gorodische and Kashpir sections (Volga River basin), the Upper Volgian and Ryazanian of Tchernaya River and Kuzminskoje sections (Oka River basin) have been used for the comparative analysis of dinocyst successions (Fig. 3). In the Volga River basin, the Lower and Middle Volgian is represented by calcareous claystone and marlstone of the Trazovskaya and Promza Formations, and by sandstone and siltstone of the Undory Formation in its upper part (Gerasimov 1969; Mesezhnikov 1993a,b; Olferiev 1997). In the Oka River basin, the Upper Volgian and the Ryazanian consist of sands of the Lopatkino and Kuzminskoje Formations. There is a hiatus near the J/K boundary including the *Craspedites nodiger* Zone of the Upper Volgian and lower part of the Lower Ryazanian.

Dinocyst successions of Siberia, the Subarctic Urals and Russian Platform

Outcrops of Upper Jurassic and Lower Cretaceous deposits on the Nordvik Peninsula represent one of the most significant sections for the analysis of Siberian dinocysts of this stratigraphic interval and provide a continuous succession of dinocyst events near the J/K boundary calibrated against ammonite zones. Here, the Upper Volgian and Berriasian yield rather rich dinoflagellate floras in moderate abundance, mostly composed of species widely distributed in Boreal regions (Fig. 2). The endemic Russian forms included are only *Ambonosphaera delicata* Lebedeva, *Leberidocysta spinosa*

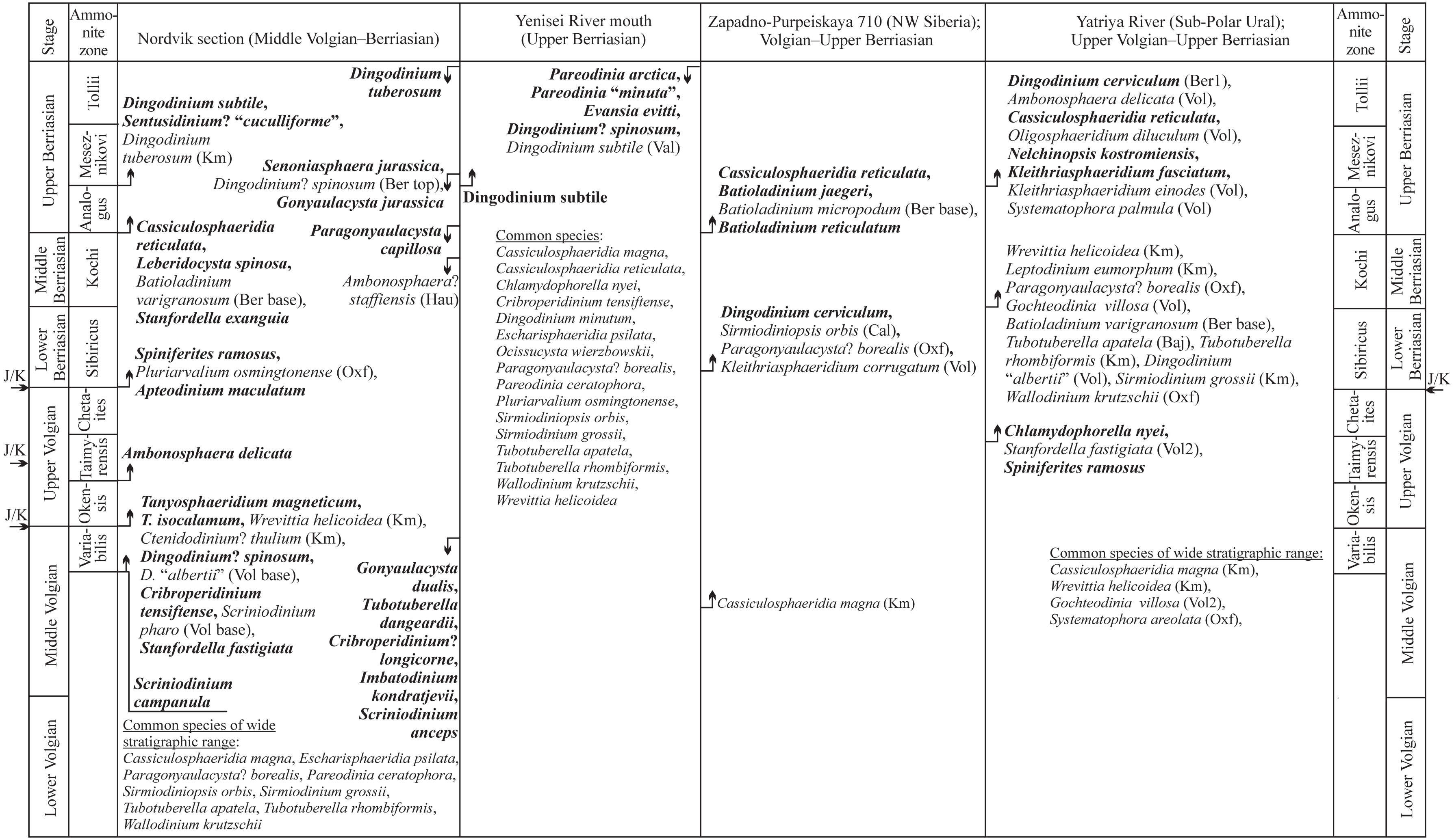

Fig. 2. Uppermost Jurassic and lowermost Cretaceous dinocyst events of Siberia and Subarctic Urals. **J/K** — indicates different versions of J/K boundary location. In the brackets, general base range (for FADs) and top range (for LADs) of the species are given. Species, which do not appear below or above certain levels, are marked by bold type. The evaluation of stratigraphical range of dinocyst species is based on original author's material and publications cited in this paper and also in Powel A.J. (Ed.) (1992), Jansonius & McGregor (1996), Riding et al. (1998), Lebedeva & Nikitenko (1998, 1999), Pestchevitskaya (2007).

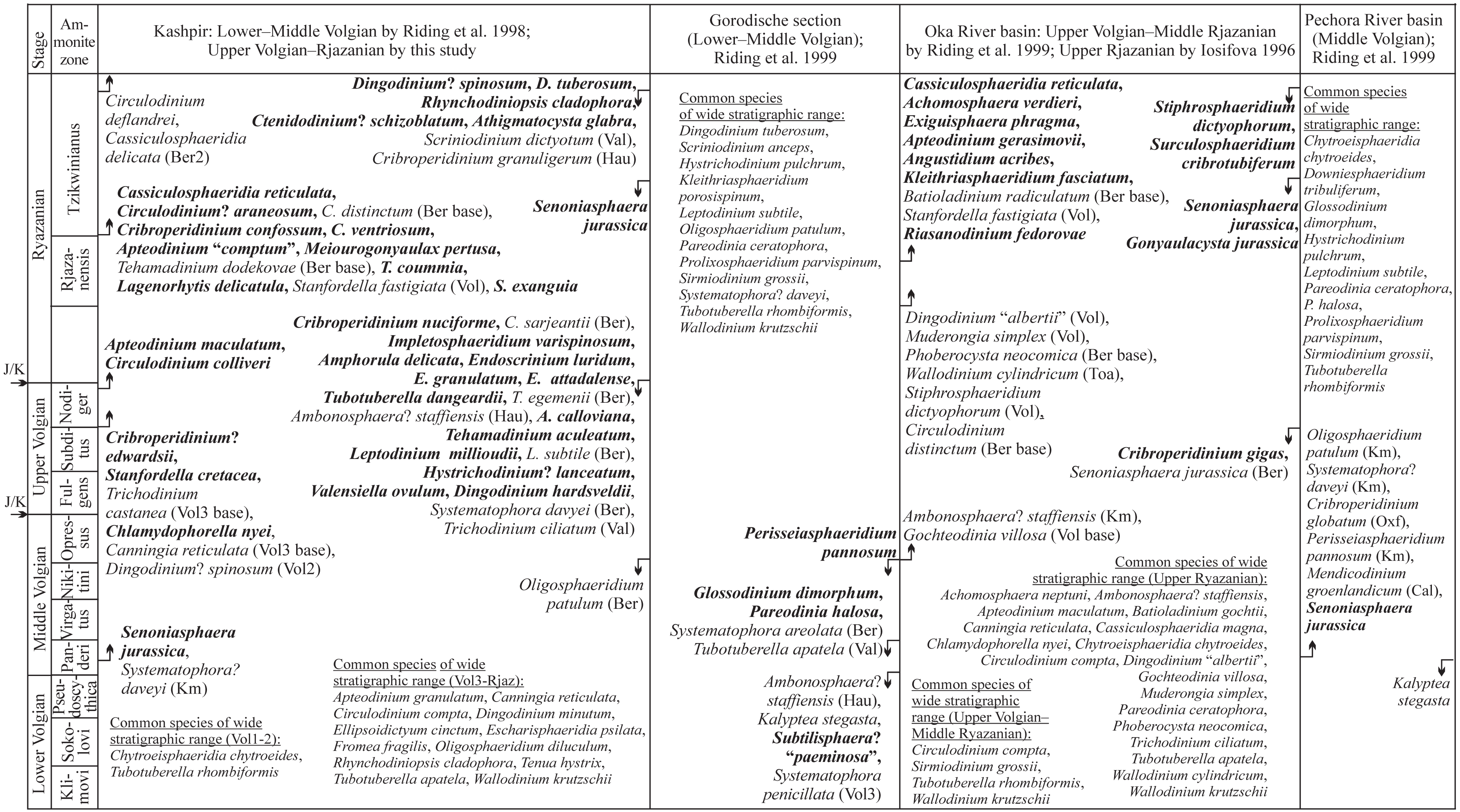

Fig. 3. Uppermost Jurassic and lowermost Cretaceous dinocyst events of the Russian Platform. **J/K** — indicates different versions of the J/K boundary location. In the brackets, general base range (for FADs) and top range (for LADs) of the species are given. Species, which do not appear below or above certain levels, are marked by bold type. The evaluation of stratigraphical range of dinocyst species is based on original author's material and publications cited in this paper and also in Powel A.J. (Ed.) (1992), Jansonius & McGregor (1996), Riding et al. (1998), Lebedeva & Nikitenko (1998, 1999), Pestchevitskaya (2007).

Pestchevitskaya, and *Dingodinium subtile* Pestchevitskaya. A characteristic feature is the diversity of the Subfamily Pareodinioideae. This succession provides the first report of *Scriniodinium campanula* Gocht from the upper part of the Middle Volgian. In the Upper Berriasian it is well correlated with dinocyst assemblages from the Yenisei River region that contain a similar taxonomic composition (Fig. 2). Berriasian microphytoplankton associations from the Zapadno-Purpeiskaya 710 well are less abundant and diverse. Middle Volgian samples are almost barren of palynomorphs, and produce residues rich in amorphogen. This situation is typical for the inner areas of West Siberia, where Volgian organic-rich shales of Bazhenovo Formation often contain neither fauna nor palynomorphs. This is commonly explained by anoxic conditions during deposition (Shurygin et al. 2000). In the Subarctic Urals and the Pechora River region, dinoflagellate floras are enriched by chorate and leptodinioid forms, which are rare in Siberia. In the Yatria River section, the endemic Siberian species *Ambonosphaera delicata* Lebedeva is found in the Upper Berriasian, while in the Nordvik section its lowermost occurrence is observed in the Upper Volgian. The diversity of dinocysts increases considerably in the sections of the Volga and Oka Rivers regions, especially in the Berriasian successions (Fig. 2). Gonyaulacoids become very abundant, while pareodinioid forms typical for Siberia are almost absent.

In spite of considerable lateral taxonomic differences of contemporaneous dinocyst assemblages, several stratigraphic marker levels can be determined on the basis of evolutionary trends and FADs/LADs of selected species. Levels of high taxonomic changes in dinocyst assemblages are observed near the bases of the Middle and Upper Volgian, near the base of the Berriasian, and in the middle and upper parts of the Berriasian (Figs. 2, 3). This is the result of the appearance both of well known Oxfordian-Kimmeridgian taxa and FADs/LADs of stratigraphically important species providing regional correlations. The FAD of *Senoniasphaera jurassica* (Gitmez & Sarjeant) Lentin & Williams is observed near the base of the Middle Volgian in the Volga and Pechora Rivers regions, while in European sections it is recognized in the Kimmeridgian (Powel 1992). The FAD of *Chlamydoforella nyei* Cookson & Eisenack is defined in the uppermost Volgian in the Yatriya and Volga River sections. The first occurrences of *Spiniferites ramosus* (Ehrenberg) Mantell are found in the uppermost Volgian in the Subarctic Urals and at the base of the Berriasian in the Nordvik section. A well correlatable marker near the Upper Berriasian/Ryazanian base is the FAD of *Cassiculosphaeridia reticulata* Davey, which is found in almost all sections (Figs. 2, 3). This level is also confirmed by the FADs of *Kleithriasphaeridium fasciatum* (Davey & Williams) Davey (Yatriya and Oka River regions) and *Stanfordella exanguia* (Duxbury) Helenes & Lucas-Clark (Volga River and Nordvik regions). The marker level in the middle of the Upper Berriasian is defined by the FAD of *Dingodinium subtile* Pestchevitskaya in the Siberian sections and the LADs of *Senoniasphaera jurassica* (Gitmez & Sarjeant) Lentin & Williams and *Gonyaulacysta jurassica* (Deflandre) Norris & Sarjeant both in Siberia and on the Russian Platform (Figs. 2, 3). The top of the Berriasian is characterized by the LADs of *Dingodinium*? *spinosum* (Duxbury) Davey and *Dingodinium tuberosum* (Gitmez) Fisher & Riley in Siberia and the Volga River region.

Interregional correlation of Russian dinocyst successions

Comparison of Russian and NW European dinocyst successions

The Upper Jurassic and Lower Cretaceous dinocyst successions of NW Europe are studied and discussed in numerous publications (Duxbury 1977; Powel 1992; Jansonius & McGregor 1996; Poulsen 1996; Duxbury et al. 1999; Herngreen et al. 2000; Abbink et al. 2001; Hunt 2004 and others). Dinoflagellate floras from the Russian Platform are similar to the microphytoplankton associations from Denmark (Davey 1982; Poulsen 1996), Netherlands (Herngreen et al. 2000; Abbink et al. 2001) and England (Duxbury 1977; Duxbury et al. 1999; Hunt 2004) comprising rich gonyaulacoids and various chorate forms, while the Siberian dinocyst assemblages are closer to those of the Norwegian and Barents Sea comprising more diverse pareodinioids (Aarhus et al. 1986; Smelror & Dypvik 2005). Nevertheless European dinocyst successions include a number of species that are absent in Russia (Figs. 2–4). Several European stratigraphic markers are well defined in the Portlandian and Ryazanian, including a level near the J/K boundary, although some species have slightly different FADs/LADs (within one ammonite zone) in different sections (Fig. 4). As in Russia, there are levels of high taxonomic changes within dinocyst assemblages. The level near the base of *Kerberites kerberus* Zone characterized by the regional FADs of *Isthmocystis distincta* Duxbury, *Perisseiasphaeridium insolitum* Davey, *Gochteodinia virgula* Davey, *Gochteodinia villosa* (Vozzhennikova) Norris can be correlated against the Russian upper Middle Volgian level by the FAD of *Dingodinium*? *spinosum* (Duxbury) Davey defined in Denmark, Netherlands and N Siberia (Figs. 2, 4). The level near the top of the *Volgidiscus lamplughi* Ammonite Zone can be correlated against the Russian dinocyst level corresponding to the *Craspedites nodiger* Ammonite Zone by the LAD of *Cribroperidiunim*? *gigas* (Raynaud) Helenes identified in offshore Norway, the North Sea and Oka River regions (Figs. 3, 4). The level in the middle of the Berriasian is well defined in NW Europe by the inception and extinction of a wide number of gonyaulacoid species, and some of them (*Kleithriasphaeridium fasciatum* (Davey & Williams) Davey, *Lagenorhytis delicatula* (Duxbury) Duxbury, *Meiourogonyaulax pertusa* (Duxbury) Below, *Sentusidinium rioultii* (Sarjeant) Sarjeant & Stover also have their FADs near this level on the Russian Platform. The extinction of *Senoniasphaera jurassica* (Gitmez & Sarjeant) Lentin & Williams in the middle of the Upper Berriasian has been indentified in North Siberia, the Russian Platform and Dorset (Figs. 3, 4). A reliable correlative marker at the top of the Berriasian is the LAD of *Dingodinium*? *spinosum* (Duxbury) Davey, which is well-defined in Siberia, the Russian Platform and NW Europe. Minor stratigraphic shifts of the FADs/LADs of some species in different sections do not provide accurate interregional cor-

Stage	Ammonite zone	Denmark (Davey 1982; Poulsen 1996)	Norway (Aarhus et al. 1986; Smelror & Dypvik 2005)	Dorset (Hunt 2004)
Ryazanian	Albidum			↓ ***Impagidinium setcheyense***
	Stenomphalus			
	Incenii	↑ *Spiniferites ramosus* (Ryaz base), *Athigmatocysta glabra* (Prt), ***Kleithriasphaeridium fasciatum***, *Muderongia simplex* (Prt), *Oligosphaeridium diluculum* (Prt), ***Cantulodinium speciosum***, *Stiphrosphaeridium abrbustum* (Ryaz base)		↑ ***Stanfordella ordocavata***, ***Kleithriasphaeridium fasciatum***, *Muderongia simplex* (Prt), *Tehamadinium evittii* (Prt); ↓ ***Senoniasphaera jurassica***
	Kochii	↓ ***Barbatacysta crebrebarbata***, ***Barbatacysta verrucosa***, ***Dingodinium jurassicum***, *Escharisphaeridia pocockii* (Val), *Pareodinia ceratophora* (Val), *Scriniodinium dictyotum* (Val), *Sirmiodinium grossii* (Hau), ***Impletosphaeridium lumectum***, ***Downiesphaeridium polytrichum***, ***Downiesphaeridium tribuliferum***, *Chytroeisphaeridia chytroeides* (Hau), ***Cribroperidinium globatum***, ***Cribroperidinium hansenii***, ***Prolixosphaeridium anasillum***, ***Sentusidinium rioultii***, ***Systematophora? daveyi***, ***Downiesphaeridium polyacanthum***, ***Rotosphaeropsis thule***, *Tubotuberella rhombiformis* (Ryaz top)	↑ ***Occisucysta tentorium***, *Cassiculosphaeridia magna* (Km), *Spiniferites ramosus* (Ryaz base), ***Wrevittia? diutina***, *Wrevittia helicoidea* (Km), *Oligosphaeridium diluculum* (Prt), *Downiesphaeridium tribuliferum* (Km), ***Sentusidinium separatum***	↑ ***Dichadogonyaulax bensonii***, ***Dapsilidinium warrenii***; ↓ *Dingodinium tuberosum* (Ryaz top), ***Cantulodinium arthuriae***
	Runctoni	↑ *Batioladinium matyjae* (Prt), ***Batioladinium varigranosum***, ***Batioladinium pomum***, ***Batioladinium radiculatum***, ***Prolixosphaeridium spissum***, *Scriniodinium dictyotum* (Oxf), *Stiphrosphaeridium dictyophorum* (Prt), *Rhynchodiniopsis pennata* (Km), *Omatidium bernieri* (Oxf)	↓ ***Cribroperidinium globatum***; ↓ *Prolixosphaeridium parvispinum* (Ryaz), ***Dichadogonyaulax? pannea***, *Gochteodinia villosa* (Vl), *Escharisphaeridia rudis* (Ryaz); ↑ ***Batioladinium pomum***, ***Batioladinium radiculatum***, ***Prolixosphaeridium granulosum***, *Isthmocystis distincta* (Prt), *Egmontodinium expiratum* (Km), *Scriniodinium pharo* (Prt), *Stephanelytron membranoideum* (Km), *Tehamadinium daveyi* (Prt), *Tubotuberella dangeardii* (Oxf)	↑ *Warrenia californica* (Prt); ↑ *Ctenidodinium? schizoblatum* (Prt), *Amphorula? monteillii* (Prt), *Dingodinium tuberosum* (Km), *Gochteodinia villosa* (Prt), ***Cirrusphaera dissimilis***, *Scriniodinium campanula* (Prt), *Downiesphaeridium tribuliferum* (Oxf)
Portlandian	Lamplughi	↓ *Amphorula expirata* (incenii), *Prolixosphaeridium mixtispinosum* (Ryaz), *Oligosphaeridium pulcherium* (Tur), *Tehamadinium evittii* (Ber)	↓ ***Cribroperidinium? gigas***	↓ *Kleithriasphaeridium porosispinum* (Ryaz), *Systematophora penicillata* (Ryaz), *Dichadogonyaulax? pannea* (Ryaz), *Dichadogonyaulax culmula* (Ryaz), ***Egmontodinium polyplacophorum***
	Preplicomphalus			
	Primitivus			
	Opressus	↑ ***Avellodinium falsificum***, ***Apteodinium spongiosum***, *Scriniodinium anceps* (Km), ***Heslertonia heslertonensis***, *Neufenia willei* (Oxf), ***Tehamadinium evittii***, ***Systematophora palmula***; ↓ ***Psaligonyaulax? cypraea***, *Gochteodinia virgula* (Prt top), *Tehamadinium daveyi* (Ryaz)		
	Anguiformis			
	Kerberus	↑ *Kalyptea stegasta* (Oxf), *Amphorula expirata* (Km), ***Cribroperidinium hansenii***, *Tubotuberella rhombiformis* (Km), *Scriniodinium pharo* (Prt base), *Stephanelytron membranoideum* (Km), ***Hystrichodinium voigtii***, *Cassiculosphaeridia magna* (Km), ***Isthmocystis distincta***, ***Perisseiasphaeridium insolitum***, ***Tehamadinium daveyi***, ***Dingodinium? spinosum***, ***Gochteodinia villosa***, ***Gochteodinia virgula***		
	Okusensis	↓ *Ellipsoidictium cinctum* (Prt top), *Egmontodinium polyplacophorum* (Prt top), *Ambonosphaera? staffiensis* (Hau), ***Hystrichosphaerina? orbifera***, ***Dichadogonyaulax chrondra***		
	Glaucolithus			
	Albani	↑ *Hystrichosphaerina? orbifera* (Km), ***Dichadogonyaulax culmula***, *Tubotuberella rhombiformis* (Km), *Xenicodinium densispinosum* (Km), ***Muderongia simplex***, *Rotosphaeropsis thule* (Km); ↓ *Occisucysta balios* (Ber)		

Fig. 4. Uppermost Jurassic and lowermost Cretaceous dinocyst events of NW Europe. Correlations of dinocyst successions against ammonite zones are given in Poulsen (1996), Duxbury et al. (1999), Herngreen et al. (2000) and Abbink et al. (2001). In the brackets, general base range (for FADs) and top range (for LADs) of the species are given. Species, which do not appear below or above certain levels, are marked by bold type. The evaluation of stratigraphical range of dinocyst species is based on original author's material and publications cited in this paper and also in Powel A.J. (Ed.) (1992), Jansonius & McGregor (1996), Riding et al. (1998), Lebedeva & Nikitenko (1998, 1999) and Pestchevitskaya (2007).

relations, but allow the comparison of certain stratigraphic intervals that are characterized by similar dinocyst events within 1–1.5 ammonite zones.

Comparison of dinocyst successions of Russia and North America

Uppermost Jurassic–lowermost Cretaceous dinocyst successions of North America are studied from differing distant areas including Arctic Canada (Davies 1983), Newfoundland (Van Helden 1986), SE Canada (Bujak & Williams 1978), and the Bahama Basin (Habib 1983). The different geographical positions of studied areas result in essential regional peculiarities of dinoflagellate floras. Microphytoplankton assemblages from Newfoundland are characterized by low species diversity. It is interesting to note the presence of the typical Russian species *Imbatodinium kondatjevii* Vozzhennikova in this section. The assemblages from Arctic Canada are more diverse and contain abundant pareodinioid forms that are also recognized in Siberia. The diversity of gonyaulacoids and the presence of *Achomosphaera neptuni* (Eisenack) Davey & Williams, *Chytroeisphaeridia chytroeides* (Sarjeant) Downie & Sarjeant, *Phoberocysta neocomica* (Gocht) Millioud, *Gochteodinia villosa* (Vozzhennikova) Norris, *Tubotuberella apatela* (Cookson & Eisenack) Ioannides et al., *Wallodinium krutzschii* (Alberti) Habib are similar features of the dinocyst assemblages from SE Canada and the Russian Platform. Dinocyst successions of the Bahama region are of transitional character comprising species typical for different areas of Europe, Russia and Australia. The levels of high taxonomic changes in American dinocyst assemblages are observed near the bases of the Tithonian and the Berriasian, and in their upper parts (Fig. 5). The Upper Tithonian level can be correlated against the Upper Volgian level of Siberia by the FAD of *Tanyosphaeridium isocalamum* (Deflandre & Cookson) Davey & Williams determined in SE Canada and Nordvik section. The appearance of *Circulodinium colliveri* (Cookson & Eisenack) Helby near the J/K boundary is recognized in SE Canada and the Volga River region. A reliable correlative level is defined in the upper part of the Berriasian: these marker events are the LAD of *Sentusidinium rioultii* (Sarjeant) Sarjeant & Stover recognized in Newfoundland and the Volga River region, the FAD of *Nelchinopsis kostromiensis* (Vozzhennikova) Wiggins recognized in Newfoundland and the Subarctic Urals, the FAD of *Sentusidinium*? "*cuculliforme*" Davies and the LAD of *Paragonyaulacysta capillosa* (Brideaux & Fisher) Stover & Evitt recognized in Arctic Canada and the Nordvik section.

Comparison of dinocyst successions of Russia, Australia and Antarctica

The dinocyst assemblages of Australia and Antarctica comprise a number of endemic species providing detailed regional zonation of Upper Jurassic and Lower Cretaceous deposits (Helby et al. 1987; Duane 1996; Partridge 2006). A succession of dinocyst zones dated by ammonites, belemnites and bivalves is defined in the Tithonian and Berriasian of Australia (Helby et al. 1987; Partridge 2006). In the Berriasian, a similar succession is also identified in the Antarctic region within the President Beaches Formation (Duane 1996). The underlying Anchorage Formation of Kimmeridgian-Tithonian age yielded only barren palynological residues (Duane 1996). Correlative levels are defined for these regions in the lowermost Berriasian by the FAD of *Senoniasphaera ptomatis* Helby, May & Partridge, and slightly upward, by the LAD of *Kalyptea wisemaniae* Stover & Helby (Fig. 6). These levels are characterized by the inception and extinction of a wide number of species, and most of them are endemics. Nevertheless the lowermost Berriasian level can be correlated against the same-aged level on the Russian Platform by the FAD of *Circulodinium colliveri* (Cookson & Eisenack) Helby determined in Antarctica and the Volga River region (Figs. 3, 6). Another marker species for the correlation of the Australian and Russian regions is *Batioladinium reticulatum* Stover & Helby, its inception in the upper part of the Berriasian is defined in Australia and NW Siberia.

Comparison of Russian, Central European and SW European dinocyst successions

South European and Central European dinocyst assemblages of the uppermost Jurassic and the lowermost Cretaceous studied in SE France (Monteil 1992, 1993), SE Spain (Leereveld 1995, 1997) and Austria (Boorová et al. 1999) are characterized by similar taxonomic composition. A distinctive succession of dinocyst events has enabled the working out of a detailed dinocyst zonation, but most of the regional stratigraphical markers cannot be identified in NW Europe, Russia, America and Australia, precluding accurate interregional correlations (Figs. 2–7). Nevertheless, several species from the Central European and SW European dinocyst assemblages are also recognized in Siberia and on the Russian Platform: *Achomosphaera neptuni* (Eisenack) Davey & Williams, *Chytroeisphaeridia chytroeides* (Sarjeant) Downie & Sarjeant, *Circulodinium distinctum* (Deflandre & Cookson) Jansonius, *Cometodinium habibii* Monteil, *Dingodinium "albertii"* Clarke & Verdier, *Dingodinium cerviculum* Cookson & Eisenack, *Exiguisphaera phragma* Duxbury, *Kleithriasphaeridium fasciatum* (Davey & Williams) Davey, *Meiourogonyaulax pertusa* (Duxbury) Below, *Muderongia tabulata* Raynaud, *Scriniodinium campanula* Gocht, *Spiniferites ramosus* (Ehrenberg) Mantell, *Stanfordella exanguia* (Duxbury) Helenes & Lucas-Clark, *Tanyosphaeridium isocalamum* (Deflandre & Cookson) Davey & Williams, *Tubotuberella apatela* (Cookson & Eisenack) Ioannides & al., *Wallodinium cylindricum* (Habib) Duxbury, *Wrevittia helicoidea* (Eisenack & Cookson) Helenes & Lucas-Clark. The FAD of *Spiniferites ramosus* in the uppermost Jurassic–lowermost Berriasian is determined in SE France, the Subarctic Urals and North Siberia, and FAD of *Dingodinium cerviculum* Cookson & Eisenack in the middle of the Lower Berriasian is defined in Austria and West Siberia. Four correlative events are observed in the upper part of the Berriasian: the FAD of *Meiourogonyaulax pertusa* (Duxbury) Below in SE Spain and the Volga River region; the FAD of *Kleithriasphaeridium fasciatum* (Davey & Williams) Davey in Austria, the Subarctic Urals and Oka River region; FAD

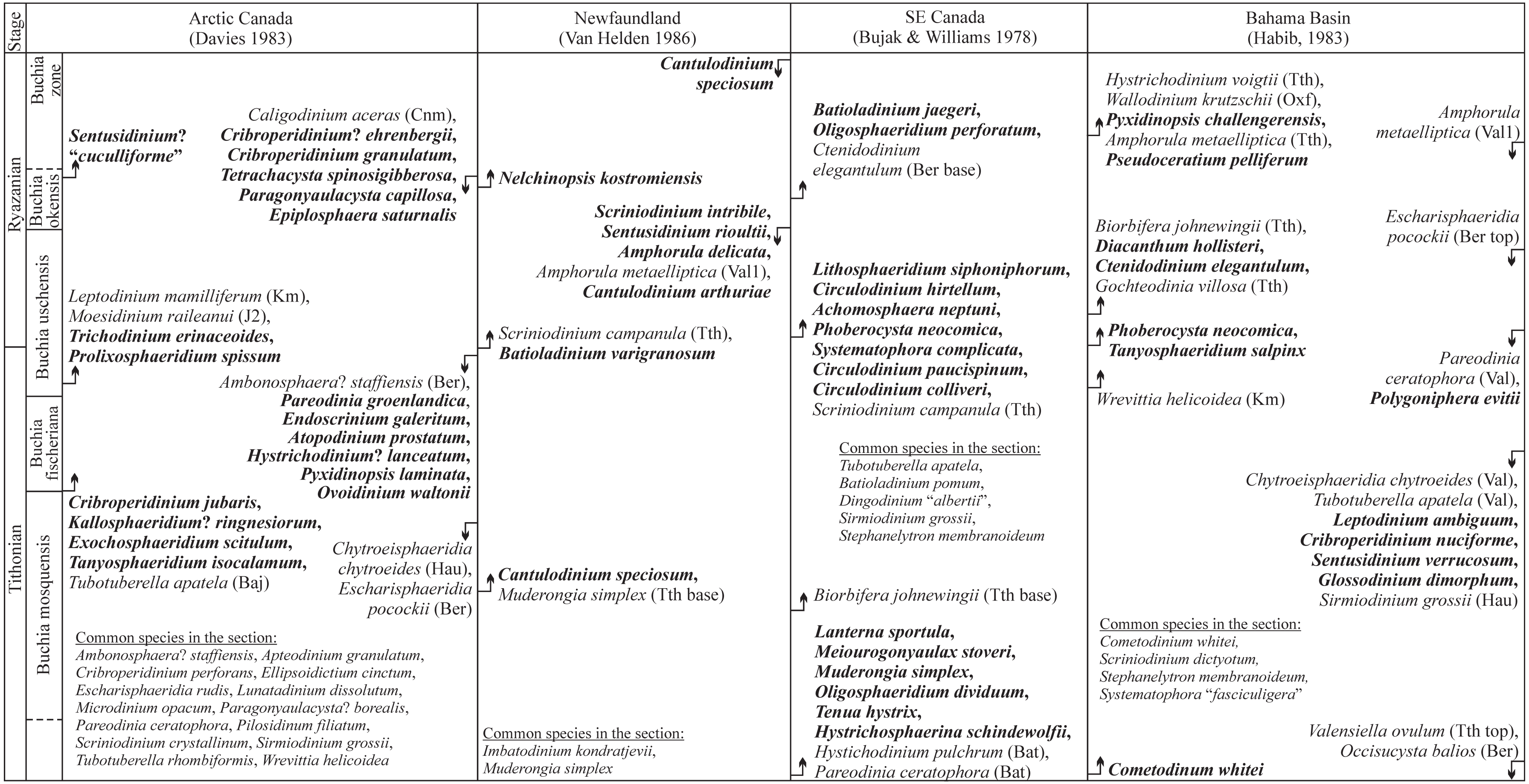

Fig. 5. Uppermost Jurassic and lowermost Cretaceous dinocyst events of N America. Correlation of dinocyst succession against *buchia* zones is given in Davies (1983). In the brackets, general base range (for FADs) and top range (for LADs) of the species are given. Species, which do not appear below or above certain levels, are marked by bold type. The evaluation of stratigraphical range of dinocyst species is based on original author's material and publications cited in this paper and also in Powel A.J. (Ed.) (1992), Jansonius & McGregor (1996), Riding et al. (1998), Lebedeva & Nikitenko (1998, 1999), Pestchevitskaya (2007).

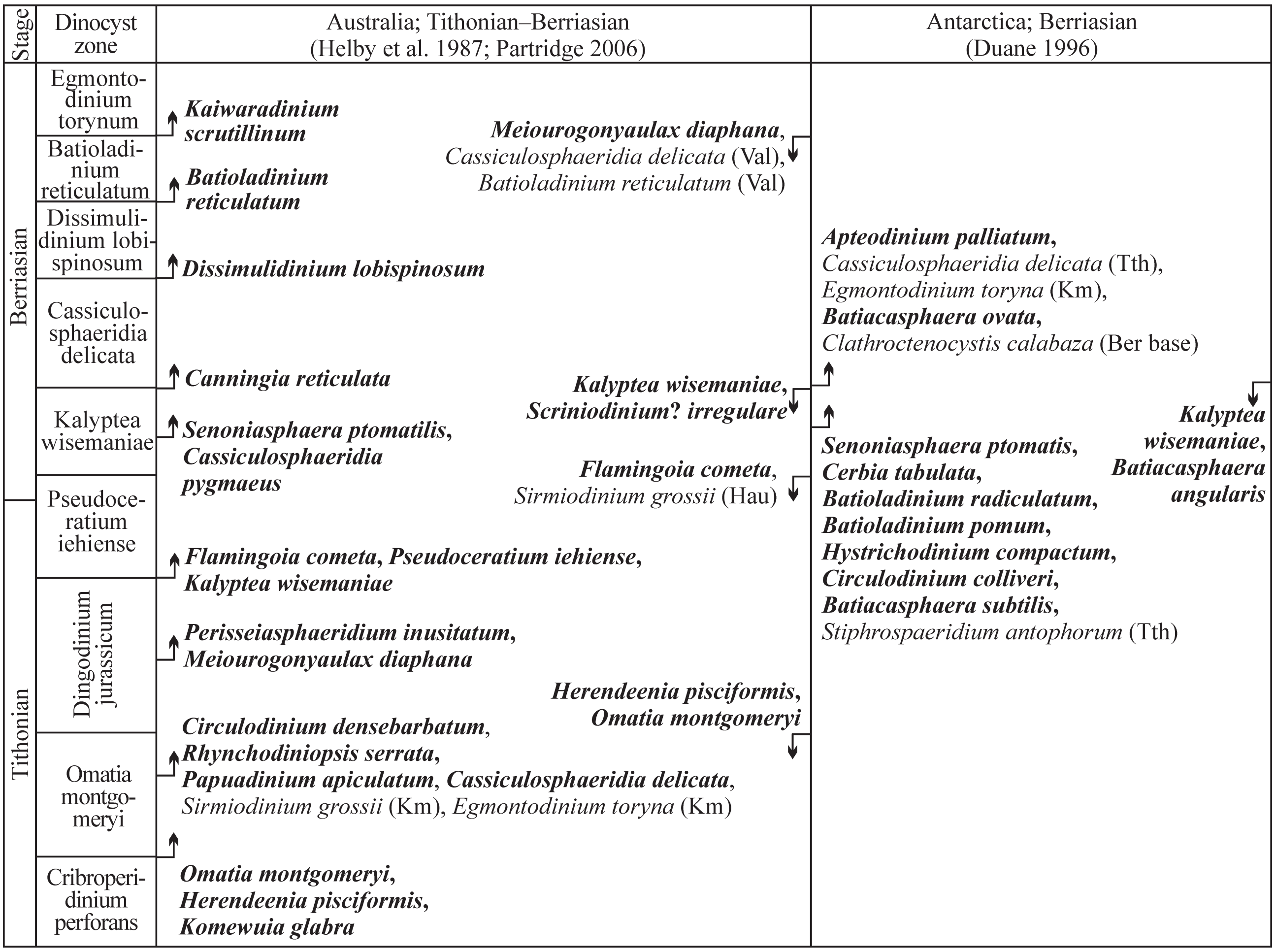

Fig. 6. Uppermost Jurassic and lowermost Cretaceous dinocyst events of Australia and Antarctica. In the brackets, general base range (for FADs) and top range (for LADs) of the species are given. Species, which do not appear below or above certain levels, are marked by bold type. The evaluation of stratigraphical range of dinocyst species is based on original author's material and publications cited in this paper and also in Powel A.J. (Ed.) (1992), Jansonius & McGregor (1996), Riding et al. (1998), Lebedeva & Nikitenko (1998, 1999) and Pestchevitskaya (2007).

of *Exiguisphaera phragma* Duxbury in Austria and Oka River region; FAD of *Stanfordella exanguia* (Duxbury) Helenes & Lucas-Clark in Austria, North Siberia and on the Russian Platform. These events appear to have stratigraphic shifts within 1–1.5 ammonite zones in different regions.

Discussion and conclusions

Our analysis of Upper Jurassic and Lower Cretaceous dinocyst successions of different regions of Russia, Europe, America and Australia demonstrates their essential regional peculiarities. The taxonomic composition of dinocyst assemblages allows the determination of regional zonations, and several regional levels of high taxonomic changes in dinocyst assemblages are defined. Nevertheless, a number of key species can provide interregional correlations (Fig. 8). In the middle of the Volgian and uppermost Berriasian, Russian dinocyst successions are mostly correlated against Boreal successions of Europe and America, while the levels of the uppermost Jurassic–lowermost Berriasian and the middle of the Berriasian also provide correlation against SE European, Australian, and Antarctic successions.

It should be noted that these key species cannot be recognized in all sections. They represent groups of correlative species for certain levels, which allow in general the possibility of step-by-step correlation of distant dinocyst successions. These levels are defined in the middle parts of the Volgian/Tithonian and Berriasian, near the J/K boundary, and in the uppermost Berriasian (Fig. 8). This correlation is controlled by similar evolutionary trends of the dinocyst floras. Upper Jurassic and Lower Cretaceous dinocyst assemblages comprise a number of species that arose in the lower horizons, but are gradually replaced by new species upward within the sections. The analysis of dinocyst renewal shows similar tendencies in the relations of ancient/new species in distant regions (Fig. 9). The quantity of Tithonian species considerably increases in the uppermost Jurassic in relation to lower strata. The characteristic feature of dinocyst assemblages of the lower and middle parts of the Berriasian is the presence of Cretaceous species, which become essentially richer in the Upper Berriasian. The renewal tendencies are less distinct in dinocyst assemblages from

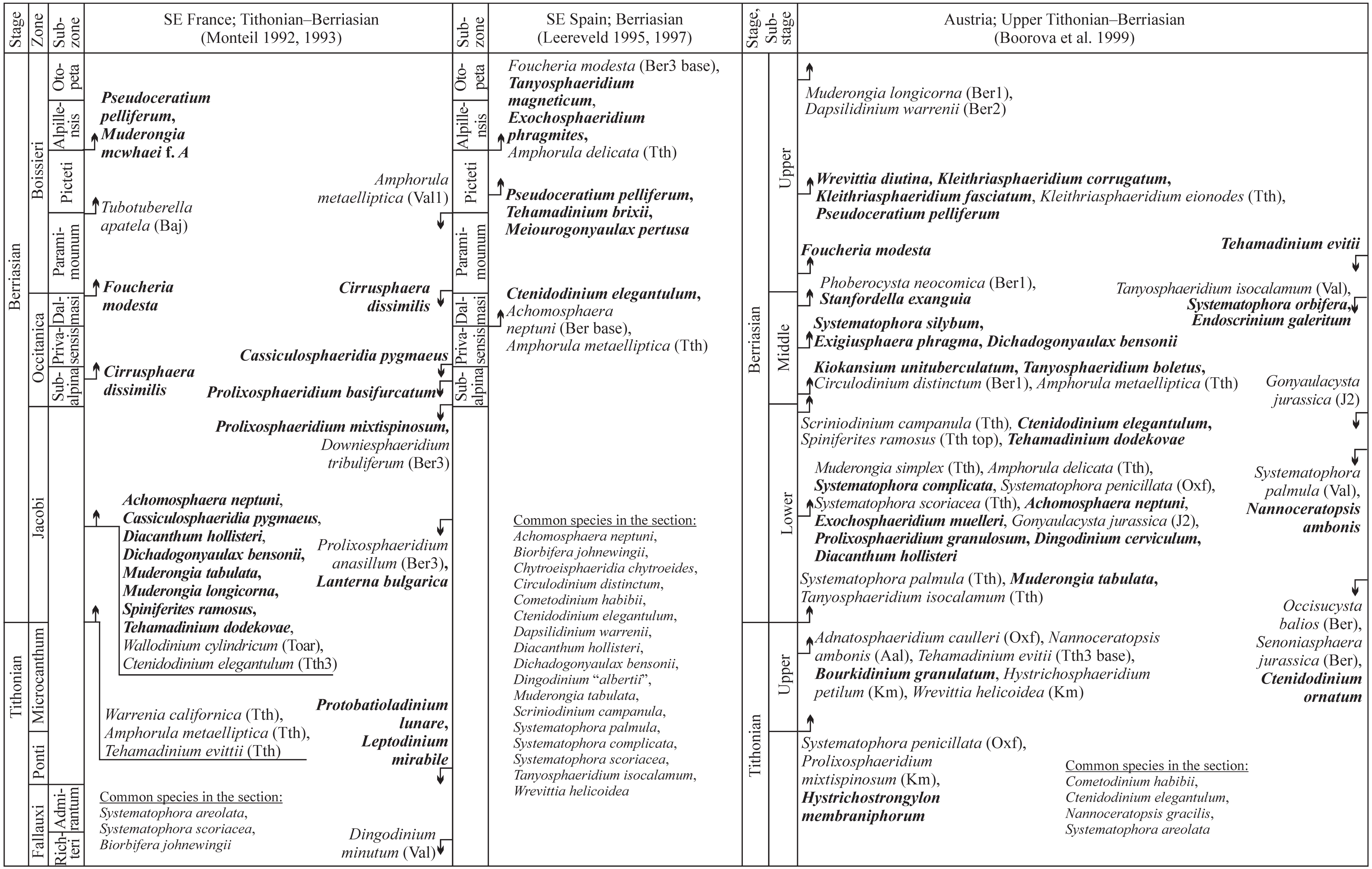

Fig. 7. Uppermost Jurassic and lowermost Cretaceous dinocyst events of Central and SW Europe. Correlations of dinocyst successions against ammonite zones are given in Monteil (1992, 1993) and Leereveld (1995, 1997). In the brackets, general base range (for FADs) and top range (for LADs) of the species are given. Species, which do not appear below or above certain levels, are marked by bold type. The evaluation of stratigraphical range of dinocyst species is based on original author's material and publications cited in this paper and also in Powel A.J. (Ed.) (1992), Jansonius & McGregor (1996), Riding et al. (1998), Lebedeva & Nikitenko (1998, 1999), Pestchevitskaya (2007).

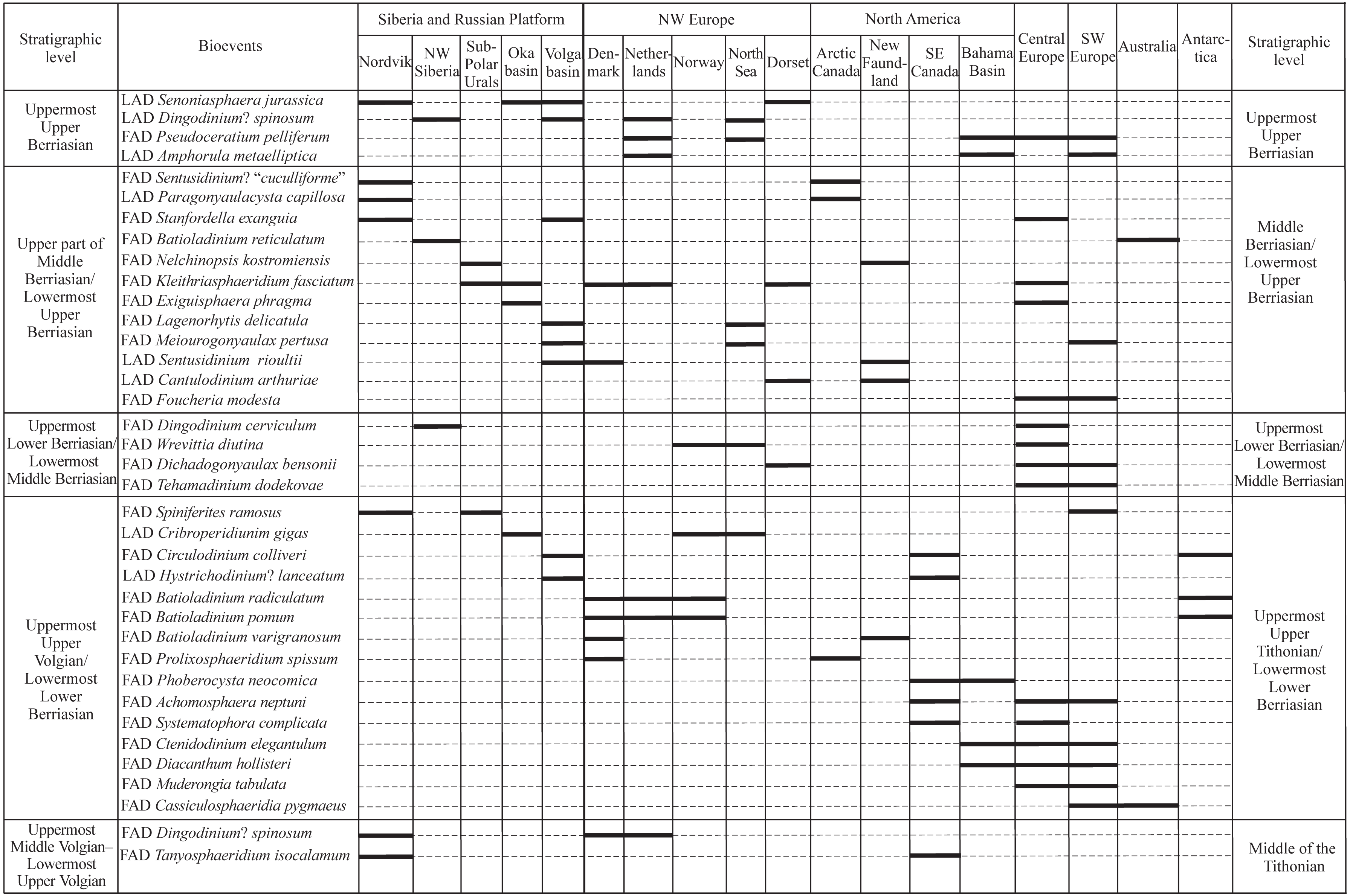

Fig. 8. Dinocyst events characterizing the defined correlative levels.

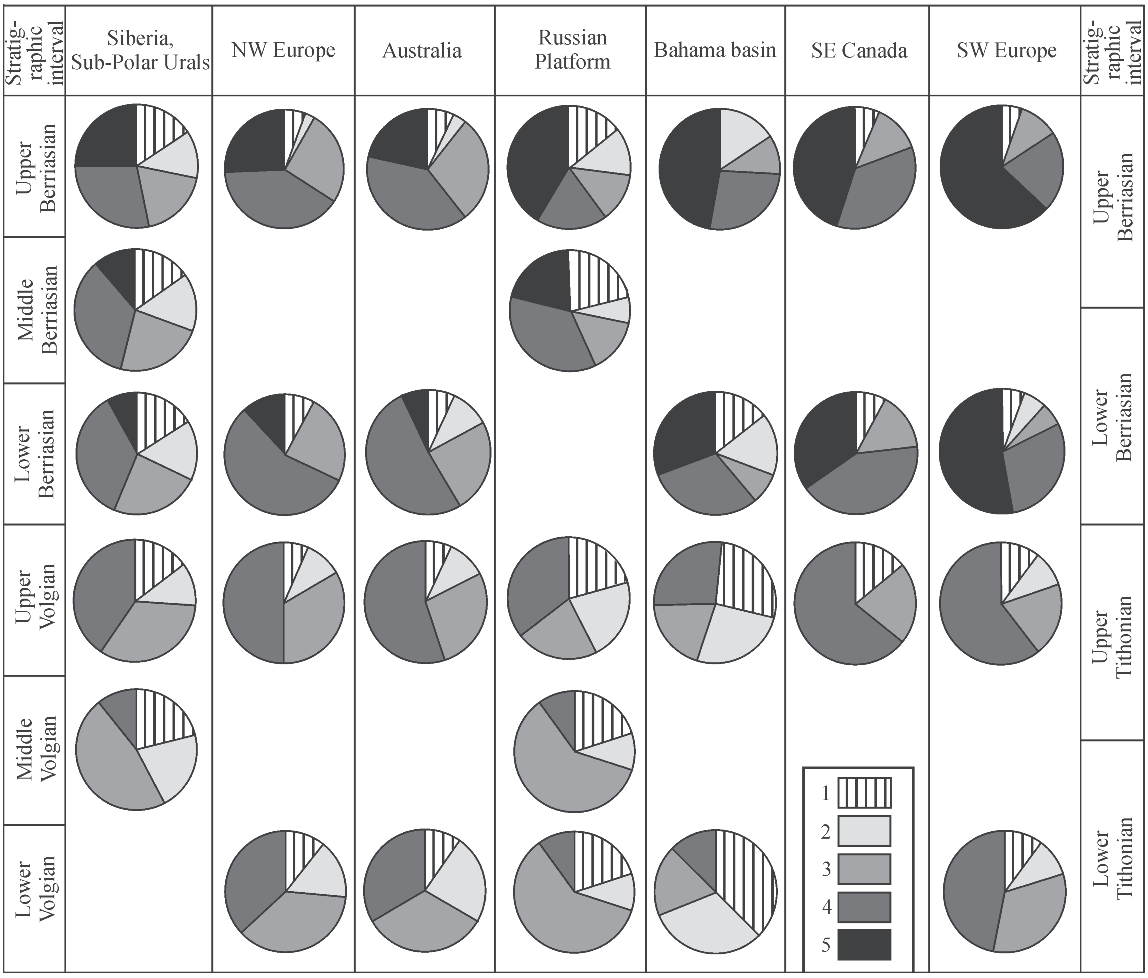

Fig. 9. Relations of ancient/new species in the uppermost Jurassic–lowermost Cretaceous in different regions. **1** — Lower and Middle Jurassic species, **2** — Oxfordian species, **3** — Kimmeridgian species, **4** — Tithonian species, **5** — Berriasian species.

Arctic and Boreal regions, a similar trend that has been demonstrated for other fossil groups, such as ammonites (Shulgina 1985) and foraminifers (Nikitenko 2009). Similar-aged dinocyst assemblages from Australia and Boreal regions of the Northern Hemisphere revealed close relations of ancient/new species possibly due to similar latitudinal positions and climatic conditions of these areas in the Upper Jurassic and the Lower Cretaceous.

Thus, the definition of correlative levels characterized by certain bioevents allows the comparison of dinocyst successions of Russia and distant regions of Europe, America, Australia and Antarctica, although dinocyst floras reveal rather high regional divergence. An important aspect is the analysis of the sequences of these levels as it provides reciprocal control of their stratigraphic positions. The correlation is proved by similar evolutionary tendencies in the development of dinocyst floras in different regions. The correlative levels range within 1–1.5 ammonite zones as the FADs/LADs of some key species may have minor stratigraphic shifts in different sections even in one region. It may be related to the migration processes or to a different understanding of the stratigraphic position of ammonite zones. Nevertheless, dinocysts show considerable potential for long distance correlations that are likely to be more accurate in the future, after more precise calibration of ammonite zones.

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