

<i>Bollettino della Società Paleontologica Italiana</i>	38 (2-3), 1999	ISSN 0375-7633	297-312	1 pl.	Modena, Dicembre 1999
---	----------------	----------------	---------	-------	-----------------------

Differentiation and spread of the Baltic Acritarch Province (Arenig-Llanvirn)

Marco TONGIORGI

Anna DI MILIA

Dipartimento di Scienze della Terra
Università di Pisa

KEY WORDS – *Acritarcha, Baltica Province, Mediterranean Province, Trophism, Eustasy, Ordovician, Arenig.*

ABSTRACT – *The taxonomic composition and the palaeogeographic and chronostratigraphic distribution of the Ordovician Mediterranean and Baltic acritarch provinces are compared and a more precise circumscription of the Baltic Province is proposed. Both southern Perigondwana and the East European Platform appear to be characterized by Mediterranean acritarch assemblages during the Billingen, while differentiation of the oldest elements of the Baltic Province commenced in South China at the base of the Volkhov. The Baltic taxa became dominant and diversified only from the uppermost Volkhov, seemingly at the same level in both Baltoscandia and South China. Starting from the same level, isolated elements of the Baltic Province also migrated into southern Perigondwana (Bohemia, Belgium, Spain, Tunisia). A possible South China origin of some Baltic taxa is suggested, even though a polycentric origin (South China and Baltoscandia) of the assemblages comprising the Baltic Province cannot be excluded. Changes in provincial affinity at middle to low latitude since the lower Volkhov are hypothesized as being controlled primarily by trophic level fluctuations, which in turn depended on sea level changes.*

RIASSUNTO – [Differenziazione e diffusione della Provincia Baltica ad acritarchi (Arenig-Llanvirn)] – *Vengono confrontate la composizione tassonomica, la distribuzione paleogeografica e la distribuzione cronostatigrafica delle province ordoviciane ad acritarchi Mediterraneo e Baltica e viene proposta una più precisa definizione della Provincia Baltica. Sia in Perigondwana meridionale che nella Cina del Sud e nella Piattaforma Est Europea, le associazioni del Billingen sono di tipo Mediterraneo, mentre solamente dalla base del Volkhov cominciano a comparire nella Cina meridionale i primi rappresentanti della Provincia Baltica. I taxa Baltici divengono però diversificati e dominanti solamente nel Volkhov terminale della Cina meridionale e della Baltoscandia, apparentemente allo stesso livello. A partire da questo livello, isolati elementi della Provincia Baltica penetrano anche in Perigondwana meridionale (Boemia, Belgio, Spagna, Tunisia). Una possibile origine in Cina meridionale di alcuni taxa Baltici viene qui suggerita, anche se un'origine policentrica (Cina meridionale e Piattaforma Est Europea) delle associazioni Baltiche non può essere esclusa. I cambiamenti nelle affinità provincialistiche alle latitudini medie e basse a partire dalla base del Volkhov vengono ipoteticamente messi in relazione alla variazione dei livelli trofici, che a loro volta si pensa prevalentemente controllati dalle variazioni eustatiche del livello marino.*

INTRODUCTION, OBJECTIVES, AND LITERATURE SOURCES

Based on relatively scant data, a provincialistic Early Palaeozoic differentiation of acritarchs, seemingly controlled by palaeotemperatures, was proposed by Vavrdová (1974) and Cramer & Díez (1974a, b). Subsequent authors supported this hypothesis with further data (see an exhaustive review in Playford *et al.*, 1995). Some two decades later, a more precise definition and dating of the currently accepted provinces is needed (Servais, 1995; Vavrdová, 1997).

This paper presents a short review and some new data on the composition, palaeogeographic distribution, and age of the Arenig-Llanvirn assemblages from Baltica and from the northern margin of Gondwana. Its main goal is to contribute to the knowledge of the taxonomic composition and chronological attribution of the acritarch assemblages which comprise Vavrdová's Baltic Province. Changes in provincialism during Arenig-Llanvirn times will also be discussed in relation to environmental factors.

SOURCES OF STRATIGRAPHIC TERMINOLOGY AND CORRELATIONS

Main bibliographic sources of chrono- and biostratigraphic terminology and correlations among British, Bohemian, Baltic, and South Chinese regional units are listed in the caption of Text-fig. 1.

In addition, the following papers provided essential biostratigraphic information: Fortey *et al.* (1991), for British chrono- and biostratigraphy; Tjernvik (1956), Jaanusson (1960), Bergström (1986), Nielsen (1995), Stouge *et al.* (1995), for Baltoscandian regional chronostratigraphy, and graptolite, trilobite, and conodont biostratigraphy; Zhang (1998), for conodont biostratigraphy of South China. Correlation of British standard to Baltoscandian units follows Grahn (1982), Nielsen (1992b), Fortey *et al.* (1995), and Bagnoli & Stouge (1997); correlation of central Bohemia to British standard units follows Paris & Mergl (1984), Kraft & Kraft (1995). Interregional correlations of South China are based on the reconstruction by Wang, X.f. *et al.* (1992).

Throughout the text, unless otherwise stated, the

reference conodont biozones are those established in Baltoscandia by Bagnoli & Stouge (1997).

LOWER ORDOVICIAN ACRITARCH PROVINCES

According to Servais (1995), only Vavrdová's "Baltic" and "Mediterranean" Ordovician provinces have been adequately defined, whereas "the introduction of further provinces is at present no more than a fertile field of speculation." In fact, only the Mediterranean Province has received a formal definition (Li, 1989).

THE MEDITERRANEAN PROVINCE

Definition – Li (1989) stated that *Arbusculidium* Deunff, 1968, *Coryphidium* Vavrdová, 1972, and *Striatotheca* Burmann, 1970 are the diagnostic genera of the Mediterranean Province. This definition has been widely accepted by subsequent authors.

Palaeogeographic distribution – The Mediterranean Province encompasses the northern Gondwana border, from western Argentina in the west, to South China in the east (Vavrdová, 1974; Cramer & Díez, 1974a; Martin, 1982; Li, 1989; Dean & Martin, 1992; Ottone *et al.*, 1992; Tongiorgi *et al.*, 1994). Thus, it includes Vavrdová's (1997) "*Coryphidium bohemicum* acritarch bioprovince", facing in the south the Tornquist Sea and the Iapetus Ocean.

Stratigraphic distribution – According to Li's (1989) definition, the Mediterranean Province is chronologically more restricted than originally envisaged by Vavrdová (1974). The latter considered it to correspond to the whole Ordovician, although she had noted (1974) that "in the Tremadoc geographical differences are not pronounced" and subsequently (Vavrdová, 1997) she observed that "increasingly uniform paleoenvironmental conditions" characterized the later Ordovician.

Based on the stratigraphic distribution of *Arbusculidium*, *Coryphidium*, and *Striatotheca*, the Mediterranean Province is indistinguishable *per se* prior to the upper Tremadoc, *H. copiosus* graptolite Zone, FAD of *Striatotheca* after Brocke *et al.* (1995). The other diagnostic Mediterranean taxa appear gradually: *Coryphidium* within the *T. phyllograptoides* Zone (Brocke *et al.*, 1995) or a little earlier (Cooper *et al.*, 1995); *Arbusculidium filamentosum* (Vavrdová, 1965) Vavrdová, 1972 within the *D. deflexus* Zone (Fang, 1986; Li, 1987, 1990).

Thus, the Mediterranean assemblages partially overlap stratigraphically with, and are transitional downwards to, the "*messaooudensis-trifidum* assemblage" of Servais & Molyneux (1997; see also Fortey *et al.* 1991; Cooper *et al.*, 1995), which extends from a probable *A. murray* graptolite Zone (uppermost Tremadoc) to a probable *T. phyllograptoides* graptolite

Zone (?lowermost Arenig). Because intermediate forms between *Vavrdovella* Loeblich & Tappan, 1976 (FAD within the *A. murray* Zone, according to Brocke *et al.*, 1995) and *Coryphidium* have been observed by Brocke (1997) in the upper Tremadoc–?lowermost Arenig of China, *Vavrdovella* could be included among the Mediterranean diagnostic taxa. In this case, the "*messaooudensis-trifidum* assemblage" would be entirely referable to the Mediterranean Province (= peri-Gondwana, *sensu* Servais & Molyneux, 1997, p. 121). This matter is beyond the aim of this paper, and is not dealt with further herein.

Li's (1989) Mediterranean Province extends stratigraphically upward to include at least part of the Llanvirn; it is reasonable to add *Frankea* Burmann, 1970 to Li's list of diagnostic taxa, thus including the entire middle Ordovician.

THE BALTIC PROVINCE

Definition – The Baltic Province has not been precisely defined. Vavrdová (1974) stated that it is characterized by the "prevalence of acanthomorphids." Actually, the Baltic Province is dominated by a few acanthomorphic genera; e.g., *Baltisphaeridium* Eisenack, 1958 *ex* Eisenack, 1959, *Liliosphaeridium* Uutela & Tynni, 1991, *Peteinosphaeridium* Staplin, Jansonius & Pocock, 1965, and *Polygonium* Vavrdová, 1966. Collectively, these account for about 80% of each assemblage from the Arenig-Llanvirn boundary interval of northern Öland, Sweden (Ribecai, 1996; Ribecai & Tongiorgi, 1995), with *Baltisphaeridium* and *Peteinosphaeridium* jointly comprising at least 60%.

Nevertheless, the acanthomorphid criterion is inadequate because acanthomorphic acritarchs are also abundant in most Arenig-Llanvirn assemblages from the Mediterranean Province. The absence of diacrodians (Vavrdová, 1974) can also no longer be regarded as diagnostic for the Baltic Province, because they also occur (albeit rarely) in Arenig-Llanvirn strata of the East European Platform and Baltoscandia (Uutela & Tynni, 1991; Ribecai & Tongiorgi, 1995).

The Baltic Province can be more precisely defined on the basis of some characteristic *Peteinosphaeridium* species (Playford *et al.*, 1995), such as *P. bergstroemii* Staplin, Jansonius & Pocock, 1965 and *P. velatum* Kjellström, 1971 (with large, mostly quadrilaminar, flaring processes); or *P. hymeniferum* (Eisenack, 1938) Fensome *et al.*, 1990 and *P. dissimile* Górka, 1969 (with unbranched, trilaminar, distally acuminate processes). It is still premature to include among the Baltic diagnostic taxa species belonging to *Baltisphaeridium* or *Polygonium*, because both genera and many of their specific components require complete revision.

At the genus level, *Liliosphaeridium* [typically represented by *L. kaljoi* Uutela & Tynni, 1991, *L. inter-*

medium (Eisenack, 1976) Playford, Ribecai & Tongiorgi, 1995; among others] can be considered as indicative of the Baltic Province. Tongiorgi *et al.* (1998a) added two informal groups to the diagnostically Baltic taxa: the “*Pachysphaeridium* group” and the “*macropylum* group”. The first encompasses species characterized by distally inflated processes with striate (fibrous) wall structure, and includes the type species of *Pachysphaeridium* Burmann, 1970 – *P. robustum* (Eisenack, 1963) Fensome *et al.*, 1990 – together with several other species (Ribecai & Tongiorgi, 1998) currently attributed to other genera [e.g., *Costatilobus bulbosus* Uutela and Tynni, 1991, *Goniosphaeridium balticum* (Eisenack, 1951) Eisenack, 1969, *G. christianii* Kjellström, 1976, and *G. connectum* Kjellström, 1971]. The second informal group includes *Peteinosphaeridium macropylum* (Eisenack, 1959) Eisenack, Cramer & Diez, 1973, together with other similar species, all featuring a “pseudopyloma” surrounded by a lobate, hollow excrescence; viz., “Auswuchs” of Eisenack (1976, p. 199). These last-mentioned species are here collectively termed “*Peteinosphaeridium macropylum* s.l.”.

Thus, for the time being, we propose to identify the Arenig-Llanvirn Baltic-type assemblages by their content of *Peteinosphaeridium bergstroemii*, *P. velatum*, *P. hymenoserum*, *Liliosphaeridium* spp., *Pachysphaeridium* spp., and “*Peteinosphaeridium macropylum* s.l.”.

Palaeogeographic distribution – These assemblages are distributed primarily in Baltica, including Norway (Ribecai, pers. comm.), Sweden (Kjellström, 1971a, 1971b, 1972, 1976; Ribecai & Tongiorgi, 1995), Estonia and Russia (Aristova, 1976, 1980a, 1980b; Uutela, 1989; Uutela & Tynni, 1991), and Poland (Górka, 1969, 1987). Baltic assemblages have also been recognized in South China (Tongiorgi *et al.*, 1998a).

Stratigraphic distribution – The Baltic Acritarch Province is known from upper Volkhov to lower Kunda strata (uppermost Arenig to lower Llanvirn) in the East European Platform, Baltoscandia, and South China (Uutela & Tynni, 1991; Ribecai & Tongiorgi, 1995; Tongiorgi *et al.*, 1998a). Some characteristic species, e.g., *Peteinosphaeridium bergstroemii*, however, extend (Playford *et al.*, 1995) up to the Lasnamägi regional Stage (upper Llanvirn).

OCCURRENCES OF THE BALTIC PROVINCE

BALTICA

East European Platform – Scant information exists on acritarch assemblages from the Baltic upper Hunneberg-lower Volkhov interval (Text-figs. 1, 2). Aristova (1980a) showed that the lower Volkhov of

the Moscow Syncline hosts poorly diversified acritarch assemblages including *Coryphidium bohemicum* Vavrdová 1972, *Cymatiogalea* Deunff, 1961, and *Stelliferidium* Deunff, Górka & Rauscher, 1974. In terms of British stratigraphic nomenclature, this means that the acritarch palynoflora of the latest early Arenig (= topmost *nitidus* and most of the *gibberulus* graptolite Zones) of the East European Platform still retains a Mediterranean affinity. By contrast, the rich acritarch assemblages of the upper Volkhov and the Kunda (= British *hirundo* and *artus* graptolite Zones, late Arenig-early Llanvirn) in the same region display typical Baltic features (Aristova, 1980a, b).

More complete information about the Arenig acritarch assemblages of the East European Platform is provided by Raevskaya (1998, and present issue; Text-fig. 2) who studied four sections in the St. Petersburg region. She courteously allowed us to examine three palynological slides from that region (with sample designations StP.1, StP.2, StP.3).

Sample StP.1, from Löfgren's (1978) comprehensive *Oepikodus evae* conodont Zone (corresponding to the entire Billingen; i.e., approximately to the *O. evae-Microzarkodina* sp. A. interval of the zonation adopted herein), yielded some early Arenig “South Chinese” species, e.g. *Baltisphaeridium denticulatum* Lu, 1987, *B. kummingense* Fang, 1986, *Peteinosphaeridium armatum* Tongiorgi, Yin & Di Milia, 1995, *P. robustiramosum* Tongiorgi, Yin & Di Milia, 1995, *P. tenuifilosum* Tongiorgi, Yin & Di Milia, 1995, *Pirea levigata* Tongiorgi, Yin & Di Milia, 1995, *Pirea* sp. aff. *P. baculifera* Tongiorgi, Yin & Di Milia, 1995, and *Veryhachium symmetricum* Lu, 1987. These species occur in South China from the *A. suecicus* graptolite Zone, together with the diagnostic Mediterranean taxa *Arbusculidium* (*A. filamentosum*), *Coryphidium*, and *Striatotheca* (Yin, 1995; Tongiorgi *et al.*, 1995).

Stratigraphically above sample StP.1, a different assemblage (StP.2) was provided by lower Volkhov deposits which are generally attributed to a stratigraphic interval defined by Löfgren's (1978) *Baltoniodus triangularis*-*B. navis* conodont Zones (= *B.?* *triangularis*-lower-middle *B. navis* of the zonation adopted herein). This interval equates to the topmost *nitidus* and to almost the entire *gibberulus* graptolite Zones of the British standard (Text-fig. 1). It is dominated by *Baltisphaeridium* and includes very abundant *Papilliferum striatum* (Lu, 1987) Yin, 1994, and *P. rhabdocladium* (Lu, 1987) Yin, 1994; both species were previously known only from the lower Arenig of South China (Yin, 1994, 1995; Tongiorgi *et al.*, 1995).

The StP.2 assemblage apparently displays an intermediate Mediterranean-Baltic provincial affinity (manifested by the dominance of *Baltisphaeridium*) but neither indubitably Mediterranean nor Baltic diagnostic taxa occur. However, its age falls within

the same stratigraphic interval whence Aristova (1980a) observed *Coryphidium bohemicum* (Text-fig. 2).

In contrast, the assemblages from the upper Volkhov (latest Arenig, *Microzarkodina parva* conodont Zone of Löfgren, 1978; equivalent to the *B. norrlandicus*-*L. antivariabilis* Zones) of the St. Petersburg area (sample StP.3) are composed entirely of Baltic taxa, including *Liliosphaeridium kaljoi*, *Peteinosphaeridium hymeniferum*, *P. eximium* Playford, Ribecai & Tongiorgi, 1995, "*Peteinosphaeridium macropylum* s.l.", and numerous forms of *Pachysphaeridium* (Text-fig. 2).

Baltoscandia – In northern Öland, Sweden (Stouge *et al.*, 1995), strata below the upper Volkhov are oxidized and non-palyniferous. As documented by Ribecai & Tongiorgi (1995) and Stouge *et al.* (1995), rich Baltic assemblages occur in strata attributed to the upper *B. norrlandicus* to *L. variabilis* Zones, i.e., in the upper Volkhov-lower Kunda interval, equivalent to the British upper *hirundo*-lower *artus* graptolite Zones, latest Arenig to earliest Llanvirn (Text-figs. 1, 2).

Ampullula suetica Righi, 1991, *Baltisphaeridium annelicae* Kjellström, 1976, *B. calicispinae* Górka, 1969, *B. hirsutoides* (Eisenack, 1951) Eisenack, 1959, *B. ingerae* Kjellström, 1976, *B. longispinosum heterospinosum* Eiserhardt, 1989, *B. longispinosum longispinosum* (Eisenack, 1931) Eisenack, 1959, *B. multipilosum* (Eisenack, 1931) Eisenack, 1959, *Dasydorus cirritus* Playford & Martin, 1984, *Liliosphaeridium kaljoi*, *L. intermedium* (Eisenack, 1976) Playford, Ribecai & Tongiorgi, 1995, *Michrhystridium* spp., *Multiplicisphaeridium* spp., *Pachysphaeridium* spp., *Polygonium dentatum* (Timofeev, 1959 *ex* Konzalová-Mazanková, 1969) Albani, 1989, *P. pellicidum* (Timofeev, 1959 *ex* Tynni, 1975) Ribecai & Tongiorgi, 1995, and *P. tenuispinosum* (Uutela & Tynni, 1991) Ribecai & Tongiorgi, 1995 are present throughout the entire stratigraphic interval. Different species of the "*macropylum* group" occur in the same interval, while *Liliosphaeridium hypertrophicum* (Eisenack, 1976) Playford, Ribecai & Tongiorgi, 1995 and *Cyclospira auriculatum* Uutela & Tynni, 1991 characterize its middle-upper part. In contrast, most species of *Peteinosphaeridium*, such as *P. bergstroemii*, *P. eximium*, *P. hymeniferum*, *P. velatum*, and "*P.*" *hystrichoreticulatum* (Eisenack, 1938) Eisenack, Cramer & Díez, 1973, are confined to the lower and middle part of the palyniferous interval.

It is noteworthy that rare representatives of the Mediterranean Province, such as *Acanthodiacrodium* Timofeev, 1958; *Barakella* Cramer & Díez, 1977, *Pirea* Vavrdová, 1972, *Stelliferidium*, and small representatives of *Veryhachium* Deunff, 1954, do occur, albeit sporadically, as in coeval Estonian strata (Uutela & Tynni, 1991).

SOUTH CHINA

In South China, the Arenig Dawan Formation of the Daping Section (Yangtze Platform, Hubei Province; as detailed by Lindström *et al.*, 1991) has been studied by the present authors together with L.m. Yin and S. Stouge (Tongiorgi *et al.*, 1995, 1998a, b). Close-spaced sampling of the entire formation, from the *D. deflexus* to the *U. austrodentatus* graptolite Zone, provided more than 40 palyniferous samples, all dated independently from associated conodont faunas (Text-figs. 1, 2).

Typical Mediterranean components were found in the lower part of the Dawan Formation (Yushanian Series, Dawan Stage), from the middle *deflexus* graptolite Zone upwards. The richest assemblages, which comprise *Arbusculidium*, *Coryphidium* and *Striatotheca*, among many other Mediterranean taxa, occur below the top of the Chinese *Oepikodus evae* conodont Zone (Wang, Z.-h. *et al.*, 1996; Wang, X.f. *et al.*, 1996); i.e., from levels correlative with the *A. suecicus* graptolite Zone (Chen *et al.*, 1997) and with the British upper *nitidus* Zone. In Baltoscandian chronostratigraphic terms, these assemblages come from the upper Billingen.

Elements of Baltic affinity, represented by *Peteinosphaeridium dissimile* locally occur in the same section within impoverished Mediterranean-type assemblages (Tongiorgi *et al.*, 1998a) and starting from the *B. triangularis* conodont Zone of Wang, X.f. *et al.* (1996), only slightly above the first appearance of the index species. This level probably corresponds to the uppermost *A. suecicus* graptolite Zone of Chen *et al.* (1997) and correlates with the equivalent Baltic zone and the lowermost Volkhov (uppermost *nitidus*-lowermost *gibberulus* graptolite Zones of the British standard).

The middle part of the Dawan Formation (tentatively referred to the *Isograptus caduceus imitatus*-*Exigraptus clavus* graptolite interval) contains oligotaxic to almost monotypic assemblages (*Cymatogalea*, locally associated with subordinate *Baltisphaeridium*). In the upper *Paroistodus originalis* conodont Zone (Wang, X.f. *et al.*, 1996), representatives of the "*macropylum* group" (Pl. 1, fig. 13) also occur (Tongiorgi *et al.*, 1998a) and a relative peak in diversity (also featuring *Coryphidium* and *Striatotheca*) is recognizable within the same stratigraphic interval. The latter is possibly correlative with the upper portion of the *Isograptus caduceus imitatus* graptolite Zone of Chen *et al.* (1997), roughly corresponding to the Baltic upper *B. navis* Zone.

In the upper part of the Dawan Formation (Zhejiangian Series, Guniu Stage, *Undulograptus austrodentatus* graptolite Zone), approximately equivalent to the Baltic upper *B. norrlandicus*-lowermost *L. antivariabilis* interval, the Baltic component increases both quantitatively and qualitatively. An initial "Baltic" peak is evident in the lower part of the *U.*

BRITISH STANDARD (1)				BOHEMIA (2)		BALTO-SCANDIA (3, 4, 5, 6)				SOUTH CHINA (7, 8, 9)			
SYSTEM, SUBSYST., SERIES - GRAPTOL. ZONES		GRAPT. ZONES, SUBZ.		VIRU		OELAND		ZHEJIANGIAN		YUSHANIAN		SERIES, STAGES - GRAPTOLITE ZONES, CONODONT ZONES	
CARAD.	MIDDLE	LLANVIRN	?			Kukruse	N. gracilis	A. tvaerensis	Xiaoxita	N. gracilis	P. anserinus		
						Uhaku	G. teretiusculus	P. anserinus		G. teretiusculus			P. anserinus
						Lasnamägi	D. murchisoni	P. serra					P. serra
						Aseri		E. suecicus		?			
							D. artus						E. suecicus
						Kunda		L. variabilis			A. ellesae		
								Lenodus sp. A					
								L. antivaribilis					A. variabilis
								B. norlandicus					M. parva
								M. parva					
								B. navis					P. originals
								M. flabellum					B. navis
								B. ? triangularis					B. triangularis
								Microzarkodina sp. A					
								T. diprion					

Text-fig. 1 - Lower Ordovician, chronostratigraphic and biostratigraphic correlations. Main bibliographic sources: a) Great Britain: 1) Fortey *et al.*, 1995; b) Bohemia: 2) Kraft & Kraft, 1995; c) Baltoscandia: 3) Tjervik & Johansson, 1980, 4) Cooper & Lindholm, 1991, 5) Bagnoli & Stouge, 1997, 6) Bergström, 1986; d) South China: 7) Wang, X.f. *et al.*, 1992, 8) Chen *et al.*, 1997, 9) Wang, X.f. *et al.*, 1996.

austrudentatus Zone; the base of the latter zone corresponds to the base of the Global Stratotype Section and Point (GSSP) of the Darriwillian (Chen *et al.*, 1997). This interval provided the first specimens of *Liliosphaeridium* (Pl. 1, fig. 1). A single succeeding sample yielded an almost monotypic (*Cymatiogalea*) assemblage.

Near the top of the Dawan Formation, Baltic acritarch taxa recur and almost exclusively dominate the acritarch assemblages of an interval corresponding to the Baltic *L. antivariabilis* conodont Zone. The richest assemblage from this interval includes the following: *Liliosphaeridium kaljoi* (Tongiorgi *et al.*, 1998a, pl. 2, fig. 1); some species of the "*Pachysphaeridium* group" (Tongiorgi *et al.*, 1998a, pl. 1, figs. 1-4; pl. 2, fig. 2; Pl. 1, fig. 6 herein); *Peteinosphaeridium dissimile* (Tongiorgi *et al.*, 1998a, pl. 2, figs. 3-5; pl. 3, fig. 1; Pl. 1, fig. 11 herein); *P. velatum* (Tongiorgi *et al.*, 1998a, pl. 3, fig. 2); *Peteinosphaeridium? hystrioreticulatum* (Tongiorgi *et al.*, 1998a, pl. 3, figs. 5, 6; Pl. 1, fig. 14 herein); and "*Peteinosphaeridium macropylum* s.l." (Tongiorgi *et al.*, 1998a, pl. 3, figs. 3, 4a, b; Pl. 1, fig. 9 herein). A minor Mediterranean-like component, mostly *Cymatiogalea*, is also present. This assemblage has also been observed just below the inferred Volkhov-Kunda boundary (Zhang, 1998); therefore, it may correlate with the Baltic *L. antivariabilis* conodont Zone, and with the British upper *hirundo* graptolite Zone (latest Arenig).

BALTIC TAXA IN SOUTHERN PERIGONDWANA

Acritarch assemblages are rarely recorded from authentically or precisely dated upper Arenig of the high latitude Perigondwana regions; i.e., from strata that accumulated while the Baltic Province was developing at middle to low latitudes (Baltica and

South China). More data are available on the presence of Baltic taxa in the Llanvirn of southern Perigondwana.

ARENIG OCCURRENCES

Bohemia – In 1996, the present authors and M. Vavrdová collected two closely spaced slaty samples (Kl.1 and Kl.2) from the Klabava Formation, locality U starého hradu, southeast of Klabava near Rokycany, Central Bohemia (loc. E, Vavrdová, 1993).

According to Vavrdová (1993, and pers. comm.; see also Martin, 1982, p. 35), these samples should be assigned to the *Tetraraptus* cf. *pseudobigsbyi* graptolite Zone of Kraft (1977), corresponding to the *T. reclinatus abbreviatus* Zone of Bouček (1973). This zone has recently been subdivided (Text-fig. 1) by Kraft & Kraft (1995) into three subzones (*Azyograptus suecicus-Acrograptus crassus*; *T. reclinatus abbreviatus-A. suecicus*; *T. reclinatus abbreviatus-Acr. cf. infrequens*). Only the two younger subzones include the zonal index species. In accord with Paris & Mergl (1984) and Kraft & Kraft (1995), the *T. reclinatus abbreviatus* Zone embraces the British *gibberulus* and almost the entire *hirundo* graptolite Zone; it corresponds approximately to the entire Baltic Volkhov.

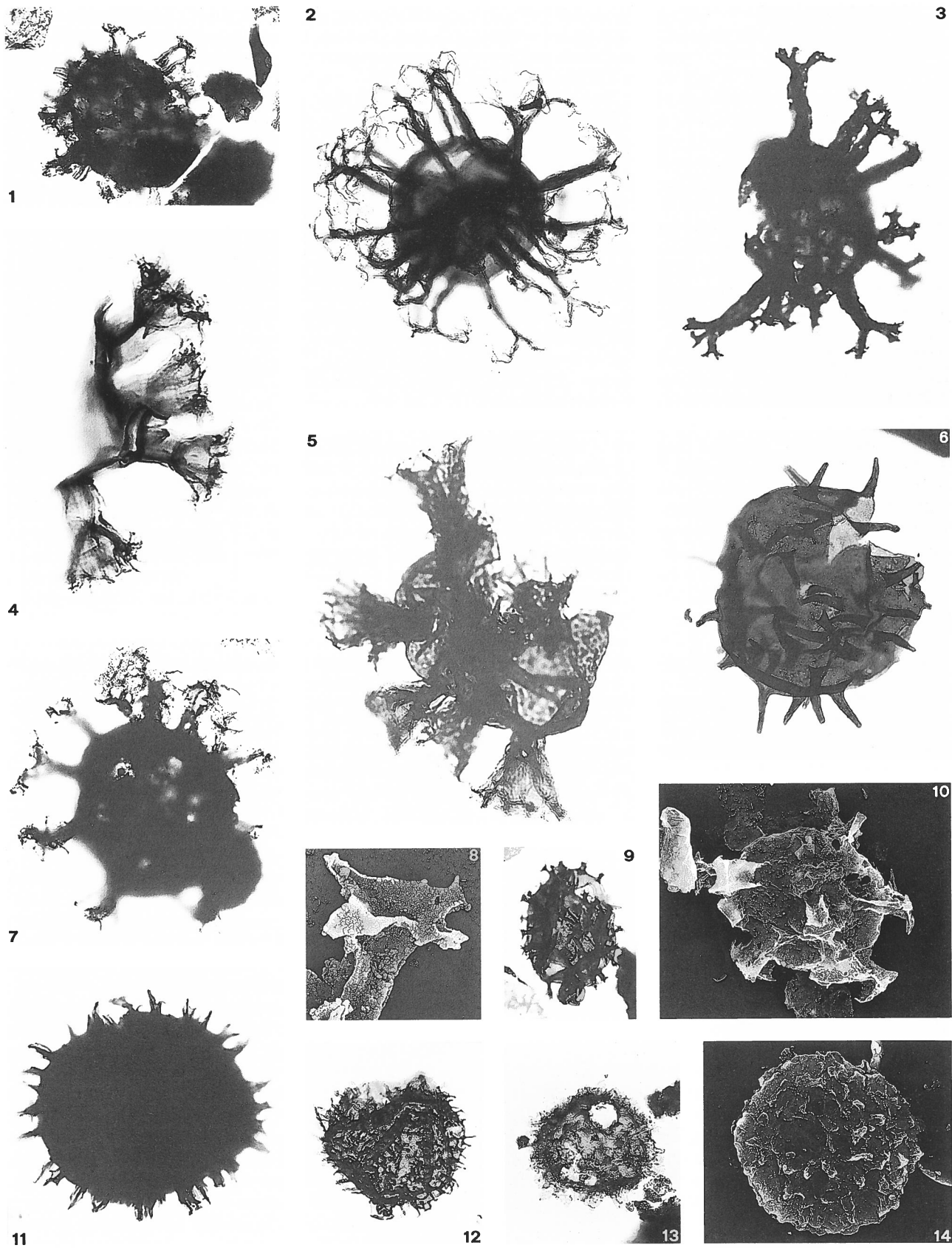
Vavrdová (1993, p. 130, tab. 1) assigned loc. E to the lower part of her acritarch Complex 3 which correlates with the *T. reclinatus abbreviatus* Zone. Accordingly, samples Kl.1 and Kl.2 should be referred to the *A. suecicus-Acr. crassus* Subzone, corresponding to the British lower *gibberulus* Zone. However, no direct palaeontological evidence supports this attribution (Text-fig. 2).

Re-examination of the samples discussed above permits recognition of numerous representatives of the Mediterranean Province; viz., *Acanthodiacrodium*

EXPLANATION OF PLATE 1

- Fig. 1 - *Liliosphaeridium intermedium* (Eisenack, 1976) emend. Playford *et al.*, 1995. CPT701071-01; slide DA46bis/tot1, EF: G45; Daping, South China.
- Figs. 2, 3 - *Liliosphaeridium hypertrophicum* (Eisenack, 1976) emend. Playford *et al.*, 1995: 2) CPT202031-04; slide Tt1car40-1504m/>50.2, EF: U49; Tunisia. 3) CPT109004-6; slide SRB732305/tot1, EF: B4-Z35/4, Sart-Bernard, Belgium.
- Figs. 4 - 5 - *Liliosphaeridium kaljoi* Uutela & Tynni, 1991 emend. Playford *et al.*, 1995: 4) CPT 202031-01; slide Tt1car40-1504m/>10.1, EF: O48/4-O49/3; Tunisia. 5) CPT202031-02; slide Tt1car40-1504m/>50.1, EF: K30/1; Tunisia.
- Fig. 6 - *Pachysphaeridium* sp.: CPT701053-05; slide DA50>50.5, EF: G40; Daping, South China. x1000.
- Figs. 7, 8 - *Peteinosphaeridium bergstroemii* Staplin, Jansonius & Pocock, 1965 emend. Playford *et al.*, 1995: 7) CPT105110-01; slide Atsu1a/>10.1, EF: Q21; Sueve, Spain. 8) CPT105110-06; slide Atsu1a/Sem5; Sueve, Spain. Detail of a process; x4000.
- Figs. 9, 12, 13 - "*Peteinosphaeridium*" *macropylum* s.l. (*sensu* Tongiorgi *et al.*, 1998a): 9) CPT701077-01; slide DA50.1/tot.1, EF: D32/2-D33/1; Daping, South China. 12) CPT202031-04; slide Tt1car40-1504m/>50.2, EF: T49; Tunisia. 13) CPT701071-01; slide DA46bis/tot.1, EF: V47/3-Z48/1; Daping, South China.
- Fig. 10 - *Peteinosphaeridium velatum* Kjellström, 1971 emend. Playford *et al.*, 1995: CPT105110-04; slide Atsu1a/Sem3; Sueve, Spain.
- Fig. 11 - *Peteinosphaeridium dissimile* Górka, 1969: CPT701053-01; slide DA50/>50.1, EF: R32/3; Daping, South China.
- Fig. 14 - *Peteinosphaeridium? hystrioreticulatum* (Eisenack, 1938) Eisenack *et al.*, 1995: CPT701053-26; slide DA50/Sem16; Daping, South China.

All figures x1000, except where otherwise stated.



BRITISH STANDARD SYSTEM, SUBSYST., SERIES - GRAPTOL. ZONES				BALTOSCANDIAN SUBSYST., SERIES, SUBS.	EAST EUROPEAN PLATFORM, SOUTH CHINA, SOUTHERN PERIGONDWANA STRATIGRAPHIC DISTRIBUTION OF THE MEDITERRANEAN AND THE BALTIC ASSEMBLAGES		
ORDOVICIAN	MIDDLE	CARAD.	<i>N. gracilis</i>	VIRU	Kukruse	East European Platform	
			<i>G. teretiusculus</i>		Uhaku		
		LLANVIRN	<i>D. murchisoni</i>		Lasnamägi		
			<i>D. artus</i>		Aseri		
	LOWER	ARENIG	<i>D. hirundo</i>	OELAND	Kunda	South China, Yangtze Platform	
			<i>I. gibberulus</i>		Volkhov		
			<i>D. extensus</i>				
			<i>D. nitidus</i>				
			<i>D. deflexus</i>				
			<i>T. phyllograptoides</i> (<i>T. approximatus</i>)		Billingen		
		TREMADOC			Latorp		
			<i>A. tenellus</i>		Hunneberg		
					Varangu		
			<i>R. flabelliformis</i> s.l.		Pakerort		

Text-fig. 2 - Stratigraphic distribution of Mediterranean and Baltic assemblages from the lower Ordovician of the East European Platform, South China, and Southern Perigondwana. Bibliographic sources: 1) Aristova, 1980a; 2) Aristova, 1980b; 3) Uutela & Tynni, 1991; 4) Ribecai & Tongiorgi, 1995; 5) Raevskaya, pers. comm. 6) present paper; 7) Raevskaya, this volume; 8) Paalits in Servais & Molyneux, 1997; 9) Yin, 1995; 10) Tongiorgi *et al.*, 1995; 11) Yin *et al.*, 1998; 12) Tongiorgi *et al.*, 1998a; 13) Brocke, 1997; 14) Vavrdová, 1993; Fatka, 1992. See Text-fig. 1 for chronostratigraphic and biostratigraphic correlations.

spp., *Arbusculidium filamentosum*, *Baltisphaeridium klabavense* (Vavrdová, 1965) Kjellström, 1971, *Coryphidium bohemicum*, *Cymatiogalea granulata* Vavrdová, 1966, *Lusatia dendroidea* Burmann, 1970, *Marrocanium simplex* Cramer, Kanes, Díez & Christopher, 1974, *Picostella perforata* Cramer, Allam, Kanes & Díez, 1974, *Pireia columbifera* Vavrdová, 1990, *Stelliferidium stelligerum* (Górka, 1967) Deunff, Górka & Rauscher, 1974, *Stephanodiacrodium stephanum* (Vavrdová, 1976) Vavrdová, 1986, *Striatotheca microrugulata* (Vavrdová, 1972) Martin, 1977, *S. principalis parva* (Burmann, 1970) Martin, 1977, *S. rarirrugulata* (Cramer, Kanes, Díez & Christopher, 1974) Eisenack, Cramer & Díez, 1976, *Vavrdovella areniga* (Vavrdová, 1973) Loeblich & Tappan, 1976, and *Tongzia meitana* Li, 1987, among many others.

In addition, very rare and badly preserved specimens, possibly referable to *Liliosphaeridium* sp. cf. *L.*

kaljoi and *Peteinosphaeridium bergstroemii*, were also encountered (sample Kl.2).

LLANVIRN OCCURRENCES

Belgium – A slate sample (SrB-72.305) was collected by the present authors and F. Martin precisely at the designated type locality of *Frankea sartbernardensis* (Martin, 1966) Colbath, 1986; i.e., at the 72.305-km datum on the railway line near the station of Sart-Bernard, Brabant Massif, Belgium (Martin, 1966, 1969, fig. 20). According to Martin (pers. comm., 1985) the sampled horizon belongs to the Huy Formation (Assise de Huy). Servais & Maletz (1992) demonstrated an early Llanvirn age (*Didymograptus artus* graptolite Zone) for this unit.

Sample SrB-72.305 yielded an acritarch assemblage which is dominated by veryhachiids, including *V. lairdii* Deflandre, 1946 ex Deunff, 1959 and *V.*

reductum (Deunff, 1959) Downie & Sarjeant, 1965, and also contains *Acanthodiacrodium* sp. (very rare), *Arkonion* spp., *Baltisphaeridium* spp. (uncommon), *Frankea sartbernardensis*, *Leiofusa* spp., *Micrhystridium* spp., *Multiplicisphaeridium* spp., *Petaloferridium florigerum* (Vavrdová, 1977) Fensome *et al.*, 1990, *Polygonium* spp., *Pirea ornata* (Burmman, 1970) Eisenack, Cramer & Díez, 1976, *Pirea* spp., *Stellechinatum uncinatum* (Downie, 1958) Molyneux, 1987, *Striatotheca principalis parva*, *S. microrugulata*, *Vogtlandia* sp. cf. *V. multiradialis* Burmann, 1970.

Within this Mediterranean-dominated assemblage (Text-fig. 2), a minor Baltic component is evidenced by rare specimens of *Liliosphaeridium hypertrophicum* (Pl. 1, fig. 3), and "*Peteinosphaeridium macropylum* s.l."

Spain – Two slate samples, labelled S2-9 and AT/SU1a, were collected respectively by J.C. Gutierrez-Marco (Madrid) and C. Aramburu (Oviedo), and by R. Albani and M. Tongiorgi, in close stratigraphic proximity, near the top of the Cerracin Member of the Sueve Formation in the Cofiño Section, Sierra del Sueve, Cantabrian Mountains, northern Spain. These samples have been studied by Albani (*in* Gutierrez-Marco *et al.*, 1996) and the present authors.

Both samples yielded *Didymograptus* (*Didymograptus*) *murchisoni* (Beck *in* Murchison, 1839) and *Linochitina pissotensis* Paris, 1981 and are hence attributed to the late Oretanian (Mediterranean terminology; see Gutierrez-Marco *et al.*, 1996), which equates (Text-fig. 2) to the British upper Abereiddian, or upper lower Llanvirn (Gutierrez-Marco *et al.*, 1996).

The rich Mediterranean-type assemblage of sample S2-9, already recorded by Albani (*in* Gutierrez-Marco *et al.*, 1996), includes such forms as *Acanthodiacrodium costatum* Burmann, 1968, *Baltisphaeridium klabavense*, *Frankea longiuscula* Burmann, 1970, *Frankea sartbernardensis*, *Orthosphaeridium ternatum* (Burmman, 1970) Eisenack, Cramer & Díez, 1976, *Stellechinatum uncinatum*, *Striatotheca principalis* Burmann, 1970, *S. quieta* (Martin, 1969) Rauscher, 1974, *Stelliferidium cortinulum* (Deunff, 1961) Deunff, Górka & Rauscher, 1974, *S. philippotii* (Henry, 1966) Deunff, Górka & Rauscher, 1974, *Veryhachium reductum*, *V. trisulcum* Deunff, 1951 *ex* Deunff, 1959, and *V. valiente* Cramer, 1964. Further species observed by the present authors in sample AT/SU1a include *Arkonion* sp., *Dicrodiacrodium normale* Burmann, 1968, *Ferromia pellita* (Martin, 1977) Martin, 1996, *Petaloferridium florigerum*, *Pirea ornata*, *P. capitata* (Burmman, 1970) Eisenack, Cramer & Díez, 1976, and others.

In addition to these Mediterranean provincial representatives, samples S2-9 and AT/SU1a yielded some Baltic dispersed elements: rare specimens of *Peteinosphaeridium bergstroemii* (Pl. 1, figs. 7, 8) and *P. velatum* (Pl. 1, fig. 10).

Tunisia – Several shaly samples have been kindly provided to the authors by D. Massa (Paris) from the borehole Tt-1 (lat. 32° 18' 23" N, long. 10° 59' 40" E), drilled within the Rhadames Basin, Tunisia, between the Djeffara and Sidi Toui uplifts. The well is located to the east of the town of Ramadah, close to the Libyan border; samples studied herein have been cut at 1485.00 m (core 39), 1494.30 m (core 39), 1504.00 m (core 40), and 1511.80 m (core 40).

All these samples belong to the Bir ben Tartar Formation, which has been dated as "Llanvirn-Llandeilo" by Deunff & Massa (1975) and by Massa *et al.* (1977), on the basis of graptolites "indicating Zone 6 of the British scale (*Didymograptus murchisoni*)": Massa *et al.* (1977, p. 8; graptolite identification by Spjeldnaes & Jaeger, *in* Massa *et al.*, 1977). However, no co-occurring megafossils were found in the interval 1485.00-1511.80 m.

Immediately below this interval (core 41) undoubted Tremadoc acritarch assemblages were recovered by the authors, including *Acanthodiacrodium angustum* (Downie, 1958) Combaz, 1967, *Cymatogalea cuvillieri* (Deunff, 1961) Deunff, 1964, *Saharidia fragilis* (Downie, 1958) Combaz, 1967, *Stelliferidium furcatum* (Deunff, 1961) Deunff, Górka & Rauscher, 1974, and *Vulcanisphaera africana* Deunff, 1961). Therefore, the thin Kasbah Leguine Formation, supposedly of Arenig age (Massa *et al.*, 1977), is missing (or not sampled) here and the Bir ben Tartar Formation apparently lies directly on the Tremadoc Sanhar Formation (the same opinion is expressed by Vecoli *in* Vecoli *et al.*, this issue).

Samples from cores 40 and 39 (Bir ben Tartar Formation) yielded assemblages of Mediterranean affinity (Text-fig. 2), composed of such forms as *Arkonion* sp. cf. *A. tenuata* Burmann, 1970, *Coryphidium bohemicum*, *Dicrodiacrodium ancoriforme* Burmann, 1968, *Frankea breviuscula* Burmann, 1970, *F. sartbernardensis*, *Orthosphaeridium ternatum*, *Striatotheca rarirugulata*, *Marrocanium simplex*, and *Vogtlandia* spp. These species (together with the paly-nofloral constituents of the overlying samples) seem to indicate (Vecoli, pers. comm.) an age slightly older (early Llanvirn) than that hypothesized by Massa *et al.* (1977).

Subordinate elements of Baltic provincial affinity, notably *Liliosphaeridium hypertrophicum* (Pl. 1, fig. 2), *L.* sp. cf. *L. intermedium*, *L. kaljoi* (Pl. 1, figs. 4, 5), and "*Peteinosphaeridium macropylum* s.l." (Pl. 1, fig. 12), occur within the same assemblages as the dominant Mediterranean elements. In addition to these species, at least one other species of *Liliosphaeridium*, perhaps referable to *L. pennatum* (Deunff, 1977) Playford, Ribecai & Tongiorgi, 1995, has been observed; it resembles some variants of *L. kaljoi* from Öland (Sweden), but seems to differ in having smaller and more numerous processes.

APPEARANCE AND SPREAD OF THE BALTIC PROVINCE

As shown in previous sections, indisputable Baltic provincial assemblages are unknown before the late Arenig. Now, the questions are "when" they appeared initially, "where" they originated, and "why" (under what ecological conditions or related to what events) these assemblages differentiated. Within some stratigraphic intervals, such as the Volkhov, slight age disparities may be pivotal in determining the first appearance of some phytoplankton assemblages in different geographical areas. Therefore, a high time resolution is obviously required.

"WHEN"

If only precisely dated assemblages are considered, it must be concluded that the Baltic Province has no representation in either Perigondwana or Baltica before the beginning of the Volkhov (*Baltoniodus? triangularis* conodont Zone) or, in terms of British biostratigraphy, before the topmost *nitidus* graptolite Zone. Both Baltica and Perigondwana, including South China, were colonized by Mediterranean taxa prior to the Volkhov.

The assemblages from the middle-upper Billingen (equivalent to almost the entire British *nitidus* Zone) of the St. Petersburg area resemble the South China assemblages of the middle-upper *O. evae* conodont Zone in sharing many "endemic" Chinese species (Raevskaya's Assemblage 3, present issue). However, in South China these species are associated with typical Mediterranean taxa that are apparently lacking in the St. Petersburg's Billingenian samples. Actually, the strictly Mediterranean elements occur very rarely in strata of the East European Platform; only *Coryphidium* has been recorded (once) from the lower Volkhov of the Moscow Syncline (Aristova, 1980b). Among the forms characteristic of the "*messauoudensis-trifidum* assemblage", *Vavrdovella areniga* has only been reported by Paalits (in Servais & Molyneux, 1997) from the upper Tremadoc (uppermost Varangu) of Estonia; some representatives of the same assemblage are also recorded (Raevskaya's Assemblages 1 and 2, upper Hunneberg) from the St. Petersburg area.

Finally, the lower Arenig acritarch palynofloras of the East European Platform (Text-fig. 2) are dominated by elements of the Mediterranean Province (with particular reference to South China). They apparently differ from coeval Perigondwana assemblages - as represented in South China, Karakorum, Bohemia, Sardinia, Spain, North Africa, etc. - in their lower diversity and extreme rarity of typical provincial markers.

It should be noted, however, that no continuous sampling for acritarchs through the entire Arenig has been accomplished. Moreover, so far as the East

European Platform is concerned, only a few descriptions of early Arenig acritarch assemblages have been published.

The first appearance - The key interval for the appearance and radiation of the Baltic taxa occurs between the *Baltoniodus? triangularis* and the *Microzarkodina parva* conodont Zones. In this respect, the acritarch assemblage StP.2 (*B.? triangularis*-lower *B. navis* Zones) from the St. Petersburg area is of particular relevance. Its most interesting feature is the abundance of *Papilliferum striatum* and *P. rhabdocladium*, whose last occurrence occurs in China just above the introduction of *Baltoniodus? triangularis*, in the uppermost part of the Chinese *A. suecicus* graptolite Zone. The same level in China yielded (from the authors' unpublished data) the older representatives of *Peteinosphaeridium dissimile*, a species which later becomes a typical component of the Baltic assemblages (Górka, 1969; Yin, 1995; Tongiorgi *et al.*, 1998a).

Papilliferum belongs to the "*Pachysphaeridium* group", because of the characteristic fibrose structure of its distally rounded to bulbous processes. The present authors (unpubl.) have observed its South China introduction in the middle part of the Chinese *O. evae* conodont Zone (roughly equating to the top of the Baltic *O. evae*). In Baltoscandia, *Papilliferum rhabdocladium* and *P. striatum* have been rarely encountered in the upper Volkhov - lower Kunda (*L. antivariabilis* to *L. variabilis*) of northern Öland, Sweden, together with *Baltisphaeridium brevispinosum* (Eisenack, 1931 *ex* Eisenack, 1938) Eisenack, 1959 (Ribecai & Tongiorgi, unpubl.). This latter species, if not conspecific with *Papilliferum rhabdocladium*, is most probably connected to it phylogenetically, and was recorded by Eisenack (1959) in Estonia with apparent FAD in the lower Volkhov (*B.? triangularis*-*B. navis* interval).

In the uppermost Volkhov, several Baltic species which evince distinctive features of *Pachysphaeridium* (e.g., *Costatilobus bulbosus*, *Goniosphaeridium balticum*, *G. christianii*, and *G. connectum*) occur in Baltica; for instance, in Öland, Sweden (Ribecai & Tongiorgi, 1995), Estonia (Uutela & Tynni, 1991) and the St. Petersburg region, Russia (sample StP.3 herein; Raevskaya, unpubl.). These species are documented at least from the upper *norrlandicus* conodont Zone and are probably linked phylogenetically to *Papilliferum* (see discussion of *Goniosphaeridium balticum* by Eisenack, 1959, p. 206, and previous remarks herein on *Baltisphaeridium brevispinosum*). Based on the history of the "*Pachysphaeridium* group", it seems reasonable to regard the lowermost Volkhov as the most likely level for inception or initial differentiation of the Baltic Province.

The subsequent differentiation - Among the "Baltic" species, and in addition to *Peteino-*

sphaeridium dissimile, only the first representatives of the "macropylum group" were found in Chinese strata predating the *austrodentatus* graptolite Zone. They range upwards from levels probably corresponding to the Baltic upper *M. parva*-lower *B. norrlandicus* interval (= *E. clavus* Chinese graptolite Zone).

Rich Baltic assemblages, containing such provincially diagnostic taxa as *Liliosphaeridium kaljoi*, *Peteinosphaeridium bergstroemii*, and *P. velatum*, abruptly became dominant and well-diversified near the Volkhov-Kunda boundary, in levels correlative with the British upper *hirundo* graptolite Zone (latest Arenig). These assemblages are indisputably documented from the Baltic *B. norrlandicus* Zone upwards. They appeared in Baltoscandia and South China seemingly at the same level, and almost completely replaced the Mediterranean taxa. Only a few representatives of *Acanthodiacrodium*, *Barakella*, *Pireia*, *Stelliferidium*, and *Veryhachium* persist into the Volkhov-Kunda boundary interval of Estonia and Sweden. In China, *Cymatogalea* occurs within the same interval, together with the Baltic elements.

Isolated Baltic elements (*Liliosphaeridium* sp. cf. *L. kaljoi* and ?*Peteinosphaeridium bergstroemii*) were introduced in southern Perigondwana in the Arenig; they occur in a Bohemian sample (Kl.2) which is dominated by Mediterranean taxa. The age of the Bohemian strata is uncertain; they are located stratigraphically somewhere within the *Tetragraptus reclinatus abbreviatus* Zone, which corresponds to almost the entire Baltic Volkhov.

Unfortunately, latest Arenig acritarch assemblages are rare in Perigondwana. However, elements of the Baltic Province occur stratigraphically higher, together with dominant Mediterranean taxa, in the Llanvirn at different localities along the Perigondwana margin.

New observations by the current authors attest to the occurrence of *Liliosphaeridium hypertrophicum* and "*Peteinosphaeridium macropylum* s.l." in the lower Llanvirn of Belgium; *Liliosphaeridium hypertrophicum*, *L. kaljoi*, *L. pennatum*?, and "*Peteinosphaeridium macropylum* s.l." in the lower Llanvirn of Tunisia; and *Peteinosphaeridium bergstroemii*, and *P. sp. cf. P. velatum* in the lower upper Llanvirn of Spain. Vecoli *et al.* (this issue) record *Ampullula suetica* Righi, 1991, *Baltisphaeridium brankaense* Górka, 1979, *Liliosphaeridium pennatum*, and *Peteinosphaeridium velatum* in the Llanvirn (*Frankea sartbernardensis-Vogtlandia ramificata* acritarch assemblage zone) of Algeria and Tunisia (boreholes St1 and NL2, respectively).

In conclusion, several lines of evidence suggest that some elements of the Baltic palynoflora began to differentiate at mid- to low latitudes (East European Platform-Baltoscandia, South China), starting in the *B. ? triangularis* conodont Zone. A distinctive change in the provincial affinities occurred near the base of the Volkhov, when the Mediterranean assemblages rapidly became impoverished at intermediate lati-

tudes. A subsequent change probably occurred, seemingly within the Baltic *B. norrlandicus* conodont Zone, enabling an abrupt radiation of the Baltic taxa. These latter almost completely supplanted the Mediterranean species in both the East European Platform-Baltoscandia and in South China. The Baltic taxa occasionally also migrated on to the platforms of the northern Gondwana margin.

"WHERE"

As previously stated, the species of the Chinese genus *Papilliferum* Yin, 1994 (*P. irregulare*, *P. rhabdocladium*, *P. striatum*) embrace most of the distinctive features of *Pachysphaeridium*. At least *P. striatum* could unquestionably be transferred to the latter genus, while *P. irregulare* and *P. rhabdocladium* exhibit slightly different characters (less obvious process striation, often rounded rather than bulbous process termini). All three species first occur at Daping (South China) in the middle part of the Chinese *O. evae* conodont Zone, which corresponds approximately to the top of the Baltic *O. evae*. In the St. Petersburg area, *P. rhabdocladium* and *P. striatum* have been found within the *B. ? triangularis*-lower *B. navis* interval, close to the last occurrence of this group at Daping. In Estonia, a species very similar to *P. rhabdocladium* ("*Baltisphaeridium*" *brevispinosum*) has been recorded from the lower Volkhov (*B. ? triangularis*-*B. navis*).

At the top of the Dawan Formation at Daping (*austrodentatus* graptolite Zone) well-differentiated representatives of the "*Pachysphaeridium* group" appear, showing the same evolutionary features of the corresponding species from the Baltic upper Volkhov assemblages.

Thus, the hypothesis could be proposed that the "*Pachysphaeridium* group" originated in South China with the genus *Papilliferum* (upper Billingen), and that the group subsequently (in the early Volkhov) moved to the East European Platform and Baltoscandia. There, a spectacular radiation occurred prior to the latest Volkhov; and the new Baltic species of the "*Pachysphaeridium* group" later re-colonized South China, together with further representatives of the Baltic Province.

The same hypothesis may perhaps be applied to the evolution and dispersal of *Peteinosphaeridium* forms bearing simple processes (*P. angustilaminae*, *P. dissimile*, *P. hymeniferum*), whose older representative (*P. dissimile*) made its first appearance in South China at least at the base of the Volkhov (*B. ? triangularis* conodont Zone), although it did not extend into the Baltic until the *norrlandicus* Zone.

The presence in both China and Baltica of *Ampullula suetica* Righi, 1991 is another evidence which supports a possible Chinese origin of "Baltic" taxa. The last-named species first appears in China in the *A. suecicus* graptolite Zone (Tongiorgi *et al.*, 1995) and is documented (Brocke, 1997) until the

Undulograptus sinodentatus Zone (= *E. clavus-I. caduceus imitatus*), always represented by rare specimens. The same species is documented (and is abundant) in Baltica since the *norrlandicus* conodont Zone, i.e. from the lowest fossiliferous bed of the Arenig of Öland, Sweden. The underlying middle and lower Volkhov beds are barren in Öland; but, the coeval, palyniferous levels from the East European Platform never provided this species.

According to Brocke's revision and emendation (Brocke, 1997) of the genus *Ampullula* Righi, 1991, *Ampullula suetica* (with no processes, excluded the "tubular extension") is part of a form-group also comprising the former genus *Stelomorpha* Yin, 1994 (with numerous processes) now *Ampullula* Righi, 1991 emend. Brocke, 1997. "*Stelomorpha*" appears in South China in the *A. suecicus* Zone, i.e. a little before the inception of *Ampullula suetica*. Thus, it may be supposed that the entire phylum *Stelomorpha-Ampullula* originated in South China and subsequently migrated to Baltica (with the sole species *Ampullula suetica*). The last-named species is present later, in the Llanvirn of Southern Tunisia (Vecoli *et al.*, this issue), as a foreign host within typical Mediterranean assemblages.

Microphytoplankton exchanges between South China and the East European Platform were surely possible during the Arenig, because of the existence of a subtropical oceanic gyre connecting these regions (Wilde, 1991). However, this current underwent a complete seasonal reversal, being directed from China to Baltoscandia during the southern hemisphere winter, and vice versa during summer, due to the effect of the Gondwanan monsoon. Thus, interchanges of phytoplankton were possible in both directions and a polycentric origin for the Baltic acritarch assemblages cannot be excluded.

Further data will be necessary to solve this problem, because no palynological information is currently available from the Baltic upper *M. parva*-lower *norrlandicus* interval, in which the main differentiation of the Baltic acritarch would be expected to have occurred.

"WHY"

Parallelism in the palynofloral history during the Ordovician between South China and Baltoscandia (see also Lindström *et al.*, 1971), together with evidence of somewhat similar events in southern Perigondwana, demand models which necessarily involve factors operating on a broad scale, such as global sea level fluctuations. Based on sections in North America and correlations with Europe, Ross & Ross (1992, 1995) postulated a large second-order eustatic cycle corresponding to the entire Ordovician and showing a minimum (regressive peak) in the Llanvirn-"Llandeilo" boundary interval.

Effects of sea level drops on the structure of phytoplankton assemblages are poorly understood. A complex model has been proposed (Hallock (1987,

1988; Hallock *et al.*, 1991) for recent and modern phytoplankton, correlating trophic resources and phytoplankton diversity/productivity with sea level fluctuations. According to this model, oligotaxic phytoplankton biofacies (*r*-selected opportunists; Lalli & Parsons, 1993) should reflect nutrient-rich conditions up to eutrophication, while polytaxic biofacies (*k*-selected equilibrium species, Lalli & Parsons, 1993; or *k*-specialists, Hallock, 1988) would prevail in nutrient-deficient habitats (see Tappan & Loeblich, 1973, and references cited therein). Also, the trophic resource continuum would expand during transgressions, from highly oligotrophic to highly eutrophic, while during regressions only mesotrophic to eutrophic conditions would be established. At subtropical latitudes (like South China during the Arenig; Scotese & McKerrow, 1990; Finney & Chen, 1990; Lindström, 1991; Tongiorgi *et al.*, 1995; Tongiorgi *et al.*, 1998a), alternations between polytaxic and oligotaxic phytoplanktonic assemblages should closely parallel eustatic sea level rises and drops, respectively (Hallock, 1988). In fact, the response of acritarchs to these fluctuations could be more effective on the mid- to low-latitude platforms, like Baltoscandia and South China, experiencing stronger trophic gradients.

An interesting implication of Hallock's model is that the trophic resource continuum (TRC) "contraction could cause extinctions because TRC contraction eliminates niches. Conversely, TRC expansion could promote evolutionary diversification because niches are created. Thus response to TRC contraction can be geologically instantaneous, while response to TRC expansion may require millions of years" (Hallock, 1998). Fluctuations in the TRC after a major extinction event may show up as blooms of opportunists.

The secular negative trend of the second-order sea level cycle of Ross & Ross (1992, 1995) may have produced a long-term tendency to eutrophication (Wood, 1993) on subtropical platforms, which in turn would produce a long-term crisis of the phytoplankton, and even mass extinctions during regressive maxima (Hallock, 1988; Hallock *et al.*, 1991). According to detailed sea level curves (Ross & Ross, 1992; Nielsen, 1992a, b; Bagnoli & Stouge, 1996), this long-term crisis would have commenced at the end of the "*Oepikodus evae* transgression" (Nielsen, 1992a; Bagnoli & Stouge, 1996), i.e., roughly at the base of the Volkhov, just when the Mediterranean assemblages began to rapidly deteriorate and oligotaxic assemblages (mostly comprising *Stelliferidium-Cymatiogalea*) occur.

From ecostratigraphic studies, Nielsen (1992a, b) and Bagnoli & Stouge (1996), recognized three third-order eustatic sea level rises (with minor oscillations) during the Arenig, separated by two correlative sea level drops. These events correspond respectively to the following zones: *O. evae*, upper *B. navis*, upper *norrlandicus*-lower *antivariabilis*, *B.?* *triangularis*, and

middle *norrlandicus*. A further sea level drop should be evident, according to Nielsen (1992a, b), just below the Volkhov-Kunda boundary.

The fluctuations in acritarch diversity at Daping (Tongiorgi *et al.*, 1998a; this paper) chronologically reflect these curves. Each regressive peak is revealed by oligotaxic assemblages and, according to Hallock's model, should correspond to extinction episodes; each eustatic sea rise is expressed by more diverse assemblages and by the appearance of new species. The crisis of the Mediterranean assemblages and the correlative diversification of the Baltic Province may well have been driven by such repeated short-term events occurring within the prolonged tendency discussed above.

Oligotaxic assemblages have been recorded by a few authors (e.g., Dorning, 1981; Jacobson, 1979). According to Jacobson (1979), the Ordovician "peteinosphaerid class" of acritarchs (which may make up as much as 69% of some assemblages) reflects a shoal environment, while the "baltisphaerid class" (associated with the "peteinosphaerid class" to comprise nearly 100% of some samples) represents an offshore, open marine environment. These two acritarch "classes" are important components of the Baltic provincial assemblages. The tendency – particularly of peteinoids – to comprise oligotaxic assemblages evidences their eu- to mesotrophic character. It is this character which could have facilitated peteinoid dominance of mid- to low latitude late Arenig palynofloras, as a selective response to the long-term tendency to eutrophication, the effects of which would have been more pronounced at mid-low rather than high latitudes. This exemplifies the character of the Baltic – in contradistinction to the Mediterranean – Province

CONCLUSIONS

From all available data, both Perigondwana and Baltica were characterized by a Mediterranean-type marine palynoflora during the Billingen, i.e., prior to the uppermost *nitidus* graptolite (British) Zone. Local qualitative disparities in palynofloral composition (possibly reflecting latitudinal or palaeophysiogeographic differences) do not mask the essential homogeneity of the acritarch assemblages of this extensive area (viz., Mediterranean Realm).

Some elements of the Baltic Province began to appear in South China no later than earliest Volkhov, *Baltoniodus? triangularis* conodont Zone, and again in the upper *Baltoniodus navis* Zone. However, the Baltic assemblages, comprising such provincially diagnostic taxa as *Peteinosphaeridium bergstroemii*, *P. hymeniferum*, *P. velatum*, *Liliosphaeridium kaljoi*, *Pachysphaeridium* spp., and "*Peteinosphaeridium macropylum* s.l."), became dominant and diversified only from the *Baltoniodus norrlandicus* conodont Zone upwards, seemingly concurrently in Balto-

scandia and South China. Here, the Mediterranean assemblages have been almost completely supplanted, except for rare representatives of a few species. Isolated elements of the Baltic Province also encroached into southern Perigondwana during the Arenig (Bohemia) and during the early Llanvirn (Belgium, Spain, Tunisia).

Concerning the geographic provenance of the Baltic palynoflora, the available data are inconclusive. However, recognition in the South China region of possible ancestors of certain "Baltic" groups (e.g., species of the "*Pachysphaeridium* group") may suggest a possible Chinese origin of some Baltic taxa. On the other hand, the seasonal reversal of the subtropical oceanic current linking South China and Baltica during the Arenig may mean a polycentric origin for the Baltic assemblages.

According to the Hallock model, the crisis of the Mediterranean assemblages (beginning in the early Volkhov) should have been controlled primarily by trophic fluctuations, in turn depending on climatic factors. These same factors are responsible of eustatic sea level cycles; thus, the changes in acritarch palaeogeographic affinity during the Arenig-Llanvirn could be related to the secular negative trend of sea level (Ordovician second-order cycle) recognized by Ross & Ross (1992, 1995). In fact, this sea level negative trend produced a long-term tendency to eutrophication and even mass extinctions during the regressive third-order peaks.

The third-order sea level fluctuations revealed by conodont biofacies analyses in Baltoscandia are synchronous with acritarch diversity fluctuations recorded from Daping (South China). Accordingly, oligotaxic acritarch assemblages and extinction episodes at Daping may relate to sea level drops, while more diverse assemblages and the appearance of new species correspond to eustatic rises in sea level.

These repeated short-time fluctuations in the complexion of the acritarch assemblages probably emphasized and accelerated, on mid- to low latitude platforms, the protracted decline of the Mediterranean assemblages and the appearance of the Baltic Province.

At higher latitudes, different environmental conditions enabled the survival of the old Mediterranean assemblages, even though some Baltic representatives occasionally migrated into southern Perigondwana during late Arenig-Llanvirn times.

ACKNOWLEDGEMENTS

This research was supported by the Italian Ministry for University and Scientific and Technological Research (MURST grant "Biodiversificazione e provincialismo di acritarchi e conodonti dell'Arenigiano-Llanvirniano in relazione a variazioni climatiche e paleogeografiche", local coordinator M. Tongiorgi). Dr. Lena Raevskaya (VNIGRI, St. Petersburg, Russia) courteously allowed access to some of her palynological slides. Dr. Svend Stouge (Geological Survey of Denmark and Greenland, Copenhagen) provided indispensable data on conodonts and highly constructive discussions; he is also acknowledged for his

very careful appraisal of the manuscript and attendant helpful suggestions. Special thanks are expressed to Prof. Reed Wicander (Central Michigan University) and Prof. Geoffrey Playford (University of Queensland) for detailed review and constructive criticism of the manuscript and suggestions for linguistic improvement. Sincere appreciation is expressed to the following: Dr. Dominique Massa (Paris) for making available relevant Tunisian samples and stratigraphic information; the Tunisian SEREPT Oil Company for allowing publication of borehole data; Dott. Roberto Albani, Mr. Giorgio Misuri, and Mr. Marcello Gini of Department of Earth Sciences, University of Pisa, for technical assistance.

REFERENCES

- ARISTOVA, K.E., 1976, Kompleksy mikrofitofossilij nizhnego i srednego ordovika etalonnij razrezov Estonii [The microfitofossil assemblages from the lower and Middle Ordovician of the type sections of Estonia]. In *Rezultaty palinologicheskikh issledovaniy Dokembriya, Paleozoya i Mezozoya SSSR* [Results of the palinological studies on the Precambrian, Palaeozoic and Mesozoic of the USSR], Mezhdunarodnaya Palinologicheskaya Konferentsiya, Laknau, Indya, 1976, Moskva: Trudy, 192: 11-20. [in Russian].
- , 1980a, Akritarkhi pograničnykh sloev tremadokskogo i arenigskogo yarusov Moskovskoi sineklizy [Acritarchs of Tremadoc-Arenig boundary beds of the Moscow Syncline]. In *Byvsheva, T.V. (ed.), Palinologicheskie issledovaniya Proterozoya i Fanerozoya neftegazonosnykh regionov SSSR* [Palynological Investigations of Proterozoic and Phanerozoic Oil and gas bearing regions of the USSR]: Trudy VNIGRI, 217: 1-18. [in Russian].
- , 1980b, Mikrofosilii llanvirnskogo yarus Moskovskoi sineklizy [Microfossils of the Llanvirnian Stage from the Moscow Syncline]. In *Byvsheva, T. V. (ed.), Palinologicheskie issledovaniya Proterozoya i Fanerozoya neftegazonosnykh regionov SSSR* [Palynological Investigations of Proterozoic and Phanerozoic Oil and gas bearing regions of the USSR]: Trudy VNIGRI, 217: 19-25. [in Russian].
- BAGNOLI, G. & STOUGE, S., 1996, Changes in conodont provincialism and biofacies during the lower Ordovician in Öland, Sweden: *Palaeopelagos*, 6: 19-29.
- & —, 1997, Lower Ordovician (Billingenian-Kunda) conodont zonation and provinces based on sections from Horns Udde, north Öland, Sweden: *Boll. Soc. paleont. ital.*, 35 (2): 109-263.
- BERGSTRÖM, S.M., 1986, Biostratigraphic integration of Ordovician graptolite and conodont zones, a regional review. In *Hughes, C.P. & Rickards, R.B. (eds.), Palaeoecology and biostratigraphy of graptolites*: Geol. Soc. spec. Publ., 20: 61-78.
- BOUCEK, B., 1973, Lower Ordovician graptolites of Bohemia: *Czech. Acad. Sci., Praha*: 185 pp.
- BROCKE, R., 1997, First results of Tremadoc to lower Arenig acritarchs from the Yangtze Platform, Southwest China. In *Fatka, O. & Servais, T. (eds.), Acritarcha in Praha 1996*: Acta Univ. Carolinae, Geol.: 40 (3-4): 337-356.
- , 1997, Evaluation of the Ordovician acritarch genus *Ampullula* Righi: *Ann. Soc. géol. Belgique*, 120 (1): 73-97.
- , FATKA, O., MOLYNEUX, S.G. & SERVAIS, T., 1995, First appearance of selected Early Ordovician acritarch taxa from peri-Gondwana. In *Cooper, J.D., Droser, M.L., & Finney, S.C. (eds.), Ordovician Odyssey: Short papers for the Seventh International Symposium on the Ordovician System, Las Vegas, Nevada, USA, June 1995*: Pacific Sect. SEPM, 77: 473-476, SEPM Books, Fullerton, California, USA.
- CHEN, X., MITCHELL, C.E., ZHANG, Y.-D., WANG Z.-H., BERGSTRÖM, S.M., WINSTON, D. & PARIS, F., 1997, GSSP of Darriwillian (Middle Ordovician) in China: *Acta palaeont. sinica*, 36 (4): 423-431.
- COOPER, R.A. & LINDHOLM, K., 1991, A precise worldwide correlation of early Ordovician graptolite sequences: *Geol. Mag.*, 127: 479-525.
- COOPER, A.H., RUSHTON, A.W.A., MOLYNEUX, S.G., HUGHES, R.A., MOORE, R.A. & WEBB, B.C., 1995, The stratigraphy, correlation, provenance and palaeogeography of the Skiddaw Group (Ordovician) in the English Lake District: *Geol. Mag.*, 132 (2): 185-211.
- CRAMER, F. H. & DÍEZ R., M.D.C., 1974a, Silurian acritarchs: distribution and trends: *Rev. Palaeobot. Palynol.*, 18: 137-154.
- & —, 1974b, Early Paleozoic palynomorph provinces and paleoclimate. In *Ross, C.A. (ed.), Paleogeographic provinces and provinciality*: Soc. econ. Paleont. Mineral., Spec. Publ., 21: 177-188.
- DEAN, W.T. & MARTIN, F., 1992, Ordovician biostratigraphic correlation in southern Turkey. In *Webby, B.D. & Laurie, J.R. (eds.), Global perspectives on Ordovician geology*, Proceedings of the 6th International Symposium on the Ordovician System, University of Sydney, Australia, 15-19 July 1991: 195-203, Balkema, Rotterdam.
- DEUNFF, J. & MASSA, D., 1975, Palynologie et stratigraphie du Cambro-Ordovicien (Libye nord-occidentale): *C. R. Acad. Sc. Paris, Série D*, 281 (1): 21-24.
- DORNING, K.J., 1981, Silurian acritarchs from the type Wenlock and Ludlow of Shropshire, England: *Rev. Palaeobot. Palynol.*, 34: 175-203.
- EISENACK, A., 1959, Neotypen baltischer Silur - Hystriosphären und neue Arten: *Palaeontographica, Abt. A*, 112 (5-6): 193-211.
- , 1976, Mikrofosilien aus dem Vaginatenkalk von Hälludden, Öland: *Palaeontographica, Abt. A*, 154 (4-6): 181-203.
- FANG, X.S., 1986, Ordovician micropaleoflora in Kunming-Luquan region, Yunnan Province, and its stratigraphical significance: *Prof. Pap. stratigr. Palaeont.*, 16: 125-172. [in Chinese with English summary].
- FINNEY, S.C. & CHEN, X., 1990, The relationship of Ordovician graptolite provincialism to palaeogeography. In *McKerrow, W.S. & Scotese, C.R. (eds.), Palaeozoic palaeogeography and biogeography*: Geol. Soc. London, Mem., 12: 123-128.
- FORTEY, R.A., BASSETT, M.G., HARPER, D.A.T., HUGHES, R.A., INGHAM, J.K., MOLYNEUX, S.G., OWEN, A.W., OWENS, R.M., RUSHTON, A.W.A., & SHELDON, P.R., 1991, Progress and problems in the selection of stratotypes for the bases of series in the Ordovician System of the hystorical type area in the U.K. In *Barnes, C.R. & Williams, S.H. (eds.), Advances in Ordovician geology*: Pap. geol. Surv. Canada, 90 (9): 5-25.
- , HARPER, D.A.T., INGHAM, J.K., OWEN, A.W., & RUSHTON, A.W.A., 1995, A revision of Ordovician series and stages from the historical type area: *Geol. Mag.*, 132 (1): 15-30.
- GÓRKA H., 1969, Microorganismes de l'Ordovicien de Pologne: *Palaeont. polonica*, 22: 1-102.
- , 1987, Acritarches et Prasinophyceae de l'Ordovicien moyen (Viruen) du sondage de Smedsby Gård no.1 (Gotland, Suède): *Rev. Palaeobot. Palynol.*, 52: 257-297.
- GRAHN, Y., 1982, Chitinozoophoran palaeoecology in the Ordovician of Öland: *Sver. geol. Unders.*, (Ser. C, 792), 76 (5): 17 pp.
- GUTIÉRREZ-MARCO, J.C., ALBANI, R., ARAMBURU, C., ARBIZU, M., BABIN, C., GARCÍA-RAMOS, C., MÉNDEZ-BEDIA, I., RABANO, I., TRUYOLS, J., VANNIER, J., & VILLAS, E., 1996, Biostratigrafía de la Formación Pizarras del Sueve

- (Ordovícico Medio) en el sector septentrional de la escama de Laviana-Sueve (Zona Cantábrica, Norte de España): *Rev. esp. Paleont.*, 11 (1): 48-74.
- HALLOCK, P., 1987, Fluctuations in the trophic resource continuum: a factor in global diversity cycles? *Paleoceanography*, 2 (5): 457-471.
- , 1988, The role of nutrient availability in bioerosion: consequence to carbonate buildups: *Palaeogeog.*, *Palaeoclim.*, *Palaeoecol.*, 63: 275-291.
- , PREMOLI-SILVA, I., & BOERSMA, A., 1991, Similarities between planktonic and large foraminiferal evolutionary trends through Paleogene paleoceanographic changes: *Palaeogeog.*, *Palaeoclim.*, *Palaeoecol.*, 83: 49-64.
- JAANUSSON, W., 1960, Graptoloids from the Ontikan and Viruan (Ordov.) Limestones of Estonia and Sweden: *Bull. geol. Inst. Univ. Uppsala*, 38: 206-366.
- JACOBSON, S.R., 1979, Acritarchs as paleoenvironmental indicators in Middle and Upper Ordovician rocks from Kentucky, Ohio and New York: *J. Paleont.*, 53 (5): 1197-1212.
- KJELLSTRÖM, G., 1971a, Ordovician microplankton (baltisphaerids) from the Grötlingbo Borehole No.1 in Gotland, Sweden: *Sveriges geol. Unders.*, (Ser. C, 665), 65 (1): 1-75.
- , 1971b, Middle Ordovician microplankton from the Grötlingbo Borehole No.1 in Gotland, Sweden: *Sveriges geol. Unders.*, (Ser. C, 669), 65 (15): 1-35.
- , 1972, Lower Viruan microplankton from a boring in Öland, Sweden: *N. Jb. Geol. Paläont., Mh.*, 12: 713-719.
- , 1976, Lower Viruan (Middle Ordovician) microplankton from the Ekön Borehole No.1 in Östergötland, Sweden: *Sveriges geol. Unders.*, (Ser. C, 724), 70 (6): 1 - 44.
- KRAFT, J., 1977, Graptolites from the Klabava Formation (Arenigian) of the Ordovician of Bohemia: *Folia Mus. Rerum nat. Bohemiae occident.*, *Geologica*, 6: 1-31.
- & KRAFT, P., 1995, Biostratigraphy of the Klabava and Sarka Formations (Bohemia, Lower Ordovician) - A brief overview of new investigations: *Acta Univ. Carolinae*, 1992 (1-2): 23-29.
- LALLI, C.M. & PARSONS, T.R., 1993, Biological oceanography. An introduction. Pergamon Press, Oxford, U.K.: 301 pp.
- LI, J., 1987, Ordovician acritarchs from the Meitan Formation of Guizhou Province, south-west China: *Palaeontology*, 30 (3): 613-634.
- , 1989, Early Ordovician Mediterranean Province acritarchs from the Upper Yangtze region, China. *In Chinese Acad. Sci., Developments in Geoscience. Contribution to 28th Int. geol. Congr.*, 1989, Washington D.C., USA: 231-234, Sci. Press, Beijing.
- , 1990, Ordovician acritarchs from the Jiuxi Formation of Jishou, Hunan: *Acta micropaleont. sinica Jun.*, 7 (2): 141-160. (in Chinese with English summary).
- LINDSTRÖM, M., CHEN, J.-Y. & ZHANG, J.-M., 1991, Section at Daping reveals Sino-Baltoscandian parallelism of facies in the Ordovician: *Geol. Fören. Stockholm Förh.*, 113 (2-3): 189-205.
- LÖFGREN, A., 1978, Arenigian and Llanvirnian conodonts from Jamtland, northern Sweden: *Fossils and Strata*, 13: 129 pp.
- MARTIN, F., 1966, Les acritarches de Sart-Bernard (Ordovicien belge): *Bull. Soc. belge Géol. Pal. Hydrol.*, 74 (3): 423-444. [imprinted 1965, issued 1966].
- , 1969, Les Acritarches de l'Ordovicien et du Silurien belges. Détermination et valeur stratigraphique: *Mém. Inst. roy. Sci. nat. Belgique*, 160: 175 pp. [imprinted 1968, issued 1969].
- , 1982, Some aspects of late Cambrian and early Ordovician acritarchs. *In Bassett, M.G. & Dean, W.T. (eds.)*, The Cambrian-Ordovician boundary: sections, fossil distributions, and correlations: *Geol. Ser., natn. Mus. Wales*, 3: 29-39.
- MASSA, D., HAVLICEK, V. & BONNEFOUS, J., 1977, Stratigraphic and faunal data on the Ordovician of the Rhadames basin (Libya and Tunisia): *Bull. Centres Rech. Explor.-Prod. Elf-Aquitaine*, 1 (1): 3-27.
- NIELSEN, A.T., 1992a, Ecostratigraphy and the recognition of Arenigian (Early Ordovician) sea-level changes. *In Webby, B.D. & Laurie, J.R. (eds.)*, Global perspectives on Ordovician geology, Proceedings of the 6th International Symposium on the Ordovician System, University of Sydney, Australia, 15-19 July 1991: 355-366, A.A. Balkema, Rotterdam.
- , 1992b, International correlation of the Arenigian (Early Ordovician) based on the sequence and ecostratigraphy. *In Webby, B.D. & Laurie, J.R. (eds.)*, Global perspectives on Ordovician Geology, Proceedings of the 6th International Symposium on the Ordovician System, University of Sydney, Australia, 15-19 July 1991: 367-380. A.A. Balkema, Rotterdam.
- , 1995, Trilobite biostratigraphy, palaeoecology and systematics of the Komstad Limestone and Huk Formation (Lower Ordovician), southern Scandinavia: *Fossils and Strata*, 38: 374 pp.
- OTTONE, E.G., TORO, B.A. & WAISFIELD, B.G., 1992, Lower Ordovician palynomorphs from the Acoite Formation, northwestern Argentina: *Palynology*, 16: 93-116.
- PARIS, F. & MERGL, M., 1984, Arenigian chionoans from the Klabava Formation, Bohemia: *Rev. Palaeobot. Palynol.*, 43: 33-65.
- PLAYFORD, G., RIBECAL, C., & TONGIORGI, M., 1995, Ordovician acritarch genera *Peteinosphaeridium*, *Liliosphaeridium*, and *Cyclospheeridium*: morphology, taxonomy, biostratigraphy, and palaeogeographic significance: *Boll. Soc. paleont. ital.*, 34 (1): 3-54.
- RAEVSKAYA, E., 1998, New data on lower Ordovician acritarchs from St. Petersburg region (north-western Russia). *In CIMP Symposium and Workshops Pisa - September 11-15, 1998*, Abstracts: CIMP Newsletter, 55: 31.
- , 1999, Early Arenig acritarchs from the Leetse Formation (St. Petersburg region, northwest Russia) and their palaeogeographic significance: *Boll. Soc. paleont. ital.*, 38 (2-3): this volume [cited in the text as Raevskaya, this issue].
- RIBECAL, C., 1996, Definizione delle Biozone ad acritarchi nell'intervallo Arenig superiore-Llanvirn inferiore nella parte settentrionale dell'isola di Öland (Svezia): Unpublished PhD Thesis, Facoltà di Scienze M.F.N., Dipartimento di Scienze della Terra, Univ. Pisa, Italy.
- & TONGIORGI, M., 1995, Arenigian acritarchs from Horns Udde (Öland, Sweden): a preliminary report: *Rev. Palaeobot. Palynol.*, 86: 1-11.
- & —, 1998, The Ordovician acritarch genus *Pachysphaeridium* Burmann 1970: new, revised, and re-assigned species. *In CIMP Symposium and Workshops - Pisa '98*, Abstracts: CIMP Newsletter, 55: 31-32.
- ROSS, C.A. & ROSS, J.R.P., 1995, North American Ordovician depositional sequences and correlations. *In Cooper, J.D., Droser, M.L. & Finney, S.C. (eds.)*, Ordovician odyssey: Short papers for the Seventh International Symposium on the Ordovician System, Las Vegas, Nevada, USA, June 1995: Pacific Sect. SEPM, 77: 309-313, SEPM Books, Fullerton, California, USA.
- ROSS, J.R.P. & ROSS, C.A., 1992, Ordovician sea-level fluctuations. *In Webby, B. D. & Laurie, J. R. (eds.)*, Global perspectives on Ordovician geology, Proceedings of the 6th International Symposium on the Ordovician System, University of Sydney, Australia, 15-19 July 1991: 327-335, A. A. Balkema, Rotterdam.
- SCOTese, C.R. & MCKERROW, W.S., 1990, Revised word maps and introduction. *In McKerrow, W.S. & Scotese, C.R.*

- (eds.), Palaeozoic palaeogeography and biogeography: Geol. Soc. London, Mem., 12: 1-21.
- SERVAIS, T., 1995, Paleobiogeography of Ordovician acritarchs: some general considerations. *In* Cooper, J.D., Droser, M.L., & Finney, S.C. (eds.), Ordovician odyssey: Short papers for the Seventh International Symposium on the Ordovician System, Las Vegas, Nevada, USA, June 1995: Pacific Sect. SEPM, 77: 457-460, SEPM Books, Fullerton, California, USA.
- & MALETZ, J., 1992, Lower Llanvirn (Ordovician) graptolites and acritarchs from the "Assise de Huy", Bande de Sambre-et-Meuse, Belgium: Ann. Soc. géol. Belgique, 115 (1): 265-285.
- & MOLYNEUX, S.G., 1997, The *messauoudensis-trifidum* acritarch assemblage (Ordovician: late Tremadoc-early Arenig) from subsurface of Rügen (Baltic Sea, NE Germany): Palaeontographia Italica, 84: 113-161.
- STOUGE, S., BAGNOLI, G., NIELSEN, A.T., RIBECAL, C., & TONGIORGI, M., 1995, Oeland (Lower Ordovician) biostratigraphy on the basis of Öland sections, Baltica. *In* Cooper, J.D., Droser, M.L., & Finney, S.C. (eds.), Ordovician odyssey: Short papers for the Seventh International Symposium on the Ordovician System, Las Vegas, Nevada, USA, June 1995: Pacific Sect. SEPM, 77: 53-68, SEPM Books, Fullerton, California, USA.
- TAPPAN, H. & LOEBLICH, A.R. JR., 1973, Evolution of the oceanic plankton: Earth-Sci. Rev., 9: 207-240.
- TJERNVIK, T.E., 1956, On the early Ordovician of Sweden, stratigraphy and fauna: Bull. geol. Inst. Univ. Uppsala, 36: 107-284.
- & JOHANSSON, J.V., 1980, Description of the upper portion of the drill-core from Finngrundet in the South Bothnian Bay: Bull. geol. Inst. Univ. Uppsala, N.S., 8: 173-204.
- TONGIORGI, M., DI MILIA, A., LE FORT, P., & GAETANI, M., 1994, Palynological dating (Arenig) of the sedimentary sequence overlying the Ishkarwaz Granite (upper Yarkhun valley, Chitral, Pakistan): Terra Nova, 6: 595-607.
- , YIN L.-M. & DI MILIA, A., 1995, Arenigian acritarchs from the Daping section (Yangtze Gorges area, Hubei province, Southern China) and their palaeogeographic significance: Rev. Palaeobot. Palynol., 86: 13-48.
- , — & RIBECAL, C., 1998, Changing palaeogeographical affinities of the acritarch assemblages throughout the Dawan Formation (Arenig, Yichang area, South China): Palynology, 22: 181-196. [cited in the text as Tongiorgi *et al.*, 1998a].
- , — & STOUGE, S., 1998, Acritarch and conodont biofacies reveal sea level changes on the Yangtze Platform, during Arenigian times (Dawan Formation, South China). *In* CIMP Symposium and Workshops - Pisa '98, Abstracts: CIMP Newsletter, 55: 22. [cited in the text as Tongiorgi *et al.*, 1998b].
- UUTELA, A., 1989, Age and dispersal of sedimentary erratics on the coast of southwestern Finland: Bull. geol. Surv. Finland, 349: 1-100.
- & TYNNI, R., 1991, Ordovician acritarchs from the Rapla borehole, Estonia: Bull. geol. Surv. Finland, 353: 1-135.
- VAVRDOVÁ, M., 1974, Geographical differentiation of Ordovician acritarch assemblages in Europe: Rev. Palaeobot. Palynol., 18: 171-175.
- , 1993, Acritarch assemblages in the Arenig Series of the Prague Basin, Czech Republic. *In* Molyneux, S.G. & Dörning, K.G. (eds.), Contributions to acritarch and chitinozoan research: Spec. Pap. Palaeont., 48: 125-139.
- , 1997, Early Ordovician provincialism in acritarch distribution: Rev. Palaeobot. Palynol., 98: 33-40.
- VECOLI, M., TONGIORGI, M., ABDESSELAM-ROUGHI, F., BENZARTI, R. & MASSA, D., 1999, Palynostratigraphy of Upper Cambrian - upper Ordovician intracratonic clastic sequences, North Africa: Boll. Soc. paleont. ital., 38 (2-3): present issue.
- WANG, X.F., ERDTMANN, B.D., & CHEN, X.H., 1992, Ordovician chronostratigraphy - A Chinese approach. *In* Webby, B.D. & Laurie, J.R. (eds.), Global perspectives on Ordovician geology, Proceedings of the 6th International Symposium on the Ordovician System, University of Sydney, Australia, 15-19 July 1991: 35-55. A.A. Balkema, Rotterdam.
- , LI, Z.M., CHEN, J.Q., CHEN, X.H., & SHU W.B., 1996, Early Ordovician sea level events in South China and its worldwide correlation: J. Geol. miner. Res. South China, 3: 1-11.
- WANG, Z.-H., BERGSTRÖM, S.M., & LANE, H.R., 1996, Conodont provinces and biostratigraphy in Ordovician of China: Acta palaeont. sinica, 35 (1): 26-59.
- WILDE, P., 1991, Oceanography in the Ordovician. *In* Barnes, C.R. & Williams, S.H. (eds.), Advances in Ordovician geology: Pap. Geol. Surv. Canada, 90 (9): 283-298.
- WOOD, R., 1993, Nutrients, predation and the history of reef-building: Palaios, 8: 526-543.
- YIN, L.-M., 1994, New forms of acritarchs from early Ordovician sediments in Yichang, Hubei, China: Acta micropalaeont. sinica, 11 (1): 41-53. [in Chinese, with English summary].
- YIN, L.M., 1995, Early Ordovician acritarchs from Huanjiang region, Jilin, and Yichang region, Hubei, China: Palaeont. sinica, n. Ser. A, 185 (12): 170 pp.
- , DI MILIA, A. & TONGIORGI, M., 1998, New and emended acritarch taxa from the lower Dawan Formation (lower Arenig, Huanghuachang Section, South China): Rev. Palaeobot. Palynol., 102: 223-248.
- ZHANG, J.H., 1998, Conodonts from the Guniutan Formation (Llanvirnian) in Hubei and Hunan Provinces, south-central China: Acta Univ. Stockholmsensis, 46: 151 pp.

(manuscript received January 8, 1999
accepted April 19, 1999)

Marco TONGIORGI
Anna DI MILIA

Dipartimento di Scienze della Terra
Università di Pisa
Via S. Maria 53, 56126 Pisa, Italy

<i>Bollettino della Società Paleontologica Italiana</i>	38 (2-3), 1999	ISSN 0375-7633	297-312	1 pl.	Modena, Dicembre 1999
---	----------------	----------------	---------	-------	-----------------------

Differentiation and spread of the Baltic Acritarch Province (Arenig-Llanvirn)

Marco TONGIORGI

Anna DI MILIA

Dipartimento di Scienze della Terra
Università di Pisa

ERRATA CORRIGE

p.302: the Explanation of Plate 1 is affected by a mistake in Fig. 13.
Here is the correct caption:

EXPLANATION OF PLATE 1

- Fig. 1 - *Liliosphaeridium intermedium* (Eisenack, 1976) emend. Playford *et al.*, 1995. CPT701071-01; slide DA46bis/tot1, EF: G45; Daping, South China.
- Figs. 2, 3 - *Liliosphaeridium hypertrophicum* (Eisenack, 1976) emend. Playford *et al.*, 1995: 2) CPT202031-04; slide Tt1car40-1504m/>50.2, EF: U49; Tunisia. 3) CPT109004-6; slide SRB732305/tot1, EF: B4-Z35/4, Sart-Bernard, Belgium.
- Figs. 4 - 5 - *Liliosphaeridium kaljoi* Uutela & Tynni, 1991 emend. Playford *et al.*, 1995: 4) CPT 202031-01; slide Tt1car40-1504m/>10.1, EF: O48/4-O49/3; Tunisia. 5) CPT202031-02; slide Tt1car40-1504m/>50.1, EF: K30/1; Tunisia.
- Fig. 6 - *Pachysphaeridium* sp.: CPT701053-05; slide DA50>50.5, EF: G40; Daping, South China. x1000.
- Figs. 7, 8 - *Peteinosphaeridium bergstroemii* Staplin, Jansonius & Pocock, 1965 emend. Playford *et al.*, 1995: 7) CPT105110-01; slide Atsu1a/>10.1, EF: Q21; Sueve, Spain. 8) CPT105110-06; slide Atsu1a/Sem5; Sueve, Spain. Detail of a process; x4000.
- Figs. 9, 12 - "*Peteinosphaeridium*" *macropylum* s.l. (*sensu* Tongiorgi *et al.*, 1998a): 9) CPT701077-01; slide DA50.1/tot.1, EF: D32/2-D33/1; Daping, South China. 12) CPT202031-04; slide Tt1car40-1504m/>50.2, EF: T49; Tunisia.
- Fig. 10 - *Peteinosphaeridium velatum* Kjellström, 1971 emend. Playford *et al.*, 1995: CPT105110-04; slide Atsu1a/Sem3; Sueve, Spain.
- Fig. 11 - *Peteinosphaeridium dissimile* Górka, 1969: CPT701053-01; slide DA50/>50.1, EF: R32/3; Daping, South China.
- Figs. 13 - 14 - *Peteinosphaeridium? hystrioreticulatum* (Eisenack, 1938) Eisenack *et al.*, 1995: 13) CPT701071-01; slide DA46bis/tot.1, EF: V47/3-Z48/1; Daping, South China. 14) CPT701053-26; slide DA50/Sem16; Daping, South China.

All figures x1000, except where otherwise stated.