

**IV FIELD CONFERENCE OF THE  
CAMBRIAN STAGE SUBDIVISION WORKING GROUP**

**INTERNATIONAL SUBCOMMISSION ON CAMBRIAN  
STRATIGRAPHY**

**SWEDEN, 24-31 AUGUST 1998**

**ABSTRACTS**



**edited  
by  
Per Ahlberg, Mats Eriksson and Ingela Olsson**

**Lund Publications in Geology  
No. 142**

**LUND 1998**

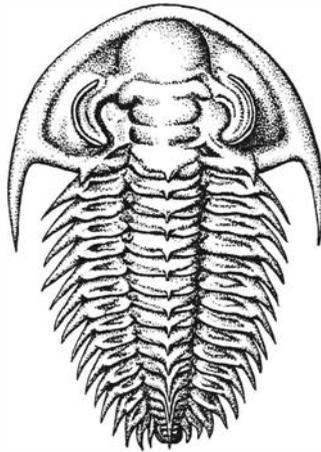


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## **Cambrian Trilobites of Laurentian and Extra-Laurentian Aspect from Shelf-Marginal Lithofacies and Native Terranes: Implications for Palaeogeography, Palaeo-oceanography, Palaeoclimate, and Intercontinental Correlation**

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During much of the Cambrian, trilobites near the shelf margin of Laurentia were evidently segregated into biofacies representing relatively shallow epicontinental sea environments and relatively deeper shelf through basinal environments (Cook & Taylor 1975; Babcock 1994). Trilobites of Laurentian aspect inhabited epicontinental seas and, at the species level, tended to be endemic to Laurentia. At the genus level, some taxa (notably dorypygids) were pantropically distributed. Trilobites of extra-Laurentian aspect that are known from shelf-margin lithofacies or native terranes tended to have wider latitudinal and depth distributions.

The shared distribution of non-agnostoid taxa, particularly at the species level, between Laurentia and other major tectonic blocks poses important questions regarding palaeo-oceanography, and palaeoclimate, while also providing data for testing palaeogeographic models and assessing intercontinental biostratigraphic correlations. Various workers have attributed disjunct trilobite biofacies distributions around the shelf margin of Laurentia to water temperature or other factors that co-vary with depth. Trilobites of Laurentian aspect are inferred to have been restricted to relatively warm, shallow shelf seas, whereas trilobites of extra-Laurentian aspect are inferred to have been restricted to relatively cool seas of variable depths (Babcock 1994). The presence of a thermocline that segregated warm water and cool water biofacies has been postulated for the Early Cambrian (Theokritoff 1985), Middle Cambrian (Babcock 1994; St. John & Babcock 1997), and Late Cambrian (Cook & Taylor 1975). Although the idea of a thermocline that governs trilobite distributions is an attractive idea, it implies the presence of continental glaciation in a polar setting. Continental glaciation may have occurred in southern Gondwana, but direct evidence for it in the form of tillites, glacial striations, dropstones, etc., is lacking. Lack of direct evidence for glaciation during the Cambrian may be due to erosion.

Regardless of whether direct evidence of continental glaciation during the Cambrian exists, disjunct trilobite distributions near the Laurentian shelf margin provides a means of testing palaeogeographic models and constraining the geologic history of terranes (Jell 1974; Babcock 1994). Biofacies segregation, in addition to other lines of geologic evidence (distribution of carbonate deposits, palaeomagnetic data, etc.) supports a low-latitude position for Laurentia. Certain trilobite species from deep water, offshore sites provide clues to which tectonic blocks were in relatively close proximity to Laurentia, and which may have been conjugate rift partners with that paleocontinent following the breakup of Rodinia. For example, taxa of Baltic aspect from North Greenland (Babcock 1994) suggest that one part of the Innuitian margin of Laurentia was a rift partner with Baltica. Likewise, taxa of Siberian aspect from southwestern Alaska (Palmer et al. 1985; St. John & Babcock 1997) suggest that another part of the Innuitian margin was a rift partner with Siberia.

As an increasing number of shelf-margin faunas from Laurentian rocks or native tectonostratigraphic terranes are described, the number of moderately widespread non-agnostoid trilobites that have value for intercontinental correlation (see St. John & Babcock

1997) is increasing. Such information, which at present is best between tectonic blocks inferred to be rift partners, is an important supplement to other intercontinental correlation tools.

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## Cambrian Trilobite Biostratigraphy of South Korea: Retrospect and Prospect

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Trilobites are among the most abundant and diverse fossils in Korea. They occur primarily in the Cambro-Ordovician sedimentary rocks, the Joseon Supergroup, exposed in the central-eastern part of the Korean Peninsula. The sediments consist predominantly of carbonates with lesser amounts of sandstones and shales. The supergroup has been conventionally differentiated into five types of sequences based on their unique lithologic successions and geographic distributions: the Duwibong, Yeongweol, Jeongseon, Pyeongchang, and Mungyeong sequences. The Duwibong, Yeongweol, and Mungyeong sequences are fossiliferous, whereas no trilobites have been reported from the Jeongseon and Pyeongchang sequences. Interestingly enough, the Duwibong and Yeongweol-Mungyeong sequences are known to share no Cambrian trilobite species.

The contrasting faunal contents between the Duwibong and Yeongweol-Mungyeong sequences resulted in two separate biostratigraphic schemes for the Cambrian of South Korea. Fourteen biozones were recognized in the Duwibong sequence, whereas twelve zones in the Yeongweol-Mungyeong sequences (Kobayashi 1966): in ascending order, the *Redlichia*, *Elrathia*, *Mapania*, *Bailiella*, *Megagraulos*, *Solenoparia*, *Olenoides*, *Stephanocare*, *Drepaneura*, *Prochuangia*, *Chuangia*, *Kaolishania*, *Dicyites*, and *Eoorthis* Zones in the Duwibong sequence, and the *Redlichia*, *Palaolenus*, *Ptychoparia-Dawsonia*, *Kootenia*, *Yabeia*, *Metagraulos*, *Tonkinella*, *Eochuangia*, *Iwayaspis*, *Olenus*, *Hancrania*, and *Aphaeorthis* Zones in the Yeongweol-Mungyeong sequences. These biostratigraphic schemes were employed in Korea without serious criticism until quite recently (Lee 1987). However, when these zones are compared with those from other parts of the world, some discrepancies are easily recognized.

The Cambrian trilobite faunas of the Duwibong and Mungyeong sequences have not been studied since early 1960's, while those of the Yeongweol sequence have been examined in detail during the past decade. The Yeongweol sequence Joseon Supergroup consists of five formations: the Sambangsan, Machari, Wagog, Mungog, and Yeongheung formations in ascending order. The lower three formations were assigned to the Cambrian and the upper two to the Ordovician. Although Kobayashi (1961) established the *Yabeia* and *Metagraulos* Zones within the Sambangsan Formation, we failed to locate the *Yabeia* Zone, but instead recognized the *Metagraulos sampoensis* and *Megagraulos semicircularis* Zones of Middle Cambrian age. The Machari Formation is well known to yield diverse trilobite faunas of Middle to Late Cambrian age, which constitute the so-called Machari fauna (Kobayashi 1962). The *Tonkinella* Zone at the basal part of the Machari Formation is the only known zone representing the Middle Cambrian within the formation and has yet to be studied. Recently, eight Late Cambrian trilobite zones were proposed for the middle part of the formation: the *Glyptagnostus stolidotus*, *Glyptagnostus reticulatus*, *Proceratopyge tenue*, *Hancrania brevilimbata*, *Eugonocare longifrons*, *Eochuangia hana*, *Agnostotes orientalis*, and *Pseudoyuepingia asaphoides* Zones in ascending order (Lee et al. 1997). The Wagog Formation is poorly fossiliferous, but has been known to represent the uppermost Cambrian.

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## New stratigraphic data from SE-Scania; preliminary results of a new drill-hole in the Andrarum area (Fågeltofta-2)

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In connection with an ongoing research project on the Baltoscandian Alum Shale Formation (Middle Cambrian-Tremadocian) a new fully cored shallow drill-hole has been made at Fågeltofta in SE Scania, Sweden. The site is situated about 7 km SE of the well known Alum Shale quarries at Andrarum. The new drill-hole was made immediately north of the old Komstad Limestone quarry east of the Fågeltofta village, about 75 m from a communal deep waterwell (referred to as Fågeltofta-1). Fågeltofta-2 is 122 m deep and penetrated the Komstad Limestone (L. Ordovician/Arenig), Tøyen Shale (L. Ordovician/Arenigian), Alum Shale (Middle Cambrian-Tremadocian), Gislöv Fm (Lower Cambrian) and ended in the uppermost part of the Rispebjerg Sandstone (L. Cambrian).

A preliminary biostratigraphy has been established by examination of fossils on the core surfaces available (see Table 1). No further splitting of the core has been undertaken as yet. Hence the zonation is coarser than that of the cores previously described by Westergård (1942, 1944). In the next phase of the project the *Peltura* interval will be investigated. The main purpose is to provide more precise biostratigraphic data and analyse the palaeo-environmental requirements of the various trilobites occurring within the zone. Comparison will be made with other Scanian drill-cores as well as with faunal data from central Sweden. It is hoped that the biofacies analysis can provide a basis for reconstruction of sea-level changes during the *Peltura* highstand.

Table 1. Stratigraphy of Fågeltofta-2 (datum is ground level).

Age	Biozone		Level in core	Remarks	
Quaternary	Overburden	Holocaen	0,00 - 4,78 m	Till. Not cored.	
E. Ord.; Aren.	-	L.Vk	4,78 - 14,10 m (9,32 m)	Komstad Limestone. Many cephalopods.	
		L. Vk	14,10 - 15,13 m (1,03 m?)	Tøyen shale. Predominantly limestone beds.	
		U.Hu	15,13 - 17,79 m (2,66 m?)		
		L.Hu	17,79 - 21,25 m (3,46 m?)	Bentonite at 21,15 m ( <i>A. murrayi</i> Zone)	
E. Ord.; Trem.	<i>Rhadinopora</i>	D 3	21,25 - 21,32 m (0,07 m?)	" <i>Dictyonema</i> " Shale. Zonal division tentative.	
		D 2	21,32 - 31,32 m (10,0 m?)		
		D 1	31,32 - 38,05 m (6,73 m?)	No <i>Ceratopyge</i> Limestone or shale observed.	
		E	38,05 - 49,95 m (11,90 m)	"Olenid" shale : 93,36 - 38,05 m (55,31)	
E. Cambrian	<i>Acerocare</i>	V I	55,30 - 61,70 m (6,40 m)	Including 55,30-49,95 (5,35 m) fossil free interval in zone Vc.	
	<i>Peltura scarab.</i>	Vc			
	<i>Peltura minor</i>	Vb	A	61,70 - 62,19 m (0,49 m)	
	<i>Propeltura praecursor</i>	Va	L	62,19 - 63,09 m (0,90 m)	No age diagnostic fossils found in zone Va
	<i>Letoplastus</i>	IV	U	63,09 - 66,95 m (3,86 m)	
	<i>Parabolina / Orusia</i>	III	M	66,95 - 75,22 m (8,27 m)	
	<i>Olenus</i>	II		85,12 - 87,61 m (2,49 m)	Including 85,12 - 75,22 (9,9 m) fossil free interval in zone II.
M. Cambrian	<i>Paradoxides forchhammeri</i>	C 3	H	89,66 - 93,36 m (3,70 m)	
		C 2	A	93,36 - 96,30 m (2,94 m)	Andrarum Limestone
		C 1	L	96,30 - 97,27 m (0,97 m)	
	<i>Paradoxides paradoxissimus</i>	B 4	E	97,27 - 98,81 m (1,54 m)	No age diagnostic fossils found i zone B3
		B 3		98,81 - 103,19 m (4,38 m)	
		B 2		103,19-107,61 m (4,42 m)	
		B 1	F	107,61-110,69 m (3,08 m)	
	<i>Eccaparadoxides oelandicus</i>	A 2	M.	110,69 - 111,82 m (1,13 m)	Exsulans Limestone
		A 1		111,82-116,20 m (4,38 m)	Alum shale. No age diagnostic fossils
	Major fault			116,20 m : By comparison with Fågeltofta-1 assumed 5-7 m Alum Shale is faulted out.	
E. Cambrian	<i>P. linnarssoni</i>	Gislöv Fm	116,20-120,95 m (4,75 m)	Gislöv Fm. Upper fossiliferous limestone. Little faulted out.	
	<i>H. kjerulf group</i>	Gislöv Fm			
	<i>H. inusitata</i>	Rispe.Fm	120,95-121,75 m (0,8 m)	Rispebjerg Sandstone. No age diagnostic fossils found.	

## Two cases of dimorphism in *Paradoxides* species (Trilobita) from Spain

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Sexual dimorphism is very common in recent and fossil arthropods. It is frequently observed in their chitinous exoskeletons, for example, in ostracods and insects. Sexual dimorphism is more difficult to recognize in trilobites because of the lack of direct comparison with recent arthropods and because of the poor morphological and biochronological knowledge of many taxa. References to possible dimorphism in trilobites include: Cambrian (Hu 1971; Liñán & Gozalo 1986); Ordovician (Hughes 1969; Owen & Bruton 1980); Devonian (Eldredge 1973; Campbell 1977); and Carboniferous (Clarkson 1969). However, to many authors dimorphism in trilobites is not yet satisfactorily demonstrated (see Whittington 1997).

In the Murero Formation (Middle Cambrian) of the Iberian Chains (Spain), Liñán & Gozalo (1986) reported the presence of some co-existing *Paradoxides* specimens with similar cranidia, but with several thoracic and pygidial differences. They concluded that this might be interpreted as an example of sexual dimorphism.

The objective of this work is to analyze possible dimorphism in the trilobites *Eccaparadoxides sequeiroi* Liñán & Gozalo, 1986 and *Eccaparadoxides brachyrachis brachyrachis* (Linnarsson, 1883) in the light of new material collected from the Rambla de Valdemiedes 1 and 2 sections.

\* The dimorphism in *Eccaparadoxides sequeiroi* is characterized as follows:

Morphotype A: The thorax is relatively homogeneous but progressively widens backward; only the 3rd segment is micropleural. The pygidium is short and the relationship  $La/Lp$  (length of axis/length of pygidium)  $\approx 7/10$ .

Morphotype B: The thorax is not homogeneous; the first two segments are macropleural and the second one is longer than the first; the next three segments are micropleural; and the other segments become progressively wider backward. The pygidium is long, with  $La/Lp \approx 1/2$ .

\* The dimorphism in *Eccaparadoxides brachyrachis brachyrachis* is characterized as follows:

Morphotype A: The thorax is relatively homogeneous and widens backward. The first and second segments are increasingly macropleural. The pygidium is short, with  $La/Lp > 1/2$ .

Morphotype B: The thorax is not homogeneous. The first and second segments are increasingly macropleural. The segments between the 3rd and 9th or 10th are micropleural but becomes progressively wider backward. The pygidium is long, with  $La/Lp < 1/2$ .

Because *Eccaparadoxides sequeiroi* has been interpreted as the ancestor of *E. brachyrachis brachyrachis*, and the dimorphism of both species has a similar pattern, we conclude that forms A and B may be interpreted as cases of sexual dimorphism.

*Acknowledgements.*- We wish to thank Dr. Allison R. Palmer for suggestions of the English version. We acknowledge support from the Dirección General de Enseñanza Superior, Project PB96-0744.

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## The Richest of Sinsk Lagerstätten (Lower Cambrian, Siberian Platform)

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The richest of the Sinsk Lagerstätten, which is coined the "algal lens", occurs in the basal part of the Sinsk Formation (Botoman Stage, *Bergeroniellus gurarii* Zone) at the Lena River, where Russian stratotypes of the Lower Cambrian stages are established on the Siberian Platform. The Sinsk Lagerstätten consist of several minor accumulations of algae of about 5 square meters in total area. Besides algae, various invertebrates are represented in the "algal lens". These organisms are preserved either as complete articulated skeletons (trilobites, sponges, palaeoscolecids), as phosphatised integuments ("soft-bodied" trilobites, bradoriids), or as differently preserved cuticles expressed by changes in rock colour (algae, eldoniids, palaeoscolecids, trilobites, lobopodians, a probable *Tuzoia*, possible wiwaxiids, and unidentified arthropod fragments). In addition, acritarchs, brachiopods (both lingulates and articulates), and probable pterobranchs are present. The primary skeletal composition seems to be less altered in the latter groups. The faunal and floral composition of the "algal lens" differs significantly from the general composition (dominated by trilobites and lingulates) of the Sinsk Formation. Some features of transportation are observed in the fossil association of the "algal lens". It is suggested that the "algal lens" was formed nearby a reefal bank as a result of transportation of most of its biotic components from a shallow photic area to the deeper aphotic and dysaerobic part of the marine basin coupled with fast burial processes.

The Russian Foundation for Basic Researches, grants 96-04-48372 & 96-05-64224, are acknowledged.

## The cause of the biomeres – a comparison with Silurian oceanic cycles

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At least 11 extinction events are now known during the Silurian. Each of these affected most higher taxa. The strongest events resulted in that as many as over 80% of the global number of marine species in one or more of studied groups were hit. These events were a part of a regular change between two stable oceanic states – primo and secundo – and interspersed unstable oceanic states – events. Each event includes a number of datum points when extinctions took place (across a bedding plane). The best known Silurian event is the Ireviken Event (I.E.) spanning the beginning of the Wenlock.

Comparisons between the end of the Symphysurinid Biomere (the S.B.e.e.) in the Ibex section (Ethington et al. 1987) and the I.E. reveal detailed similarities, e.g. **1.** An overlap of pre- and post-event taxa during parts of the event; **2.** A stepwise character (the S.B.e.e. includes at least three datum points and the I.E., which has been studied with more closely spaced and larger collections yielding more taxa, ten datum points); **3.** Trilobite faunal changes are more concentrated (to Datum 2 during the I.E. and the second datum during the S.B.e.e.) than those of conodonts; **4.** The final event fauna had a lower diversity than early event and post event faunas; **5.** The probable duration of the event (reflected in the thickness of the strata: the S.B.e.e. is at least c. 8 m in the Ibex section and at least 3 m in the Chandler Creek Section in Oklahoma, the I.E. is c. 12.8 m in the Luskliint 1 - Lickershamn 2 composite section on Gotland, Sweden, and between 7.3 and 8.4 m in the Vikki core from Estonia); **6.** The order of conodont extinctions is the same from section to section (the S.B.e.e. from Utah to Oklahoma; the I.E. from Alaska to eastern North America to Europe to N.S.W. in Australia; i.e. not the the kind of controversial last records as described from the K/P (K/T) event); etc.

The model developed to understand the changes in faunas, lithologies, stable isotope ratios, and sea level derives these changes as consequences of coupled oceanic, atmospheric and climatic changes. The most important aspect of this model is that it permits predictions of yet undiscovered changes to look for and to verify. One of the verified predictions is: the characters of the events differ considerably depending on whether it followed after a primo or a secundo episode. The Ireviken Event was a primo-secundo event. The detailed similarities show that the S.E.e.e. also followed after a primo episode and probably was succeeded by a secundo episode. As developed in studied Silurian sections, primo episodes are characterized by more argillaceous sediments in marginal carbonate areas, and secundo episodes by an expansion of the area with reefs and other carbonate deposition. During the events each datum was caused by a brief stop in the deep upwelling resulting in a decrease in the primary planktic production. One consequence was famine among planktic larvae, holoplanktic taxa and all those depending on any of these.

Applying this model to the biomeres and to their boundaries would require: **1.** Recognition and separation of a distinct event interval (from less than 50 000 to 200 000 years in the Silurian). At least a part of the event would consist of those controversial intervals which have been placed both in the preceding and in the succeeding biomere. **2.** Existing high resolution trilobite data must be supplemented with studies of the pattern in the changes in prevailing lithologies in order to separate primo and secundo events. If all biomere boundaries were due to primo-secundo events, then each biomere started with a secundo episode and ended with a primo episode. However, one or more of the hitherto described biomere

boundaries may instead have been due to secundo-secundo or to secundo-primo events which also could cause very extensive extinctions. These two kinds of events differ from primo-secundo events in e.g. that the most severe part of the event is found early during the event.

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## **A preliminary study of the Cambrian strata in Albjära-1 (western Scania, Sweden)**

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A 238 m deep, fully cored drill-hole, Albjära-1, has been made in western Scania, southern Sweden. The drilling penetrated the Middle Ordovician-Lower Cambrian *Dicellograptus* Shale (lower main part of unit only), Upper *Didymograptus* Shale, Komstad Limestone, Tøyen Shale Formation, *Ceratopyge* Limestone, Alum Shale Formation and ended in the upper part of the Gislöv Formation. The main focus of the present study is on the Alum Shale (M. Cambrian-Tremadoc). The encountered succession below level 135 m in the core comprises *Ceratopyge* Limestone (0.3 m), Alum Shale (79 m, of which the "*Dictyonema* Shale" accounts for approx. 7 m), *Andrarum* Limestone (1.2 m), Alum Shale (14.2 m), *Exsulans* Limestone (0.6 m), Alum Shale (2.8 m) and Gislöv Formation (4.8 m). A first phase of the study includes a lithologic description and the establishment of a preliminary biostratigraphy of the succession. A second, future phase of the work will focus on the evolution and palaeoecology of trilobites in the *Olenus* interval (Upper Cambrian). Repeated series of changes in the shape, from a narrow to a wide skeleton, in the trilobite genus *Olenus* was recognized by R. Kaufmann in the 1930's. These findings were published as an example of iterative evolution. The aim of my study will be a modern documentation of the iterative morphological changes among *Olenus* species as well as a detailed study on the distribution of trilobites. Based on that, I will hopefully be able to show whether the morphological changes are a result of evolution or relate to ecophenotypic variability.

## The Cambrian acritarch biodiversity and the Lower-Middle Cambrian boundary in Baltica and at the margin of Gondwana

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The Cambrian System is recognized by a profound biotic diversification that is evidenced by the appearance of most extant metazoan phyla and an exponential radiation among photoautotrophic protists. The biodiversity of acritarchs is of particular significance because, being primary producers, they affected the entire food chain of marine ecosystems. The recognisable changes in phytoplankton assemblages reflecting major biotic events such as radiations, decline in diversity and extinctions resulted in establishing four formal acritarch zones in the Lower Cambrian and several informal zones in the Middle and Upper Cambrian. The Lower-Middle Cambrian siliciclastic and carbonate successions have been well-studied in various depositional settings and faunal provinces in shelves of Baltica (the East European Platform and Baltoscandia), Gondwana (Iberia, Avalonia, Morocco), and Laurentia (Greenland). Throughout Early Cambrian times acritarch diversity progressively increased, following the abrupt radiation at the Vendian-Cambrian boundary. The acritarch records derive from various environments of extending shelf basins rich in nutrients and well-oxygenated surface layers. The conditions were those of a prograding transgression and sea level rise. The highest taxonomic diversity of phytoplankton is observed within the *Holmia kjerulfi* Biozone and it coincides with the maximum flooding of the Early Cambrian transgression. Subsequently, acritarch diversity declined in the *Protolenus* Biozone due to the initiation of a severe extinction event, with a contemporaneous moderate rate of surviving species and a very low rate of speciation. A substantial number of species, however, survived (almost 50% of the global record) as it is evidenced by their ranges surpassing the Lower-Middle Cambrian boundary. The low diversity of phytoplankton in the *Protolenus* Biozone corresponds to the shallowing event that ended in some areas with the Hawke Bay regression and a hiatus separating Lower and Middle Cambrian successions in North America and in some areas of Baltoscandia (southern Norway and southern Sweden). A significant radiation is documented in the succeeding Middle Cambrian *Acadoparadoxides oelandicus* Biozone. The percentage of the first appearing species in the acritarch assemblage of this time interval was higher than at any other time in the Cambrian. This radiation was of the same magnitude as those at the beginning of Cambrian and in the *Holmia kjerulfi* Biozone, but contrary to them, it was preceded by and contemporaneous with the two-stage extinction event. The two-stage extinction began in the *Protolenus* Biochron and continued in the *A. oelandicus* Biochron. The first stage of the crisis (*Protolenus*) was less drastic because it was paralleled by a moderate rate of surviving species, while the second stage (*A. oelandicus*) was more severe as it was characterized by the highest rate of extinction and the lowest rate of surviving species in the entire Cambrian Period. This extinction is considered a two-stage event rather than two individual extinctions because of the estimated short time interval separating both episodes of the crisis. The pattern of acritarch changes is consistent in all mentioned areas, and it is taken to reveal the true global bio-event marking the Lower-Middle Cambrian boundary that is placed slightly below the trilobite-based *A. oelandicus* Zone in Baltica and the *Paradoxides (Acadoparadoxides) mureoensis* Zone in Gondwana (Spain). The *A. oelandicus* Biochron was the time of the most significant turnover of phytoplankton during the Cambrian. This happened during the transgression recorded by the overstepping *A.*

*oelandicus*/*P. mureroensis* strata, which continued uninterrupted from early Cambrian times as evidenced by sedimentologically continuous successions across the Lower-Middle Cambrian boundary in Poland (the Lublin Slope of the East European Platform), central Sweden (Östergötland, Gotland, Gotska Sandön), and Spain (the Iberian Chains).

## Morphology of agnostids in time and space

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The aim of this paper is to analyze the dynamics of the appearance of some morphological characters in the order Agnostida (Trilobita). The following characters of the pygidium are considered: presence or absence of the first and second transaxial furrows (F1, F2), the degree of development of the axial furrow (M) which can be complete (M1-3), effaced around posteroaxis (M1-2), effaced to F1 (M1) or completely effaced (M0). The table shows the number of new genera with different combinations of M and F that appeared during different time intervals. Most genera that appeared during the Middle Cambrian had pygidia with effaced transaxial furrows. At the end of the Mayaian age, forms with two transaxial furrows dominated. The effaced axial furrow camouflages these two evolutionary trends, because the effacement of the axial furrow usually leads to the disappearance of the transaxial furrows. It is noteworthy that during the Late Cambrian genera with the axial furrow partly effaced but with two transaxial furrows appeared. According to modern data, there were no such genera during the Middle Cambrian.. The first agnostids appeared in the basins of the eastern part of North America, Siberia and East Europe. The Siberian basins are characterized by the most rapid origination of genera, by the highest morphological diversity, and by the largest number of first occurrences of cosmopolitan genera. The cosmopolitan genera with effaced F1 and F2 appeared only in Siberia. In the second half of the Amgaian age new cosmopolitan genera appeared mostly in East Europe. In the same region there was the highest morphological diversity of new genera. By this time the new cosmopolitan genera with effaced F1 and F2 appeared everywhere. On the contrary, the cosmopolitan genera with well developed F1 and F2 appeared only in East Europe. At the end of Mayaian and in the Ayusokkanian age the cosmopolitan genera appeared mostly in Australia and western North America. The rate of origination was higher in Australia, where all morphological series of pygidia were also present. The cosmopolitan genera with well developed F1 and F2 now appeared everywhere. During the Sakian and Aksayan ages both the origination of cosmopolitan genera and the highest morphological diversity were located in Australia and China. This study shows that the centers of diversification were characterized by the origination of cosmopolitan genera. The morphology of these genera tended to become dominant during the next epoch. At the same time genera with dominant morphology started to appear everywhere, while in the new center of diversification new dominant morphology formed.

Є3sak-aks

	M1-3	M1-2	M1	M0
F1,F	7	1		
F1				
F2		2		
F0		2	1	1

Є2may3 - Є3ay2

	M1-3	M1-2	M1	M0
F1,F2	12	2		
F1				
F2	1	1		
F0	6	4		1

Є2amg2 - may2

	M1-3	M1-2	M1	M0
F1,F	9			
F1				
F2	1			
F0	14	1	1	2

Є1tn3 - Є2amg1

	M1-3	M1-2	M1	M0
F1,F2	6			
F1				
F2				
F0	4			1

## **Cambrian sea-level changes in Baltoscandia**

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The deeply peneplanised Baltoscandian craton was transgressed in the early Early Cambrian, and on a first order level the sea-level rose all through the Cambrian to reach a maximum in the Early Tremadoc. The craton was almost totally flooded from the late Early Cambrian onwards, a circumstance which led to extreme sedimentary starvation of the epicontinental sea.

The lithofacies distribution shows an overall simple decrease in grain size with increasing depth. A tidal zone with sand characterised the nearshore area. Basinwards this facies was fringed by a silt belt, probably ranging down to about or a little above the storm wave base (estimated at about 40-50 m of depth), below which deposition of mud took place. The latter lithofacies, known as the Alum Shale, ranged to the shelf break (estimated at about 150 m water depth) and was denoted by dysoxic-anoxic depositional conditions. It appears that the oxygen content of the Cambrian sea was lower than present day levels. Glauconite formation appears to have been concentrated at the sand- and silt-belt transition, i.e. at very shallow water. This may be another result of a low oxygen level. Because of the sedimentary starvation sea-level falls were not accompanied by progradation and lowstands were characterised by wave-driven submarine erosion; profound lowstands were accompanied by deposition of condensed shallow cold-water bioclastic carbonates. Each limestone intercalation typically overlies an unconformity formed during the initial phases of the sea-level lowering. The midshelf was characterised by sedimentary by-pass due to numerous erosional events associated with an oscillating sea-level.

The Alum Shale contains an abundant trilobite fauna specialised to dysoxic conditions, and a range of biofacies characteristic of different oxygen levels is recognised. Provided the palaeo-oxygen levels in the bottom waters reflect the general depth (decreasing oxygen levels with increasing depth) sea-level changes can be reconstructed for the black shale intervals using biofacies data. Available sedimentary and geochemical information corroborate the resulting sea-level curve.

## The Lower - Middle Cambrian boundary in Poland

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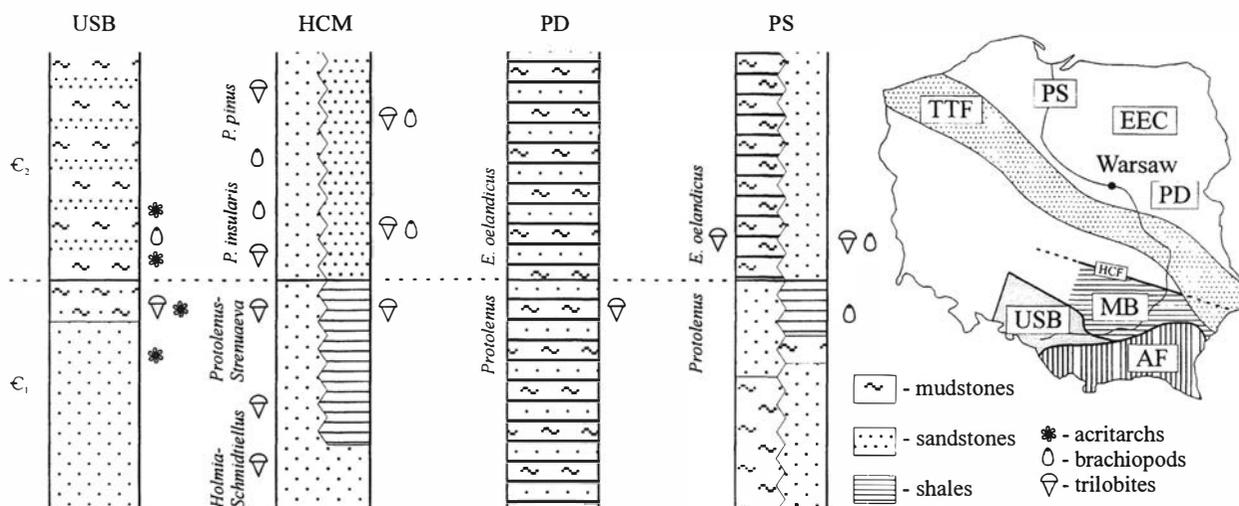
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The Lower and Middle Cambrian deposits in Poland occur either in outcrops (in the southern part of Holy Cross Mts. (HCM) representing the northern margin of the Malopolska Block) or have been noted in other areas in boreholes within the East European Craton - Peribaltic Syncline (PS) and Podlasie Depression (PD) and the Upper Silesian Block (USB). The sequence is typically developed as clastic sediments with a varied fossil content, indicating the Acado-Baltic trilobite province.

The Cambrian of the HCM, comprising thick formations of sandstones and shales (Orlowski 1992), is exposed in almost half of the entire area. The Lower and Middle Cambrian is present only in the southern part, i.e. within the northern margin of the Malopolska Block. The southern part is separated from the northern part by the Holy Cross Fault (HCF). The uppermost Lower Cambrian is developed either as sandstones with *Ellipsocephalus sanctacrucensis* and *Strenuaeva orlovinensis* in the western part of the area, or as shales with *Protolenus (P.) expectans*, *Serrodiscus primarius* and *Strenuaeva trifida* in the eastern part of the region. These trilobites indicate the *Protolenus - Strenuaeva* Biozone of the Lower Cambrian. The deposits pass into sandstones with *Paradoxides oelandicus*, *P. insularis* and *P. pinus*, as well as other trilobites, body fossils and trace fossils of the *Eccaparadoxides oelandicus* Biozone (Orlowski 1985a, 1985b).

The PS and PD represent depressions within the East European Craton infilled with Palaeozoic deposits. The Cambrian has been documented in several boreholes. In the PS the uppermost Lower Cambrian is represented either as unfossiliferous sandstones or as mudstones passing into shales yielding the brachiopods *Acrothele prima* and *Acrothele gemmula*. The mudstones and shales correspond to palaeontologically determined (by trilobites) Lower Cambrian shales from other areas, e.g. the PD. These are overlain by mudstones or by sandstones containing *Paradoxides pinus*, *Ptychagnostus (T.) praecurrens*, *Bailiella emarginata*, *Solenopleura cristata*, *Paradoxides sjogreni*, *Ellipsocephalus polytomus* and *Trematobolus pristinus*, indicative of the *Eccaparadoxides oelandicus* Biozone. In turn, mudstones and sandstones composing the Lower - Middle Cambrian transition in the PD contain only trilobites suggestive of the *Protolenus* Biozone of the uppermost Lower Cambrian. The upper part of the sequence is correlated with the Middle Cambrian of the Peribaltic Syncline based on lithological features (Lendzion 1976, 1983).

The USB occurring south of the Malopolska Block contains clastic deposits of Early and Middle Cambrian age, confirmed by a few trilobites and acritarchs. The Lower Cambrian acritarchs include different species of *Skiagia*, followed by *Heliosphaeridium dissimulare*, *Granomarginata squamea*, *Multisphaeridium dendroideum* and *Estiastra minima*. Trilobites are present only in shales of the Goczalkowice IG 1 borehole and include *Schmidtiellus panowi*, *Ellipsocephalus nordenskjoldi* and *Strenuaeva primaeva*. Middle Cambrian acritarchs have so far been traced only in the Sosnowiec IG 1 borehole and include *Adara alea*, *Eliasum llaniscum*, *Micrhystridium notatum* and *Cristallinum cambriense* (Bula & Jachowicz 1996; Bula et al. 1997).



Tentative correlation of the Lower - Middle Cambrian boundary in Poland. Explanations: USB - Upper Silesian Block, MB - Małopolska Block, PD - Podlasie Depression, PS - Peribaltic Syncline, EEC - East European Craton, TTF - Teisseyre-Tornquist Zone, AF - Alpine Front, HCF - Holy Cross Fault.

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## Late Middle-Late Upper Cambrian chronostratigraphy of China

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The traditional Chinese late Middle-Upper Cambrian stages, including the Changhsian, Kushanian, Changshanian and Fengshanian, were introduced on the basis of the same-named lithostratigraphic formations of platform facies in North China (Shandong, Hebei). Recent studies on the Cambrian in China prove that the endemic trilobite succession, established previously on a generic level for each of the existing stages, is difficult to consider as a standard for the precise interregional or international correlation. In addition, the lower and upper boundaries are poorly defined, and the concept of the stages is not clear. In view of chronostratigraphy, we suggest that the old Chinese stages should be abandoned and replaced by new chronostratigraphic units.

Four new, stratotype-defined Cambrian stages, the Wangcunian, Youshuiian, Waergangian and Taoyuanian Stages, have been proposed for the late Middle through the Upper Cambrian of China. They are all erected according to well successive slope facies faunas. The base of each stage is defined by its lower boundary, while the top is defined by the lower boundary of the succeeding stage. All the boundaries are defined by the first appearance of characteristic agnostoid species.

The Wangcunian is named after Wangcun town in the County of Yongshun, northwestern Hunan. The lower boundary is placed at the base of the *Ptychagnostus punctuosus* Zone and defined by the first appearance of the index species in the Wangcun section. It is equivalent to the base of the Australian Undillan, the base of the Kazakhstan Mayanian (or the base of the Siberian *Anoplenus henrici* Zone, within the Mayanian), or the base of the *P. punctuosus* Zone in Scandinavia and North America.

The Youshuiian is named from the Youshui River in the County of Yongshun, northwestern Hunan. Its lower boundary is drawn at the base of the *Linguagnostus reconditus* Zone, which is defined by the first appearance of *L. reconditus* in the Wangcun section. This level is close to the base of the Swedish *Agnostus pisiformis* Zone of the Maentwrogian, and it is proposed to define the global Middle-Upper Cambrian boundary.

The Waergangian, is named after Waergang Village in the County of Taoyuan, northwestern Hunan. The lower boundary is at the Waergang section, defined by the first appearance of *Glyptagnostus reticulatus*. This level is recognizable elsewhere in the world.

The Taoyuanian is named after the County of Taoyuan in northwestern Hunan. The lower boundary is defined by the first appearance of *Agnostotes clavatus* in the Waergang section, Taoyuan. This level is equivalent to the base of Iverian in Australia, the base of the *Proceratopyge reticulatus* fauna (near the top of the Steptoean) in Northwest Canada, and the base of the *Pseudagnostus cartare* Zone (near the top of the Sackian) in Kazakhstan.

## Two approaches to the Cambrian Stage scale

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Recently, some members of the Cambrian Stage Subdivision Working Group suggested that certain datum planes can serve as a useful tool for the elaboration of the Cambrian stage subdivision. This suggestion follows the practise used for the establishment of the stratotype of the Precambrian/Cambrian boundary on Newfoundland. The appearance of "*Phycodes*" *pedum* above *Harlaniella podolica* was actually the only criterion for the recognition of this boundary. However, scarcity of shelly fossils, lack of possibilities for use of stable isotopic and magnetic methods, as well as extreme difficulties in finding the same succession of trace fossil assemblages in the same facies ("conspecific" trace fossils from other facies represent an ethological and ecological nonsense), makes this stratotype useless for stratigraphical practice. As a result, attempts to correlate this boundary into other regions reveal that there is a difference in amplitude of up to two stages or about 15 Ma (which is about one third of the entire Cambrian Period) according to the present radiometric calibration. The Burin Peninsula remains the only place on the planet where we are aware of the correct Precambrian/Cambrian boundary position.

The same fate inescapably awaits the datum planes recommended us for the further discussion. For instance, what is the meaning of "eodiscid trilobites of the *Serrodiscus bellimarginatus*/*Triangulaspis annio* assemblage"? Geyer & Palmer (1995, Fig. 1) clearly understands it as the first appearance of any species belonging to *Triangulaspis*, because on the Siberian Platform several *Triangulaspis* species appear in the Atdabanian *Judomia/Uktaspis* (*Prouktaspis*) Zone while *Triangulaspis annio* as well as *Serrodiscus* and alike eodiscids appear in the Botoman Stage (Rozanov & Sokolov 1984; Zhuravlev 1995). The acceptance of other suggested Early Cambrian datum planes would create even more difficulties because they are based on very restricted regional faunas. The same problem dominates when we use any other datum plane based on a single criterion. For instance, stable isotope investigations independent of other data, and without accounting for section completeness, would lead to very different correlation charts (e.g. Brasier et al. 1996, Fig. 1). The use of pure archaeocyathan assemblages without data on trilobites and other skeletal fossils also has resulted in major differences in regional correlation (cf. Siberian Platform/South Australia correlation in Debrenne et al. 1990, Fig. 64 and Zhuravlev & Gravestock, 1994, Fig. 4).

These are just a few of numerous examples of datum plane correlations. They clearly show, that we have to correlate successions of events rather than isolated arbitrary datum planes for acquisition of a better correlation. Such event successions would be available if we accept any complete and continuous stage scale (for each series at least) established within a single region rather than occasional sets of datum planes randomly scattered through the world. In conclusion, we emphasize again that the stage stratotypes have to be chosen in strata which (1) are deposited continuously (as much as possible) in a normal marine basin, (2) contain rich and taxonomically diverse fossils, (3) are suitable for application of stable isotopic and magnetic methods. The entire set of the above mentioned features have to be confined to the same section. The notorious criterion of accessibility has to be denied completely, because that application would lead to establishment of multiple regional stratotypes.

In our opinion, the only stage succession that satisfies these criteria, occurs in the middle Lena-Aldan basin on the Siberian Platform. This succession includes in ascending order, the Tommotian, Atdabanian, Botoman, and Toyonian stages. The Nemakit-Daldynian Stage can be added to this succession below the Tommotian Stage. The stratotype of this stage occurs in the Anabar area of the northern Siberian Platform, but the hypostratotype can be chosen in the eastern part of the middle Lena-Aldan basin.

The Russian Foundation for Basic Research, projects 96-05-64224, 96-04-48372 and 96-05-64130, are acknowledged.

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## Earliest arthropods and sponges in black shale sequences of Early Cambrian exhalation areas in Hunan and Guizhou Provinces, China

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Lower Cambrian black shales are distributed practically on the whole Yangtze platform. This organic rich sequence reflects an Earliest Cambrian black shale transgression which advanced from the South China Basin toward the Proterozoic platform core with its recent position in central to eastern Sichuan. This so-called Niutitang transgression ("Badaowan" event) is clearly diachronous. The organic rich sediments of the upper Shiyantou (former "Badaowan" Member) and lower Yuanshan Formations of the Kunming area (Yunnan) contain small shelly fossils (SSF) of the *Lapworthella-Sinosachites* Assemblage. An age estimate for the onlap of the black shale sequence is difficult for this area, because of a hiatus at the base and lacking SSF in the lower Shiyantou Formation. Its lower age is limited by the Nemakit-Daldynian to lower Tommotian *Siphonuchites-Paragloborilus* Assemblage of the underlying Meishucun Formation. However, in some slope profiles of the back-arc basin of central Guizhou and northern Hunan basal black cherts and black shales are interlayered with phosphates containing SSF of the Nemakit-Daldynian *Anabarites-Protohertzina* Assemblage, indicating an earlier onlap of the Niutitang transgression.

The lithology of the basal Niutitang transgression is characterized by black shales with high TOC intercalated with phosphates and dark cherts. This basal unit further contains unusual high element enrichments of Ni, Mo, Ba, V, Cr and U in a vast area spanning from Yunnan via Guizhou, Hunan to Anhui Province. At some places in northern Guizhou and northern Hunan the basal unit is terminated by one or more thin syngenetic ore debris layers, indicating hydrothermal venting during earliest Cambrian times in South China. Mass accumulation layers of bivalved arthropods occur at several hydrothermal venting localities in northern Guizhou and northern Hunan a few cm above the ore debris layers. Hexactinellid sponges existed nearby the venting sites as it is indicated by sponge spicules in the ore layers and first body imprints associated with the mass accumulations of bivalved arthropods. A Tommotian age may be assumed for these early arthropod and sponge records, predating the earliest trilobite association in China. This view is also supported by the first appearance of arthropod traces in the top part of the Nemakit-Daldynian *Anabarites-Protohertzina* Assemblage in the Kunming area (Zhu 1997). Sponge spicules and complete sponges are common in the whole black shale sequence of the Niutitang Formation in Guizhou and Hunan Provinces. Vendotaenids are far distributed in basal Cambrian black shales of Hunan, Guizhou and Hubei Provinces.

We further report an association of Chengjiang type fossils, dominated by the arthropods *Isoxys* and *Naraoia* from the *Parabadiella/Mianxiandiscus (Tsunyidiscus)* Zone of northern Guizhou. This new occurrence indicates an earlier appearance of Chengjiang type fossils in China and a distribution as far as at least 500 km apart from the Kunming area.

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## Early Cambrian archaeocyathan assemblages of Mongolia

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Four successive archaeocyathan assemblages, which embrace Atdabanian and early Botoman strata, are distinguished in Mongolian facies provinces. The earliest of them, the early Atdabanian *Alataucyathus jaroshevitschi/Tabulacyathellus bidzhaensis/Pretiosocyathus subtilis* assemblage, occurs in the Tsagaan Olom (Salaany Gol Formation) and eastern Ozernaya (Lake) provinces (Khan Tayshir Formation). Previously, its age was regarded as late Atdabanian-early Botoman (Voronin et al. 1982). However, the absence of distinct late Atdabanian-early Botoman archaeocyathan genera, abundance of species belonging to the genera *Coscinocyathella*, *Alataucyathus*, *Cambrocyathellus*, *Okulitchicyathus*, *Spinocyathus* and *Archaeopharetra*, as well as recent data on the presence of similar assemblages in the early Atdabanian strata of the Altay Sayan Foldbelt (Kotel'nikov 1995; Zhuravleva et al. 1997a, 1997b) prove its early Atdabanian age. This interpretation solves also the puzzle of the complete absence of trilobites in coeval strata. Trilobites appear in the middle Atdabanian across the Altay Sayan Foldbelt as they do in Mongolia.

The second, the middle Atdabanian *Gordonicyathus subhowelli/Inessocyathus heterospinosus* assemblage, is the most widespread and occurs through the western Ozernaya (Ak Bashi and Burgasutay formations), Ider (Sortantuin Formation), Khan Khukhiy (Ichituin Formation), Khubsugul (Egryn Gol and Khoridulin formations), and Dzida (Burgel'tin Formation) provinces of western Mongolia as well as in unnamed strata of Kerulen and South Kerulen provinces of eastern Mongolia. *Leptosocyathus*, *Taylorcyathus*, *Gordonicyathus*, *Inessocyathus*, *Formosocyathus*, and *Mikhncyathus* are common genera in the assemblage. The accompanying trilobites of the genera *Bigotinella*, *Elganellus*, *Malykania*, and *Resimopsis* indicate its middle Atdabanian age as well (Korobov 1989).

The third, the late Atdabanian *Thalamocyathus continuus* assemblage, occurs in the western Ozernaya (Ak Bashi and Burgasutay formations), Ider (Sortantuin Formation), Khan Khukhiy (Ichituin Formation), and Khubsugul (Egryn Gol Formations) provinces. *Orbicyathellus*, *Stapicyathus*, *Thalamocyathus*, and *Sagacyathus* are typical genera in this assemblage.

The fourth, the early Botoman *Irinaecyathus grandiperforatus/Clathricoscinus vassilievi* assemblage, is present in the western Ozernaya (Ak Bashi and Burgasutay formations), and Khubsugul (Egryn Gol Formations) provinces only. Possibly, it also occurs in the Zavkhan-Khungiy rivers' basin of the Tsagaan Olom Province. *Palaeoconularia*, *Kisasacyathus*, *Stillicidocyathus*, *Mackenziocyathus*, *Irinaecyathus*, *Kordecyathus*, *Ladaecyathus*, *Tegerocyathus*, *Polythalamia*, *Clathricoscinus*, *Ardrossacyathus*, *Archaeocyathus*, and *Altaicyathus* are among the characteristic genera in the *I. grandiperforatus/C. vassilievi* assemblage. This assemblage is coeval with trilobites of the genera *Neocobboldia*, *Serrodiscus*, *Redlichina*, *Erbiopsis*, and *Erbia* (Korobov 1989).

Analysis of the composition of archaeocyathan faunas indicates that Atdabanian archaeocyaths of Mongolia are typical of the entire Altay Sayan Foldbelt while the Botoman ones show a closer affinity with archaeocyaths of Tuva than with other provinces of the Altay Sayan Foldbelt.

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**Distributor:**  
**The Geolibrary**  
**Dept. of Geology**  
**Sölvegatan 13**  
**SE-223 62 Lund, Sweden**

**ISBN 91-86746-28-6**  
**ISSN 0281-1316**