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Foreword and acknowledgements

This abstract volume has been prepared for the 3rd annual meeting of the IUGS/UNESCO International Geoscience Programme Project 591 *The Early to Middle Palaeozoic Revolution*. The meeting was hosted by the Department of Geology, Lund University, in June 9–19 2013 and followed the successful annual meetings held in Madrid/Ludlow (2011) and Cincinnati (2012). The Lund conference was arranged jointly with the annual meetings of the Cambrian, Ordovician and Silurian subcommissions on stratigraphy, and included a post-conference excursion to key geological localities in Skåne, Västergötland and the Oslo Region. The conference was a focus for cutting-edge research in Lower and Middle Palaeozoic geology and palaeontology, and the presentations covered a wide range of topics from morphology and taxonomy of various fossil groups through advances in geochemistry and stratigraphy to biogeography, palaeoecology and palaeoclimatology. We would like to express our sincere gratitude to Anders Lindskog and Kristina Mehlqvist for their meticulous editing of the meeting proceedings. We are also grateful for valuable input from the organization and scientific committee associated with the meeting. We acknowledge financial support from the Swedish Research Council (grant D0013001 to MC), the Geological Survey of Sweden, the Geological Society of Sweden, the Department of Geology at Lund University, and the municipality of Lund.

Lund on 8 May 2013

Mikael Calner (meeting chair)
Oliver Lehnert (vice chair)
Per Ahlberg

Contents

Keynote

Prospects for a Paleozoic Astronomical Time Scale

LINDA A. HINNOV[1]

Fossilized Milankovitch cycles have been found in cyclostratigraphy throughout the Cenozoic and Mesozoic eras. Numerical astronomical models have been used to calibrate these cycles to an "Astronomical Time Scale" (ATS). Today, most of the Cenozoic Era has an "absolute" ATS, referred to time in years before present with a resolving power of 20–100 kyr from Earth's precession, obliquity and orbital eccentricity forcing. Prior to 50 Ma, the ATS is "floating", i.e., not yet linked to absolute time with an astronomical model, but anchored to geochronology. The resolving power is lower as well, at 405-kyr, due to loss of high-frequency accuracy in the astronomical models. However, both Cenozoic and Mesozoic successions exhibit strong 405-kyr cyclicity, interpreted as from the dominant term in Earth's orbital eccentricity variation. The widespread occurrence of this robust stratigraphic cycle promotes the long-standing notion that a "405-kyr metronome" can be used to define the ATS. Numerous projects are ongoing to document the stratigraphic record of 405-kyr cycles back to the start of the Mesozoic Era.

The time is now ripe for extending the ATS into the Paleozoic Era. There is already compelling evidence for Milankovitch cycles in Paleozoic stratigraphy. For example: Late Permian 405-kyr stratigraphic cycles in basinal formations in South China have been calibrated to high-precision geochronology and used to discriminate the astronomical model that defines the 405-kyr orbital eccentricity cycle with the best-fit phase. A continuous Permian cyclostratigraphy is emerging from decades-long research of continental deposits in the Bogda Mountains, China that could become the "Newark Series" of the Paleozoic Era. One of the most remarkable paleoclimatic time series ever measured is from the annually resolved Early Permian Castile evaporite sequence. The Carboniferous time scale has now been defined by high-precision geochronology, constraining major marine cyclothems to a 405-kyr scale. Devonian marine and continental cyclic sequences show evidence Milankovitch forcing, some with strong 405-kyr cyclicity. The Early Paleozoic has an extensive Milankovitch-band cyclostratigraphy that is badly in need of quality geochronologic controls and reanalysis.

The interpretation of Paleozoic cyclostratigraphy presents a unique set of challenges and limitations. Unlike the younger eras, Paleozoic biogenic sediment does not derive from pelagic phytoplankton, but from the shallow shelf and near-shore, which is in part controlled by sea level change. Thus Paleozoic deep-sea cyclostratigraphy may be more hiatus-prone than its Mesozoic-Cenozoic counterparts. Paleozoic shallow-marine cyclostratigraphy is the main archive to be researched for Milankovitch forcing. Continental formations presumably have high-quality cyclic successions comparable to those in the younger eras, but they suffer the same problems of correlating to a marine-based global stratigraphic framework. The astronomical models do not provide accurate targets for calibration of Paleozoic time. The astronomical parameters are expected to continue to operate in a similar fashion, but a faster Earth length-of-day will result in shorter period precession and obliquity cycles, and the precise evolution of length-of-day is unknown. Chaotic motions of inner Solar System planets, including Earth, will alter Earth's orbital eccentricity variation, but the precise changes are likewise unknown. The notable exception is the 405-kyr eccentricity cycle, which is predicted to remain stable on account of the large mass of Jupiter. In sum, Milankovitch cycles should continue to be recognizable throughout the Paleozoic Era, replete with a 405-kyr metronome for defining a Paleozoic ATS.

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Keynote

Marine biodiversity dynamics and reef evolution in the Early Paleozoic

WOLFGANG KIESSLING[1]

Revisions of the Early Paleozoic time scale and new geochemical and paleoclimatic data require a fresh look at Paleozoic diversity dynamics and ecosystem evolution to test for potential links. Our view of global diversity patterns is still strongly influenced by Sepkoski's compendium on the first and last appearances of marine animal genera. This view must be revised because the underlying time scale and taxonomy are now outdated and simple range data cannot be standardized for sampling. The Paleobiology Database is more comprehensive and up to date, but published biodiversity dynamics are currently too coarsely resolved stratigraphically to explore potential links with climate change, especially at critical boundaries.

Although revisions of the time scale are still ongoing, some new patterns emerge due to a revised stratigraphic assignment of collections to current stage definitions, sampling-standardized analysis, and correcting for the Signor-Lipps effect: (1) Extinction rates in nearly every Cambrian stage were greater than in the rest of the Paleozoic and the extinction events at the end of the former Early Cambrian (Sinsk and Hawke Bay events) were not above Cambrian background levels, although a major reef crisis is still evident. (2) Two big extinction pulses occurred in the latest Cambrian (Stage 10) and the Tremadocian, both exceeding the magnitude of the end-Permian mass extinction. (3) The Ordovician radiation occurred in two pulses, the first in the Tremadocian and the second in the Darriwilian. (4) The end-Ordovician mass extinction was hardly a mass extinction at all and the peak of extinction rates is concentrated at the end of the Hirnantian whereas the end-Katian extinctions were even below Ordovician background rates. This suggests that extinctions were caused by warming after the Hirnantian glaciations rather than cooling at the Katian–Hirnantian boundary. The same applies to reef-volume data, which indicate that the global carbonate production of reefs increased from the Katian to the Hirnantian and then dropped significantly in the Rhuddanian. (5) Silurian extinction rates were among the lowest in the entire Paleozoic suggesting that the several "events" reported from this period did not have much effect on the survival of marine genera. Origination rates were declining erratically throughout the Silurian. (6) The Kellwasser event (Frasnian–Famennian boundary) and the Hangenberg event (near the Devonian–Carboniferous boundary) were each approximately of equal intensity (and both nearly equal to the end-Hirnantian event), although the Kellwasser event stands out as the first significant post-Cambrian reef crisis.

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The risk of misleading eustatic and ‘epeirogenic’ processes in the correlation of the Cambrian Series 2–3 boundary interval in rift and drift (passive margin) basins

J. JAVIER ÁLVARO[1]

In the Mediterranean region of West Gondwana, two regional Cambrian Series 2–3 boundaries have been proposed based on trilobites (Álvaro et al. 1993 for the Iberian Peninsula and Geyer & Landing 1995, 2004 for Morocco) and a third one based on acritarchs (Palacios & Moczydłowska 1998). Although the three boundaries are obviously located at different biohorizons they are perfectly correlatable between Morocco and Iberia (e.g., Álvaro et al. 2003). Although the selection of a GSSP for the Cambrian Series 2–3 boundary is presently at the core of an intense and constructive debate in the International Subcommission on the Cambrian Stratigraphy (ISCS), the discussion of which of these boundaries must survive as the ‘regional’ standard for the western Mediterranean region (including Morocco and Iberia) is becoming a Byzantine debate based on unilateral proposals that are exclusively followed by their own supporters. Fortunately, the day a GSSP for the Cambrian Series 2–3 boundary will be selected by the ISCS, this regional debate will be out of fashion... or that is what I hope.

One of the major problems found by stratigraphers and palaeontologists when correlating Morocco and SW Europe is the misleading of rifting and drifting (passive margin) geodynamic processes. Regional tilting and uplifts recorded in rift basins (in some papers, called ‘epeirogenic’ movements; e.g., Landing et al. 2006), like those of the Moroccan Atlas and the Iberian Ossa-Morena, cannot be directly correlated with modifications in space accommodation in passive margins. As a result of which, the stratigraphic gaps and condensation levels found in rift basins must not be found necessarily in passive margins. The stratigraphic setting and time span of possible cryptic unconformities need facies and biostratigraphic confirmation.

A case study is offered by the rift-related tectonic uplift and tilting processes recognized across the Cambrian Series 2–3 boundary in the Tatelt and Brèche à Micmacca units of Morocco, which display local extension (Álvaro & Clausen 2005, 2006, 2008; Landing et al. 2006). They cannot be recognized all around the Anti-Atlas, the High Atlas, and less in the Coastal Meseta of Morocco. In addition, the reported Cambrian tectonic breakdowns of the Iberian Chains are related to extension and characterized by development of local slopes with breccia deposits or fragmentation of the platform into horsts and grabens: no uplifts are described. Therefore, the tectonically induced unconformities recorded in the Moroccan-Ossa Morena rifts must not be blindly correlated with supposed cryptic unconformities across the Iberian passive-margin basin.

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The nature of Ordovician limestone–mudstone alternations in the Oslo-Asker area (Norway): Primary or diagenetic rhythms?

CHLOÉ AMBERG[1], TIM COLLART[2], WOUT SALENBIEN[2], THIJS R. A. VANDENBROUCKE[1], LISA M. EGGER[3], AXEL MUNNECKE[3], ARNE T. NIELSEN[4], ØYVIND HAMMER[5] AND JACQUES VERNIERS[2]

The Hirnantian glaciation is implicated for causing one of the great Phanerozoic mass extinctions at the end of the Ordovician. An emerging body of evidence now suggests that global cooling and the onset of the Early Palaeozoic Ice Age (EPI), started much earlier than previously assumed, during the Early or Mid Ordovician. This has fundamental importance as an early phase of cooling could provide a driving mechanism for the major changes in biodiversity during the Great Ordovician Biodiversification (Trotter et al. 2008). At present, however, this new evidence is not yet conclusive. In our project, we revisit the Oslo-Asker sections in Norway to obtain additional data on Ordovician climate change.

The Ordovician eustatic sea level curve for Baltica, to some extent based on lithological evidence from the Oslo-Asker area in Norway (Nielsen 2004), indicates a number of lowstands of Mid and Late Ordovician age, interpreted as glacioeustatic. During the lowstands calcareous rhythmites were deposited, potentially recording short-term palaeoclimatological fluctuations and potentially implying the presence of a significant ice-sheet on the South Pole. However, alternatively, these limestone-mud alternations could also be the result of differential diagenesis (Egger et al. 2013, this volume).

Our methodology consists of a bed-by-bed sampling of the calcareous rhythmites, for an integrated geochemical (XRF) and palynological (chitinozoans) study. The XRF analyses allow us to assess if there has been diagenetic redistribution, which would result in an enrichment of insolubles in the mudstones/marls and a dilution of insolubles in the limestones; these results are presented in a separate paper by Egger et al. (2013, this volume). A true, original cyclic signal should also be reflected in the chitinozoan microfauna, sensitive to climatic and environmental changes (e.g., Vandenbroucke et al. 2010) whilst a uniform distribution points toward a diagenetic origin of the rhythmites. Over 800 samples have been collected for analyses in the fall of 2012. Results of the detailed palynological analyses will be presented for the Lysaker Member of the Huk Formation (Dapingian–Darriwilian), the Frognerkilen Formation (Sandbian), the Solvang Formation (Katian), and the Hovedøya Member of the Skogerholmen Formation

(Katian). Preliminary palynological data from these units indicate surprisingly well-preserved and relatively abundant palynomorphs that at first glance do not show any major difference between the assemblages from the mudstones and limestones, at the species level. Based on these first results, the palaeontological data thus seems to be in agreement with the geochemical data from the Hovedøya Member, provided by Egger et al. (2013, this volume).

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Wenlock on the northeastern margin of the European platform

ANNA I. ANTOSHKINA[1]

Wenlock type sections for the stratigraphical scheme of the Western Urals have been defined in the Kozhym River of the Subpolar Urals in the 1980s. Detailed study of the conodont faunal change and lack of the early Sheinwoodian $\delta^{13}C_{carb}$ positive excursions in sections (36–48 m) of the Durnayu River area have showed an incompleteness of the Wenlock succession in the Subpolar Urals (Männik & Martma 2000). The Kozhym Uplift during the lower Paleozoic was characterized by tectonic activity that confirms wide development of carbonate breccias and conglobreccias in Ordovician–Silurian deposits. The Wenlock deposits are characterized by very shallow-water carbonates with poor faunas dominated by stromatolites. However, just above the Llandovery–Wenlock boundary occurs an interval of limestones with tabulate corals and stromatoporoids, indicating a short-term transgression that caused a temporary return of normal marine conditions into back-reef basin.

In the eastern areas of the Kozhym River an unsorted bioclastic matrix of the Manyuku Fm carbonate conglobreccias uppermost beds underlaying the Wenlock–Ludlow Balba'yu Reef contains mixed late Telychian–early Sheinwoodian conodont complex (Antoshkina 2008). The presence of *Kockelella* cf. *walliseri* (Helfrich) testifies to the middle Sheinwoodian age. This fact speaks about the Wenlockian cement formation above the Llandovery boundary.

Westward of the Subpolar Urals, in the Iz'yayu River of the Chernyshev Swell, a clear positive $\delta^{13}C_{carb}$ excursion indicative of the Ireviken Event was observed in the middle part of the Ust'Durnayu Fm (Shebolkin 2011). The Wenlock section (21 m) represents a complete succession because there are well-defined sedimentological and paleontological data of lower and upper boundaries. Dolostones, specific vadose ooids, stromatolites, microbial-micritic muds sometimes with terrigenous silt, and euryfacies fauna especially as bioclasts are typical for this succession. Northward of the Chernyshev Swell (the Shar'yu River), the Wenlock deposits (about 40 m) are characterized by a more varied fauna, tidal-upper subtidal facies. Possibly the thickest Wenlock succession (146 m) is located in the Chernov Swell (the Padimejtyvis River area) and distinguished by various and numerous benthic faunas, and the most of facies diversity – from supratidal to subtidal (Antoshkina & Beznosova 1988).

In the 2000s, detailed lithological study of whole cores in the Khorejver Depression revealed some beds of brecciated carbonate-siliceous-clayey rocks in which ooids were cemented by kaolinite and bituminous matter in the Middle Member of the Veyak Formation in the Pechora Syneclise (the Bagan area). The presence of these red-colored rocks and the oxidized oil testifies to a break in sedimentation. The kaolinite clay characterizes this break as rather long with formation of weathering crusts. These rocks evidently resulted from a hiatus and can be correlated with a sharp regression above the Llandovery–Wenlock boundary. The Khorejver Depression during the Silurian was characterized by local tectonic structural uplifts, especially in the Bagan-Sandivej areas.

During the Silurian, the Timan-northern Ural sea basin was closely related to the evolution of the Paleo-Uralian Ocean and the Pechora Plate, under geodynamic conditions responsible for the passive margin platform, intra-plate depressions and uplifts, so the most of bio- and sedimentologic events are close in time to eustatic and regional sea-level changes (Antoshkina 2007). Nevertheless, Ireviken and Mulde events do not clearly correlate with the formation of sequence boundaries because tectonic evolution of basement blocks mask or enhance sea-level change. But it is common to follow sequence stratigraphical concepts and identify sequence boundaries as important levels for past extinctions.

Analysis of successions in the Pechora Syneclise, Chernyshev and Chernov swells, and the Subpolar Urals sections are essential to the solution of the Wenlock stratigraphic problems on the northeastern European Platform margin. Different completeness of the Wenlock successions is the reflex of different character of sedimentation, which occurred in periodic changes of regressions and transgressions environments in the very shallow-water sea basin during this time.

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Placing Upper Ordovician "butter shale" Lagerstätten within a sequence stratigraphic framework

CHRISTOPHER D. AUCOIN[1], CARLTON BRETT[1], THOMAS MALGIERI[1] AND JAMES THOMKA[1]

The Upper Ordovician Cincinnatian contains several bed packages colloquially referred to as "butter shales" or "trilobite shales". These packages are typified by 1–2 meter intervals of claystone with isolated lenticular limestone beds found throughout. The limestone beds display the usual brachiopod-bryozoan dominated fauna typical of the Cincinnatian. Conversely, butter shales typified by the *Treptoceras duseri* shale of the Waynesville Formation have faunas dominated by bivalve mollusks, orthoconic cephalopods, and trilobites (Frey 1987). This suggests a persistent change in environmental conditions from the rest of the Cincinnatian and the butter shales. Similarly, some of the butter shales have been shown to range laterally over at least 135 km (Key et al. 2010) indicating that these are not merely isolated localized event. These claystones are most widely known for their Lagerstätten quality preservation of the trilobites *Isotelus* and *Flexicalymene*. As a result, much of the previous work has focused on the taphonomy of the trilobites, which can be found in a variety of orientations including prone, oblique and enrolled.

Butter shales have been identified in a number of the Cincinnatian formations including the Grant Lake, Arnheim, Waynesville and Liberty formations in ascending order (Frey 1987; Ferree 1994; Schumacher & Shrake 1987). In addition to better characterizing the faunal content of the various claystone packages, we are also working to understand the position and relationships of the butter shales within sequence stratigraphy. One study, which focused on the Mt Orab butter shale of the Arnheim Formation (Hunda et al. 2006), has been placed by the authors within the highstand systems tract of sequence C4 (Holland & Patzkowsky 1996). We agree with this interpretation and argue that the butter shales are typically situated within highstands of fourth order cycles, nested within late highstands to early falling stages of third order cycles. The amplification of sediment influx into relatively deep offshore areas created a sedimentary "sweet spot". We suggest that the butter shales represent periods of fairly rapid background mud deposition punctuated by episodic depositional events, which smothered organisms allowing for the exceptional preservation. Likewise, this steady deposition was also disrupted by periods of sediment starvation representing smaller transgressive phases within an overall regressive package.

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The $\delta^{13}C_{carb}$ curve from the Green Point succession in western Newfoundland, Canada and correlation of the GSSP section of the Cambrian–Ordovician boundary

KAREM AZMY[1], SVEND STOUGE[2], GABRIELLA BAGNOLI[3] AND UWE BRAND[4]

The Green Point Formation of the Cow Head Group in western Newfoundland (Canada) represents the Global Stratotype Section and Point (GSSP) for the Cambrian–Ordovician systems boundary. A new $\delta^{13}C_{carb}$ curve from the Green Point section has been constructed (Fig. 1) because (1) no high-resolution carbon isotope profile was previously presented for the GSSP section and (2) the exact stratigraphic level of the Cambrian–Ordovician boundary, based on conodont biozonation, has become recently an issue of debate (Terfelt et al. 2012). The previously constructed C-isotope profile (Nowlan 1995) was based on lower resolution field sampling protocols and whole-sample analyses that resulted in overlooking the significant variations associated with the boundary.

The middle Cambrian to Middle Ordovician Cow Head Group (up to 500 m thick) is composed of marine fine-grained clastic and carbonate sediments that accumulated on the slope along the Laurentian margin. Significant conglomerate beds (megabreccias) interrupt the succession and contain blocks of marine shallow and deep water carbonates (James & Stevens 1986).

The deep slope marine Green Point Formation is dominated in the lower part by shales (Martin Point Member) and in the upper part (Broom Point Member) by lime mudstones that retained their micritic textures and sedimentary fabrics (rhythmites).

The $\delta^{13}C$ values of 84 well-preserved micrite microsamples range from -4.7‰ to +1.7‰ (VPDB) (Fig. 1). The $\delta^{13}C$ values show insignificant correlation with their Mn/Sr ($R^2 = 0.06$) and total REE (ΣREE) counterparts, which suggests that they retain their near-primary $\delta^{13}C$ signatures that can be utilized to reconstruct a reliable C-isotope profile for high-resolution global correlations.

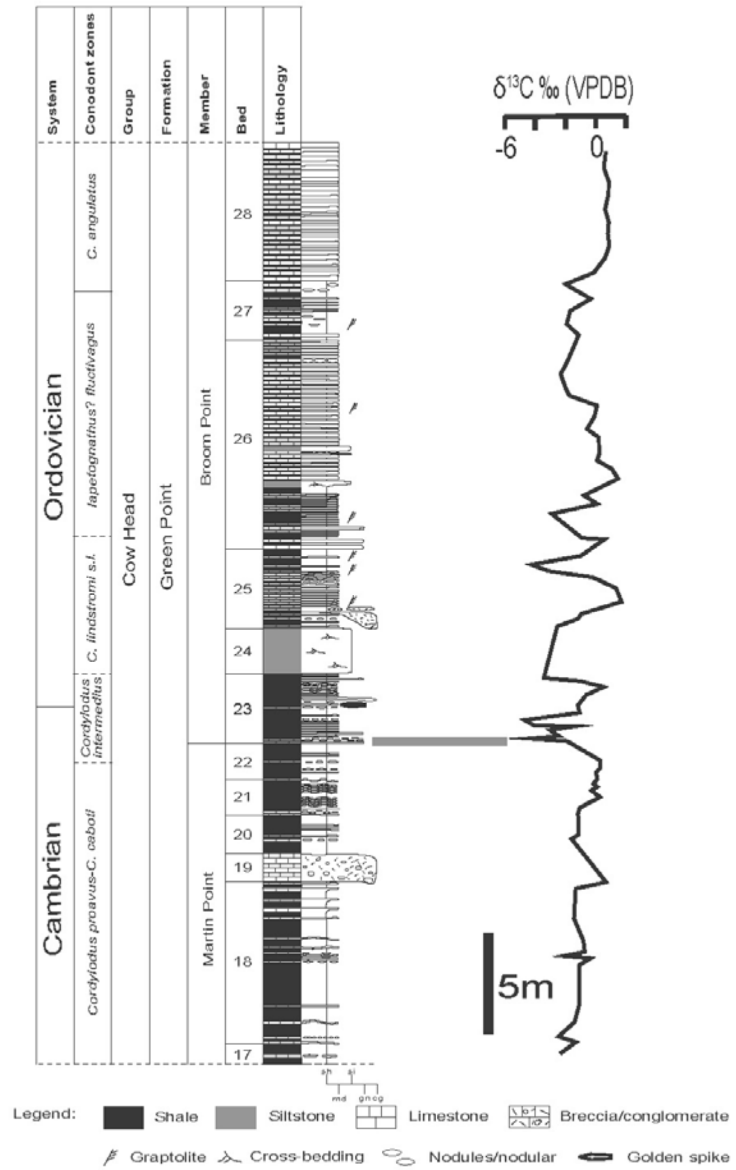

Fig. 1. The Green Point section of western Newfoundland, Canada, the GSSP section for the Cambrian–Ordovician boundary, and the detailed δ^{13}C$_{carb}$ profile. The grey horizontal line at the base of Bed 23 marks the initiation of a composite negative shift (several peaks) starting at the base of the Broom Point Member of the Green Point Formation (Cow Head Group). These reflections indicate a significant change in sea level and the composite negative shift begins two meters below the GSSP level. The conodont biostratigraphy is modified from Terfelt et al. (2011).

The $\delta^{13}C_{carb}$ profile reveals a composite negative shift (three peaks) of ~6.0‰, which starts at the base of the Broom Point Member reflecting a significant change in sea-level. The negative $\delta^{13}C_{carb}$ shift is consistent with the change from relatively shale-dominated (Martin Point Member) to more carbonate dominated lithology (Broom Point Member) and reflects a drop in sea-level.

The combination of C-isotope stratigraphy with biozonation provides a powerful tool of high-resolution global correlations. The C-isotope curve presented here shows that the negative $\delta^{13}C$ shift starts at the Martin Point/Broom Point members boundary, a level slightly lower than that of the suggested golden spike, that was placed in the *Clavohamulus hintzei* conodont Subzone of the *Cordylodus intermedius* conodont Zone, and below the FAD of *Iapetognathus*? *fluctivagus* (Terfelt et al. 2012) and the FAD of planktic graptolites (Cooper et al. 2001).

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The early Rhuddanian survival interval of the Ordovician/Silurian extinction in the Central Oslo Region

B. GUDVEIG BAARLI[1]

The Asker District in the central Oslo Region records the entire Rhuddanian Stage with a continuous presence of shelly fossils through 168 m of strata. Baarli & Harper (1986) published a preliminary investigation on a relict Ordovician brachiopod fauna from the basal layers of the Rhuddanian. As later confirmed by Rong & Zahn (2006) and others, they found that Ordovician relicts phased out gradually during the Early Rhuddanian and that, likewise, new Silurian species came in gradually. This study concentrates on the interval when the relict Ordovician fauna was phased out, but before the Silurian fauna became fully present. This corresponds to the survival interval, a pause often found after a mass extinction before extensive radiation takes place (Harris & Knorr 2009).

A survival stage is characterized by long ranging, eurytopic, opportunistic taxa of small sizes and assemblages with low diversity (Harries & Knorr 2009, among others). As expected, the brachiopods in this interval from the central Oslo Region are long ranging, both with solid roots in the Ordovician and a strong Silurian presence. Most recorded earliest Rhuddanian brachiopod faunas belong to Benthic Assemblage (BA) 2–3 and seldom 4 (Rong & Zahn 2006). In contrast, some of the early Rhuddanian assemblages of the Solvik Formation belong to BA5. The Rhuddanian to mid-Aeronian Solvik Formation shows two shallowing events that range from BA5 to 3. The three dominant genera from the survival interval, *Protocortezorthis*, *Leangella* and *Eoplectodonta*, occur continuously through the Solvik Formation and, thus, span BA5 to 3, testifying to eurytopic life styles. In addition, *Leangella* is a genus with an opportunistic behavior: at times overwhelmingly dominant, but more often only present.

Samples were compared for abundance and diversity from the two BA5 intervals, the survival interval between 50 and 80 m above the base of the formation, and the one from the base of the Aeronian where a normal ecosystem is expected. The survival interval had the lowest number of brachiopod species per sample (average 8.8) and lowest average number of normative brachiopod specimens (54) for a 10-kg sample. This is in stark contrast to the BA5 assemblages at the base of the Aeronian with the former numbers being 207 and the latter 15.4 per sample. High diversity in BA5 faunas is frequently reported from Silurian strata.

Decrease in body size during a crisis, the Lilliput Effect, is here used as originally defined for decrease in the body size of certain species during the crisis and increase during recovery (Urbanek 1993). *Protocortezorthis prima*, *Leangella scissa*, *Dicoelosia osloensis* and *Eoplectodonta duplicata* were measured for maximum width and length from the two intervals with BA5. Despite limited material, the first three genera showed a statistically significant increase in size from the Rhuddanian to Aeronian (i.e., a Lilliput Effect in earliest Rhuddanian) while *E. duplicata* showed no significant size differences. Contrasting trends in size after the Ordovician/Silurian mass extinction also were found for higher taxonomic ranks in South China (Huang et al. 2010).

Protocortezorthis prima occurred in sufficient numbers to show that there also was a decrease in average size from the base of the formation towards the survival interval, possibly indicating increasingly adverse growth conditions (Fig. 1). Insufficient food supply and low temperatures are frequently blamed for the Lilliput Effect, among many other factors. One contributing cause may be lack of bottom stabilizing shell litter and algae causing soft bottoms where many larger shells founder.

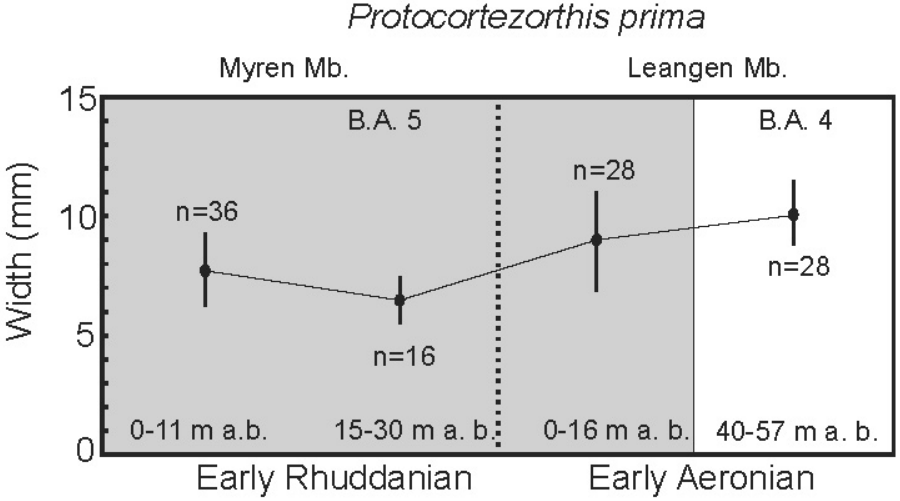

Fig. 1. Variation in width for *P. prima* through the Solvik Formation. Nodes denote average width. Vertical lines are error bars calculated from Inter Quartile Range estimates.

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"Cedaria" woosteri and the *Cedaria* Zone (Cambrian: Guzhangian) of Laurentia

LOREN E. BABCOCK[1,2] AND MARK T. BARANOSKI[3]

Chronostratigraphic correlation of Cambrian strata across the Laurentian palaeocontinent has for a long time posed a number of challenges. Among the challenges are strong biofacies contrasts between lithofacies, and taxonomic issues, both of which are exemplified in the application of some polymerid biozones such as the *Cedaria* Zone.

Lithofacies indicate that the Laurentian craton was encircled by a broad marine shelf. Shallow-water carbonate platforms commonly separated muddy inner-shelf or restricted lagoons from open-shelf and slope environments. During times of carbonate platform development, inner-shelf and outer-shelf to slope environments normally hosted separate trilobite biofacies (e.g., Robison 1976; Robison & Babcock 2011). Strata of the inner shelf are characterized by endemic trilobites, and strata of the outer shelf strata contain a mix of endemic and cosmopolitan forms including agnostoids. There are few taxa in common between these regions, which results in uncertainty about correlations based on the ranges of trilobites.

Traditional subdivisions of the Laurentian "Upper" Cambrian were based on taxa from inner-shelf environments, but correlations around the margin of the continent and to other palaeocontinents have been based principally on taxa from outer shelf facies. Chemostratigraphic information, which can bridge the gaps in biostratigraphic information between shelf areas, is not available for some key areas.

The *Cedaria* Zone, which was commonly used to mark the base of the traditional "Upper" Cambrian in Laurentia (e.g., Lochman-Balk & Wilson 1958; Robison 1964), was largely founded on the range of a putative *Cedaria* species, *C. woosteri* (Whitfield 1878), from the Eau Claire Formation of Wisconsin, USA, where it occurs in lithofacies of the inner shelf. The type species of *Cedaria*, *C. prolifica* Walcott 1924, and other species assigned to the genus are from open shelf to slope environments (e.g., Robison 1988). In most places, the *Cedaria* Zone is applied in outer shelf lithofacies (see Babcock et al. 2011; Robison & Babcock 2011).

Cedaria prolifica is a libristomate (corynexochid) trilobite that has a functional facial suture. All other species assigned to the genus except "*C.*" *woosteri*, likewise have functional facial sutures. "*C.*" *woosteri* has a cephalic morphology unique among trilobites: an ocular plate delimited by a circumocular suture (Hughes et al. 1997). The species lacks a facial suture. "*C.*" *woosteri* probably has a sister group relationship to the clade that includes *Cedaria prolifica* and its close relatives. Taxonomic reassignment of the inner-shelf-dwelling "*C.*" *woosteri* casts some uncertainty on the meaning of the *Cedaria* Zone.

Work on trilobites recovered from the subsurface of Ohio and adjacent areas of the USA is helping to resolve generalities of the correlation of the *Cedaria* Zone. Based on available evidence, most, if not all, of Ohio's subsurface Cambrian is limited to provisional Series/Epoch 3 through the Furongian Series/Epoch. A new, incomplete exoskeleton recovered from the Mt. Simon Formation is consistent with an age of provisional Epoch 3 (probably Guzhangian). Sclerites recovered from the lower part of the Knox Dolomite, including *Crepicephalus*?, *Aphelaspis*?, and *Elvinia*?, indicate that this part of the Knox is of Furongian age. The presence of "*C.*" *woosteri* in the Eau Claire Formation (Babcock 1994), which lies above the Mt. Simon Sandstone and below the Knox Dolomite, is, based on its stratigraphic position, consistent with an age of Epoch 3 (Guzhangian Age).

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Palynology and sedimentology of the Upper Ordovician–lowermost Llandovery in the Röstånga-1 core, southern Sweden

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The Röstånga-1 drillcore from west-central Scania (Skåne), southern Sweden, has provided important information on the Ordovician and Silurian stratigraphy of southern Scandinavia (Bergström et al. 1999; Pålsson 2002; Koren' et al. 2003). The core drilling penetrated an approximately 96 m thick sedimentary succession of Upper Ordovician–Llandovery rocks. In ascending order, this succession comprises the upper Sularp (Sandbian), Skagen (Sandbian–Katian), Mossen (Katian), Fjäcka (Katian), Lindegård (Katian–Hirnantian), and Kallholn (uppermost Hirnantian–Telychian) formations (Bergström et al. 1999). A palynological and sedimentological study has been performed on the Katian–lowermost Llandovery succession of the core, with the aim to refine the biostratigraphic framework and interpret the depositional environments.

The Skagen Formation has a thickness of 2.5 m and consists of calcareous mudstone and grey, bedded limestone rich in trilobite fragments. It has been interpreted as reflecting a shallowing of the depositional environment caused by a eustatic sea level drop (Bergström et al. 1997). In the Röstånga-1 drillcore, this interpretation is supported by the development of a discontinuity surface with solution structures at the top of the Skagen Limestone, inferably a sequence boundary. This regressive episode was succeeded by a return to deeper-water conditions and deposition of the Mossen Formation and the Fjäcka Shale during the late Katian (cf. Bergström et al. 1999). The Fjäcka Shale is a widespread dark grey to black, organic-rich shale containing graptolites of the *Pleurograptus linearis* Zone (Pålsson 2002; Calner et al. 2010). The base of Fjäcka Shale represents a flooding surface and in the Röstånga-1 core, the lowermost part of the formation was likely deposited under anoxic conditions during a pronounced transgression. The Kallholn Formation represents a new deepening period in the latest Hirnantian and forms a thick unit of anoxic–dysoxic dark grey, graptolitic shales over much of southern Scandinavia. It reflects a eustatic sea level rise related to the Hirnantian deglaciation.

Based on palynology, the succession can be subdivided into three informal palynozones. Palynozone I occurs in the uppermost Fjäcka and lower Lindegård formations (upper Katian) and is characterized by the occurrence of the key acritarchs *Baltisphaeridium*, *Buedingiisphaeridium balticum* and *Orthosphaeridium inflatum*. The cryptospore species *Tetrahedraletes medinensis* has also been identified. The record of cryptospores within this palynozone provides the oldest evidence of early land plants in Baltica. The occurrence of diagnostic Early–Middle Ordovician reworked acritarchs (e.g., *Striatotheca*, *Coryphidium* and *Acanthodiacrodium* spp.) suggest a detrital Avalonian sediment provenance and foreland-type sedimentation.

Palynozone II occurs in the upper Lindegård Formation (Hirnantian) and is characterized by the occurrence of long-ranging acritarchs (e.g., *Veryhachium* and *Micrhystridium*) and a micro-phytoplankton turnover recognized by the appearance of several taxa with a Silurian affinity (e.g., *Ammonidium* spp., *Diexallophasis denticulata* and *Tylotopalla caelamenicutis*). The cryptospore assemblage comprises the species *Tetrahedraletes medinensis*, *T. grayii* and *Pseudodyadospora petasus*, taxa that have been reported globally from coeval assemblages.

Palynozone III occurs in the lower Kallholn Formation (uppermost Hirnantian–lower Llandovery) and is characterized by the presence of sphaeromorph acritarchs together with a relatively high abundance of graptolites. Throughout this palynozone, the acritarchs show a low abundance, which is in accordance with palynological studies from coeval strata in other parts of the world.

The acritarchs from the Lindegård Mudstone are brownish black, indicating a Thermal Alteration Index (TAI) of 4, which is considered to be post-mature with respect to oil generation. The high thermal maturity is probably the combined result of a relatively deep burial in a foreland basin setting and extensive magmatic activity during the early Permian.

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New mid-Cambrian palaeoscolecid sclerites of *Hadimopanella oezgueli* from the Cantabrian Mountains, northern Spain

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Statistical analyses have been carried out in a representative collection of *Hadimopanella oezgueli* Gedik 1977 sclerites, sampled in the middle Cambrian Genestosa Member (Oville Formation) of the Cantabrian Mountains, Spain. The aim of the study was to determinate the morphological variability of these phosphatic button-like palaeoscolecid sclerites. Several characteristics of the dorsal side of the measured sclerites were considered, such as the number of dorsal tubercles/nodes; the diameter and cusp roundedness of dorsal nodes; the eccentricity of the tuberculated/ornamented surface inside the sclerite outline; the relative width of the marginal brim; the relative size of the smooth surface versus the tuberculated surface. The statistical analysis (cluster and principal coordinates) identifies two broad morphogroups (A and B), with subsequent subgroups. Morphogroups A and B have been compared through principal coordinates with other sclerites classified as *Hadimopanella oezgueli* and those genera that contain this paraspecies, found in Gondwana and Siberia, including the Mila Formation (Iran; Wrona & Hamdi 2001), the Láncara Formation (northern Spain; Boogaard 1983), the Georgina Basin (Australia, Müller & Hinz-Schallreuter 1993), the Campo Pisano formation (Sardinia; Elicki 2006), the Ülgase-Kallavere Formation (Kirgizia; Märss 1988), the Korrelasyonunda Formation (Gedik 1977) where the holotype was described, the Çal Tepe formation (Sarmiento et al. 2001), western area of Taurids (Gedik 1989) all of them from Turkey and the Sinsk Formation (Siberia; Ivantsov & Wrona 2004). Only the Siberian sclerites are part of a complete and articulated scleritome. This analysis shows three broad groups (previous A and B, and new C). Two isolated sclerites belonging to Siberian specimens are out of all ellipses of 95 per cent of confidence (Fig. 1).

These results emphasize the idea that isolated sclerites are useless for taxonomic assignment of palaeoscolecids because (1) the same sclerital morphotype can appear in different complete palaeoscolecid scleritomes (e.g., morphotype C occurs in the genera

Wronascolex and *Sahascolex*), and (2) a single palaeoscolecid scleritome can display different sclerite morphotypes (e.g., morphotypes Ps1, Ps2 and Ps3 forming the scleritome of *Wronascolex spinosus* Ivantsov & Wrona 2004).

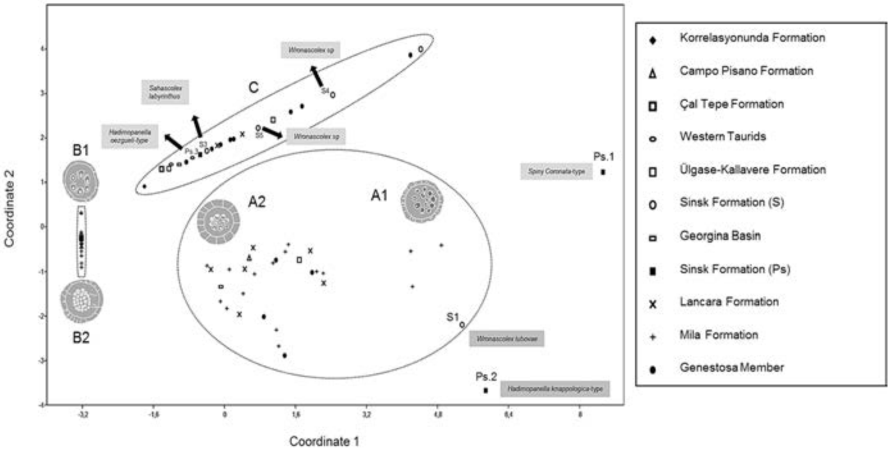

Fig. 1. Principal coordinates diagram showing the main morphogroups of *Hadimopanella oezgueli* from Gondwana and Siberia and the erected genera that contain this paraspecies. The schematic drawings are representative examples of the morphogroups identified in dregs from the Genestosa Member. Only the Siberian sclerites are taxonomically reported.

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Chitinozoan biostratigraphy in the Haljala Regional Stage, Upper Ordovician: A new high-resolution approach from NE Estonia

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Chitinozoans are among the most useful index fossils in the Upper Ordovician strata of Baltoscandia (Nõlvak & Grahn 1993) and frequently used for identifying regional stage boundaries as well as aiding interregional correlations. In this study we test the usefulness of chitinozoans for subdividing the Haljala Regional Stage and tracing its boundaries, based on high-resolution sampling of three borehole sections from NE Estonia. The Haljala Stage was introduced by Jaanusson (1995) as a single unit in place of the previously used Idavere and Jõhvi stages (now used as substages). The reason for erecting this new chronostratigraphic unit was laid on a ground that no conspicuous changes in macrofossil nor in microfossil faunas occur at this boundary (Jaanusson 1995). However, few detailed data on chitinozoan distribution within the Haljala Stage have hitherto been available.

The current study is based on 128 closely spaced samples from the variably argillaceous calcarentic limestones of the uppermost Viivikonna Formation (Kukruse Stage) to lowermost Kahula Formation (Keila Stage) of the Tamsalu-565, Piilsi-729, and Vasknarva-0639 drill cores. In total, 13 chitinozoan genera and 38 species were recorded in the studied sections. A particular feature of the assemblage is high diversity of desmochitinids (11 species). The number of species per sample is rather high, mostly 10–14 in the studied interval, while the average for the Upper Ordovician in Estonia is less than ten. Based on chitinozoan ranges in the studied sections, 13 species were identified as biostratigraphically most valuable. These include the zonal species *Eisenackitina rhenana*, *Armoricochitina granulifera*, *Angochitina curvata*, *Lagenochitina dalbyensis*, *Belonechitina hirsuta*, *Spinachitina cervicornis* and *Angochitina multiplex* (Nõlvak & Grahn 1993). Moreover, it was confirmed that beside the named zonal forms, several other chitinozoan species like *Hercochitina* sp. aff. *spinetum*, *Desmochitina juglandiformis*, *D. nodosa*, *D. lata* and *Pistillachitina* sp. 1 can be successfully applied for correlating sedimentary rocks of Haljala age in the East Baltic area as well as in some areas of Sweden. The most prominent changes in the chitinozoan fauna were observed at the Kukruse/Haljala boundary, which is marked by a set of well-developed hardgrounds in the studied cores. These hardgrounds represent a hiatus in the rock record, which, based on chitinozoan distribution, is of variable temporal extent.

The chitinozoan distribution in the Haljala Stage of the studied cores in NE Estonia revealed that the observed ranges and assemblages match well with those described from other sections in Estonia but also in Sweden (see Grahn & Nõlvak 2010). The high-resolution sampling used in this study has allowed us to considerably refine the stratigraphic usefulness and precision of distribution of several previously distinguished key species, increasing thus the reliability of their FAD and LAD data. Our study confirmed that the Idavere–Jõhvi substage boundary does not mark any substantial change in chitinozoan assemblages in NE Estonia and this level can only be traced by the presence of Grefsen complex of K-bentonite beds (Bergström et al. 1995). It is also worth mentioning that a number of volcanic ash-falls recorded within the Haljala and Keila stages seem to have had no impact on chitinozoan faunas.

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Depositional environments of Ordovician and Silurian sediments of the Siljan impact structure (Sweden) – insights from organic geochemistry

ULRICH BERNER[1], OLIVER LEHNERT[2,3] AND GUIDO MEINHOLD[4]

Geochemical investigations in the vicinity of Europe's largest impact structure (Siljan, Central Sweden) focused for years on abiogenic concepts (Gold 1999). These models largely neglected state of the art inorganic and organic geochemistry. Past investigations of the hydrocarbon potential of the early Palaeozoic sedimentary rocks in the ring-shaped structure already suggested that hydrocarbon generation of the organic-rich sediment was induced by heating through the impact of the large bolide which led to sufficient thermal maturation of the source rocks (e.g., Vlierboom et al. 1986). Vattenfall started a Deep Gas project in the early 1980s (e.g., Donofrio et al. 1984) aiming at the evaluation of possible abiogenic gas production from the Siljan structure.

In the depression around the 30 km wide central uplift (Siljan Ring; e.g., Juhlin & Pedersen 1987), Ordovician and Silurian strata were preserved from post-impact erosion, and we studied sediments recovered from three drill sites (Mora 001, Stumsnäs 1 & Solberga 1) for their geochemical variability to evaluate depositional environments and possible diagenetic alterations of organic matter.

At Mora 001, organic carbon and sulfur concentrations suggest changes between lacustrine and marine environments during Silurian times, and indicate that organic matter was likely affected by microbial sulfate reduction (diagenesis). Biomarker data provide additional information on depositional environments and the organo-facies of the sediments (Fig. 1), and clearly indicate that Silurian sediments at Mora 001 were deposited at either fully lacustrine to slightly brackish conditions with no or low marine algae present, but significant input from landplants.

The organic carbon and sulfur concentrations of Solberga 1 suggest sedimentation in marine environments, and diagenesis of the organic matter was obviously affected by sulfate reduction. Biomarkers derived from marine algae are abundant in the sediments and clearly support marine environments for Ordovician and Silurian rocks. In addition, significant concentrations of landplant-derived biomarkers indicate likely coastal rather than open marine conditions (Fig. 1).

The studied strata in the Siljan ring structure formed during the Early Palaeozoic on the western shelf of Baltica (present-day geography) and were affected by Caledonian movements to the west already during late Middle Ordovician. At that time we see the Caledonian forebulge reaching the Mora area. In the early Silurian, this forebulge moved further to the west due to tectonic loading by the Caledonian nappes and a backbulge basin filled by siliciclastic sediments formed in the Mora-Solberga region. Seismic data show a thinning of the more than 200 m thick shale succession in the depocenter around the Mora-Orsa area towards the east (Juhlin et al. 2012). Our biomarker study (Fig. 1) clearly supports Silurian shales being deposited in a backbulge basin of the eastern part of the Caledonian foreland basin system.

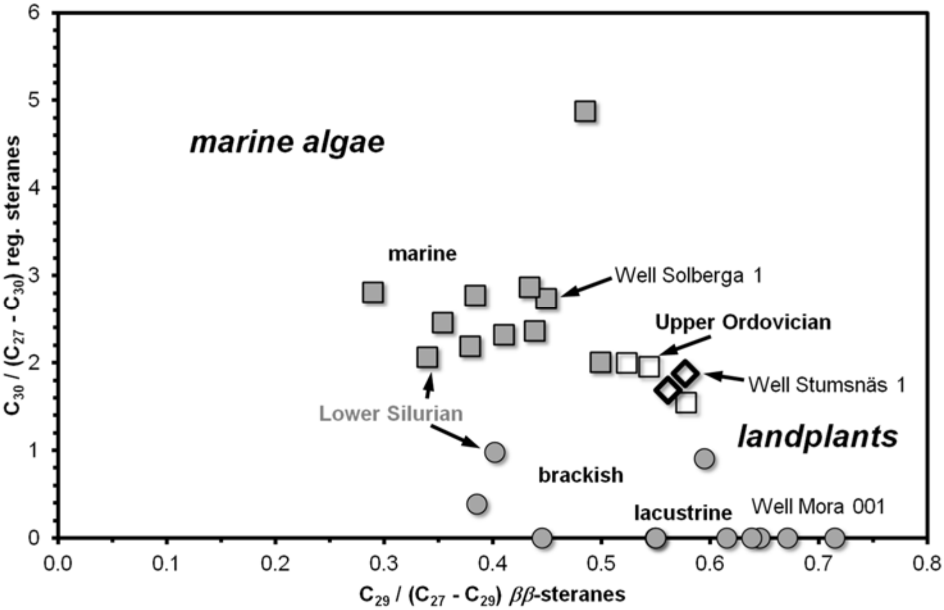

Fig. 1. Environmental characterisation based on biomarker data – $C_{30}/(C_{27}$-$C_{30})$ regular steranes vs. $C_{29}/(C_{27}$-$C_{29})$ *ββ*-steranes – from organic matter of samples from three drill cores in the Siljan ring structure.

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Middle Ordovician cephalopods from the Abarsaj area, northern Iran

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Four cephalopod taxa are recognised from a locality near the village of Abarsaj, eastern Elborts of northern Iran. The new fossil locality is in the Abastu Formation, which is made up of a basal white to light pink sandstones which pass up into thin-bedded brownish limestone, then into interbeds of grey to green limestones and shales, and dolostones at the top. The Formation is 140 m thick. Contacts with the underlying late Cambrian Mila Formation and the overlying Katian–Hirnantian Abarsaj Formation are unconformable. In Abarsaj, all cephalopod specimens were collected from the middle part of the section, represented by thin-bedded brownish limestone, at 80 m above the basal unconformity. The described fauna includes *Proterovaginoceras ?incognitum*, *Eosomichelinoceras* n. sp., *Sactorthoceras* n. sp. and Orthocerida indet. suggesting a late Dapingian to Darriwilian (Middle Ordovician) age for the strata. The reported assemblage belongs to an open water fauna and suggests a close affinity with those of Baltica and South China.

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The first Silurian chitinozoans from Severnaya Zemlya, Arctic Russia

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Silurian chitinozoans have not previously been reported from the Arctic Russia. By comparison, in the northern part of East Siberia (e.g., the Noril'sk area), chitinozoans are abundant and have a relatively diverse species composition (9 genera, 20 species), throughout the Silurian (Zaslavskaya 1983, 1986). The provincial affinities of the Siberian chitinozoan fauna, however, remain uncertain due to their endemism. Here we report the first record of early Silurian chitinozoans from the Severnaya Zemlya Archipelago. The new material originates from a mudstone bed of the Sredny Formation, exposed along the Ushakov River on the October Revolution Island. The recorded chitinozoan assemblage is monospecific and is represented by *Conochitina* aff. *emmastensis*. *Conochitina emmastensis* is the index species for the *C. emmastensis* Biozone (early Telychian, Llandovery, Silurian) defined in Baltica (Nestor 2009). This biozone is an important correlative level with other areas on a global scale. The presence of *Conochitina* aff. *emmastensis* suggests the early to late Telychian age for the strata bearing them. This is in accordance with the previous biostratigraphic dating based on graptolites (Bogolepova et al. 2000) and conodonts (Männik et al. 2009).

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A reexamination of the contributions of biotope and geographic range to extinction risk in Ordovician graptolites

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Planktic Ordovician graptolites exhibit a distinctive pattern of species occurrences in which some species are known only from sites inferred to have been deposited in outer shelf to abyssal settings (group 1) in contrast to the more common pattern in which species occur in both shallow shelf and deep oceanic sediments (group 2; see Cooper et al. 2012). Based on a sample of 153 Ordovician graptolite species ranges from a global composite sequence, Cooper & Sadler (2010) provided evidence that extinction risk was significantly different between the two species groups. Group 1 taxa had species durations that, on average, were nearly 50% shorter than those in group 2. From this observation and the lack of any significant correlation with the degree of endemicity or sampling effects, they concluded that these differences in occurrence and duration reflected differences in habitat: that the group 1 taxa inhabited the mesopelagic biotope and that this environment lead to higher species turnover than the more stable epipelagic biotope of the group 2 taxa.

Here we report the results of a restudy of the distribution of 151 taxa utilizing a greatly expanded global composite based on nearly twice the number of sites. This data set also yields a significant difference in the mean durations of the two groups (mesopelagic = 2.95 Myr, epipelagic = 5.24 Myr), with both groups having slightly longer durations on average than previously reported. We have also compiled a suite of more detailed determinations of these species' geographical range via PaleoGIS as well as several proxies for sampling completeness. For the majority of geographical range measures and all sampling proxies there is a significant difference between the means of the two groups. A maximum likelihood and AIC-based model choice approach allows us to compare relatively simple models that rely on biotope alone to explain the variation in species durations to a set of increasingly more complex models that include multiple measures of geographic range and sampling. This approach provides a direct means to test the relative role of biotope and geographic range as controls on species turnover. The model choice results suggest that biotope, geographic range, and sampling alone are all relatively weak predictors of durations, and that a more complex model that includes measures of all three factors and their interactions is the best fit. This difference in outcomes is probably driven by the more precise measures of geographical range and sampling employed in this analysis, possibly also by the higher variability in species durations calculated from the expanded composite sequence, and a consideration of a greater variety of models. These results show that although biotope may have had a significant effect on graptoloids species durations, this effect may not have been as large as the mean difference in duration suggests when one also takes into account the effects of differences in a variety of geographical range and sampling measures.

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Comparative facies and carbon isotope analysis of the Sheinwoodian succession in the western Baltic and eastern North America: Evidence for a composite Ireviken Event

CARLTON BRETT[1], PATRICK MCLAUGHLIN[2] AND POUL EMSBO[3]

The relationship between sea level fluctuation and carbon isotope excursions remains unresolved within the broader research community. The extensive and pristine coastal exposures and inland quarries of Gotland, Sweden, and abundant and widespread outcrops and substantial subsurface collections in eastern North America provide an opportunity to compare the complex stacking patterns of facies and carbon isotope values present within the late Telychian–Sheinwoodian Ireviken Event between three basins spanning two paleocontinents.

Study of sections in Gotland and eastern North America followed similar methodologies, though over significantly different distances. Sections studied along the northwest margin of Gotland provide an onshore–offshore transect covering over 50 km. By comparison, our data sets from eastern North America include multiple transects across portions of the Appalachian and Michigan basins cumulatively covering more than 2000 km, along both depositional strike and dip. The Gotland transect features three major Sheinwoodian pinnacle mud mound/microbial reef growth episodes (Högklint-Tofta formations); each of these is associated with facies patterns in laterally-equivalent deposits interpreted as transgressive systems tracts. These extend upward into thinly bedded, argillaceous facies of the highstand. Carbon isotope chemostratigraphy indicates that these mud mound/microbial reef events have age-equivalent counterparts in the Appalachian and Michigan basins.

We infer that upward building of mounds and pinnacle reefs occurred in distinct episodes in the early Wenlock, associated with eustatic deepening. The combination of a shallow chemocline (related to extensive carbon burial) and rising base level fostered rapid upward growth of microbially-dominated structures. Collectively, these patterns indicate that the destabilization of the carbon cycle during the Ireviken Event resulted in at least three closely spaced excursion episodes, each associated with a cycle of sea level fall and rise and widespread microbialites.

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A $\delta^{13}C$ composite standard for the Ordovician of Sweden based on the Tingskullen (Öland) and Borenshult (Östergötland) cores

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$\delta^{13}C$ chemostratigraphy has become a highly important method to correlate sedimentary strata on a basin-wide to intercontinental scale. Most studies on the $\delta^{13}C$ chemostratigraphy in the Lower Palaeozoic of Baltoscandia come from the East Baltic area. In comparison only a few $\delta^{13}C$ records have been published from Sweden (Bergström et al. 2012, and references therein). We have conducted a chemostratigraphic analysis of two continuous core sections that together form a representative record of the highly condensed Ordovician limestone succession in Sweden (Fig. 1).

The Tingskullen core was drilled on Öland and is mainly composed of temperate-water limestone ('orthoceratite limestone') of Tremadocian through Darriwilian age. The Borenshult core was drilled in Östergötland, some 200 km to the northwest in the same palaeobasin, and includes limestone and subordinate shale ranging from upper Darriwilian through Hirnantian in age. The total thickness of the entire Ordovician in the two cores is less than 115 m. Based on more than 300 samples, with a sampling density of up to four samples per metre (whole-rock samples retrieved with a micro-drill), we present the first continuous $\delta^{13}C$ record for the Ordovician of Sweden. Most of the major Ordovician carbon isotope excursions are recognized and the data therefore provide a reliable base for intra- and intercontinental correlation of the Swedish Ordovician.

In the Tingskullen core the $\delta^{13}C$ data set starts in the late Tremadocian Köpingsklint Formation and continues upwards through the core. $\delta^{13}C$ values are initially stable and scatters around baseline values. A protracted positive excursion of more than 1.5‰ spans much of the upper portion of the core section and can confidently be assigned as the Middle Darriwilian Isotopic Carbon Excursion (MDICE). $\delta^{13}C$ peak values for the MDICE are identified in a red limestone unit ca. 13 m below the top of the core succession, a level that presumably correlates with the Segerstad–Skärlöv–Seby limestone interval.

Conodonts in the basal Borenshult core indicate a level just above the MDICE, and four named $\delta^{13}C$ excursions are recognized in the overlying succession (Bergström et al. 2011, 2012). These are the Guttenberg Isotopic Carbon Excursion (GICE) in the lower–middle Freberga Formation; the Kope (or Rakvere) carbon isotope excursion in the uppermost Freberga Formation–?Slandrom Formation; the Whitewater (or Moe) carbon isotope excursion in the lower red unit of the Jonstorp Formation; and the Hirnantian Isotopic Carbon Excursion (HICE) in the oolitic Loka Formation.

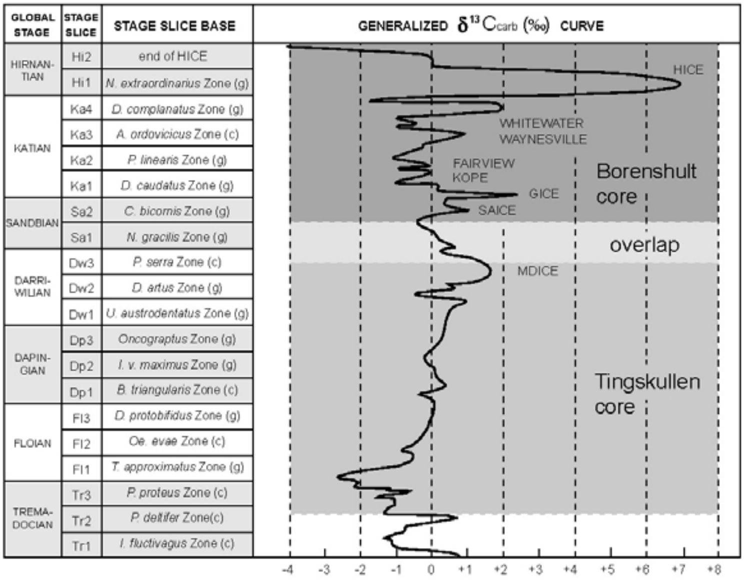

Fig. 1. Global $\delta^{13}C$ chemostratigraphy as presented by Bergström et al. (2009) and later modified by Bergström et al. (2012). Note that we have only indicated the stratigraphic ranges of the Tingskullen and Borenshult cores in the diagram, not added any $\delta^{13}C$ data.

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First evidence of unmineralized and non-cuticular organisms in the Cambrian 'Orsten' assemblages of the Alum Shale Formation of Sweden

CHRISTOPHER CASTELLANI[1], ANDREAS MAAS[1], JOACHIM T. HAUG[2], CAROLIN HAUG[2] AND DIETER WALOSZEK[1]

For more than 30 years now, the Swedish Cambrian 'Orsten'-type Lagerstätten have yielded diverse assemblages of three-dimensional secondarily phosphatized microfossils of arthropod affinities of various different evolutionary levels (Maas et al. 2006). Until now similar material has also been recorded from Canada, the UK, Poland, Siberia, China and Australia, but so far only localities in Australia have added also nemathelminth fossils (Maas et al. 2007; 2009) and problematica (Müller & Hinz 1992). This led to assume that 'Orsten'-type preservation is more or less restricted to the phosphatization of animals bearing chitin-containing cuticles. The only exception to date is the preservation of muscles in Lower Ordovician pentastomids from the Isle of Öland, Sweden (Andres 1989).

We report here for the first time the presence of secondarily phosphatised, filamentous microfossils etched from the †*A. pisiformis* Biozone of the Swedish Cambrian 'Orsten'-type lagerstätten. On the basis of morphological evidence, the phosphatized thread-like forms are interpreted as unbranched and uniseriate, originally unmineralized, filamentous cyanobacteria. The material comprises at least two different species, one identifiable as †*Siphonophycus kestron* Schopf 1968 and one as a new species to be described in due course. Specimens of the new species are preserved as, at least, four degradational variants, as follows: 1) empty tubular sheaths, 2) pseudoseptate filaments, i.e., tubular structures with an imprint of the so-called trichome onto the sheath, 3) sheaths with partial remains of cellular material and 4) possible moulds of multi-cellular trichomes. Additionally, our morphological investigations, combined with a morphometric approach, allowed grouping of the specimens of the new species in three different size classes, but their interpretation remains difficult.

The preservation of filamentous cyanobacterians as secondarily phosphatized replica represents the first extensive record of non-mineralised and non-cuticular organisms in the 'Orsten'-type assemblages of Sweden. In addition, this finding hints at the presence of microbial-cyanobacterial mat consortia on the sea floor of the Alum Shale Sea during, at least, the †*A. pisiformis* Biozone. The disappearance of cyanobacterial mats from the sea floor of the Alum Shale Sea at the †*A. pisiformis* Biozone/Furongian boundary points to relatively drastic changes in the substrate conditions at that time. This again coincided with a major change in the trilobite communities and the globally recognized Steptoean Positive Isotope Carbon Excursion (SPICE) in Scandinavia (Ahlberg et al. 2009).

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Re-appraisal of the faunal diversity of the 'Orsten' assemblages of Sweden – new insight into the late Cambrian Alum Shale ecosystem

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The late Cambrian Alum Shale Formation of Scandinavia consists of condensed sedimentary deposits of dark, organic-rich, finely laminated shales with intercalated limestone concretions. The shales were deposited across a broad, poorly oxygenated, sediment-starved and sulphur-rich epicontinental sea of relatively shallow depth (Buchardt et al. 1997). The shales are highly fossiliferous and have yielded mostly polymerid and agnostoid euarthropods. With the discovery of fossils etched from limestone nodules our view of the benthic faunal communities of the Alum Shale Sea has changed radically. These 'Orsten' nodules yielded, besides a rich conodont fauna, diversified exceptionally three-dimensionally preserved assemblages of 0.1 to 2 mm sized, secondarily phosphatized arthropods. Assignable fossil taxa comprise "Lobopodia", Pentastomida, Chelicerata, and Crustacea. Many of these were originally representatives of the so-called meiofauna, a size-defined community of tiny animals living, temporarily or not, on and within a nutrient-rich flocculent bottom layer (Maas et al. 2006).

Recent re-investigations of the large material of 'Orsten' fossils revealed the presence of much more complex and diversified biocommunities than known so far, not least because the focus was, until now, almost exclusively on arthropods. New faunal elements comprise sponge spicules, in which a part of the collection could be assigned to a species closely related to †*Rigbykia ruttneri* Mostler & Mosleh-Yazdi 1976. The material scarcely includes also shelly fossils identified as hyoliths (†*Microcornus*? sp.), possible tomotiids (†*Lapworthella*? sp.), putative monoplacophoran molluscs (†*Costipelagiella*? sp.), eocrinoids (stem columnals) and organophosphatic shells of linguliform brachiopods of the acrotretid- and obolid-type of brachiopods. The latter are relatively common but mostly occur as fragments making their precise taxonomic identification difficult. Along these new faunistic elements, also previously unrecorded fragments of unknown affinities occur throughout the Alum Shale succession. These problematica consist of ornamented plates, sclerites and tube- to cone-like structures, known mostly only by a few specimens, representing an additional faunistic pool of more than 15 taxa. Also non-animal material could be identified in the form of cyanobacteria (†*Sipho-*

nophycus kestron Schopf 1968 and a new species to be described). Additionally, fragments of previously unknown cuticle-bearing animal taxa round up the search for new material, arthropods such as new pentastomid larvae, crustacean larvae, stalked eyes of †*Henningsmoenicaris scutula* and unknown taxa such as a set of six distinct worm-like morphotypes, of which one is possibly related to cycloneuralian Nemathelminthes.

This re-study highlights that 'Orsten'-type assemblages do not only consist of 'Orsten'-type fossil elements, but also these include numerous organic remains, originally mineralised, other than the common trilobites and conodonts. In addition, the presence of numerous fragments larger than 1 mm in size indicates that the 'Orsten' assemblages do not exclusively consist of benthic elements that formed part of meiofaunal communities, but also of macroscopic benthic organisms. These macroscopic elements are of particular interest because they provide new insight into the possible connections between the 'Orsten' biota and those of the other major Cambrian Lagerstätten with macroscopic fossils.

With the new finds and the discovery of meio- and macrofaunal components, the 'Orsten'-type assemblages from the nodules provide a reliable and complete view of the original ecosystem of the Alum Shale Sea in the late Cambrian Period. The presence of a rich benthic fauna suggests that the water at and above the sea floor was not anoxic and that the bottom may have been occasionally firm enough to allow colonization also by sessile organisms. These conditions were most likely restricted spatially and temporarily. The complexity of the Alum Shale biota indicates that much of the structure of modern marine ecosystems with hierarchical level of the food web had already been established in the Cambrian.

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Temporal and spatial distribution of the Wufeng black shales (Upper Ordovician) in South China

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The period of the late Katian to Hirnantian was a time of the end Ordovician mass extinction, which was associated with a widespread continental glaciation and sea level changes. The strata of this time interval in South China consist mainly of 0–10 m thick black shales and a few interbedded mudstones in the lower and/or upper part, named the Wufeng Formation. A diverse graptolite fauna has been discovered in these strata and systematically studied since the 1980s.

The database for the present study comprises 389 sections in South China. They cover the time interval from the *Dicellograptus complexus* Biozone to the *Metabolograptus extraordinarius* Biozone, which was subdivided into four time slices herein. ArcGIS software was employed to calculate the distribution area, rock volume and average thickness of the Wufeng Formation of each time slice. The results showed that the distribution area, rock volume per Myr, and average thickness per Myr. all decreased with time, which probably indicates a regional response in sedimentation rate to the global sea level fall.

Similarity coefficients between these lithostratigraphic variables and the graptolite biodiversity were calculated to evaluate their relationship to the graptolite diversity change from the late Katian to Hirnatian. A strong correlation between the distribution area of the black shales and/or mudstones and the graptolite richness and a weaker correlation between the rest variables (such as rock volume and thickness) and the richness, may suggest that, among these external factors, the distribution area is the major factor that influences the diversity changes of the graptolite fauna during the late Katian to early Hirnantian.

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The Lower Palaeozoic palaeogeography of Gondwana

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From the Late Neoproterozoic until its merger with Laurussia in the Carboniferous to form the Pangea supercontinent, Gondwana was by far the largest superterrane for about 200 million years, and its remnants occupy 64% of all land areas today. New maps presented for the Early Cambrian (540 Ma) to the Early Devonian (400 Ma) show the land and shallow- and deeper-shelf areas of Gondwana and its surrounding terranes and smaller continents (Torsvik & Cocks in press). Gondwana was formed in the Pan-African and coeval orogenies, which started in the Late Precambrian but did not finish until the Early to Middle Cambrian in some areas. Since the superterrane lay over the South Pole for all the Lower Palaeozoic, on it is preserved much evidence of changing palaeoclimates, including the extensive icecap formed during the brief end-Ordovician (Hirnantian) glaciation at 445 Ma. The widespread *Hirnantia* brachiopod fauna at that time reflected more the deeper levels of oxygenation at the sea surfaces caused by the glaciation, rather than being itself indicative of cold waters, since it lived in both equatorial and at higher latitudes.

After the end of the Pan-African orogenic activity, for most of the Lower Palaeozoic the southwestern (mainly South American) and western (mainly eastern Australian) margins were active and the northern margin passive. A long subduction zone lay all round the southern two-thirds of Gondwana from Mexico to Australasia for much of the period; but active orogeny was variable in the southern sector of the superterrane at the South African and Antarctic margins.

The palaeogeographical reconstructions, although chiefly derived from palaeomagnetic data (Torsvik et al. 2012), can be independently assessed by plotting the positions within the larger continents of both kimberlite intrusions and the massive volcanic outpourings of Large Igneous Provinces (LIPs) at various times. Both LIPs and kimberlites are now known to emanate only from the edges of heterogeneities at the core-mantle boundary, and those heterogeneities have certainly moved little during Mesozoic to Recent times and probably also during the Palaeozoic. Thus the positions of the Cambrian (512 Ma) Kalkarindli LIP in Australia and other LIPs and kimberlites confirm the locations of the major continents. The new sequential reconstructions also provide more realistic platforms for the plotting and analysis of the various benthic provincial faunas during the Cambrian, Ordovician and Silurian.

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A draboviid association from Portugal: Palaeoecological and palaeogeographical significance

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At the beginning of the Late Ordovician draboviids started to diversify and become dominant taxa in some of the Benthic Assemblages present in the Mediterranean Province. The study of a brachiopod collection from the Cabeço do Peão Formation of the Upper Ordovician of Portugal has provided a low-diversity association composed exclusively by draboviids. The commonest component in this association is very close to *Drabovia redux* (Barrande 1848) from the middle part of the Letná Formation, Bohemia. This species was cited in Portugal by Mitchell (1974) in the Louredo Formation and by Young (1985, 1988) in the mudstones of the lower part of Cabeço do Peão Formation, the Queixopeira Member. The second most represented taxon is *Hirnantia kinnelloides* Havlíček, 1977. This species was only known up to date in the greywackes of the top of the Letná Formation (upper Sandbian, Sa2), Bohemia. The presence of *H. kinnelloides* in the bioturbated micaceous sandstones of the Cabeço do Peão Formation (middle Berounian, Katian 1–2 substages of the global scale, according to Sá et al. (2011) constitutes the youngest known occurrence of this taxon, which involves a considerably extension of its stratigraphical range (Sa2–Ka1 global stage slices). The fact that this species has not been found in correlative formations in Bohemia (Vince and Zahorany formations) is a circumstance to investigate. Recently, the utility of brachiopods as biostratigraphical markers has been questioned (Colmenar et al. in press) due to the close relation of each brachiopod to a concrete environment and substrate. This could be an explanation for the absence of this species in the Vinice and Zahorany Formations, both with predominant thin grain, deeper lithofacies than those present in the Letná Fm and in the middle and upper parts of the Cabeço do Peão Fm. The presence of *H. kinnelloides* and other form very close related to *Drabovia redux*, both exclusively typical of Bohemia, strengthens the palaeogeographical relationship between Portugal and the Bohemian region during the early Upper Ordovician.

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Muscles versus environment: Morphofunctional analysis of the brachiopod genus *Svobodaina*

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The brachiopod genus *Svobodaina* was common across north Gondwanan shelves during the Late Ordovician. Previous criteria used by a number of authors (Babin & Mélou 1972; Havlíček 1981; Villas 1985) to differentiate between the three south-western Europe species were based mainly on differences in the ratios of the length/width of the ventral muscle field, since the dorsal valves are more or less indistinguishable across all these peri-Gondwanan species. But the ratios of these species overlap and have proved equivocal in taxonomic discrimination (Colmenar et al. 2013).

The application of geometric morphometric methods to analyze the ventral muscle field outline of the various species of *Svobodaina* from south-western Europe, has allowed identify criteria for discriminating amongst these brachiopod species.

Brachiopod muscles control the opening (diductors) and closing of the shell (adductors) as well as the rotation of the valves and the pedicle movements (adjustors). Variations in environmental parameters, mainly the energy of the bottom currents and sedimentation rate, may clearly affect changes in the size and morphology of the muscle field. Carls et al. (1993), in their study of species of *Howellella*, related large diductor muscles to high-energy and turbulent environments. Therefore strong muscles would help prevent sudden shell closure that could damage the mantle margins.

The data indicate the close relationship between the patterns of the ventral muscle field in the *Svobodaina* species and the environmental conditions where each inhabited; the fields are better developed in species related to high-energy environments. For example, *S. armoricana*, with the smallest diductor scars, would have inhabited the quiet marine environments of the lower offshore or within protected lagoonal settings. *S. feisti* would have inhabited the upper offshore, a more energetic environment than *S. armoricana*. Finally *S. havliceki*, with the largest diductor scars, would have thrived in the most energetic environments amongst all the south-western Europe *Svobodaina* species, living just above the fair-weather wave base in the lower shoreface. The palaeoecological results suggest a distribution of *Svobodaina* species during the Late Ordovician along an onshore–offshore transect across the shallow-marine platforms of the Mediterranean margin of Gondwana.

On the other hand, the occurrence in some localities of several species with overlapping ranges or within the same assemblage indicates that the biostratigraphical efficacy of the genus is restricted. Thus, the previously defined taxon range biozones characterized by *Svobodaina* species of the North Gondwanan margin, are in need of reassessment. The morphology of *Svobodaina* may be a considerable aid to environmental analyses rather than to precise biostratigraphical correlation.

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Revised conodont biostratigraphy of the Silurian of Cellon, Carnic Alps

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The Cellon section probably is the most famous Silurian section in the world and is the reference section for many Silurian studies. It is located in the Austrian side of the Carnic Alps near Plöckenpass, a few hundred meters from the Italian/Austrian state border. The conodont fauna was studied in the pioneer work by Walliser (1964), who also proposed the first zonation scheme of the Silurian mainly based on this section. Later several studies have been carried on Cellon section, documenting several fossil groups, microfacies, isotope signatures, taphonomic and palaeoenvironmental indicators and eustatic sea-level changes (see references in Histon 2012). All these studies were mainly based on Walliser (1964) conodont biostratigraphic framework.

Since Walliser's (1964) paper, conodont studies proceeded all around the world: several new taxa have been discovered and established, the systematic is now based on multielement apparatuses, and taxonomic revisions have been carried out on several groups. Also, new, more detailed, zonation schemes were proposed by various authors on selected time intervals or geographic regions (e.g., Corradini & Serpagli 1999; Jeppsson 2006; Männik 2007; Cramer et al. 2011; Corradini & Corriga 2012).

An updating of the conodont data and biostratigraphy of the Cellon section is therefore necessary. Our revision is based both on restudy of Walliser collection, stored in Göttingen University, and on several new samples collected from selected levels.

In the Llandovery part of the section *Pterospathodus amorphognathoides angulatus* (samples 10B–?10H)*, Pt. a. lennarti* (sample 10H/J) and *Pt. a. amorphognathoides* (samples 11–12A) biozones were recognized. The boundary between the Lower and Upper *Pt. a. amorphognathoides* subzones lies below sample 11F. The *Pt. a. lithuanicus* Biozone (corresponds to the uppermost part of the *Pt. celloni* Superzone) has not been identified but probably occurs in the interval of unsampled shales between samples 10J and 11.

As was indicated already by Walliser (1964) two biozones, *Kockelella patula* (samples 12B–12D) and *Ozarkodina sagitta sagitta* (samples 13C–15A), are identifiable in the Wenlock part of the section. The Llandovery–Wenlock boundary, and number of lower Wenlock biozones (from the uppermost *Pt. a. amorphognathoides* to the middle *K. walliseri*), lie in the condensed (?) interval of shales between samples 12A and 12B. Samples 12E–13B did not yield diagnostic conodont taxa which can be assigned to a particular zone, but based on their location the interval suggests the upper *K. walliseri* and *K. o. ortus* biozones.

The Ludlow and Pridoli part of the section is more continuous, as all the zones of the schemes applied are represented. In the Ludlow the *K. crassa* (samples 15B1–16A), *K. v. variabilis* i.Z. (samples 16B–17A), *Wurmiella hamata* (samples 17B–17E), *Ancoradella ploeckensis* (samples 18–20A), *Polygnathoides siluricus* (samples 21–24A), *Pedavis latialata-Ozarkodina snajdri* i.Z. (samples 25–30) and *Oz. crispa* (samples 30A–33) zones are discriminated.

In the Pridoli the *Z. eosteinhornensis* s.l. i.Z. (samples 33A-37), the Lower *Oulodus elegans detortus* (37A?-42B) and the Upper *Oul. el. detortus* (samples 43-47A) zones have been discriminated. The Silurian/Devonian boundary is equivalent to the base of the *Icriodus hesperius* Zone in sample 47B.

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Upper Silurian and Lower Devonian conodonts and crinoids from the scyphocrinoid beds of southeastern Morocco

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Scyphocrinoids are a group of crinoids widely distributed in uppermost Silurian and basal Devonian sediments. They have a highly specialized bladder-like root, the lobolith, which served for a planktonic mode of life as a buoy. Two types of loboliths are known: the cirrus lobolith, having walls typically built of a dense network of rootlets (cirri), and the biotechnically advanced plate loboliths with a wall of a double layer of polygonal ossicles. In general, plate loboliths occur in younger levels than cirrus loboliths, but in places contemporary occurrence has been reported (Prokop & Petr 1994; Haude & Walliser 1998).

Three sections were investigated in southeastern Morocco (Tafilalt region), named Atrous 3 (loc. 477), Atrous 7 (loc. 540), and Bou Tchrafine N2 (loc. 474). Here the "Scyphocrinoid Limestone" forms more or less recognizable ridges within the shales of the Silurian–Devonian transition. Several limestone beds and lenses consist of crinoidal detritus, whereas other are micritic with nautiloids (Haude & Walliser 1998). In the stratigraphically lower part only cirrus loboliths are present, whereas in the middle part cirrus and plate loboliths are alternating: both types never occur together. In the uppermost levels only plate loboliths are present. Beside loboliths, well preserved crowns of scyphocrinoids belonging to genera *Scyphocrinites*, *Camarocrinus*, *Carolicrinus* and *Marhoumacrinus* are present in some levels.

For discussion on contemporaneously existing scyphocrinoids with cirrus or plate loboliths in the middle part of the sequences, but their strict separation in different layers, see Haude & Walliser (1998).

Rich and quite well preserved conodont faunas allow a precise biostratigraphy of the sections. Four conodont zones of the Corradini & Corriga (2012) zonation scheme have been documented from the "Scyphocrinoid Limestone" (*eosteinhornensis* s.l., Lower *detortus*, Upper *detortus* and *hesperius*), documenting a Pridoli–basal Lochkovian age for these beds.

Cirrus loboliths occur only in the Pridoli, from within the *eosteinhornensis* s.l. Zone to the top of the Upper *detortus* Zone, whereas plate loboliths are present in the uppermost

Silurian and the basal Devonian. The two types overlap in the uppermost Silurian beds (upper part of the Upper *detortus* Zone).

As for calices, *Scyphocrinites* and *Carolicrinus* occur in the whole Pridoli, *Camarocrinus* and, probably, *Marhoumacrinus* across the Silurian/Devonian boundary (Upper *detortus* and *hesperius* zones) and also in the basal Devonian beds.

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Rapid geochemical change in Silurian oceans: Implications for global $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ systematics

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Paleozoic records of the global carbon and strontium systems ($\delta^{13}C$ and $^{87}Sr/^{86}Sr$) contain episodes of extreme geochemical change, yet precise determinations of the rates and durations of these events are largely unavailable. The lack of precise temporal control for these events has limited our ability to determine the nature and causes of these changes due to our inability to address rates, durations, and cause-and-effect relationships within the global stratigraphic record of these intervals. Two new high-precision U/Pb (zircon) dates from volcanic ash deposits from the Ludlow Series of Podolia, Ukraine, combined with four recently published high-precision U/Pb dates from the Llandovery and Wenlock, provide considerable improvements to the calibration of the Silurian time scale, and can now constrain the age and duration of the largest perturbation of the global carbon cycle (Lau Excursion) and one of the most rapid increases in $^{87}Sr/^{86}Sr$ (Ludlow rise) during the past 500 Myr. These chronostratigraphically well-controlled age dates demonstrate rates of geochemical change during the Ludlow Epoch of the Silurian Period that significantly exceed model predictions and challenge our understanding of the Paleozoic Earth system.

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A complete record of the 'Lower' Cambrian–Middle Ordovician succession of Öland, southern Sweden, based on the Tingskullen core

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The exposed Lower Palaeozoic succession on the island of Öland, southeastern Sweden, encompasses strata of 'Middle' Cambrian (provisional Cambrian Epoch 3) through Darriwilian age. These strata were deposited in the interior parts of the palaeocontinent Baltica, during a time when the continent experienced little tectonic influences and global sea level was exceptionally high. Later tectonic influences from the evolving but distant Caledonian foreland basins to the south and northwest were relatively minor to this area, and the thin sedimentary succession on Öland has never been buried to considerable depths (not below the oil window). In order to study the succession using new methods, such as carbon isotope geochemistry, the Tingskullen drillcore was recovered in the year 2010 (Crafoord grant 20050748 to MC). It was drilled c. 670 m northeast of the old church ruin at Källahamn in the northeastern part of the island. This area yields the youngest outcropping strata on Öland and thus is the only place where a complete succession can be retrieved in one single core. The total cored interval is 107 m and the diameter of the core is 39 mm.

The oldest strata in the core are 'Lower' Cambrian (provisional Cambrian Series 2) sandstone of which only the upper five metres were cored before the drilling was stopped. Petrographically, the sandstone is a quartz arenite with greenish mudstone intercalations. It represents the När Sandstone Member of the File Haidar Formation, which is sharply overlain by a 55-m -thick 'Middle' Cambrian (provisional Cambrian Series 3) succession of bioturbated, shaly mudstone with thin siltstone stringers belonging to the Borgholm Formation. The upper part of this succession is of particular interest since it represents a more basin marginal equivalent to the organic-rich alum shale that formed in dysoxic to anoxic environments in the central parts of the basin. A provisional subdivision of the formation into the Mossberga, Bårstad and Äleklinta members is possible. The Bårstad Member is richly fossiliferous and has yielded abundant trilobites indicative of the *Ptychagnostus praecurrens* agnostoid Zone (equivalent to the *Acadoparadoxides pinus* trilobite Zone; e.g., Ahlberg 1989). The trilobite fauna from this member is dominated by *Ellipsocephalus polytomus* and paradoxidid trilobites of the *Acadoparadoxides oelandicus* plexus. Agnostoids are rare but represented by the zonal index. The silt- and very fine-grained sandstone facies with wrinkle structures that are typical for the Äleklinta member at its type locality on western Öland (Calner & Eriksson 2012) is not present in the core, in which the corresponding interval is much more argillaceous. The Borgholm Formation grades upwards into a 0.5 m thick shale succession with 'orsten' lenses. This succession likely represents the Furongian part of the Alum Shale Formation. It is overlain by the Tremadocian '*Obolus* bed', which has a thickness of 0.5 m and shows palaeokarstic features at the top. The palaeokarst surface is overlain by a 2-m-thick interval of a conspicuously dark shale belonging to the Djupvik Formation (Ceratopyge Shale; Fig. 1). The Djupvik Formation reflects the end of siliciclastic sedimentation and is overlain by a 46-m-thick Lower to Middle Ordovician succession of grey and red, temperate water limestone (the 'orthoceratite limestone'). This succession can be subdivided into the Köpingsklint, Bruddesta, Horns Udde, and Gillberga formations, and equivalents to the Segerstad, Skärlöv, Seby, Folkeslunda, Källa and Persnäs limestones. Where possible, we have followed the lithostratigraphic subdivision of the Öland succession provided by Stouge (2004). The lower portions of the Ordovician δ^{13}C composite curve for Sweden presented by Calner et al. (2013, this volume) are based on the Tingskullen core.

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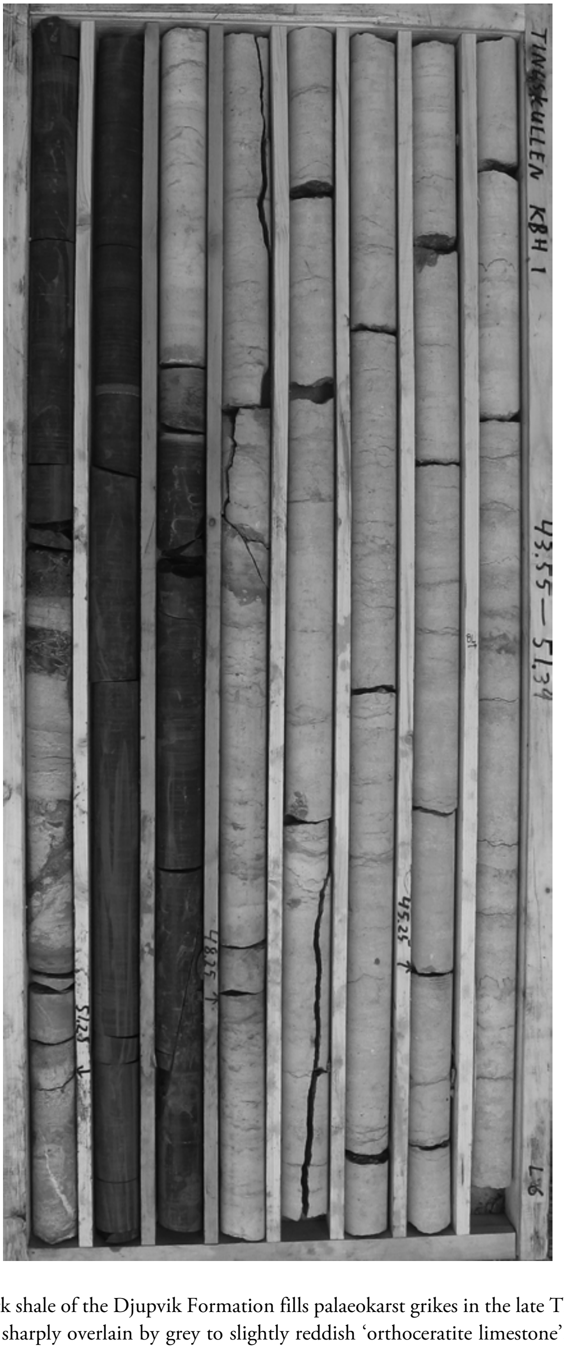

Fig. 1. Conspicuously dark shale of the Djupvik Formation fills palaeokarst grikes in the late Tremadocian ‘*Obolus* bed’ (leftmost column) and is sharply overlain by grey to slightly reddish ‘orthoceratite limestone’. These transitions mark major changes in sea-level and in the type of sedimentation in the early Ordovician of Sweden. Tingskullen core, Öland. Stratigraphic up is from left to right.

Latitudinal constraints on an intra-Iapetus terrane based on biotic and abiotic data from the Upper Allochthon of Västerbotten, Sweden

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Since the pioneer work of Neuman (1984), an increasing number of studies have demonstrated the presence of intra-oceanic islands within the Iapetus Ocean, all now amalgamated within the Caledonian Orogen (e.g., Harper et al. 1996; Harper et al. 2008). The relative position of these terranes within the Iapetus Ocean is very uncertain. Traditionally they have been placed based on their biogeographical affinities to either Laurentia or Baltica, or, based on their relative stratigraphical position within the various allochthons. Based on sedimentological and palaeobiological evidence, the current study is the first attempt to relatively constrain one of the Upper Allochthon terranes latitudinally.

The Caledonian foreland basin developed along the western margin of Baltica during the Iapetus closure and Baltica–Laurentia collision. The strata are preserved from the Oslo region northwards in the Caledonian Lower Allochthon to Norrbotten in northern Sweden. Successions are dominated by turbidites in the early to mid Ordovician, and in the early to mid Silurian. These deep-water, westerly-derived siliciclastics are separated by an interval of proximal marine sediments, reflecting Late Ordovician–early Silurian climatic and tectonic events.

The current study has sampled and compared sections from the foreland basin in Jämtland and from an island-arc setting in the Upper Allochthon of Västerbotten. The late Ordovician to early Silurian successions in these different tectonic environments show facies changes that are very similar. However, the Västerbotten succession display a highly unusual fauna dominated by bivalves, rugose and tabulate corals, macluritid gastropods and pentamerid brachiopods. Whereas the bivalves and pentamerids are confined to a sandy limestone facies, the corals are more common in the pure limestone intervals.

Especially the occurrence of the pentamerid brachiopod *Holorhynchus giganteus* Kjær 1902, is noteworthy as it indicates an uppermost Katian age for this part of the Västerbotten succession. The distribution of *Holorhynchus* includes most of the tropical to subtropical terranes stretching from North China in the east to the marginal settings of Laurentia in west. It has been reported from several localities within Baltica, such as the Oslo and Siljan regions, and further is often referred to as deposited within

Benthic Assemblage zones 2–3 of Boucot (1975). The *Holorhynchus*-bearing beds in the Västerbotten area are associated with abundant corals indicating a tropical depositional environment. However, unlike the contemporaneous Baltic occurrences of this genus, the association with abundant and diverse bivalves at this intra-Iapetus terrane is unique. A high diversity bivalve fauna is more typical of Laurentian inland basins at this time (Novack-Gottshall & Miller 2003a, 2003b).

At this point in the Late Ordovician bivalves were apparently able to migrate and track shallow-water semi-siliciclastic facies within the tropical zone possibly aided by west bound equatorial currents off the low-latitude Gondwanan margins. Therefore, we suggest that the influx of a high diversity bivalve fauna within the Iapetus Region, but not on Baltica, demonstrate that the Västerbotten Upper Allochthon was positioned within the tropical belt – northwest of the Baltic margin – at this time in the Late Ordovician. This, again, would indicate that the deposition of tropical limestones in the Västerbotten area predates the onset of this depositional regime in Jämtland and the rest of Baltica.

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New data on Middle–Upper Ordovician chitinozoa distribution from Pestovo drill core (Moscow Syneclise, East-European Platform)

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The Ordovician has a wide distribution on the Russian Plate. It has been found in central and western parts of the Moscow Syneclise on 800–2500 m depth. The first data on chitinozoa from the Ordovician of the Moscow Syneclise have been published by N.V. Sennikov and O.T. Obut (2002). Their work allowed to specify the stratigraphy of the separate ranges in this area. In the Pestovo drill core this level is between 1176.0–1192.0 m. There, N.V. Sennikov and O.T. Obut marked out the chitinozoa zone *Cyathochitina primitiva*, that corresponds to the Floian and Dapingian stages (Billingen and Volkhov Regional stages).

In the present work, the upper part of the core (980.0–1163.0 m) was investigated. Chitinozoans were separated from ten samples of dolomite and clay limestones. Quantity and preservation of chitinozoa differs greatly between the lower, upper and middle parts of the core. The most chitinozoa (more than 100 specimens per sample) is in the 990.0–1068.0 m interval, the least is in the lower part of the core (less than 20 specimens per sample). Preservation is poor in the lower part of the core and satisfactory in the middle and upper parts (990.0–1111.0 m). Obtained data preliminarily enables to separate two associations of chitinozoa in the examined range.

The lower association is found within the 1084.0–1144.0 m interval and is represented by *Laufeldochitina striata* Eisenack, *Lagenochitina tumida* Umnova, *Cyathochitina calix* Eisenack, *Cyathochitina campanulaeformis* Eisenack, *Conochitina clavaherculi* Eisenack, *Conochitina insueta* Umnova, *Conochitina decepiens* Taugourdeau et Jekhowsky, *Belonechitina micracantha* Eisenack, *Belonechitina castacea* Eisenack, and *Rhabdochitina magna* Eisenack. Due to a presence of the zonal species *Laufedochitina striata* Eisenack this core range can be correlated to the Lasnamägi–Uhaku Regional stages (Nõlvak 2001). The species *Conochitina clavaherculi* Eisenack and *Conochitina insueta* Umnova were found earlier in drill cores from the Moscow Syneclise by N.V. Sennikov and O.T. Obut (2002). Based on the distribution of these species, these investigators marked out the *Conochitina insueta* Zone for the Moscow Syneclise region. The range of the *Conochitina insueta* Zone in the Moscow Syneclise completely includes the *Laufeldochitina striata* Zone and the lower part of the *Laufeldochitina stentor* Zone of Baltoscandia.

The upper association is found within the 990.0–1084.0 m interval. *Rhabdochitina magna* Eisenack, *Cyathochitina campanulaeformis* Eisenack, *Cyathochitina kukersiana* Eisenack, *Belonechitina micracantha* Eisenack are species that characterize this range. They are typical for the *Laufeldochitina stentor* Zone in Ordovician deposits from the Volynia region (Saadre et al. 2004). At present, the zonal species has not been found in this level. An appearance of the *Cyathochitina kukersiana* Eisenack species in the lower part (1077.0–1084.0 m) of this association allows to relate the upper complex of chitinozoa to the lower part of the *Laufeldochitina stentor* Zone. This zone corresponds to the Kukruse Regional Stage of Baltic region (Saadre et al. 2004).

Consequently, in the 1077.0–1168.0 m range of the Pestovo drill core, beds with *Laufeldochitina striata* species can be marked. The upper boundary of these beds approximates to the level of the combined find of the species *Laufeldochitina striata* Eisenack and *Cyathochitina kukersiana* Eisenack. The latter two species identify the lower boundary of the Kukruse Regional Stage in adjacent areas. Based on this data, the investigated interval of the drill core can be correlated with the Darriwilian and Sandbian stages of the international geologic time scale.

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Widespread, time-specific facies motifs on late Hirnantian shallow-water carbonate platforms: A global signature?

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During the end-Ordovician (Hirnantian) glacial maxima, carbonate platforms in the tropics were extensively exposed and their own diverse endemic faunas, displaced to the continental margins, suffered massive extinction. One of the best-exposed and most complete stratigraphic records from a paleotropical area spanning the Ordovician/Silurian (O/S) boundary is on Anticosti Island in eastern Canada. The Anticosti sequence developed within a far-field foreland basin along the eastern margin of Laurentia under the influence of high tectonic subsidence and sustained carbonate sediment supply. Our biostratigraphically well controlled $\delta^{13}C$ curves and depth sensitive facies analysis allow us to recognize a distinctive Hirnantian stratigraphic architecture and its related sea level curve at the Milankovitch-cyclicity scales. The sudden appearance of abundant oncolites and calcimicrobial-coral reefs and local oolitic limestones marks the Anticosti succession near the O/S boundary at the same time of a major faunal turnover (conodont, chitinozoan, acritarch, shelly faunas). These distinctive limestones, associated with a prominent regional marker unit on Anticosti Island known as the Laframboise Member, formed mainly during the peak interval and falling limb of the main Hirnantian positive isotopic carbon excursion. A comparison with the sequence stratigraphy of Morocco suggests that the Laframboise limestones correspond to the rapid deglaciation following the Late Ordovician glacial climax (middle to late Hirnantian in age) characterised by a continental-scale ice sheet. A comparison between the Laframboise succession and other coeval shallow-water tropical successions in Laurentia, Avalonia, Baltica, Siberia and South China shows striking facies similarities with widespread microbial and/or oolithic limestone production and points to time specific transgressive facies present on far-field carbonate platforms during the major Hirnantian ice sheet collapse.

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Chronostratigraphic and palaeogeographic revision of the early Cambrian of northern Montagne Noire (Southern France)

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The northern Montagne Noire possesses one of the most complete pre-trilobitic early Cambrian successions in western Gondwana. Up to now, this succession was supposed to be devoid of useful fossils for biostratigraphy and the complex tectonostratigraphic framework of the broad area exacerbated problems regarding regional correlations and palaeogeographic reconstructions. The Montagne Noire is constituted by three main structural domains: (1) the axial, metamorphic zone; (2) the southern flank, composed of well-studied, fossiliferous nappes involving lower Cambrian to Carboniferous sedimentary rocks; (3) and a poorly fossiliferous, complex, northern flank arranged into imbricated tectonic units bearing lower Cambrian to Silurian rocks.

The chronostratigraphic context of the early Cambrian of northern Montagne Noire is uncertain and stratigraphic reports have broadly relied on putative lithostratigraphic correlations with southern Montagne Noire. This work is aimed at assessing the biostratigraphic potential of the skeletal microfossils extracted from carbonate rocks from the early, pre-trilobitic Cambrian of northern Montagne Noire. Two outcrops occurring in two different tectonic units were investigated: the newly defined Heraultia Limestone Member (Marcou Formation; Álvaro et al. submitted) of the Avène-Mendic Parautochthon and the Marcory Formation of the Mélagues Unit. The relatively thick (c. 60 m) Heraultia Limestone yielded a diverse faunal assemblage dominated by molluscs, hyoliths and problematica, the global stratigraphic range of which arguing for a Terreneuvian (Nemakit-Daldynian/Tommotian) age (Devaere et al. in press). The assemblage allowed the definition of the *Watsonella crosbyi–Oelandiella korobkovi* Interval Zone. Its base is correlated with the base of the Cambrian Stage 2 (Tommotian in the Siberian chart) in Siberia, China, Mongolia and Avalonia. These results suggest the Marcou Formation was deposited laterally to the Terreneuvian Marcory Formation reported from northern and southern flanks of the Montagne-Noire. To test this hypothesis, the rare phosphoritic limestones of the silicoclastic-dominated Marcory Formation were sampled in the Mélagues unit (northern flank). They yielded a faunal assemblage constituted of molluscs, hyoliths, chancellorids and tommotiids. The presence of the tommotiid *Lapworthella rete* argues the upper part of the Marcory Formation is Cambrian Stage 3 in age (Atdabanian according to the Siberian chart). This is congruent with dating of the formation in the southern Montagne Noire (Álvaro & Vizcaïno 1999).

The present study allowed the revision of the early Cambrian chronostratigraphic scheme of Montagne Noire (Álvaro et al. submitted). From a palaeogeographic point of view, it points out one of the earliest (Terreneuvian), relatively thick but geographically limited, carbonate platform on the western margin of Gondwana, questioning the present tectonic and palaeogeographic models of this area. Factors that controlled the setting of isolated platforms such as described in the Avène-Mendic Parautochthon of the Montagne noire need further investigations.

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Simulating the Late Ordovician cooling with the ocean-atmosphere model FOAM

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The Ordovician is an exciting period for climate modelers as this is a completely different Earth characterized by an asymmetric distribution of the continents with a northern hemisphere covered by ocean from the North pole to 50°N. In addition, recent studies point to a cooling slowly beginning in the Katian and with an acceleration during the Hirnantian. Here we use the fully coupled ocean atmosphere model "FOAM" to test the impact of the land–sea distribution on the global climate and on the oceanic surface currents. Despite glacial conditions, atmospheric CO_2 levels during this period were thought to be elevated with estimated ranges from as high as 16x, to low values such as 4x pre-industrial levels (i.e., 280 ppm). We apply FOAM to test climate state for atmospheric CO_2 levels ranging from 16x to 4x. Preliminary results show a tipping point between 8x and 6x with a mean global temperature fall of 8°C. We will show the consequences of this non-linear instability on the tropical surface currents, on the equatorial temperatures and on the geometry and on the volume of the ice-sheets (using the GRISLI ice-sheet model).

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Long-term lithologic changes in the Ordovician of Siberia, Baltica and Laurentia: Comparative analysis

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During the Ordovician Period, the mode of sedimentation in the epicontinental Tungus basin of the Siberian palaeocontinent underwent significant changes. The Lower Ordovician and the lower part of the Middle Ordovician series (from Nyaian to Kimaian regional stages) of the basin are represented by a succession of warm-water tropical-type carbonates. The Upper Ordovician series (from Chertovskian to Burian regional stages) by contrast is represented by a succession of cool-water carbonates dominated by bioclastic wackestone and packstone beds intercalated with fine-grained terrigenous sediments. The two carbonate successions of contrasting lithologies are separated by a unit of pure quartz sandstones up to 80 m thick (Baykit Sandstone) that is overlain by the fine-grained phosphate-rich terrigenous deposits of the Volginian and Kirensko-Kudrinian regional stages (Dronov et al. 2009; Kanygin et al. 2010).

Comparative analysis of the Ordovician successions of Siberia and Baltica demonstrates an opposite trend in the long-term lithologic changes. In the Ordovician basin of Baltoscandia siliciclastic sediments at the base of the succession (Tremadoc) are successively replaced first by cool-water (Floian–Sandbian) and then by tropical carbonate (Katian–Hirnantian) in shallow-water environments (Dronov & Rozhnov 2007). These climate-controlled changes in sedimentation reflect a drift of the Baltic palaeocontinent during the Ordovician from near-polar latitudes of the Southern Hemisphere into the Equatorial zone (Cocks & Torsvik 2005). On the other hand, comparative analysis of the Ordovician successions of Siberia and Laurentia demonstrates a striking similarity in the long-term lithologic changes. On both platforms, the Ordovician succession starts with tropical stromatolite-bearing carbonates which abruptly change to siliciclastic deposits (Baykit Sandstone in Siberia and Eureka Sandstone in Laurentia, respectively) and terminates with cool-water carbonates (Ettensohn 2010; Kanygin et al. 2010). Numerous K-bentonite beds in the Upper Ordovician of Laurentia and Siberia stress this similarity (Huff et al. 2010; Dronov et al. 2011).

Similarly to Laurentia, the Siberian palaeocontinent was located in the tropical zone during the Cambrian, Ordovician and Silurian (Cocks & Torsvik 2007). Therefore, similar to Laurentia (Holland & Patzkowsky 1996; Pope & Steffen 2003), the shift from tropical-type to temperate-type carbonates in the Middle and Late Ordovician of

Siberia can be explained by upwelling of cold oceanic waters into the intracratonic basin. The onset of cooling marked by distribution of cool-water carbonates and phosphate-rich deposits starts earlier in Siberia (late Darriwilian–early Sandbian) than in Laurentia (early Katian). This observation contradicts the hypothesis that the onset of cool-water carbonates in Laurentia reflects a global cooling event. Rather, regional cooling events in Siberia and Laurentia started at different times and merged at later stages, leading to global cooling of the Earth system, which initiated the Hirnantian glaciation.

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The Floian GSSP at Mount Hunneberg, Västergötland, Sweden – sedimentology of a critical interval in Earth history

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The definition and correlation of chronostratigraphic intervals in Earth History has been a major aspect of geological and especially stratigraphical research in the last decades and many GSSPs (Global Stratotype Sections and Points) have been established to accomplish this goal. The Floian GSSP at Mount Hunneberg in Västergötland (south central Sweden) is one of the Ordovician stratotype sections and has been ratified in 2002. It defines the base of the second stage of the Ordovician System at the FAD of *Tetragraptus approximatus* and *Tetragraptus phyllograptoides*. While the biostratihraphy and fossil faunas are well known, little work has been done on the understanding of the sedimentology of the succession and the environment of its deposition.

The lithological succession of the Ordovician succession at Mt. Hunneberg consists of intercalated siliciclastic mudstones and carbonates of Tremadocian to Floian age. Above an unconformity with underlying Furongian (upper Cambrian) shales, siliciclastic mudstones with graptolites and overlying glauconite packstones of the upper Alum Shale Formation are exposed showing a sharp top contact to the carbonates of the upper Tremadocian Bjørkåsholmen Formation. Above, the Tøyen Shale Formation consisting of siliciclastic mudstones and intercalated up to decimeter-thick carbonate beds forms the stratigraphically youngest Ordovician unit at Mt. Hunneberg. The Tøyen Shale Formation is characterized by a lower marl- and carbonate-rich part, exclusively present in the SW of Mt. Hunneberg, and an upper portion made up of mainly siliciclastic mudstones, extending from the *Tetragraptus phyllograptoides* graptolite Biozone on upwards.

The siliciclastic mudstones of the Alum Shale Formation are interpreted as open shelf sediments reflecting sea-level highstands of two trans- and regressions. Overlying glauconite packstones represent a transgression of *Adelograptus* Zone age or younger. The Bjørkåsholmen Formation carbonates indicate a relative sea-level lowstand. The overlying Tøyen Shale Formation records a deepening of the sedimentary environment during sea-level rise initially establishing offshore conditions, with the siliciclastic mudstones forming the upper part of the Tøyen Shale Formation indicating open shelf deposition.

Abundant burrows throughout the succession reflect overall hospitable living conditions in the Mt. Hunneberg area, also during deposition of the Floian black shales. A pronounced decrease in thickness of the Hunneberg succession towards the NE reflects erosion in the proximal compared to distal Hunneberg areas. The succession shows that alternating offshore to open shelf conditions form an ideal sedimentary environment to establish a GSSP with abundant and detailed biostratigraphic information.

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Primary or diagenetic rhythms? Geochemical investigations on limestone–marl couplets from the Late Ordovician Skogerholmen Formation (Hovedøya Island, southern Norway)

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The question whether regular limestone–marl alternations represent environmental changes in a one-to-one manner is a topic of controversy. Although it is tempting to assume that such alternations are sedimentological mirrors of, e.g., climatic cycles, the question is difficult to answer because of the potential occurrence of differential diagenesis. Early in diagenetic history, carbonate dissolution can take place in the marl layers, and the dissolved carbonate precipitates in the pore space of the emerging limestones. This diagenetic redistribution results in a relative enrichment of insolubles (immobile elements bound to clay minerals) in marls and a relative depletion of the same insolubles in the limestones.

Consequently, assuming a homogeneous precursor sediment for both limestones and marls, the concentrations of insolubles in a diagenetically mature succession will deviate from the initial value in opposite direction within the two lithologies. Therefore, these concentrations cannot be employed as proxy data for environmental changes. Instead, the ratio of insoluble element concentrations can be used to test for the diagenetic origin of limestone–marl alternations. In case of different ratios of a pair of insoluble elements (e.g., Ti and Al) in marls vs. limestones, a primary, environmental signal causing the rhythmic lithological succession has to be assumed. In case of identical ratios for these elements in marls and limestones, the initial concentration values of the pristine sediment have been preserved, and thus may indicate a diagenetic origin of the rhythmic lithology.

In our project we investigate several limestone–marl alternations from the Late Ordovician of the Oslo region both by means of geochemistry (XRF) and palynology (chitinozoans). Here we present the first results of the geochemical analyses. The palynological results will be presented in a separate paper by Chloé Amberg and co-workers at the same meeting (Amberg et al. 2013, this volume).

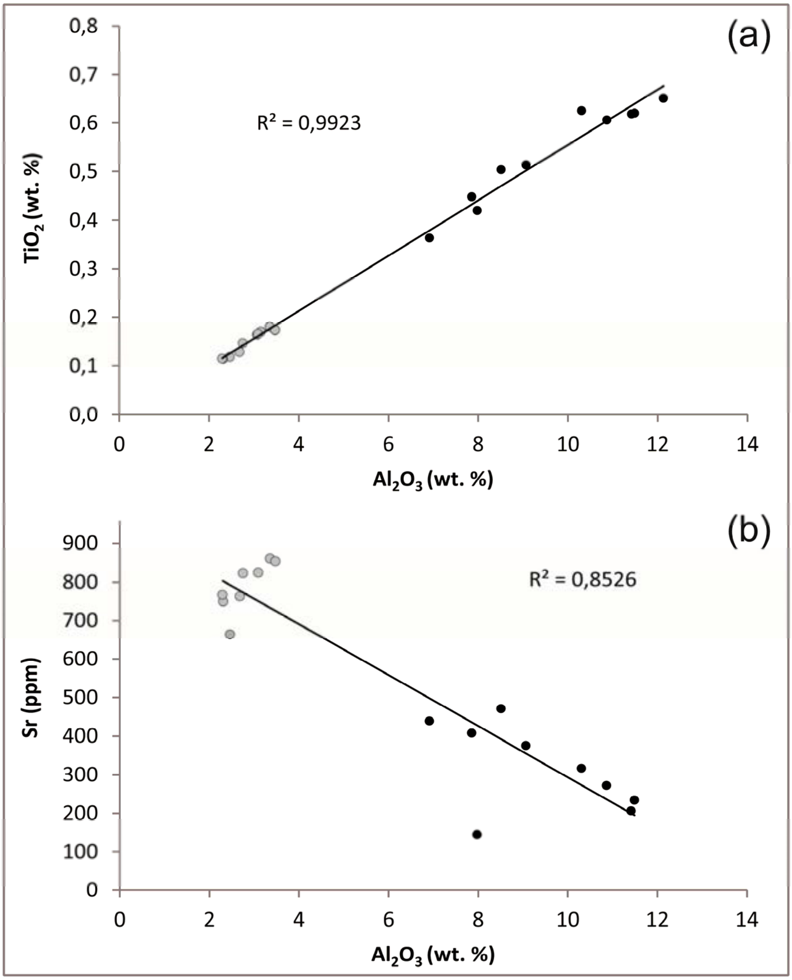

Fig. 1. Contents of TiO_2 (a) and Sr (b) plotted against Al_2O_3 (black dots = marls; grey dots = limestones).

The major and trace elements can be subdivided into three groups. The first group includes oxides and elements which are bound to clay minerals, such as TiO_2 (Fig. 1a), K_2O, or Rb. These elements show a high correlation with Al_2O_3 ($r^2 \geq 0.98$). The second group comprises elements and oxides that can be included in both the calcite lattice and in clay minerals, such as MgO, Fe_2O_3, or Zn. They show a weaker correlation with Al_2O_3 between $r^2 = 0.66$ and 0.97. A negative correlation with Al_2O_3 is observed for elements and oxides which are bound to carbonates, such as Sr (Fig. 1b) and MnO ($r^2 = 0.85$ and 0.79, respectively). These results are in good agreement with the process of carbonate redistribution by differential diagenesis. The high correlation of diagenetically stable elements in limestones and marls indicates that the original clay mineral composition was rather homogeneous. Obviously, there was no major difference in clay mineral input during "limestone times" and "marl times". This, however, does not provide unambiguous evidence for an entirely diagenetically steered unmixing of $CaCO_3$ during diagenesis because primary differences could have been developed by other parameters, such as porosity or content of organic material. Preliminary palynological results from the Hovedøya Member (only four samples at the time of writing) do not seem to record major differences in species occurrences between the two lithologies, and thus, awaiting confirmation from further samples, do not seem to contradict the geochemical results (see Amberg et al. 2013, this volume).

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Synchrotron Radiation X-ray Tomographic Microscopy of Cambrian 'Orsten' fossils: Revealing the soft-tissue anatomy of half a billion year old microscopic animals

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The Cambrian Period was a crucial time in the evolution of life on Earth. Rapid and profound changes in ocean chemistry and substrate composition were coupled with the emergence of a wide array of new life forms and hard-shelled animals. The most important information on these ecosystems derives from fossil Lagerstätten, of which there are unusually many in Cambrian strata. One such example is the world-famous 'Orsten' Konservat-Lagerstätte from Mount Kinnekulle, on the southern border of Lake Vänern, Sweden, which contains remarkably well-preserved minute fossils from the uppermost mid-Cambrian through Furongian (upper Cambrian) bituminous limestones ('Orsten'). The discovery of this incredible fauna in the mid-1970s has been followed by a sequence of investigations disclosing, among other things, morphological details of utmost interest for the evolution of, and relationships among, early arthropods (e.g., Müller 1979; Walossek & Müller 1992; Maas et al. 2006).

The fossils are represented by phosphatized ecdysozoans (moulting animals), most of which are arthropods, in the size range of 0.1–2 mm (e.g., Waloszek 2003; Maas et al. 2006). Phosphatization is generally thought to have involved early diagenetic encrustation/impregnation of the external layers of animals, producing a pristine three-dimensional fossil preservation, with the source of phosphorous being coprolites (Maeda et al. 2011). The external morphology, including cuticle-bearing extremities, of the 'Orsten' metazoans has been thoroughly described (see Maas et al. 2006, and references therein). However, the internal organs and tissues (such as intestines and muscles) of these fossils have rarely been addressed and the lack of knowledge of internal anatomy is a drawback as it limits the extent to which paleobiological conclusions can be drawn.

The cutting edge Synchrotron Radiation X-ray Tomographic Microscopy (SRXTM) analytical technique can provide an opportunity to overcome that problem and offers novel ways to explore the soft-tissue anatomy of these unique fossils (Eriksson & Terfelt 2012; Eriksson et al. 2012). The technique allows non-invasive analyses of uniquely preserved fossils which result in 3D-rendered images showing external as well as internal anatomy with sub-micron resolution. These data offer tools for interpreting functional morphology, mode of life, paleobiology, taphonomy, and for making comparisons with the internal anatomical features of closely related extant organisms.

For our analyses, we utilize the TOMCAT beamline station at the Swiss Light Source, Paul Scherrer Institute in Switzerland, which provides optimal resources for the study of microfossils. During consecutive analyses and refinements of sample handling we (FT in particular) have developed new methods for improvements in speed and efficiency, making optimal use of valuable beamtime. We carefully attach the specimens onto a low light refractive fishing line, which is cut to appropriate length and mounted in a sample holder. This allows for sets of multiple specimens to be subsequently scanned without changing sample holder and re-setting and adjusting the instrument.

We have for example analyzed the well-known microscopic arthropod *Skara minuta* and two species of phosphatocopines, the most abundantly occurring faunal element among the 'Orsten' fossils. The results revealed fossil remains identified as soft tissue structures that facilitated comparisons to extant relatives and allowed (re)interpretations of functional morphology. Our *S. minuta* specimen shows the digestive system (esophagus and midgut) and muscles (to the antennae, mandibles and maxillae). The slanting anterior portion of the head and anteriorly directed mouth with a straight esophagus suggest a primarily browsing and gnawing way of feeding. The prominent head appendage muscles indicate muscle strength and good capacity for food manipulation. In the phosphatocopines the bulbous labrum is one of the most prominent morphological structures of the body. All of our specimens, belonging to *Hesslandona*, reveal pairs of muscle bundles within the labrum. Compared to extant crustacean relatives, these muscles would fulfill the function of moving the labrum up and down in order to open the buccal cavity.

These pilot studies show that there is still much to be learned about the unique 'Orsten' fossils in particular and Cambrian organisms in general and that SRXTM works exceptionally well with this material. Sampling of 'Orsten'-yielding strata in the province of Västergötland, southern Sweden, is ongoing and it is our vision to analyze a wide array of 'Orsten' taxa in order to explore their concealed soft-tissue anatomy. Collectively, the results are expected to open up new horizons in the fields of paleobiology, soft tissue preservation and evolutionary biology and to help closing gaps in our knowledge with regards to the phylogeny of long extinct animals.

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Geobiodiversity Database (GBDB) in stratigraphic and palaeontological research – graptolites as an example

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The Geobiodiversity Database (GBDB) Project (www.geobiodiversity.com; Fan et al. 2011) is dedicated to the construction and maintenance of a web-enabled taxonomic, stratigraphic, and geographic database for information gathered from the fossil record. Its goal is to facilitate regional and global scientific collaborations focused on studying the history, diversity, geography, and environmental context of life on Earth. Graptolites are a major fossil group of the Early Paleozoic. Since 2008 to present, we have compiled an abundance of graptolite data into GBDB.

How many graptolite-bearing sections are there in GBDB?

As of March 28, 2013, 6198 sections have been compiled into GBDB, 1238 of which contain graptolite records. These sections are widely distributed in China, USA, Canada, UK, Italy, Kazakhstan and Poland.

How many graptolite taxa are there in GBDB?

Most graptolite monographs from around the world have been compiled into GBDB. After removing the names with “aff.”, “cf.”, “ex gr.”, “sp.” (such as *Climacograptus* sp. 1, *Didymograptus* sp. A, *Tetragraptus* sp.), there are 7319 formal, unique taxonomic names of graptolites entered, among which, there are 125 family names (including subfamily and superfamily), 466 genus and subgenus names, and 6723 species and subspecies names. As a comparison, 10 103 trilobite taxa and 12 762 brachiopod taxa have been compiled into the GBDB taxonomic database as the present time.

How many graptolite occurrences are there in GBDB?

Howe (2011) made an independent investigation of the graptolite occurrence data in available online databases. As of August 1, 2011, he found 18 427 graptolite occurrences in GBDB, which was greater than the total number of those distributed in the rest eight databases. As of March 28, 2013, there are 194 055 fossil occurrences compiled into GBDB, among which 39 758 are graptolite occurrence records. As a comparison, there are 18 997 trilobite records and 30 682 brachiopod records in the occurrence database.

How to use these graptolite-related data in GBDB?

1. Systematic study of graptolites. One important usage of the graptolite occurrence data is systematics. Through the search engine in GBDB, users can search graptolite occurrence records by using any combination of over 30 fields, such as fossil name, locality, lithology and time duration. Through this function, the users can find all the occurrences of any particular taxon and any related ones. By critically examining them one by one, a complete synonym list can be achieved. GBDB also provides the function to record different taxonimic opinions on species occurrences from expert users and the ability to preserve and incorporate the history of opinion differences.

2. Graptolite stratigraphy. The powerful stratigraphic visualization tool, TS Creator, which was designed by Jim Ogg and Adam Lugowski, was integrated into GBDB in the summer of 2010. Furthermore, two programs for numerical stratigraphy are now supported by GBDB: SinoCor 4.0 (designed by Junxuan Fan and others), and CONOP 9 (Sadler et al. 2003).

3. Graptolite biogeography. GeoVisual 1.0, a tool used for geographic visualization and preliminary biogeographic analysis was designed and integrated in GBDB in 2010, and further updated in 2012. It provides the function of illustrating the distribution of a single taxon or several taxa and the spatial interrelationship between them, calculating the area of distribution, and conducting paleogeographic reconstruction using PointTracker (PaleoGIS, www.paleogis.com).

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Llandovery graptolite biozonation of the Lungmachi Formation on the Yangtze Platform, China

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Llandovery graptolite-bearing strata are widely distributed on the Yangtze platform, which covers most part of the Sichuan, Chongqing, Guizhou, Hubei, Hunan, Jiangxi, Anhui, Jiangsu and Zhejiang provinces or municipalities from west to east. On the Upper and Middle Yangtze platform, the corresponding strata were named as the Lungmachi Formation, which can be divided into two parts, the black shales ("hot shales") in the lower and the grey and yellowish shales and siltstones in the upper (Fan et al. 2011). The black shales of the lower Lungmachi Formation contain abundant organic matter, yield a rich, diverse graptolite fauna, and are considered as one of the key petroleum source beds in China.

In most sections of the Lungmachi Formation, a continuous graptolite sequence from the upper Hirnantian to the Aeronian can be recognized from the black shales, i.e., the *Metabolograptus persculptus*, *Akidograptus ascensus*, *Parakidograptus acuminatus*, *Cystograptus vesiculosus*, *Coronograptus cyphus*, *Demirastrites triangulatus*, *Lituigraptus convolutus* and *Stimulograptus sedgwickii* biozones, in ascending order (Chen 1984; Fan et al. 2011). However, the Telychian graptolite fauna are only known from a few contemporaneous formations in some scattered places along the margin of the Yangtze Platform, such as southwestern Shaanxi and northern Sichuan provinces (Chen 1984; Chen et al. 1990; Ge 1990) in the northwest. Our recent field work in the Hubei and Sichuan provinces and the Chongqing Municipality reveals a considerable distribution of the Aeronian/Telychian boundary strata in the central and northern margin of this area. The graptolite sequence from the upper *Stimulograptus sedgwickii* Biozone to the *Spirograptus guerichi* Biozone can be recognized from the gradual transition between the lower black shales and upper grey and yellowish shales and sandstones at many localities. At a few localities, such as Shennongjia (Songbai County, Hubei Province) and Qiaoting (Nanjiang County, Sichuan Province), the *Spirograptus turriculatus* Biozone can be recognized as well. Therefore, a continuous graptolite sequence of ten biozones from the upper Hirnantian Stage to the lower Telychian Stage can be established in South China and could be considered as one the of standards of global correlation among the contemporaneous strata.

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Contact relationship between the Shihtzupu Formation and the Pagoda Formation in the Sichuan Basin, Southwest China

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Since the Middle Ordovician Shihtzupu Formation and the Late Ordovician Pagoda Formation were named in the 1920s, they have been considered to be conformably contacting in the Sichuan Basin, Southwest China. Herein, samples from two Middle–Upper Ordovician sections in the Sichuan Basin are analyzed for their conodont biostratigraphy and carbon isotope stratigraphy. Both biostratigraphic and chemostratigraphic results indicate a gap between the Shihtzupu and Pagoda formations. The gap corresponds to more than four Sandbian conodont biozones at the study sections, at least including the *Pygodus anserinus*, *Yangtzeplacognathus jianyeensis*, *Baltoniodus variabilis* and *B. alobatus* zones. Besides, $\delta^{13}C_{carb}$ data show that the mid-Darriwilian excursion (MDICE) reported from northern Europe is observed in the upper part of the Shihtzupu Formation, while the global Guttenberg excursion (GICE) of the early Katian Stage occurs near the bottom of the Pagoda Formation. Therefore, most of the Sandbian Stage is probably not recorded in study area. Further study found that the gap can be roughly correlated with the unconformity between the middle Ordovician Yijianfang Formation and its overlying strata in Xinjiang Province, Northwest China, as well as the M4/M5 sequence boundary in North America.

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The base age of the Early Ordovician Honghuayuan Formation on the Upper Yangtze Platform, South China

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The Early Ordovician Honghuayuan Formation is extensively developed on the entire Yangtze Platform. It is mainly composed of grey, thick-bedded to massive, limestone and bioclastic limestone. Previous studies have been indicated that the top of the formation is diachronous and gradational into overlying siliciclastic dominated facies of the Meitan Formation (Zhen et al. 2006). Herein, conodonts from the Honghuayuan Formation at two localities (one in Guizhou Province and another in Chongqing City) have been researched. The results show that the base of the Honghuayuan Formation belongs to the *Triangulodus bifidus* conodont Biozone in the Guizhou Province, whereas it belongs to the *Serratognathus diversus* Zone in Chongqing City. Obviously, it is diachronous, as is its top. According to the present data, from the southwest to the northeast, the base age of the Honghuayuan Formation should gradually vary from the late Tremadocian Stage to the early Floian Stage on the Upper Yangtze Platform.

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Long-legged lobopodian from Cambrian of the Barrandian area, Czech Republic

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Lobopodians constitute a small group of tiny to middle-sized spectacular ecdysozoans closely related to arthropods. Diverse types of lobopodians are known from the Cambrian, and very restricted information on this group exists from the Upper Ordovician, Silurian, Carboniferous and Eocene. Articulated lobopodians have been rarely described from several early/'middle' Cambrian Burgess Shale-type Lagerstätten. We report the first find of a trunk of a long-legged lobopodian animal *Onychodictyon* sp. from the 'middle' Cambrian Jince Formation in the Czech Republic (Fig. 1). The new fossil shows a trunk with at least nineteen long thin lobopods marking the ventral side of the body and bases of thin outgrowths protruding from the dorsal trunk surface. The second lobopodian specimen was collected from the Skryje Member of the Buchava Formation (Skryje-Týřovice Basin) of 'middle' Cambrian age. This specimen contains twenty partially mineralized elements, the majority of which are arranged in symmetrical pairs.

The recent findings of rare lobopodians in Russia, Spain and the new Bohemian specimen demonstrate that the lobopodians were much more widespread in the early/'middle' Cambrian interval than supposed.

Fig. 1. Mineralized lobopodian elements from the Buchava Formation of the Skryje-Týřovice Basin.

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A new early Cambrian arthropod illuminates the origin of the biramous limb

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The biramous limb of marine arthropods is almost universally distributed and appears to have evolved deep in arthropod phlyogeny, as reflected in the Cambrian fossil record (Boxshall 2004). However, both its function, mode of attachment and fate in subsequent evolution have been highly controversial (Whittington 1975; Budd 1993; Walossek 1993; Damen et al. 2002; Zhang & Briggs 2007; Wolff & Scholtz 2008). Here we describe a new early Cambrian arthropod from the Chengjiang fauna, *Soleaprimarium sperare* gen. et sp. nov. that sheds light on the origin and evolution of the biramous limb. The new arthropod is 71 mm in length. The body is divided into two tagmata: a prosoma and an opisthosoma, distinguished by further differentiation of the limbs. The prosoma which is covered by a large head shield possesses anteriomost stalked eyes and nine biramous appendages; the opisthosoma is characterized by an absence of the limb endopods and bears only four pairs of large flap-like outer branch. The outer branch is evidently bilobate: the proximal lobe with gill-like structures connects directly to the body wall (thus suggests that part of the outer branch of the Cambrian biramous limb is homologous to the extant protopod) and the distal lobe (evolved into true exopod). Such a state can be seen in other Cambrian taxa such as *Kwanyinaspis* (Zhang & Shu 2005), *Parapeytoia* (Hou et al. 1995), *Misszhouia* (Zhang et al. 2007) and *Jugatacaris* (Fu & Zhang 2011). The overall unity of these important taxa suggests that a tripartite limb consisting of a gill-bearing protopod that was attached both to the body wall and to two rami is plesiomorphic for a large clade of Cambrian arthropods. This reconstruction offers a novel way out of the problems presented by the features of mandibulate and chelicerate biramous limb, and suggests that the arthropod biramous limb really is a deep apomorphy of all euarthropods.

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Indication of gypsum evaporites in a patch reef of the upper Slite Group (lower Homerian, Wenlock) in the Silurian of Gotland, Sweden

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New evidence for evaporitic conditions in the Silurian of Gotland is given by the presence of probable calcite pseudomorphs after gypsum in a patch reef in the abandoned quarry of Furilden in the upper Slite Group (lowermost Homerian, Wenlock) on NE Gotland (Sweden). In order to reconstruct the facies composition, palaeoenvironmental conditions, and facies development during reef growth, the section has been measured, and litho- and microfacies analysis have been accomplished within the scope of the first author's master thesis. The rocks in the quarry are mainly composed of bedded crinoidal limestones, cortoid grainstones, and peloidal grain-/packstones, intercalated with thin layers of reef debris. Within the bedded limestones a small patch reef is developed, which is marginally exposed in the center of the quarry, and predominantly built up of stromatoporoids, tabulate corals, and crinoids forming a bafflestone fabric. Idiomorphic pseudomorphs of calcite after gypsum are observed randomly distributed all over the exposed parts of the reef body. They occur (a) in silt-sized carbonate sediment, which fills former moldic porosities, (b) in the micritic matrix of bioclastic rudstones, and (c) in the thrombolitic matrix of bioclastic floatstones. The pseudomorphs are lenticular–rhombic in shape, with an average length of 400–500 µm and a width of 180–200 µm. Commonly the crystals show dark micritic inclusions, which might represent impurities of the former gypsum crystals. The dominance of stenohaline organisms such as corals and echinoderms in the reef indicate normal-marine salinities during reef growth. The development of evaporitic conditions and the formation of evaporitic minerals therefore postdate reef growth. Possibly, the authigenic gypsum crystals were formed by downward percolating hypersaline brines, which formed on an extremely shallow carbonate platform during the early Homerian (latest *C. lundgreni* graptolite Zone) regression.

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Late Middle and Late Ordovician graptolite biostratigraphy and biogeography – a reassessment from Polish and Baltoscandian drill core data

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Trans-Iapetus graptolite correlations of late Darriwilian through Katian strata have historically been problematic. This is due in part to the very different faunal assemblages that occur in regions that occupied different paleo-latitudes, such as Avalon and Laurentia (Zalasiewicz et al. 1995). A large amount of work has been invested in recognizing the key paleo-tropical (Pacific Province) index species that occur in both regions (e.g., Finney & Bergström 1986; Zalasiewicz et al. 1995), a task that successfully achieved better global correlations but tended to obscure the distinctiveness and diversity of mid and high paleo-latitude graptolite faunas.

Several drill cores that cut through the Ordovician strata of Baltoscandia and Poland contain rich graptolite faunas in the interval that spans the *Pseudamplexograptus distichus* to *Dicellograptus complanatus* zones. Individually, these drill cores have diverse faunas in different and limited parts of the late Middle and Late Ordovician, but together they provide a detailed and nearly continuous record of mid paleo-latitude graptolite biostratigraphy in this interval. We re-examined the graptolites from drill cores in Sweden (Koängen; Nilsson 1977), Poland (Łeba-8, Dębki-2, Białogóra 1, Białogóra 2, Darżlubie IG-1; Podhalańska 1980), and Latvia (Kandava-25; Goldman & Nõlvak in prep.) in order to update the taxonomy, revise species ranges, corroborate key zonal ties between provinces, and gain a better understanding of mid paleo-latitude graptolite faunal composition and diversity through an exceptionally well sampled stratigraphic sequence.

The Kandava-25 and Koängen drill cores contain diverse graptolite faunas in late Darriwilian and Sandbian age strata. The Łeba Elevation drill cores (Poland) have more abundant graptolites in the late Sandbian (*Diplograptus foliaceus* Zone) through middle Katian (*Pleurograptus linearis* Zone). This indicates a slightly delayed but longer lasting period of transgression in the western part of the Baltic Depression than in the East Baltic or Scandinavia. In the late Dariwillian and Sandbian, graptolite faunas are dominated by species of *Pseudoclimacograptus*, *Archiclimacograptus*, and *Haddingograptus*, and although nemagraptids, dicranograptids, and dicellograptids do occur, they are uncommon relative to the Climacograptoidea. In addition to the relatively well known *A.*

sebyensis, *H. eurystoma*, *H. oliveri*, and *Pseudamplexograptus disthicus*, a group of derived *Archiclimacograptus* species such as *A. skagensis*, *A. antiquus*, and *A. rugosus* are common in this interval. Additionally, a number of new species of *Pseudoclimacograptus* and *Archiclimacograptus* that had previously been lumped together in *P. scharenbergi* are abundant in the Sandbian. Other distinctive elements of this interval include *Gymnograptus linnarssoni*, *Oepikograptus bekkeri*, and several species of *Normalograptus*. Large diplograptid species such as *Orthograptus whitfieldi* and *O. calcaratus* occur abundantly in both Pacific and Atlantic faunal provinces.

Faunal differences become more pronounced in the Katian. The *Dicranograptus clingani* Zone contains a low diversity fauna that is dominated by taxa unknown in Pacific Province successions. These include *D. clingani*, "*Diplograptus*" *compactus*, and several new species of *Diplograptus* and *Normalograptus*. Most interesting is the low diversity of *Orthograptus*, *Amplexograptus*, and *Rectograptus* species (astogenetic Pattern G diplograptids), faunal elements that are exceedingly common in paleo-tropical successions. This morphologic and ecologic niche seems to be occupied by similarly large Climacograptoidea with a Pattern C proximal development, such as "*Diplograptus*" *compactus*. Apparently similar patterns occur in the perigondwanan realm where unusual late climacograptoids such as "*Diplograptus*" *bohdalecensis* are relatively common. Diversity remains low in the *Pleurograptus linearis* Zone where the fauna becomes dominated by non-spinose climacograptinids (*Styracograptus styloideus*, *S. tubuliferus*) and species of *Normalograptus*. Although several dicellograptid taxa are present in this interval of the Polish drill cores (e.g., *D. johnstrupi*, *D. pumilus*, *D. flexuosus*), they are limited to a few horizons and the diverse assemblage of mid Katian dicellograptids that is so common in the Australasian succession, for example, is generally missing. Interestingly, in the lower and mid Katian Avalon-type faunas become even more dominant as the drill core localities move closer to paleo-shoreline. This may indicate some general correspondence between latitudinal and onshore–offshore controls on faunal gradients.

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Ordovician chitinozoan biogeography and paleoecology: Examining the effect of habitat on species longevity

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The relationships between geographic range and evolutionary dynamics, including taxonomic duration, have been analyzed for a number of fossil groups, particularly benthic macrofossils. Ordovician drill cores from the East Baltic region and Scandanavia are extremely fossiliferous and well sampled, providing an excellent microfossil data set for evolutionary studies. In this study we examined the relationship between habitat preference and species longevity in Ordovician chitinozoans. Baltoscandian boreholes and outcrops span three confacies belts, the Scanian (slope, black shale), Central Baltoscandian (outer shelf, argillaceous limestones), and North Estonian (carbonate platform) belts (Jaanusson 1995). We first used chitinozoan distribution patterns across the three confacies belts to develop a model of chitinozoan paleoecology. We found that chitinozoan biotopes tended to reflect onshore/offshore distribution as opposed to depth stratification. These findings are consistent with those of Vandenbrouke et al. (2010). We grouped the species into three biotopes: generalist (taxa occurring in all three confacies belts), platform to outer shelf (taxa occurring only in the North Estonian and Central Baltoscandian confacies), and platform restricted (taxa occurring only in boreholes from the North Estonian Platform). Seven species occurred only in the Central Baltoscandian confacies belt, but constituted too small a group to be included in the statistical analyses.

We then used the quantitative stratigraphic correlation program CONOP9 (Sadler et al. 2003) to construct a Middle and Upper Ordovician composite range chart from the stratigraphic range data of 132 chitinozoan species from 26 boreholes and outcrops in Estonia, Poland, Latvia, and Sweden. After using CONOP9 to construct a composite section, we converted it into a timescale by assigning the absolute ages of chitinozoan biozone bases (taken from Webby et al. 2004) to the FADs of the key chitinozoan index taxa in the composite and then scaled the composite appropriately. Durations in millions of years were calculated for each taxon based on their stratigraphic range in the composite section, and examined for dependence on biofacies affinity and spatial range. Average species longevities are 8.1 million years for generalist taxa, 3.4

million years for platform and outer shelf taxa, and 2.0 million years for platform restricted taxa.

In an initial ANOVA examining the dependence of average taxon durations on biofacies and number of sections, our data indicate that both biofacies affinity and species prevalence are statistically significant. T-tests indicate that generalist species, those that occur in all three confacies belts, do have significantly longer durations than taxa with more restrictive biofacies affinities, as seen in the pairwise tests. These results indicate that this set of chitinozoa follow two commonly held hypotheses, that generalist species have longer durations, and that species geographic ranges also exhibit a positive correlation with duration, independent of the biofacies contribution.

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Early Ordovician molluscs with an exceptional preservation from the Timan-Pechora Basin of Russia

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In the Timan-Pechora Basin of northeast Baltica, the Bol'shepul'skaya-1 borehole penetrated coarse-grained sandstones unconformably overlying Riphean metamorphic rocks at a depth of 1587 m. The limestone lenses, 50 meters above these unfossiliferous sandstones and grey mudstones, yield abundant monoplacophoran molluscs with preserved colour pattern. Higher in the drill-hole are siltstones intercalated with limestones with rare acrotretid brachiopods and conodonts that suggest a late Tremadocian age for these strata.

Collection of monoplacophoran molluscs is represented by more than fifteen specimens with preserved colour pattern. Several specimens show muscle scars. The shells have obviously been sorted and transported but not far from the habitat due to an excellent preservation. Most of the shells have a rather uniform size, about one centimeter, though several shells cut by the borehole exceed two centimeters in size.

Muscle scars are arranged in circum-apical ring, with the two smallest pair of rounded scars on the supra-apical slope closer to the apex. The third to fifth (from the medium line of the supra-apical slope) pairs are tightly fused. The sixth to eighth elongated pairs are approximately the same size.

The colour pattern consists of eight well-preserved pairs of radial brown bands. These bands vary in width. Two pairs of narrow bands on the supra-apical slope of the shell correspond with the least muscle scars that situated closer to the apex. A pair of the widest bands obviously related to the muscle scars of fused retractors. The sub-apical area consists of a wide light-brown sector with two pairs of darker radial narrow strips that probably correspond to a sub-apical muscle field that is often obscured in coarsely preserved fossil material.

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The extent of the Dapingian Stage (Middle Ordovician) in peri-Gondwanan Europe and North Africa: Stratigraphic record, biostratigraphic tools, and regional chronostratigraphy

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The Dapingian Stage is widely recognizable throughout middle- to low-paleolatitudinal areas at a global scale, but not in high-paleolatitude regions such as the peri-Gondwanan Europe and north Africa, where their characteristic biostratigraphic markers (some key conodonts and graptolites) are absent or replaced by long-ranging species of graptolites and shelly fossils.

None of the naming taxa that favoured the subdivisions of the Dapingian into the 'Time Slices' 3a to 3b or the 'Stage Slices' Dp1 to Dp3 are so far recorded in south-polar Gondwana, so that in the regional scale for this area we broadly adopted the British-derived 'upper Arenigian' stage, which unifies an undifferentiated Dapingian plus the lower Darriwilian and perhaps the uppermost Floian (Gutiérrez-Marco et al. 2008). This operative and obscure regional unit extends from the top of the widespread Armorican Quartzite, which was dated as mid-Floian by means of chitinozoans of the *Eremochitina brevis* biozone, until the FAD of the pendent didymograptids (Darriwilian 2) in the overlying shales. When Lower to Middle Ordovician graptolitic shales regionally replace the Armorican Quartzite, such as occurs for instance in Bohemia and Morocco, the absence of Dapingian fossils is also striking. Due to the lack of conodonts or valuable macrofossils, Dapingian rocks can be only envisaged in south-polar Gondwanan paleolatitudes by a limited record of chitinozoans and acritarchs. However, the regional chitinozoan biostratigraphy has gone through large conceptual variations in the last years, from considering a single *Desmochitina ornensis* Biozone placed in the 'upper' Dapingian (Paris *in* Webby et al. 2004), followed by a 'lower' Dapingian *D. ornensis* Biozone and an 'upper' Dapingian *Belonechitina henryi* Biozone (Paris *in* Chen et al. 2009), to an essentially 'upper' Dapingian combination of both biozones (Paris *in* Videt et al. 2010). These confusing interpretations should be clarified in order to refine the sequential analysis and the relative sea-level changes recorded in the south-polar Gondwana platform prior to the *bulla* and *protocalix/calix* transgressive events (Paris et al. 2007; Videt et al. 2010).

Two contrasting Dapingian sedimentary successions have been recorded in south-western Europe: the first is represented by a 'condensed' sequence, with some stratigraphic gaps, where the entire Dapingian and the lower Darriwilian strata are only 6 to 8 m thick, as occurs in some places of Britany and Normandy (Dabard et al. 2007). The second one is recorded in the southern Central-Iberian Zone of Spain, where Dapingian strata are probably represented by a thick unit of sandstones and sandy shales (the Pochico beds and equivalents), over 200 meters in thickness, that include at the base the same lingulid bed that occur at the top of the Armorican Quartzite in western France. In the remaining European and north African areas, Dapingian strata are absent or are represented by scattered records of thin shale beds bearing some of the palynomorph assemblages mentioned above. In fact, the Dapingian Stage seems impossible to identify over a huge area of south-polar platform in absence of chitinozoan datings, that still need re-calibration.

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A hint of Hirnantian ocean chemistry from Jämtland, Sweden

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The late Ordovician extinction is currently attracting substantial attention by workers using multiple geochemical tools, and these efforts increase our understanding of environmental changes during this interval, such as the continental ice cover, cooling (Finnegan et al. 2011) and ocean chemistry (Hammarlund et al. 2012). Nevertheless, there is still no consensus as to which kill mechanism drove the biotic crisis; candidates range from cooling, amalgamation of continents (Rasmussen & Harper 2011) to marine anoxia. Here, we investigate the extinction interval in Jämtland, Sweden, by extracting pyritic sulfur isotopes (^{34}S) and iron speciation in shales from two different environmental settings perpendicular to the paleocoastline, the Kogsta Silstone Formation (deep and low energy) and the Kyrkås Quartzite Formation (shallower and higher energy). At these localities, pyrite sulfur is enriched in the Hirnantian, and then particularly at the deeper site. The ^{34}S pattern, overall, resembles what is described for six other Hirnantian sites (Hammarlund et al. 2012), and we argue that geochemical indications for a Hirnantian sulfidic ocean event may also be captured in Jämtland, with the potential of a differentiation between depositional depths.

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Late Ordovician carbonate mounds from North Greenland: A peri-Laurentian dimension to the Boda Event?

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The Upper Ordovician and lower Silurian succession in Peary Land, North Greenland, exposes a carbonate succession recording environmental and faunal events through the Katian, Hirnantian and Rhuddanian stages on this part of marginal Laurentia (Harper et al. 2007). A number of small carbonate mounds, comprising largely microbial but with some coral material, overlie variably developed brachiopod-dominated shell beds in the Børglum River section. The microbial laminae are typically crinkly, undulating, and medical, whereas the corals are delicate, digitate to phacelloid colonies. The mounds rarely exceed one metre in height, generally forming isolated to laterally coalesced, domal structures. The mounds occur within the lower 25 metres of the Turesø Formation. This part of the formation is dominated by thick-bedded *Thalassinoides* ichnofacies (Jin et al. 2012) and elsewhere in North Greenland coeval beds contain thick, nonamalgamated shell beds of the pentameride *Proconchidium*. Both biofacies suggest that this part of Greenland occupied the hurricane-free, equatorial belt during the Late Ordovician (Jin et al. 2013). The carbonate mounds are equivalent in age to those in the Alegatsiaq Fjord Formation (Kap Ammen Member) to the west and farther afield the Keisley and Kildare mounds on Avalonia, the Boda mounds on Baltica and those in Kazakhstan. This interval has variably been defined as a warming (Fortey & Cocks 2003) or a cooling event (Cherns & Wheeley 2007) but is associated with high sea-levels, local endemicity around carbonate mounds and a general poleward migration of brachiopod faunas. The Peary Land succession exhibits a similar phase of carbonate mound construction in the deeper-water facies of the equatorial belt.

Further up section, the microbial mound unit changes into organic-rich, non-fossiliferous, thin-bedded limestone to calcareous shale of probable latest Katian age. Thus, the upper Katian succession in the pericratonic equatorial setting of North Greenland records a drastic environmental change from normal marine, well-oxygenated substrate conditions to a dysaerobic to anoxic setting, likely coupled also with abnormal salinity, coinciding with an episode of global ocean anoxia (Page et al. 2007).

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The *Hirnantia* brachiopod fauna in the East Baltic: Offshore–onshore gradients in Estonia and Latvia

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The terminal Ordovician Hirnantian faunas document a unique interval in the evolution of the Early Palaeozoic life, and have been intensively studied in the last few decades in association with the definition of the base of the Silurian and ecosystem change at and near this horizon. In Baltoscandia, the *Hirnantia* brachiopod fauna is well documented from Norway and Sweden, where Upper Ordovician strata crop out at numerous localities. However, in the East Baltic, coeval strata occur subsurface down to depths of several kilometres and here the Hirnantian faunas are virtually unknown. To date, the distribution of Hirnantian brachiopods and associated shelly faunas have been analysed in about 700 rock samples from 43 drill core sections, where the thickness of the Porkuni Stage is commonly less than 25 m. *Dalmanella*, *Cliftonia*, *Hindella*, *Plectothyrella*, *Hirnantia* and *Eostropheodonta*, typical of the *Hirnantia* fauna of the Kosov Province, are present, often in association with the trilobites *Mucronaspis* and *Brongniartella.* Data on brachiopod occurrences were analysed using PAST software (Hammer et al. 2001). Analyses of the occurrences of brachiopods in 21 core sections in westernmost Latvia reveal that typical Hirnantian brachiopods represent about 80% of all occurrences, whereas the monotaxic occurrences of *Eostropheodonta*, *Cliftonia* and *Dalmanella* form 5%. The distribution of the brachiopods from the Latvian sections indicates that diversity increases upwards within the Kuldiga Formation. The invasion of the cold-water brachiopod fauna is coeval with the development of the Gondwana ice cap, which is marked also by the rising limb of the carbon isotope curve. *Hirnantia sagittifera*, *Paromalomena polonica*, *Eostrophedonta hirnantensis*, *Leptaena rugosa*, *Plectothyrella crassicosta* and *Hindella crassa* belong to the most diverse association. The diversity drop and increase in the number of montaxic occurrences (particularly *D. testudinaria*, *E. hirnantensis* and *P. crassicosta*), in several cases *in situ*, characterises the mid-Hirnantian brachiopod fauna. The uppermost Ordovician sandy and oolitic lithologies are almost barren of shelly fauna in the Baltic sections, in contrast to the siltstones, sandstones and oolitic limestones of Scandinavia (Brenchley & Cocks 1982; Bergström et al. 2013).

Multivariate investigation of the brachiopod data (particularly cluster analysis using the Raup-Crick similarity coefficient) supports the distinction of two separate groups:

the *Hindella-Cliftonia* and *Dalmanella* associations (Hints et al. 2010). The third association, provisionally named the *Eoplectodonta* association, belongs partly to the lower Hirnantian *S. taugourdeaui* chitinozoan biozone. It characterises the first stage in the development of the *Hirnantia* brachiopod fauna. This earliest, low-diversity association comprises *Kinnella* sp., *Cliftonia* sp. A, *Onniella* sp. and *Eoplectodonta* sp., together with the first representatives of *Dalmanella*; these are often associated with orthoconic cephalopods, common in the drill cores.

The changes in the *Hirnantia* brachiopod fauna in a shoreward direction are evident in three sections in southern Estonia. Among the associated organisms, the increasing abundance of rugose corals and the calcareous alga *Rhabdoporella* and the occurrence of some ostracodes (Meidla 1996) indicate a link with the faunas of the reef complex in Central Estonia. In the onshore–offshore transitional area, the occurrence of cystoids in the lowermost Porkuni Stage is similar to assemblages below the diverse brachiopod associations in the central Oslo Region, Norway and may provide a means of correlation westwards.

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Small carbonaceous fossils (SCFs) as a new measure of early Palaeozoic biostratigraphy

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Fossils provide a crucial measure of Cambrian stratigraphy. However, in successions and time intervals that lack conventional zonal fossils, correlations remain problematic. More generally, a broader understanding of fossil ranges will be crucial in testing correlations based on non-biostratigraphic data. Small carbonaceous fossils (SCFs) represent a category of gently-extracted organic-walled microfossils that are larger and more delicate than those recovered using traditional palynological techniques (Butterfield & Harvey 2012). Although SCFs have been largely overlooked, they potentially represent a widespread source of data for biostratigraphic as well as palaeobiological studies.

To test this potential, we have conducted a large-scale study of Cambrian SCFs in the Western Canada Sedimentary Basin. Our focus has been on the subsurface succession in Saskatchewan, which consists of up to 500 m of sandstone, siltstone and shale, with minor carbonate and flat-pebble conglomerate; macrofossils are sparse but include linguliform brachiopods and occasional graptolites. The succession was deposited in a wide intracratonic sea and represents the 'Inner Detrital Facies', in distinction to the offshore, shale-carbonate 'Grand Cycles' now exposed to the west in the Rocky Mountains. In Saskatchewan, internal divisions and wider correlation of the succession have been obscured by the repetitive nature of the sedimentation, the lack of exposure, and the absence of trilobites and traceable carbonate horizons. However, thickness variations across the region, with the extension of the units into trilobite-bearing strata in neighbouring Alberta and the northern United States, predict a depositional age range from middle Cambrian (Series 3) to early Ordovician. In broad terms, the middle Cambrian part corresponds to the Basal Sandstone Unit and Earlie Formation, and the younger part to the overlying Deadwood Formation (Dixon 2008).

Samples of mudstone and siltstone from the Earlie and Deadwood formations were collected from petroleum exploration drill-cores, from twelve wells located across central and southern Saskatchewan. In total, more than 100 horizons have been processed using a gentle hydrofluoric acid technique; all but three have yielded SCFs (Harvey et al. 2012). The fossils include large acritarchs, filamentous algal and cyanobacterial fossils, and the tough body parts of diverse metazoans, notably crustaceans, priapulids, graptolites, molluscs, de-mineralized shelly taxa, and various problematica. The recovered assemblages vary in specimen abundance, diversity and quality, but overall the succession is notable for its remarkably widespread preservation of SCFs.

Two categories of Saskatchewan SCFs are promising for biostratigraphy. We have recovered de-mineralized para- and euconodonts, which despite being flattened are clearly comparable to phosphatic forms that are routinely recovered from limestones. The conodonts add important biostratigraphic tie-points locally, and demonstrate the potential for recovering Cambrian conodont data from siliciclastic-dominated successions. In addition, some SCFs that represent entirely non-mineralizing, 'Burgess Shale-type' animals, are proving to have wide distributions in space but limited distributions in time. For example, the sclerites of the lophotrochozoan worm *Wiwaxia* occur conspicuously in the Earlie Formation and in other middle Cambrian (Series 3) rocks in western Canada and beyond. However, *Wiwaxia* has not been encountered in the higher parts of the Deadwood Formation, equivalent to the later Furongian, which may indicate a genuine biological decline, or even extinction. A further category of widely distributed western Canadian SCFs – molluscan radulae with boot-shaped denticles – exhibits a similar pattern. Overall, we tentatively recognise distinct Earlie, lower Deadwood, and upper Deadwood assemblages.

In addition to sampling for SCFs, we have carried out a preliminary survey of smaller organic-walled microfossils, using traditional palynological procedures. Many of the SCF-type forms are recognisable in the palynological slides, albeit in a fragmentary condition, showing a useful degree of insensitivity to extraction method. Of the more traditional palynomorphs, sphaeromorphs are ubiquitous; however, more complex forms including small acanthomorphic acritarchs are localized, and occur in low abundances.

Overall, small carbonaceous fossils offer a new measure of biostratigraphy in the subsurface Cambrian succession of Saskatchewan, complementing the extremely sparse data from macrofossils, carbonate-hosted microfossils, and conventional palynomorphs. Though still in an early stage of investigation, SCFs have the potential to resolve correlations of problematic siliciclastic successions in the Cambrian and beyond.

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The palaeontology and sedimentology of the Downton Bone Bed

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As a component of the current research a section from the upper Silurian (Ludlow Series) of the Welsh borderland is being documented. The locality contains a previously very poorly documented bone bed. Previous studies of analogous bone beds have yielded fossil remains of jawless fish and early jawed vertebrates in addition to early plants and some of the first land animals (Arthropoda).

The aims of the research include the documentation of all of the macro- and microfauna and flora found in the section, and sedimentological including palaeoichnological analysis to enable interpretation of the palaeoenvironment and palaeoecology of the locality during the late Silurian.

In order to process large amounts of the bone bed to extract the fossil content a sample was sent to the Swiss organization (SELFRAG) to see if a new technique using high voltage electric pulses could fragment the rock so that the microfossils could be extracted quickly and easily as an alternative to the time-consuming methods that are being used otherwise. Once processed, scanning electron and light microscopy are being used to identify the fossils. The sedimentology is being studied by using hand specimens and thin sections.

Progress so far has involved curating the lithological specimens, a lithostratigraphical review, initial processing, lithological descriptions of the bone bed and its component horizons, and fieldwork to collect more samples, placing the Downton Bone Bed in a stratigraphical context and determining its lateral extent.

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Viki drill core — an Ordovician bio- and chemostratigraphic reference section from Saaremaa Island, western Estonia

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The 363 m deep Viki borehole is located in western Saaremaa Island, Estonia, penetrating Ordovician and Silurian carbonate rocks of the Baltoscandian paleobasin. The Ordovician part of the succession was thoroughly investigated only recently and published in Põldvere (2010). However, the latter publication is not widely available and does not cover the stable isotope record and Middle Ordovician conodont biostratigraphy. Our current report aims to fill these gaps, discuss the integrated results and promote further research of the Viki reference section.

The 120 m thick succession of Ordovician limestones and marls in the Viki section embraces Baltic regional stages from Volkhov (Dapingian) in the bottom to Porkuni (Hirnantian) in the top. The entire section is well characterised biostratigraphically. Based on 175 samples, 21 regional chitinozoan zones and 22 conodont zones were identified. In the condensed Middle Ordovician (18 m) conodonts provide the best temporal resolution, whereas chitinozoans turn most useful in the Upper Ordovician (except in the Porkuni Stage, which is barren of chitinozoans in the Viki core). The distribution of both conodonts and chitinozoans is in good agreement with data from other Estonian and Scandinavian sections, aiding interregional correlations and enabling to trace regional stage boundaries.

Carbon isotopes were studied in 204 bulk rock samples. The resulting $\delta^{13}C_{carb}$ trend in Viki generally corresponds well to the Baltic standard curve and respective chemostratigraphy (Ainsaar et al. 2010). The MDICE is well represented in the Aseri-Lasnamägi stages, followed by low values in the Kukruse and Haljala stages. Probably only the rising limb of GICE is present, and the Rakvere excursion cannot be clearly distinguished due to condensed sequence and/or gaps. However, the Saunja and Moe excursions are prominent reaching unusually high values of 3‰. Above the Moe excursion an interval with negative values (to -1.2‰) is observed. The Paroveja excursion most likely falls into a gap, which is supported by lithological data and biostratigraphy. The HICE is well defined in the Porkuni Stage, starting in the Röa Member and having maximum values (5.2‰) in the oolitic Piltene Member. In the overlying Broceni

Member a short plateau of ca 3‰ occurs, followed by continuous decline reaching to 0‰ only in the topmost Koigi Member, Juuru Stage.

Middle Pirgu to lower Juuru strata were analysed also for sulfur isotope variations. The $\delta^{34}S_{pyr}$ curve generally follows the $\delta^{13}C$ trend and shows a prominent positive excursion in the Porkuni Stage. This $\delta^{34}S$ excursion has been recorded in different parts of the world (Zhang et al. 2009), but thus far not in the eastern Baltic shelf. The maximum values for both $\delta^{34}S$ and $\delta^{13}C$ occur in the Piltene Member. However, $\delta^{34}S$ drops rapidly to near-background values in the Broceni Member, where the $\delta^{13}C$ curve shows relatively high values. The amplitude of the Hirnantian $\delta^{34}S$ excursion reaches 65‰ (-25 to +40‰) in Viki. This is similar to that from the Billegrav section, Bornholm (Hammarlund et al. 2012), but notably larger than excursions reported from Scotland, South China and Anticosti. The global nature of the positive $\delta^{13}C$ and $\delta^{34}S_{pyr}$ excursions observed in the Hirnantian suggests enhanced burial rates of carbon as organic carbon and sulfur as pyrite. This coupling of burial likely occurs under anoxic marine environments where reduced carbon and sulfur are deposited (Zhang et al. 2009; Hammarlund et al. 2012). There are, however, differences in $\delta^{34}S_{pyr}$ amplitudes among different basins worldwide. These differences indicate the intimate interplay of carbon and sulfur cycling in the Hirnantian oceans and provide new insights into ocean chemistry changes accompanying the end-Ordovician mass extinction.

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Trilobites of the suborder Illaenina from the lower Silurian of Queensland, Australia

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The Silurian Quinton Formation in the Broken River region of north Queensland, located approximately 200 km west of Townsville (Fig. 1A, B), is a thick (possibly up to 5000 m) turbiditic sequence of predominantly siltstones, shales and mudstones that have been interpreted as deposits of a submarine fan system (Withnall 1993). The lower part of the formation at several localities also contains conglomerates and associated limestone bodies that are considered to be allochthonous blocks and channel-fill (Talent et al. 2002). The limestones contain diverse but mostly undescribed faunas including corals (Munson & Jell 1999), stromatoporoids, brachiopods, molluscs and trilobites (e.g., Lane & Thomas 1978), and have yielded conodonts indicative of late Llandovery (Telychian) to possibly early Wenlock age (*celloni* to possibly *amorphognathoides* biozones; Simpson 1999). Graptolites from the Quinton Formation were assigned to the *sedgwickii*? to *crenulata* biozones by Rickards & Jell (2002). The largest of the limestone bodies in the Quinton Formation is discontinuously exposed for about 250 m along strike (Munson & Jell 1999) to the east of Tomcat Creek in the vicinity of 'Top Hut' (Fig. 1C). The diverse trilobite fauna of the Tomcat Creek limestone includes members of the Scutelluidae, Illaenidae, Harpetidae, Proetidae, Aulacopleuridae, Brachymetopidae, Cheiruridae, Encrinuridae, Calymenidae, Lichidae and Odontopleuridae.

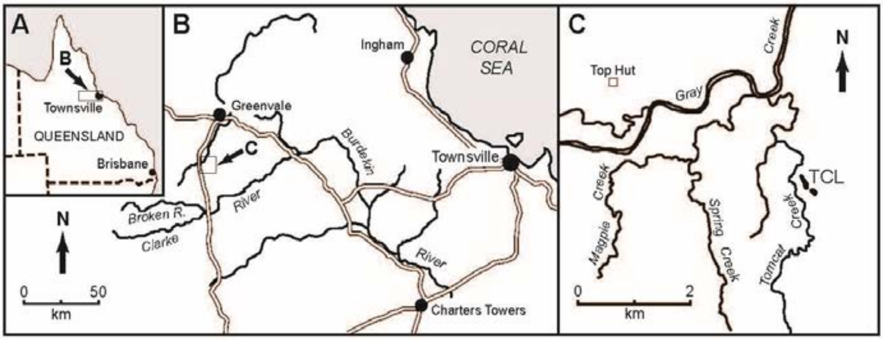

Fig. 1. **A.** Map of north-eastern Australia; approximate area of B indicated by rectangle. **B.** Map of the Townsville-Greenvale region; approximate area of C indicated by square. **C.** Map showing approximate location of Tomcat Creek limestone outcrops (TCL).

The fauna differs markedly in composition from that described by Holloway (1994) from late Telychian clastics of the Quinton Formation (= Poley Cow Formation) at a locality almost 30 km to the south. The Tomcat Creek fauna is dominated numerically by scutelluids and effaced illaenimorph forms (both belonging to the Suborder Illaenina), which are the subject of the present study. Scutelluids are represented by ten species belonging to *Australoscutellum*, *Illaenoscutellum*, *Japonoscutellum*, *Kosovopeltis* and four new genera, and illaenimorphs are represented by about five species belonging to *Cybantyx*, *Bumastella*?, *Stenopareia*? and possibly other genera. *Japonoscutellum*, *Kosovopeltis*, *Cybantyx* and *Stenopareia* were widely distributed in temperate and tropical regions in the Silurian, from Laurentia to the eastern margin of Gondwana. *Illaenoscutellum* and *Bumastella* are presently known only from eastern Australia and Japan, and *Australoscutellum* only from eastern Australia (Holloway & Lane 1998, 2012). The species of *Australoscutellum* and *Illaenoscutellum* in the Tomcat Creek fauna represent the oldest known occurrences of these genera.

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Cambrian Series 3 agnostoid trilobites from the lower part of Machari Formation, Yeongwol Group, Korea

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The biostratigraphy of the Cambrian Series 3-equivalent part of the Machari Formation of Korea has not been well known compared to that of its Furongian interval due to scarce occurrence of trilobites: only three biozones, *Tonkinella*, *Lejopyge armata*, and *Glyptagnostus stolidotus* zones, have been established for the Cambrian Series 3. Well-preserved agnostoid trilobites were collected from a newly discovered locality about 12 km northwest of Yeongwol where the lowermost 10 m interval of the Machari Formation is well exposed. A total of 12 species from 14 horizons of two neighboring sections are identified: *Peronopsis taitzhuhoensis*, *Ptychagnostus sinicus*, *Ptychagnostus atavus, Yakutiana ovale*, *Hypagnostus parvifrons*, *Diplagnostus planicauda*, *Tomagnostella exsculpta*, *Lejopyge armata*, *Kormagnostus minutus*, *Nahannagnostus nganasanicus*, *Glyptagnostus stolidotus* and *Glyptagnostus reticulatus*. The lower part (ca. 5.8 m thick) is characterized by a massive bioclastic grainstone and yields Cambrian Stage 5 trilobites previously known from the *Tonkinella* Zone. The middle part (ca. 1.7 m thick) is composed of dark gray wacke- to packstone and black shale. *Peronopsis taitzhuhoensis* and *Ptychagnostus sinicus* occur successively from the lower 1.2 m interval of the wacke- to packstone beds, while *Ptychagnostus atavus*, the index taxon of the base of the Drumian Stage, appears scarcely along with abundant *Yakutiana ovale* in the upper 0.5 m interval of the beds. The upper part (ca. 2.5 m thick) is a succession of laminated lime mudstone, and relatively diverse species including *Yakutiana ovale*, *Hypagnostus parvifrons*, *Diplagnostus planicauda*, *Tomagnostella exsculpta*, *Kormagnostus minutus* and *Nahannagnostus nganasanicus* are recovered from the lower 1.4 m interval. Notably, *Lejopyge armata* is yielded at 1.2 m above the base of the interval, indicating that the boundary between the Drumian and the Guzhangian stages lies somewhere within the interval. *Glyptagnostus stolidotus* is recorded from the 1.6 m level, while *Glyptagnostus reticulatus* appears at the top of the interval. In short, the 10 m-thick interval of the section spans from the Cambrian Stage 5 to the lower part of the Paibian Stage. Three new biozones in ascending order, *Peronopsis taitzhuhoensis*, *Ptychagnostus sinicus*, and *Ptychagnostus atavus* zones, are established between the previously-known *Tonkinella* and *Lejopyge armata* zones.

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A survivor species of *Dicoelosia* (Brachiopoda) from lower Rhuddanian (Silurian) shallow-water biofacies in South China and its ontogenic study

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The brachiopod genus *Dicoelosia* is generally considered a typical deep-water taxon. New data suggest that some species of the genus may have invaded relatively shallow-water habitats during its geological history. However, there is scant evidence for its invasion of shallow-water environments after the terminal Ordovician mass extinction. *Dicoelosia cathaysiensis* occurs in the shallower-water benthic shelly assemblages of the lower Niuchang Formation (upper Rhuddanian, Llandovery) of Meitan County, northern Guizhou Province, South China. Evidence of a move to shallow water includes its morphology and population structure, regional paleogeography and sedimentology, together with the abundance and diversity of its shallow-water associates. Following the biotic crisis, deep-water environments were barely habitable, and may have driven *Dicoelosia* into shallower-water niches. The taxon endured the less suitable shallow-water environments until the deep-water benthic zones ameliorated after the recovery, implying a shallow-water refugium existed after the biotic crisis. There is only one record of this genus in South China and this unique occurrence may reflect the distinctive paleobiogeography and environments of this region.

The genus *Dicoelosia* is characterized by a strongly bilobed outline. To date studies have concentrated on its functional morphology, taxonomy and evolution; little attention has been paid to its ontogeny. Here we map population variation by PCA for 75 specimens distributed across five species of *Dicoelosia*. Using geometric morphometrics with landmarks for some 40 specimens, the ontogenic trends in *D. cathaysiensis* are compared with those of *D. biloba*. In addition, the ontogenic pathway in *D. cathaysiensis* is investigated by morphing with control point. Combining the results above, the ontogeny of the key character of the genus, emargination, is modeled. Within single populations taxa may develop from broad weakly-emarginate forms into those that are elongate and deeply emarginate.

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Paleozoic K-bentonites in drill cores from the Siljan impact structure

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New drill cores from the largest known impact structure in Europe, the relict of the late Devonian Siljan meteorite crater in central Sweden, provide new possibilities to reconstruct Early Paleozoic marine environments and ecosystems, and to document changes in sedimentary facies, sea level and paleoclimate in Baltoscandia. Three cores, provided by the private Swedish company Igrene AB, comprise more than 1500 m of Proterozoic basement and strata ranging from the late Tremadocian to Wenlock in age (Lehnert et al. 2012).

The crater relict is an important target of the project "Concentric Impact Structures in the Paleozoic" within the framework of the "Swedish Deep Drilling Program". The two core sections recording K-bentonites, Mora 001 and Solberga 1, have been analyzed. The volcanic record, expressed by Ordovician and Silurian K-bentonites, may be compared to occurrences of ash layers in other parts of Baltoscandia which serve as time-lines in a detailed stratigraphic framework including litho-, bio-, chemo- and sequence stratigraphic parameters. This report is focused on the mineralogy and geochemistry of these ash beds with the intent to explore possible correlations with previously described K-bentonites throughout Baltoscandia.

Fig. 1 shows the K-bentonite samples in the Mora 001 core from the lower shale and the lower shale-mudstone members in the siliciclastic succession (Telychian). The Solberga 1 core has a series of K-bentonites in the Dalby Ls (Sandbian) to Freberga Fm (Katian) interval as well as the Motala Fm (Rhuddanian-Aeronian) to Kallholn Fm (Aeronian–Telychian) interval. A portion of each sample was gently disaggregated and suspended in distilled water after particle separation by ultrasonic disaggregation. The <2 μm was used to make oriented slides by the smear technique for powder X-ray diffraction (XRD) analysis. After drying and vapor saturation with ethylene glycol for 48 hours at 50°C, the slides were analyzed by powder X-ray diffraction using a Siemens D-500 automated powder diffractometer. Slides were scanned at 0.2° 2θ/minute using CuKα radiation and a graphite monochromator. Biotite from the SO32–SO35 samples was also analyzed by EDAX. In addition, these samples contain euhedral zircon and apatite phenocrysts. The Sandbian samples consist of mixed-layer I/S with 80% illite while the Llandovery and Wenlock samples vary from I/S to dominantly illite and chlorite, but some with substantial amounts of kaolinite, particularly in the Telychian sequence SO16–SO20. The Middle Ordovician section at Röstånga in Scania (Bergström et al. 1997) contains eighteen K-bentonite beds ranging from 1–67 cm in thickness, and all occur within the *D. multidens* graptolite biozone. Several beds correlate equally well with the Kinnekulle bed and thus argue strongly for the composite nature of what is called the Kinnekulle K-bentonite. We suggest the same for the OS32–OS35 sequence. And similarly, the succession SO16–SO20 in the Lower Telychian Kallholn Fm is both kaolinite-rich and has a much higher proportion of smectite in the I/S phase compared with the Kinnekulle samples. This succession is consistent both stratigraphically and mineralogically with the position and composition of the Osmundsberg K-bentonite that is known throughout the Baltic (Huff et al. 1997), and thus we suggest that these samples represent a composite succession of the Osmundsberg K-bentonite.

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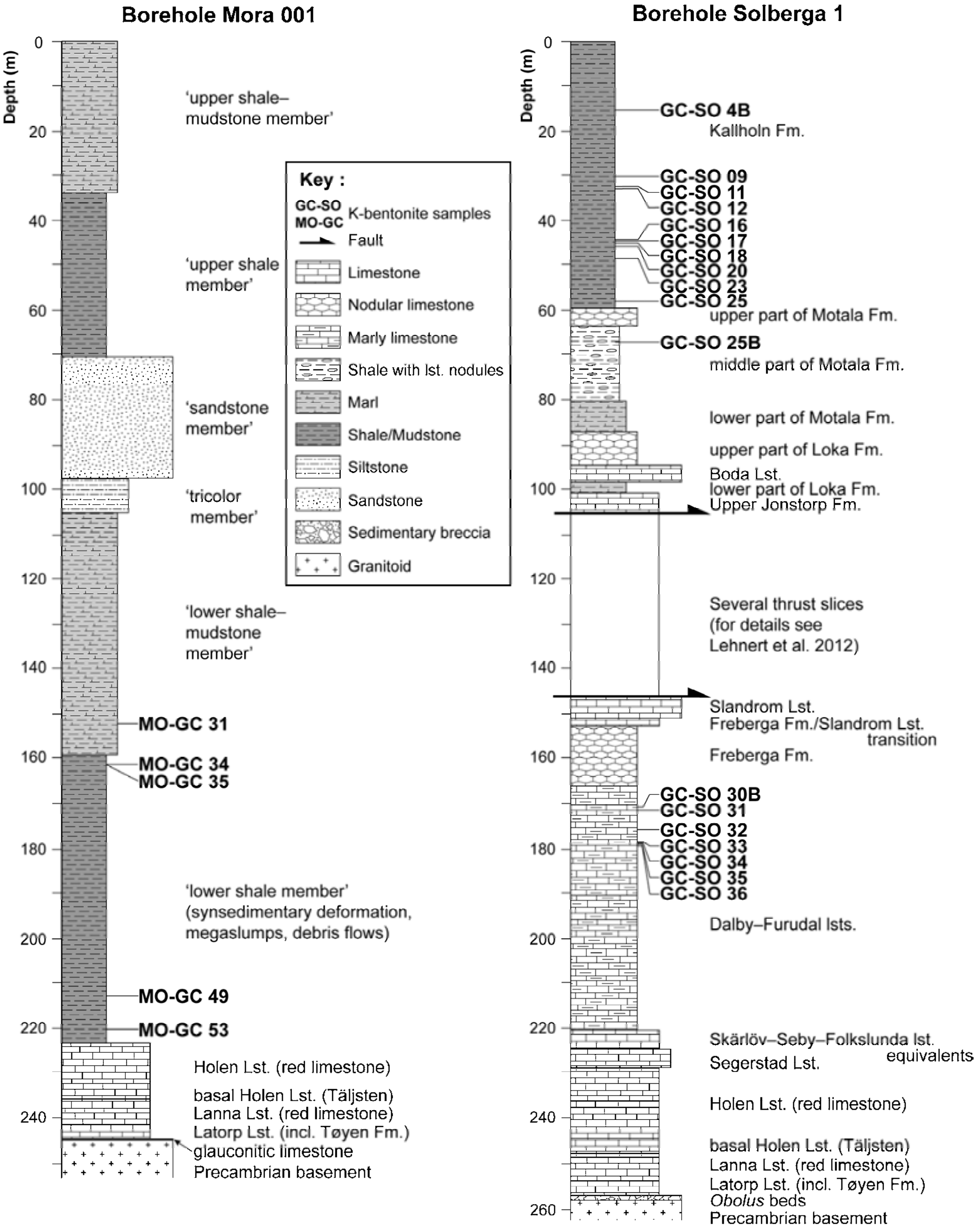

Fig. 1. Position of K-bentonite beds in the Mora and Solberga cores.

Stratigraphical implications of $\delta^{13}C_{carb}$ data from the Sheinwoodian of the Midland Platform, UK

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The stratigraphy of the Wenlock Series of the Midland Platform, UK, has become increasingly well constrained over the past decade. In particular, the carbonate platform deposits of the Homerian have now been interpreted both in terms of their sequence stratigraphy and carbon isotope stratigraphy (Ray et al. 2010; Cramer et al. 2012). This has not been the case for the Sheinwoodian however. Here, $\delta^{13}C_{carb}$ data from the Sheinwoodian of the Midland Platform are presented for the first time. Integrated sequence stratigraphy and carbon isotope analyses of bulk rock samples were conducted at Brinkmarsh (Gloucestershire) and Scutterdine (Herefordshire) quarries located in the Tortworth and Woolhope inliers, respectively.

Brinkmarsh Quarry and nearby Brinkmarsh Lane comprise a mixed clastic/carbonate succession belonging to the lower and middle limestones and intervening shales of the Brinkmarsh Beds. $\delta^{13}C_{carb}$ values from the site show an overall increase within the lower limestone of the Brinkmarsh Beds and immediately overlying shales. Values below the level of a distinctive fossiliferous horizon (characterized by abundant brachiopods and the rugose corals *Pycnactis* and *Phaulactis*) known as the *Pycnactis* Band vary from +1.2‰ to +3.9‰ VPDB, and increase above the *Pycnactis* Band to +5.8‰ VPDB. An interval of no exposure corresponding to c. 35 to 50 m of shales occurs prior to the middle limestone of the Brinkmarsh Beds. Diminishing $\delta^{13}C_{carb}$ values between +1.0‰ to +2.7‰ are associated with the middle limestone. Scutterdine Quarry comprises the impure limestones and silty mudstones of the Woolhope Limestone Formation, and the overlying Coalbrookdale Formation. $\delta^{13}C_{carb}$ values from Scutterdine Quarry show an overall decrease from +4.0‰ to +1.5‰ VPDB, with a superimposed positive excursion from +1.6 to +2.8‰ VPDB near the boundary between the Woolhope Limestone Formation and the Coalbrookdale Formation.

The Sheinwoodian (Ireviken) excursion has previously been identified through analysis of organic carbon at the Banwy River Section, Wales, UK, and was found to correlate with that recognized in the East Baltic (Loydell & Frýda 2007). The behaviour of $\delta^{13}C_{carb}$ values demonstrated at Brinkmarsh Quarry, rising by an approximate magnitude of 3‰, to +5.8‰ VPDB, above the *Pycnactis* Band, are particularly reminiscent of those recorded in Gotland (Sweden). There, the onset of the positive excursion is coincident with the *Phaulactis* layer, a distinctive horizon abundantly populated by rugose corals of *Phaulactis* sp. (Munnecke et al. 2003) marking a rise in $\delta^{13}C_{carb}$ values from +1.4‰ to + 4.5‰ VPBD.

Increasing $\delta^{13}C_{carb}$ values suggest that the sediments at Brinkmarsh Quarry represent deposition during the rising limb of the Sheinwoodian (Ireviken) positive carbon isotope excursion and are therefore in close proximity to the Telychian/Sheinwoodian boundary. Such a stratigraphic position suggests that the pronounced transgression between shallow-marine limestones and sandstones of the lower Brinkmarsh Beds and the overlying shales corresponds to the earliest Wenlock transgression reported from the Midland Platform (S1a sequence of Ray & Butcher 2010). The decreasing $\delta^{13}C_{carb}$ values at Scutterdine Quarry and also within the middle limestone of the Brinkmarsh Beds represent the falling limb of the excursion, indicating a stratigraphically younger age within the Sheinwoodian and synchronicity between these sections. Such an arrangement suggests that the pronounced deepening associated with the transition between the Woolhope Limestone and Coalbrookdale formations and the middle limestone of the Brinkmarsh Beds and overlying shales may represent the same transgressive event (S1b sequence of Ray & Butcher 2010). In addition, the Brinkmarsh and Scutterdine sections can be correlated to the sequence stratigraphy and carbon isotope data currently being finalised from the Eastnor Park Borehole (Herefordshire) by the authors, and which when completed, will provide an isotope reference section for the lower Wenlock of the Midland Platform.

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Significance of brachiopods in stratigraphic correlation of Silurian deposits of the Siberian Platform

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Brachiopods are among the most widespread and, as a matter of fact, the only organisms that occurred under all conditions in every stage of the Silurian in the epicontinental sedimentary basin of the Siberian Platform. There are a percentage of cosmopolitan fossils. Brachiopods are abundant and generally well preserved (Nikiforova & Andreeva 1961; Lopushinskaya 1976, 2010; Tesakov et al. 2000, 2002). They serve as markers of sedimentation processes and are part of different biocoenoses and associations with dominant organisms such as graptolites, corals and stromatoporoids. They form successions of complexes replacing each other, providing an opportunity to use this group as a reliable tool for dating and determining boundaries of local units, and for correlating horizons and comparing them with the International Stratigraphic Chart. Brachiopods as a faunal group are important not only for dating of host deposits, but also for intra-basinal inter-facies correlations.

The Silurian System according to the International Stratigraphic Chart is comprised of four subdivisions: Llandovery, Wenlock, Ludlow and Pridoli (Gradstein et al. 2004; Ogg et al. 2008). The Llandovery Series in turn is divided into three stages: the Rhuddanian, the Aeronian and the Telychian. The Wenlock Series includes two stages: the Sheinwoodian and the Homerian. The Ludlow Series comprises the Gorstian and Ludfordian stages. The Pridoli lacks stages. Regional Silurian stratigraphic units within the Siberian Platform are represented by six horizons (bottom up): Moierokan, Khaastyr, Agidy (Llandovery), Khakoma (Wenlock), Tukal (Ludlow) and Postnichny (Pridoli). A new Silurian standard hierarchy was established as a part of the General stratigraphic scale, by the Commission on the Ordovician and Silurian Stratigraphy, Interdepartmental Stratigraphical Committee of Russia, at a meeting in St. Petersburg in April 2012. The Silurian System was divided into two subsystems, the lower of which includes the Llandovery and Wenlock series, and the upper comprises the Ludlow and Pridoli series.

Lately, T.V. Lopushinskaya, N.V. Melnikov and colleagues (involving this author) have developed a new outline of the regional stratigraphic scheme of the Silurian System in the Siberian Platform, which was presented at the All-Russian stratigraphic meeting on development of regional stratigraphic charts for Siberian Precambrian and

Paleozoic deposits, in Novosibirsk 26–30 November 2012. The stratigraphic scheme was improved and updated. It is used by geologists in geological survey and exploration.

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Ordovician terrigenous clastics in Japan and the link to South China

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The Japanese Islands have nearly 700 million year old history that started at the breakup of the Rodinia supercontinent (Isozaki et al. 2010, 2011). Proto-Japan originally developed from a passive margin along South China (Yangtze) block detached from Rodinia, and was later converted tectonically into an active continental margin along the western Pacific (Panthalaasa) around ca. 520 Ma (Middle Cambrian) as marked by the oldest arc-granite and the oldest high-P/T metamorphic rocks in Japan.

The oldest non-metamorphosed sedimentary unit in Japan hitherto known is represented by the Middle Ordovician fore-arc deposits, although their distribution is limited solely in two separate areas (i.e. the Hida marginal belt in central Japan and the South Kitakami belt in NE Japan); and their sizes are extremely small. In the Hida marginal belt, Sandbian (early Late Ordovician; 453–458 Ma) conodonts occur from siliceous mudstone (Hitoegane Fm; Tsukada & Koike 1997); however, the strata were chopped into fragments in a serpentinite mélange zone (Nakama et al. 2010). In the S. Kitakami belt, the Middle Ordovician (466 Ma) trondhjemite (Kagura ophiolite suite) is covered by a 457 Ma (Sandbian) felsic tuff (Koguro Fm dated by detrital zircon; Shimojo et al. 2010).

Also in the S. Kitakami belt, we recently recognized an apparently much thicker coherent sedimentary unit of terrigenous clastics (nearly 1500 m thick Nameirizawa Fm), which may span from the mid-Ordovician (this study) to lower Silurian (Shimojo et al. 2010), by virtue of detrital zircon chronology for the sandstones. This unit is covered by the Wenlockian (mid-Silurian) clastics (Orikabe Fm) with trilobites (*Encrinurus*) and corals (*Halysites*) of strong affinity to the contemporary fauna from South China and Australia (Yamazaki et al. 1984; Kato 1990). In addition, we could identify much older zircons of Proterozoic age; e.g., 1070, 1116, 1204, 1773 and 1993 Ma, from the Ordovican–Silurian sandstones. It is noteworthy that possible source of the first three ages can be found solely in South China in the neighboring areas in East Asia. Together with the paleobiogeographical proximity, the new detrital zircon ages positively suggest that Paleozoic Japan formed a segment of the Pacific margin of South China. Moreover, the calc-alkaline nature of the felsic volcaniclastics recorded active subduction-related processes that occurred in a matured arc-trench system in Paleozoic Japan. The highly limited preservation/occurrence of these orogenic elements of the

Ordovician arc-trench system, in particular in SW Japan, was likely related to the severe tectonic erosion occurred afterwards (Isozaki et al. 2010, 2011).

As the S. Kitakami belt is located more than 1000 km to the east of modern S. China margin, the present documentation of the Ordovician arc-trench system and its link to S. China provides strong constraints in reconstructing paleogeography of the Paleozoic western Panthalassa.

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An acid-free method of microfossil extraction from clay-rich lithologies using the surfactant Rewoquat: Examples of application to Silurian and Devonian fossils

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Marine rocks characterized by high clay content provide excellent conditions for fossil preservation, particularly for organic-walled microfossils such as graptolites and chitinozoans. Nevertheless, the phyllosilicate minerals which constitute the clay component make microfossil extractions difficult. The problem results from the tendency of phyllosilicates to form aggregates in low pH values, as typical methods of microfossil extraction employ acids for rock digestion. Consequently, the use of acids for clayey rocks is often inefficient and time-consuming. In the case of rocks which are not extensively cemented, e.g., with carbonate or silica, an alternative method is more efficient: disintegration using the cationic surfactant Rewoquat W 3690 PG, which acts as a clay dispersing agent.

We have compared acid digestion protocols with disintegration in Rewoquat using two Palaeozoic examples which we have identified as causing problems in acid extractions:

1. The Mulde Brick Clay Member (MBCM) from the middle Silurian of Gotland (Blåhäll 1): Two samples have been processed using (1) the buffered acetic acid method of Jeppsson et al. (1999), (2) disintegration in Rewoquat;
2. Transition layers between the Zlíchov Limestone and the Daleje Shale from the Emsian of the Barrandian area in the Czech Republic (Pekárek Mill section): Two samples from 5 different beds have been processed either by (1) digestion in 35% HCl, 30% HF and concentrated hot HCl, (2) using Rewoquat.

Disintegration in Rewoquat followed a very simple protocol: the samples were poured over with the surfactant, stored in a tightly sealed container for several days, optionally soaked with water for one more day, and sieved. For each sample, we have also performed bulk XRD analysis to identify the dominant clay component. Both samples exhibited a very high content of illite: 35.63% in the case of the MBCM sample and 24.76% in the case of the Daleje Shale (bed no. CH15b *sensu* Chlupáč & Lukeš 1999).

In both experiments, disintegration in Rewoquat was faster (days) than digestion in acid (months), and allowed to recover calcareous in addition to organic-walled fossils. With respect to the MBCM sample, formation of clay aggregates during acid extraction lowered the number of recovered chitinozoan and scolecodont specimens by nearly two-thirds. The preservation of palynomorphs was comparable, and with respect to retiolitid graptolites in the MBCM sample, Rewoquat extraction yielded a higher proportion of specimens which did not suffer from compaction and fragmentation.

Recovered calcareous fossils included stratigraphically important groups such as dacryoconarid tentaculites (Daleje Shale), brachiopods and trilobites (both samples). Moreover, elimination of acid dissolution in the extraction protocol offered the possibility to recover calcareous and phosphatic elements which are most prone to be affected by etching and dissolution, i.e., those with the highest surface/volume ratio, for example small conodont elements and micromorphic brachiopods. We were able to recover brachiopod shells as small as 450 µm in length, representing in most cases juvenile forms with well preserved protegula.

Based on our experiences with marls and shales we recommend the use of Rewoquat for extraction of microfossils, including organic-walled, calcareous and phosphatic groups, as it presents the following advantages:

1. It is several times faster and can give higher yields than digestion in acids,
2. It allows to recover all types of fossils in one single extraction, and thus to make the best use of the sample when the available rock volume is limited (as in the case of drillcores),
3. It does not require the use of hazardous chemicals,
4. As opposed to techniques employing acids, Rewoquat does not dissolve or etch any chemical structures, making it possible to recover the full spectrum of fossils, including the smallest and most delicate forms.

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The record of the middle Silurian Mulde Event in Podolia, Western Ukraine

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During the Homerian Age of the Wenlock Epoch a stepwise extinction has been proposed among hemipelagic fauna, in particular among graptolites (known as the *lundgreni* Event, Urbanek 1993) and among conodonts (the Mulde Event, Jeppsson 1993). The crisis was preceded by the onset of a double-peaked positive stable carbon isotope excursion recognized in the carbonate platform and platform slope environments in low palaeogeographical latitudes, i.e. in the palaeocontinents of Baltica, Laurentia and Avalonia. The biotic changes in the open shelf environments coincide in the shallow-water realm with evidence of a rapid regression and emersion of large parts of the carbonate platform, followed by the expansion of post-extinction facies dominated by microbial carbonates and atypical low-diversity biota (Calner 2005).

We have examined the Homerian succession in Podolia, Western Ukraine, formed in a carbonate ramp environment, which developed in an arid climate, as evidenced by the presence of evaporites (Tsegelnyuk et al. 1983) and widespread sabkha deposits. During the middle Silurian the area was located in the south-west part of a vast epeiric basin in western Baltica. The $\delta^{13}C$ excursion, initially identified by Kaljo et al. (2007), has been studied in the sections exposed in the Bahovichka River valley and on the south bank of the Dniester River. The excursion begins in the uppermost part of the Sursha Formation developed as nodular limestones. In the lower part of the overlying Muksha Formation, the $\delta^{13}C$ record reaches its maximum value of 5.15‰ (V-PBDB) and subsequently stretches in a plateau of values around 4.5‰ throughout a 9-meter-long interval. The Muksha Fm is formed as alternating microbial-stromatoporoid autobiostromes and inter-biostrome calcareous mudstones rich in organic matter. The main framework-building organisms of the autobiostromes are calcimicrobes of *Garwoodia* type (*sensu* Wray 1977), oncoid-forming *Rothpletzella*, and stromatoporoids. Associated biota includes green algae, trilobites, ostracods and unusually common rostroconchs. The assemblage differs in composition from the typical stromatoporoid-tabulate biostromes present elsewhere in the Silurian succession of Podolia. In the uppermost part of the Muksha Fm the biostromes are succeeded by stromatolites with abundant wrinkle structures and mudcracks, intercalating with argillaceous dolomites marking the onset of the sabkha-type sedimentation, characteristic for the overlying Ustya Formation. This lithological complex contains an event bed ranging in thickness from

20 cm in its most distal parts to ca. 2 m in the proximal part. It is formed by a conglomerate of angular sand- to boulder-size extraclasts embedded in calcareous claystone. The clasts and the matrix exhibit highly scattered $\delta^{13}C$ values, indicating redeposition of material eroded from a wide stratigraphic interval. The event bed marks the end of the Mulde excursion, with the $\delta^{13}C$ values remaining close to 0‰ in the Ustya Fm. It reaches a thickness of ca. 20 m and is characterized by massive and thin-bedded argillaceous dolomites with evidence of episodic emersion and formation of evaporites.

The facies development across the Mulde Event in Podolia supports the collapse of skeletal carbonate factory during the excursion interval, accompanied by the development of microbial carbonates, which seems to be a widespread phenomenon throughout the entire basin (Kõrts 1991; Calner 2005). This microbial expansion during the post-extinction interval may reflect the recovery of marine ecosystems following the proposed geochemical perturbation associated with the Mulde Event.

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Late Ordovician brachiopod faunal gradient along paleotropical latitudes in Laurentia

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During the Late Ordovician, Laurentia straddled the equator and extended into mid-tropics to the north and into the subtropics to the south (Cocks & Torsvik 2011; Jin et al. 2013). After the mid-Darriwilian major faunal turnover event, the brachiopod faunas that newly evolved in Laurentia were confined largely to pericratonic settings and remained semi-cosmopolitan from late Darriwilian to Sandbian (Llanvirn–early Caradoc) times. Marine transgression and extensive flooding of the Laurentian continental interior began in the early Katian, when the brachiopod faunas invaded the epicontinental seas and began to manifest provincialism at global scale as well as endemism within Laurentia. This is demonstrated by the clear differentiation of the Epicontinental Brachiopod Fauna (EBF) from the pericratonic Scoto-Appalachian Brachiopod Fauna (SABF) within Laurentia (Sohrabi & Jin 2013). The SABF originated during the late Darriwilian, became most distinct and diverse from the Sandbian to early Katian (late Chazyan–Chatfieldian), and disappeared by mid-Katian (Edenian) time. During the mid-Katian (Edenian–Maysvillian), the EBF became virtually ubiquitous in the epeiric seas of Laurentia, showing a high degree of homogeneity in faunal composition. At the global scale, however, the EBF was strongly endemic, and many of the newly originated genera (e.g., *Hiscobeccus*, *Lepidocyclus*, *Nasutimena*) in Laurentia rarely occurred in other paleoplates.

During the late Katian (Richmondian) greenhouse episode, much of the paleocontinent Laurentia was inundated by shallow tropical seas, and the Richmondian brachiopod fauna achieved an unusual degree of homogeneity in generic composition across the epicontinental seas. At the generic level, the ancestors of many predominant brachiopods in the Richmondian EBF can be traced to the continental margin brachiopod faunas (CMBF) within Laurentia. Some common genera of the CMBF rarely invaded epicontinental seas, especially the paleoequatorially located Hudson Bay and Williston basins in central Laurentia (e.g., *Platystrophia*, *Hebertella*, *Cincinnetina*, *Paucicrura*, *Tcherskidium*, *Proconchidium*, *Rhynchotrema*, *Rostricellula*). Inversely, many EBF genera can usually be traced to CMBF, represented by the same or different congeneric species. Among several discrete evolutionary lineages, some common trends of morphological modification are recognizable when the ancestral forms are compared to their descendants in epicontinental seas. 1) Notable increases in shell size, shell-wall thickness, and shell globosity, as typified by the *Rhynchotrema–Hiscobeccus* lineage (Sohrabi & Jin 2013), the *Plaesiomys subquadrata–P. occidentalis* species cline (Sproat & Jin in press), and the *Strophomena–Nasutimena* lineage (Jin & Zhan 2001). 2) Conspicuous rugosity in phylogenetically unrelated clades (e.g., the strophomenide *Nasutimena* and the rhynchonellide *Hiscobeccus*). 3) Convergent evolution from a bilobed to a trilobed cardinal process, as observed in the *Cincinnetina–Diceromyonia* lineage in the superfamily Dalmanelloidea, and in the *Plaesiomys subquadrata–P. occidentalis* morphocline in the superfamily Orthoidea (both represent transitions from CMBF to EBF taxa). 4) Clear paleogeographic differentiation of dalmanelloid genera between intracratonic equatorial seas and higher tropical pericratonic shelves, the former being dominated by *Diceromyonia* with strongly aditiculate shells, whereas the latter by *Cincinnetina* and *Paucicrura* with much weaker aditicules in their shells (Jin 2012).

The high degree of provinciality of the EBF at the global scale, as well as the strong paleogeographic separation of species and genera as a result of regional and local niche partitioning and paleolatitudinal gradient within Laurentia (Holland & Patzowsky 2007) effectively rendered the Katian brachiopod faunas of Laurentia as island faunas through faunal insularization. Such endemic fauna of relatively low diversity would be particularly susceptible to drastic environmental change, which may explain their extinction at the onset of Hirnantian glaciation and the drawdown of the epicontinental seas.

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North American turnover from mollusk-dominated Depauperate Zone (Late Ordovician) to brachiopod-dominated (early Silurian) faunas

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The Ordovician–Silurian unconformity through the central part of North America separates the Maquoketa shale (pre-Hirnantian) with multiple horizons of phosphorite from overlying Silurian (Llandoverian) carbonates. In Iowa, Illinois, and Missouri, the basal Maquoketa features a Depauperate Zone (Ladd 1929), characterized by diminutive mollusks including chitons, scaphopods, palaeotaxodont bivalves, archeogastropods, hyolithoids, and orthoconic cephalopods (Snyder & Bretsky 1971; Frest et al. 1999). Many species reappear through subsequent levels in the Maquoketa, but vary in diversity and dominance. A single occurrence of this fauna is traced to the lower Silurian on the western flank of Ohio's Cincinnati Arch (Harrison & Harrison 1975). In contrast, corals and brachiopods dominate Silurian faunas. The most prolific in terms of preserved populations are the large-shell pentamerid brachiopods (Johnson 1997).

Previous studies on the Depauperate Zone struggled with difficulties of mechanical extraction of fossils from a dolomitized matrix. Results on size variations and comparative allometry provided in this study are based on a large sample of naturally disaggregated material screened from the basal Maquoketa at Dubuque, Iowa. The fossils are phosphatized internal molds, although in rare cases replaced shells conserve growth lines. Sixteen species were recovered, including three-dimensional graptolites (*Rectograptus peosta*). Most abundant are the bivalves *Palaeoneilo fecunda* and *Nuculites neglectus*. The largest bivalves have a shell length of 12 mm, ranging downward in size to <2 mm. Also common is an orthid brachiopod, *Plaesiomys subquadrata*. Bivariate analyses were conducted on the bivalves and the brachiopod, as well as two species of gastropods (*Liospira micula* and *Cyrtolites carinatus*), a reputed sponge (*Hindia sphaeroidalis*), and the graptolite. A full range of growth stages in all mollusks shows isometric growth. The same pattern is especially characteristic of the orthid brachiopod (Fig. 1).

The Depauperate Zone is unusual both for reflecting a range of infaunal, epifaunal, nektonic, and planktonic members and for retention of very small growth forms. Winnowing by waves or bottom currents was minimal, at least during deposition of certain intervals in the Maquoketa. Pene-contemporaneous replacement of delicate features is linked to high concentrations of P_2O_5 in seawater intermittently brought across the shelf through upwelling from the margin of the paleocontinent off Arkansas. Ladd

(1929) speculated on the development of a stunted or "dwarf" fauna. More contemporary terms that might apply are the Lilliput effect and selection for paedomorphosis. The former is rejected because reoccurrences of the depauperate fauna are unrelated to extinctions. The latter is appealing because some members like the brachiopod *Plaesiomys subquadrata* show a record of larger individuals (up to 150% in adult size) in other regions.

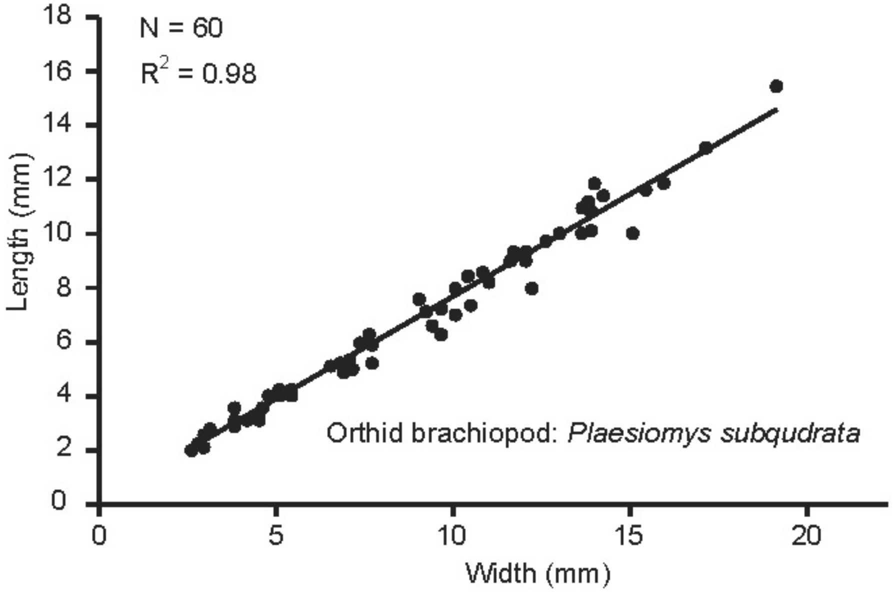

Fig. 1. Bivariate plot of shell width vs. length in an orthid brachiopod.

Coral colonies and brachiopods from the lower Silurian of North America are normal in size. Populations of *Pentamerus oblongus* from Iowa preserve a range of immature to adult individuals with shell lengths from 10 mm to >130 mm. Bivariate analysis shows a curvi-linear growth pattern in *Pentamerus* that implies allometric growth (Johnson 1977). Dense crowding surely played an environmental role in the control of shell shape. Clear-water deposition under conditions of good marine circulation prevailed during much of the Silurian in North America. Based on novaculite deposits in Texas and Arkansas, upwelling continued on the southwest margin of the paleocontinent with a possible influence on secondary silicification of original $CaCO_3$ corals and shells. The muddy substrate typical through much of the Maquoketa shale disappeared soon after the end of the Ordovician due to sea-level rises that progressively flooded sediment sources in lowlands along the trans-continental arch as well the Taconic highlands to the southeast.

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Upper Silurian chemostratigraphy of Podolia revisited: Carbon isotopes, bentonites and biostratigraphy

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Besides traditional biostratigraphy, carbon isotopes and bentonites have become new authorities in stratigraphy. Biostratigraphy applied in the carbonate rock area, is more oriented on microfossils (chitinozoans, conodonts). The popularity of these trends derives from successful studies performed, but sometimes possibilities are overestimated. The best results are achieved in co-operation of all.

Three positive carbon isotope excursions have been identified in the upper Silurian of Podolia (Ukraine). The first occurs in the upper Ludlow (Isakivtsy and Prygorodok formations). Upwards, one excursion follows in the upper Přídolí (at the boundary of the Trubchin and Dzvenygorod fms) and the SIDE excursion at the Silurian–Devonian boundary (junction of the Dzvenygorod and Khudykivtsi fms). The first and the third excursion are well known also elsewhere. The second excursion is very conspicuous in the Kotuzhiny core, but not in Dniester outcrops and Lithuanian cores. A negative excursion of $\delta^{13}C$ values (the Post-Prygorodok low) has been noted in the lowermost Přídolí (Varnytsya Formation), having a counterpart in the East Baltic, called the Šilale low. New data obtained confirm our earlier observations (Kaljo et al. 2012).

Fourteen metabentonite beds are known from our study interval (three in the Isakivtsy Fm, six in the Prygorodok Fm, two in the Varnytsya Fm, two in the Trubchyn Fm, one in the Dzvenygorod Fm). Some of them are better studied (Huff et al. 2000; Kiipli et al. 2000) and help correlation of sections. We analysed bentonites C5 and C6 (in the topmost Prygorodok Fm) and C7 (lowermost Varnytsya Fm) in order to clarify chemostratigraphy of the Ludlow–Přídolí transition and higher. The first two are clearly identifiable; C7 is more like a terrigenous marlstone, but it cannot be mixed up with C6. Bentonite C7 from the Kotuzhiny core contains 1.7% Sr, referring to a possible occurrence of celestine associating with gypsum-bearing rocks. The composition of bed C9 in the Trubchyn Fm is rather variable but bed C11 from the Dzvenygorod Fm is well identified.

The Silurian biostratigraphical data set of Podolia is rich, especially in part of macrofossils (Gritsenko et al. 1999). Microfossil data need certain modernisation. Paris & Grahn (1996) identified (repeated by Racki et al. 2012) *Eisenackitina barrandei* from the upper Dzvenygorod Fm at Volkovtsy (= Dnistrove). This chitinozoan dates in the

Baltic and elsewhere the very end of the Ludlow (Nestor 2012) and pushes the Skala Regional Stage nearly entirely into the Ludlow.

Our combined bio- and chemostratigraphical data show that the Isakivtsy and Prygorodok fms are of latest Ludlow age. The Post-Prygorodok carbon isotope low, located between bentonite beds C6 and C7, belongs to the lowest Přídolí. The upper Přídolí $\delta^{13}C$ excursion and C11 predate the occurrences of *E. barrandei* in the uppermost Dzvenygorod Fm. These seem to represent a curious case of Lazarus-type occurrence or something else.

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Ordovician stratigraphy of the Siberian Platform: State of the art

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The Ordovician succession of the Siberian Platform consists of twelve regional stages, which are based on benthic shelly fossils, predominantly brachiopods, trilobites and ostracodes. Their boundaries correspond to visible changes in sedimentology and fossil composition (Kanygin et al. 2010a) and most of them are recognized sequence boundaries (Dronov et al. 2009; Kanygin et al. 2010b). Due to relative isolation of the Siberian palaeocontinent, Ordovician faunas in shallow-water Siberian epicontinental basins are mostly endemic and precise correlation with global stages is difficult. It can be accomplished only on some levels corresponding to biotic and eustatic events (Bergström et al. 2009; Dronov et al. 2009). The principal ties to the global Ordovician time scale are provided by graptolites from surrounding territories of the Verkhoyansk-Chukotka fold belt, Taimyr, Altai and Sayany, and conodonts, which in most cases demonstrate closer affinities to coeval North American Midcontinent species associations than to those of the Russian Platform.

The lower boundary of the Ordovician system is now placed within the Nyaian regional stage based on the stratigraphic distribution of conodonts of the *Cordylodus* lineage. The *C. proavus* has been identified from the lowermost part of the Nyaian stage and *C. angulatus* from its uppermost part. Recently *C. lindstroemi* was recovered from carbonate sediments of the upper Nyaian stage in the key section along the Kulumbe River valley (Tolmacheva & Abaimova 2009). The precise level of the Lower/Middle Ordovician Series boundary is difficult to recognize due to the highly endemic conodonts and absence of graptolites in the Siberian sections. There is a consensus of opinions, however, that it roughly corresponds to the boundary between the Ugorian and the Kimaian regional stages (Bergström et al. 2009; Kanygin et al. 2010a).

The most distinct correlation level within the Middle Ordovician Series of the Siberian Platform is the base of the Volginian regional stage. This level coincides with a well-developed surface of erosion and sequence boundary at the base of the Volgino sequence (Kanygin et al. 2010b). It also represents the beginning of a prominent transgression, which was associated with significant biotic changes across the entire platform. The Volginian assemblage of brachiopods and ostracodes shows close affinities to the apparently coeval one of the Verkhoyansk-Chukotka region, where it is associated with graptolites of the *Hustedograptus teretiusculus* graptolite Zone of the Upper Darriwilian global stage (Bergström et al. 2009; Kanygin et al. 2010a).

The base of the Upper Ordovician Series on the Siberian Platform corresponds to the base of the Chertovskian regional stage, which coincides with a sequence boundary and marks the most prominent deepening event. The brachiopod and ostracode faunal assemblage of this regional stage is easily recognizable also in the Verkhoyansk-Chukotka fold belt where it is associated with graptolites of the *Nemagraptus gracilis* graptolite Zone. Recognition of the boundaries between the Chertovskian, Baksian, Dolborian, and Burian regional stages is based on conspicuous changes in the shelly faunas, but biostratigraphic correlation of these stage units to global stages remains uncertain. Recently extracted zircon crystals from the K-bentonite beds within the Baksian stage (Dronov et al 2011) provides $^{206}Pb/^{238}U$ age of 450.58±0.27 Ma, (B. Sell personal communication) which corresponds to the early Katian global stage. The Upper boundary of the Ordovician succession across most of the Siberian Platform is marked by a regional hiatus, which corresponds to most of the Hirnantian global stage.

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Bioconstructions from the Lower Cambrian of Sonora State, Mexico

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The Sonora state, Mexico, records thick, mixed, Neoproterozoic (Cryogenian?) to middle Cambrian platforms deposited on a southern Laurentian margin. A short, discontinuously recorded, reefal interval developed during the early Cambrian times through the platforms of the modern Caborca area (north-western Sonora; Cordilleran miogeoclinal according to Stewart et al. 2002). Presence of archaeocyaths was previously reported by Okulitch (*in* Cooper et al. 1952) and their taxonomy reviewed by Debrenne (1987), based on sparse, not precisely located material from the Cerros de la Proveedora and Sierra Rajón (West and South of Caborca, respectively). Further study of the previous area was carried out by Debrenne et al. (1989). The aims of this study is (1) to assess for the first time the sedimentological settings of the archaeocyaths-calcimicrobes bioconstructions from the Sierra Rajón area based on extensive recent field investigations and (2) to review their archaeocyath assemblage.

Two distinct bioconstuctions, separated by a short regressive sequence and fall of carbonate productivity, have been identified. The first bioconstruction displays some well preserved bioherms constituted by the superposition of meter-scale lenticular patches sparsely aligned, about 20 to more than 100 meters from each others, along the platform margin and separated by shale deposits. The second episode starts with condensed beds of reworked archaeocyaths remains separated from oolitic packstones by erosional surfaces occasionally marked by millimeter scaled stromatolites. This episode is registered in an approximately 25 m-thick bioherm toped by siltstone and oolitic shoal deposits.

The studied field sections are almost devoid of trilobitic remains. Therefore, the archaeocyaths are of prime importance for the chronostratigraphic correlation of investigated levels.

Archaeocyaths genera from the two episodes were identified using the archaeocyaths interactive-key developed by Kerner et al. (2011, www.infosyslab.fr/archaeocyatha). The identification key is built from a knowledge base containing the description of all the 308 recognized valid genera. The description tool consists of extensive set of descriptors unrestricted to morphological information (87 morphologic and ontogenetic, 8 stratigraphic and geographic and 27 referring to traditional classification data). The presence of both stratigraphic and geographic data allows to quickly identifying lists of genera per area. It is also a powerful tool for stratigraphic purposes: a rapid selection of all archaeocyaths genera observed is immediately interpreted in term of age (up to date according to the Siberian chart). The recovered assemblage includes 55 genera and species: SP1, SP2 and SP3. This assemblage can be correlated with assemblage biozones CCC from Spain. Two genera were previously unknown from the assemblage. As a preliminary result, we can indicate that the studied field section was interpreted as early Botomian in age.

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Stromatoporoid diversity and growth in late Wenlock reefs and associated facies (Silurian) at Wenlock Edge, UK

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Wenlock reefs and associated limestones of central England have been studied for more than 100 years, and detailed work on reef structure, composition and stratigraphy is well known, together with some general information on the stromatoporoids. However, up to now there is little detailed work on the stromatoporoids, and there has not been a comprehensive study of the relationship between stromatoporoid growth forms, taxa and sedimentary environments. Stromatoporoids make up an important component of the reef biota, together with tabulate corals. Field measurements and sampling of ca. 80 stromatoporoid specimens, in Coates and Lea South Quarries on Wenlock Edge reveal that stromatoporoids show low taxonomic diversity, with only six taxa found within the reefs and adjacent bedded limestones; of those six taxa, only three are abundant: *Labechia,* which is the main reef frame-builder with a laminar anastomosing growth form (Fig. 1); plus *Actinostroma* and *Ecclimadictyon*, both of which are low-to-high domical growth forms up to 30 cm in basal dimension; detailed taxonomy and distribution in facies will be completed later. Although 80 samples is not a large collection, almost every stromatoporoid specimen, accessible from the ground, was sampled, so that the collection is as representative of the assemblage as can be achieved from the current exposures in the quarries. Samples were collected from reef bases, middles and tops as well as through the associated bedded limestones.

Such a low stromatoporoid diversity is unusual in comparison with similar reef-bearing facies on Gotland, where Mori (1969, 1970) found 22 taxa in the Slite Group (slightly older than Wenlock Edge), 11 taxa in the Klinteberg Group (approximately equivalent in age to Wenlock Edge) and 23 taxa in the Hemse Group (slightly younger than Wenlock Edge). However, Mori (1970) found only 6 taxa in the Halla Formation, in which *Labechia* and *Ecclimadictyon* are also the two most abundant taxa; the Halla Formation episode on Gotland is partly equivalent to the Nodular Limestone facies in Wenlock Edge, below the sampled horizons, and was a time of suppressed reef-building, presumably related to the Mulde Extinction event.

The reasons for the poor diversity of Wenlock Edge stromatoporoids are not clear, but there are at least two possibilities: 1) the episode of reef growth of Wenlock reefs in England was very short, in this location on the margin of the Avalon-Baltic continent and may not have been long enough to develop into the diverse assemblages in more stable carbonate platforms of the continent interior, such as on Gotland; 2) the biota was affected by the Mulde Extinction event, when the reefs grew in the recovery phase after extinction. Nevertheless, the time-equivalent Klinteberg Group on Gotland contains more abundant taxa, pointing towards option 1 above, the short time of growth of the Wenlock Edge reefs, as the more likely control on stromatoporoid diversity.

Further work is required, and one line of enquiry is to establish tabulate coral faunas, which grew along with stromatoporoids; preliminary observations of tabulates in the sample set reveals only a few taxa of tabulates, in parallel with stromatoporoids. A comprehensive tabulate coral and stromatoporoid study may help to enhance understanding of the growth and controls of these late Wenlock reefs and related facies.

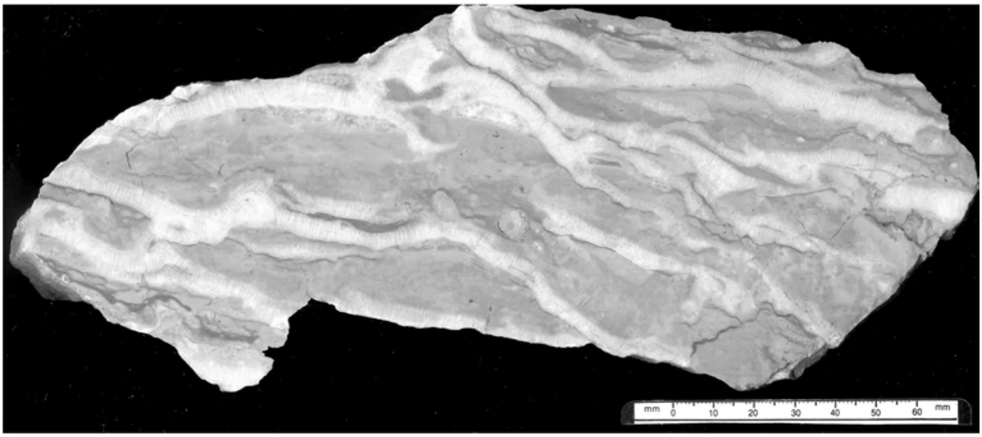

Fig. 1. Labechia reef frame from Much Wenlock Limestone Formation, Coates Quarry, Wenlock Edge, UK.

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The Ordovician of the Sauerland (western Germany) revisited

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Ordovician sediments in Germany are mostly located in the central and eastern parts of Germany (Thuringia, Saxony, northern Bavaria) or in the subsurface of northern Germany (Rügen Island). However, Ordovician outcrops in western Germany are rare (Servais et al. 2008). Among the French-Belgian inliers (Rocroi, Givonne, Serpont, Condroz Inliers, etc.) that include Lower Palaeozoic rocks, only the Stavelot Inlier extends into western Germany, with a few Lower Ordovician outcrops near the Belgian-German border (Ribbert et al. 2002). The very small Remscheid-Altena and Ebbe inliers (also known as 'Remscheid Anticline' and 'Ebbe Anticline'), being part of the Rhenish Massif, are the most important western German outcrop areas. The most complete stratigraphical succession is present in the Sauerland (south-eastern part of North Rhine-Westphalia) in the Ebbe Inlier. The Ordovician age of these sediments was first documented by the discovery of Ordovician trilobites by Rudolf and Emma Richter in 1937. The present paper reviews the extensive stratigraphical, palaeontological and palaeobiogeographical studies since the 1990s.

The Ordovician sediments all belong to the Herscheider Schichten (Herscheid Beds) and are attributed to four lithological units. The four formations are now attributed to the Middle to Upper Ordovician, including the Plettenberg-Bänderschiefer (Plettenberg Banded Slate) Formation and the Kiesbert-Tonschiefer (Kiesbert Slate) Formation (Darriwilian), the Rahlenberg-Grauwackenschiefer (Rahlenberg Greywacke Slate) Formation (earliest Sandbian) and the Solingen-Tonschiefer (Solingen Slate) Formation (Katian) (e.g. Maletz 2000).

The fossils from the Ebbe Anticline not only include trilobites (reviews available in Koch 2010 and Koch et al. 2011), but also graptolites and acritarchs (e.g., Maletz & Servais 1993), chitinozoans (e.g., Samuelsson et al. 2002), ostracods (e.g., Schallreuter & Koch 2011), foraminiferans (e.g., Riegraf & Niemeyer 1996) and trace fossils (e.g., Eiserhardt et al. 2001). The Remscheid and Ebbe inliers are today considered as the German extension of the French-Belgian inliers, and they present a stratigraphical succession of Ordovician age with fossils that are typical of the eastern part of the microcontinent Avalonia.

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Trilobites evolutionary levels and the lower boundary Cambrian Stage 4 on the Siberian Platform

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At the present time search is on for potential correlative levels for the lower boundary of Cambrian stages in connection with the development of a new international scale. One of these levels is the base of Stage 4 of the Cambrian system. Some experts believe that as a marker of this level can be the FAD of *Olenellus* or *Redlichia* (Babcock & Peng 2007), *Arthricocephalus chauveaui*, *Olenellus* or *Redlichia* (Peng & Babcock 2011), or the FAD of *Olenellus*, *Redlichia*, *Judomia* and *Bergeroniellus* (Peng et al. 2012). Earlier, G. Geyer and J. Shergold (2000) pointed to the level of appearance of the trilobites *Hebediscus attleborensis*, *Calodiscus*, *Serrodiscus* and *Triangulaspis*. Later studies (Geer 2005) have shown that the level of occurrence of the associated trilobites *Serrodiscus bellimarginatus*, *Triangulaspis annio*, *T. schucherti* and *Hebediscus attleborens* is widespread and can be used for a reliable correlation of the Lower Cambrian in many regions. Finds of these trilobites are known in, for example, Sweden, Canada, Spain, Morocco, Siberia and Kazakhstan. On the Siberian Platform, they appear in the sections near the lower boundary of the Botomian.

The Siberian Platform is an essential part of the Earth's crust with widespread Cambrian rocks. It would be right to choose trilobites that are also represented in the Siberian Platform as key species to determine the lower boundary the Cambrian Stage 4.

Olenellus

On the Siberian Platform, finds of this genus are absent. Therefore, when choosing the genus *Olenellus* to establish the lower boundary of Cambrian Stage 4 correlation of the Lower Cambrian of the Siberian Platform to other regions will be difficult and controversial.

Redlichia

This genus is rare in the Siberian Platform. The first finds are known in the lower part of the Botomian on the south-western of the Siberian Platform (Repina 1966). The following finds of this genus are much higher in the section, in the middle part of the Toyonian on the south-east of the platform in Keteme Formation (Egorova 1983).

Arthricocephalus chauveaui

This species is not present in the Siberian Platform. There are finds *Arthricocephalus snegirevae* on north-east of the platform (Suvorova 1964) and *Arthricocephalus* sp. (Korovnikov & Shabanov 2008). However, these finds are confined to the lower part of the Amga Stage. This is the lower part of the Cambrian Stage 5.

Judomia

This genus is found only in the Siberian Platform. Their findings are characteristic of the upper part of the Atdabanian and lower part of the Botomian. Because *Judomia* is endemic, it is unsuitable for interregional correlations.

Bergeroniellus

This genus is widely distributed in the Lower Cambrian of the Siberian Platform. The first species appears in the lower part of the Botomian. All species are endemic. They are characteristic for shallow and deep water sediments. In addition to the Siberian Platform, the genus has been found in the Altai-Sayan region and in the Sichuan province in China (Lin 2008).

Hebediscus attleborensis

These trilobites are found on the Siberian Platform in the lower part of the Botomian. Also, this species has been found in China, North America, Great Britain and Morocco (Hupe 1952). It may be suitable for interregional correlations.

Triangulaspis annio

This species has been found on the Siberian Platform in the lower part of the Botomian. Also, the species has been found in Great Britain (Cobbold 1910).

Calodiscus

This genus is widely distributed on the Siberian Platform, in the lower part of the Botomian. Three species are present: *Calodiscus granulosus* Jegorova et Schabanov 1972, *Calodiscus resimus* Repina 1972 and *Calodiscus schucherti* (Matthew 1896). All the finds are confined to relatively deep facies. It should be noted that in the Altai-Sayan region, *Calodiscus lobatus grandis* Poletaeva 1960 is present (Repina & Romanenko 1978). *Calodiscus lobatus* is widespread in the Lower Cambrian. It is has been found in North America, Greenland, the Baltic Sea and Kazakhstan (Cederström et al. 2009). It can be a key species for interregional correlations.

Serrodiscus

This genus is not found on the Siberian Platform. However, numerous *Serrodiscus* have been found in the Cambrian of the Altai-Sayan region. All finds are confined to the lower part of the Botomian. Various representatives of *Serrodiscus* have been found in North America, Australia, Greenland, the United Kingdom, Spain, Germany, Poland, Morocco and China. This genus has great potential for interregional correlation.

Thus, *Hebediscus attleborensis* and *Calodiscus lobatus* have the greatest correlation potential. In further revisions and more detailed studies of *Serrodiscus*, it is possible that a representative of this genus can be used as a key species to establish a GSSP.

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The mystery of the simplest retiolitid (Graptolithina) form *Plectodinemagraptus* gracilis from Ludlow of Poland

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Retiolitids have been studied over the past two decades and new forms are still being discovered. They are known from Llandovery to Ludlow, mostly from the Arctic Canada, Poland, Czech Republic and Lithuania. Some attempts have been made to explain their evolution, phylogeny and style of life (Bates & Kirk 1984, 1992; Lenz 1994; Melchin 1999; Kozłowska-Dawidziuk & Lenz 2001; Kozłowska & Radzevicius 2013). It is difficult to compare any graptolites, extinct Silurian plankton, to the recent plankton. It is also difficult to compare the retiolitids to other graptolites. The reason is their most complex rhabdosome, with the ancora sleeve, an additional outside layer, being an extension of the ancora umbrella growing upward from virgella. Their rhabdosomes are composed by lists built by bandages and between of them there was a thin, usually not preserved, membrane.

One of the most surprising retiolitid forms is the smallest and most reduced *Plectodinemagraptus gracilis* Kozłowska-Dawidziuk 1995 from the lower Ludfordian of Poland. Its rhabdosome comprises a very simple ancora umbrella divided into four meshes marked by two very short lateral lists, free nema and two parallel rods of ventral walls. There are no lateral walls. The size of the rhabdosome, having two pairs of thecae, reaches four millimetres (Kozłowska-Dawidziuk 1995). The thecal rows in *Plectodinemagraptus* are parallel, as in some Ludlow forms, e.g., *Plectograptus* (Moberg & Törnquist 1909) and *Semiplectograptus* Kozłowska-Dawidziuk 1995. Opposite arrangement of rhabdosome lists is seen in *Holoretiolites* species (Kozłowska-Dawidziuk 2004, fig. 4). They have small rhabdosomes tapering distally, with last modified theca forming a small tube called appendix. *Holoretiolites helenaewitoldi* Kozłowska-Dawidziuk 2004 has reduced thecal walls and well-developed lateral walls forming zigzag. Thus, this is the opposite arrangement of rhabdosome compared to *Plectodinemagraptus.*

At any rate, the main big dissimilarity with that and other retiolitids is the total lack of ventral walls. The small individual lists coming from thecal lips are very thin distally, which means they were not fully developed. So, there were no skeletal lists to support the rhabdosome on their lateral side. Thus, *Plectodinemagraptus* represents some different organization of the colony. It is an intriguing problem, what kind of material supported the ventral walls to keep their parallel arrangement. Thus, the origin of *P. gracilis* is still problematic, together with some other strange retiolitids, such as *Kirkigraptus inexpectans* Kozłowska & Bates 2008, *Valentinagraptus simplex* Piras 2006 and *Sokolovograptus polonicus* Kozłowska-Dawidziuk 1995 (see Kozłowska & Bates 2008, fig. 1).

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Ontogeny of the trilobite *Ellipsocephalus hoffi* and its phylogenetic implication

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Ellipsocephalus hoffi is a small, common ellipsocephalid trilobite in upper part of the Jince Formation (Příbram-Jince Basin, Barrandian area). Holaspid specimens of *E. hoffi* show twelve thoracic segments with blunt distal parts of pleurae and no genal spines. New discoveries of late meraspid and early holaspid articulated specimens of this species show yet unknown and quite surprising features. Late meraspides have long macropleural spines on the second thoracic segment; its length attains a length of the thorax (Fig. 1). Specimens with librigenae show long genal spines. Early holaspides of *E. hoffi* are typified by the presence of short genal spines but not for macropleural segments.

The phylogenetic position of ellipsocephalids is still a subject of discussion. They were generally classified as members of the order Redlichiida. Nevertheless, Fortey (1990) suggested that at least some of them (including the genus *Ellipsocephalus*) should be transferred to the order Ptychopariida, within the subclass Libristoma, because of their natant hypostomal condition. However, macropleural spines on the second thoracic segment do not belong to typical patterns in the ontogeny of ptychoparids; they rather resemble spines known during the ontogeny of some redlichids (e.g., paradoxidids). Early stages of paradoxid trilobites show two pairs of macropleural spines on the first and second thoracic segment. In case of paradoxidids, the first pair of spines disappears in middle to late meraspides, while the second pair vanishes in early holaspides (cf. Šnajdr 1958). On the other hand, spines in the first thoracic segment of *E. hoffi* have not been confirmed and those of the second segment disappear obviously close to the meraspid–holaspid transition. Such ontogenetic similarities with redlichids vs. some ptychoparid features could be explained generally in two ways: (1) ellipsocephalids belong among the basal libristoma (Ptychopariida) and thus share several ancestral features with redlichids; or (2) ellipsocephalids are redlichid trilobites that might have developed convergent forms to ptychoparids.

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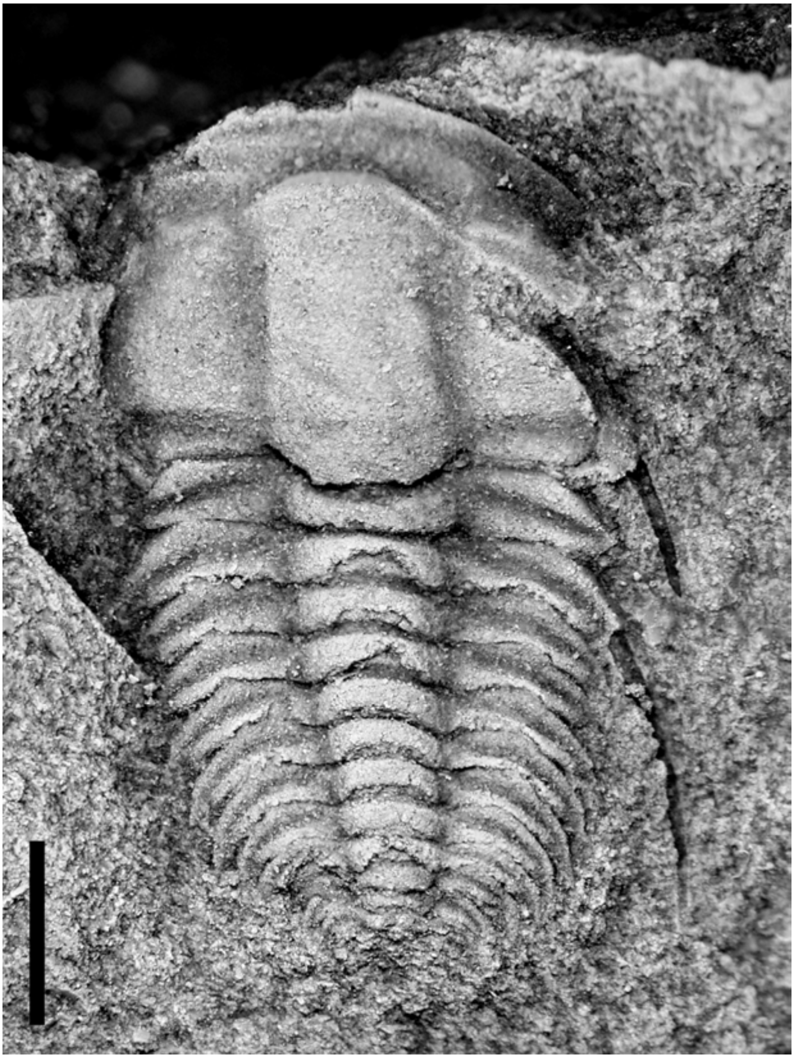

Fig. 1. Meraspid specimen of *Ellipsocephalus hoffi* showing macropleural and genal spines. Scale bar represents 1 mm.

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Palaeokarst formation in the early Palaeozoic of Baltoscandia – evidence for significant sea-level changes in a shallow epicontinental sea

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In the Lower Palaeozoic sedimentary succession of Sweden palaeokarsts have been reported from different stratigraphic levels in the Silurian strata of Gotland by Calner (2008; see references therein). Until last year there were no records of Cambrian karsts and in the Ordovician only the basin-wide Katian palaeokarst horizon in the Upper Ordovician Slandrom Limestone has been described in detail (Calner et al. 2010a). The unconformities and disconformities on top of the slightly older Kullsberg mounds in quarries located in the Siljan impact structure (Dalarna) presumably represent an earlier regression and karstic development (Calner et al. 2010b). Beside these reports, there is only the statement by Nielsen (1995) that karst may have formed at the top of the Darriwilian Komstad Limestone. During the last two years, however, several new and significant palaeokarst surfaces have been detected in the Cambrian–Ordovician successions of Sweden (Lehnert et al. 2012).

At Kakeled Quarry (Västergötland), a palaeokarst cave with a breccia fill (large, angular Orsten clasts in a dark limestone matrix) is exposed beneath a ‘Middle Cambrian’ palaeokarst surface (Jiangshanian Stage) located close to the top of the Kakeled Limestone Bed of the Alum Shale Formation (Lehnert et al., 2012). In the karstic pockets, a mass occurrence of *Orusia lenticularis* occurs. These shallow-water brachiopods originally settled on hard substrates after a major regression exposing, regionally, the sea floors of the alum shale basin. Their reworking and concentration in the conglomeratic bed overlying the irregular palaeokarst surface reflects deposition during transgression in extremely shallow marine environments.

A younger karst surface is exposed in Tomten Quarry at Torbjörntorp (Västergötland). In two dimensions in the quarry wall it resembles the “Schrattenkalk”, but rock slabs cut vertically and parallel to bedding planes display a karren system that resembles “Napfkarren” or cockling features. Trilobites of the Furongian *Ctenopyge bisulcata* and *C. linnarssoni* zones occur in the 1–2 cm thick, glauconitic packstone bed that overlies the palaeokarst surface and which represents the upper Tremadocian Bjørkåsholmen Formation. The associated stratigraphic gap comprises the six uppermost trilobite zones of the Furongian plus most of the Tremadocian. Darriwilian conodonts with reworked older material within a limestone bed slightly above the glauconitic packstone bed indicate yet another substantial gap in the succession.

In the new Tingskullen core from northeastern Öland, another palaeokarst surface with grikes and evidence of repeated exposure marks the top of the upper Tremadocian *Obolus* conglomerate (?) or a lower limestone part of the Djupvik Formation ("Ceratopyge Shale"). This palaeokarst surface is overlain by glauconitic limestone of the Köpingsklint Formation and inferably reflects the global *Ceratopyge* Regressive Event (CRE).

At the base of the Lanna Limestone in the Siljan area, palaeokarst is associated with the Dapingian Blommiga Bladet ('flowery sheet') hardground complex, which can be correlated across most of Baltoscandia.

The basin-wide palaeokarst in the Katian Slandrom Limestone (Calner et al. 2010a) no longer marks the youngest Ordovician karst record. Recently, Hirnantian karst caves and solution cavities filled with greenish marls of the Glisstjärn Formation have been recognized in sections of the Boda Limestone in the Siljan Ring structure (Dalarna). Solution and karst cave formation reflects an interval of the regression during the Hirnantian glaciation and the youngest period of subaerial exposure during the Ordovician.

Some earlier sedimentary models suggesting that Baltoscandia was flooded by a deep epicontinental sea are challenged by the discovery of multiple palaeokarst development together with other shallow-water features. Instead, palaeokarst formation implies subaerial exposure during a number of major regressions.

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The Drumian Isotopic Carbon Excursion (DICE) in Scania, southern Sweden – a mirror of the onset of the Marjumiid Biomere at a time of increased primary production?

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Only one prominent $\delta^{13}C_{org}$ excursion, the Steptoean positive carbon isotope excursion (SPICE) from the Andrarum 3 drillcore in Scania (Skåne), has been documented in detail from the provisional Cambrian Series 3 through Lower Ordovician (Tremadocian) Alum Shale Formation of Scandinavia (Ahlberg et al. 2009). Here we report on the Drumian carbon isotope excursion (DICE) from Cambrian Series 3 outer shelf deposits in the biostratigraphically well-controlled Almbacken drillcore from south-central Scania.

The DICE is a prominent negative $\delta^{13}C$ excursion that is well-known from the Great Basin, western United States (Montañez et al. 2000; Howley & Jiang 2010), and South China (e.g., Zhu et al. 2004). In the Almbacken drillcore, a study on the $\delta^{13}C_{org}$ chemostratigraphy has been performed in an interval ranging from the ?*Ptychagnostus praecurrens* Zone or lower *Ptychagnostus gibbus* agnostoid Zone (upper part of provisional Cambrian Stage 5; corresponding to the Topazan regional Stage of Laurentia) through the *Lejopyge laevigata* agnostoid Zone (lower Guzhangian Stage; upper Marjuman regional Stage of Laurentia). A detailed zonation in the core section was provided by Axheimer & Ahlberg (2003). The shift in the biofacies of the trilobite and agnostoid assemblages reflects a first order sea-level change. In the Almbacken drillcore, a prominent negative excursion has been recorded within an interval of dark grey to black mudstones and shales in the lowermost part of the Alum Shale Formation, i.e., between the top of the Gislöv Formation and the base of the *Exsulans* Limestone Bed. The macrofauna in this interval is largely restricted to linguliformean brachiopods and cannot be biostratigraphically constrained. However, in terms of the global agnostoid zonation, it probably represents the *P. praecurrens* Zone or the lower *P. gibbus* Zone. The prominent negative excursion in this trilobite- and agnostoid-barren interval (lingulid biofacies) can be correlated wih the DICE in the *Ehmaniella* Zone in the Great Basin (Montañez et al. 2000). The appearance of an open-marine assemblage with polymerids and agnostoids in the overlying *Exsulans* Limestone Bed (25.08–25.47 m) reflects a sudden shift in water depth. This sea-level rise is accompanied by a positive shift of more than 1.5‰ (rising upper limb of the DICE). Most of the remaining part of the succession in the core is dominated by agnostoid trilobites that reflect deeper-water, open-shelf conditions. These deeper water conditions are associated with more positive $\delta^{13}C_{org}$ values (ca. 0.5‰ higher) following the rising upper limb of the DICE.

The Guzhangian Andrarum Limestone Bed (4.10–5.65 m) has yielded polymerids and linguliformean brachiopods, reflecting shallower water depth and a regressive trend in the youngest part of the Alum Shale succession where stable $\delta^{13}C_{org}$ values between -31.5 and -31.0‰ have been recorded.

The increase of $\delta^{13}C_{org}$ values after the negative peak of the DICE roughly coincides with the base of the Marjumiid Biomere. The base of this biomere, however, does not coincide with the base of the Marjuman Stage (base of *Ptychagnostus atavus* Zone; Ludvigson & Westrop 1985 emend. Palmer 1998) in the biomere concept of Palmer (1998). In Laurentia, the base of the Marjumiid Biomere is placed at the base of the *Proehmaniella* Subzone of the *Ehmaniella* Zone (*Ptychagnostus praecurrens* agnostoid Zone; see Babcock et al. 2011).

The record of the DICE in the *Ehmaniella* Zone of Laurentia suggests that a substantial part of the lowermost part of Alum Shale Formation in the Almbacken core, i.e., the interval below the first occurrence of trilobites and agnostoids of the *Ptychagnostus gibbus* Zone, may be correlated with at least part of the *P. praecurrens* Zone. The increase in $\delta^{13}C_{org}$ values after the $\delta^{13}C_{org}$ minimum of the DICE may represent a time of increased primary productivity, which could have triggered the radiations observed within the Marjumiid Biomere.

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The ‘Přídolí hothouse’, a trigger of faunal overturns across the latest Silurian Transgrediens Bioevent

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During IGCP 503 it became more and more evident that the Silurian represents a period of major climatic changes, faunal overturns, drastic sea-level fluctuations and plate-tectonic reorganisations. Llandovery through Ludlow faunal extinctions, sedimentological changes and isotopic events have been well studied. For the Přídolí, however, we have only limited information about faunas, sedimentology or stable isotopes due to the fact that sediments of this Epoch are rarely preserved and that the remaining recorded successions are not investigated in detail. There are detailed reports on the major graptolite extinctions across the *Transgrediens* Bioevent (TBE; “C4” or “*Pseudoneocolograptus transgrediens* event” of Urbanek 1993, which correlates to the “Klonk Secundo-Unnamed Event” of Jeppsson 1998). Even when data are limited, it turns out that many faunas were affected by extinction (e.g., chitinozoans, conodonts, trilobites, ostracods, cephalopods, bivalves, brachiopods, corals, stromatoporoids and other groups among reef communities).

New oxygen isotope data from the Prague Basin document drastic climate changes from a cold interval during the early Přídolí followed by moderate to rapid warming and development of supergreenhouse conditions during the late Přídolí *transgrediens* graptolite Zone. This extremely warm climate presumably triggered the flooding of northern Gondwana shelf areas. The corresponding fine-grained siliciclastics are widely distributed in Romania, Turkey, Saudi Arabia, Libya, the Algerian Sahara, NW Spain, and central and northern Armorican Massif (see references in Jaglin & Paris 2002). In cratonal and shelf successions in tropical and subtropical areas (e.g., Laurentia; Ross & Ross 1996), the Přídolí successions are often not recorded due to widespread palaeokarst development in the areas covered by shallow epicontinental seas. However, the highstand during the *transgrediens* interval is recorded in deeper shelf and basinal areas (e.g. eastern Baltoscandian Basin, Lazauskiene et al. 2003).

The TBE represents the most severe graptolite extinction event during the Silurian (79% of taxa). Patterns in cephalopod diversity (Manda & Frýda 2010) represent another good example of a group severely affected by the Přídolí warming event. There was a major demise in reef development during the Middle Přídolí supergreenhouse (‘hothouse’) resulting in a drastic reduction in the diversity of reef taxa (Brunton et al.

1998). Thus, the event is comparable to the reef demise associated with the Late Devonian climate warming (Joachimski et al. 2009). Přídolí warming event is expressed by an increase in surface seawater temperatures of more than 8°C in the mid latitudes of northern peri-Gondwana, and was followed by cooling in the latest Přídolí and across the Silurian–Devonian boundary. During the TBE, high seawater temperatures stressed shelf faunas culminating in high extinction rates and presumably affected the entire food chain including planktonic organisms.

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A strategy for education and outreach of IGCP 591

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Selling the broader impacts of science has become a necessity in a time when competition for grant money is high. Merely involving graduate and/or undergraduate students in the research is no longer a satisfactory plan for scientific broader impacts. While this is still important for maintaining a pipeline of trained scientists, the bar has been raised and it is increasingly incumbent on us to communicate to the public what is so important about our work. In order to be competitive in the search for smaller and smaller pools of national and international funds, there must be a plan for the science funded by national and international agencies to be disseminated to the public. To this end, we have taken a multi-pronged approach to education and outreach for IGCP 591, involving both informal and formal science outlets in order to have the broadest impact.

Informal science, for the purposes of this paper, simply refers to any science learning that takes place outside the traditional classroom (Hofstein & Rosenfeld 1996). To that aim, the scientists working on IGCP 591: *The Early to Middle Paleozoic Revolution* have recruited a global network of museums to participate. Museums around the world, specifically in China, Argentina, the U.S., Denmark, Sweden, and the U.K., are collaborating and helping to develop a plan for the broader impacts of IGCP 591: *The Early to Middle Paleozoic Revolution.* Involving museums is particularly important, since they tend to have a more positive impact on how science is viewed by the public, as compared to traditional classroom learning (Ramey-Gassert & Walberg 1994; Wojnowski 2006). Museums also serve the essential research function of curating and managing collections that are available to researchers in perpetuity. A student who learns about these collections as a result of the broader impacts mission of this project, could potentially work on them as a researcher in the future. Our goal for the museums is for them to: 1) link to a still-to-be developed educational website, 2) develop a digital collection that would be available to anyone with an internet connection, and 3) arrange a traveling exhibit that would cycle through the participating institutions.

Regarding the more formal educational aspect of the project, modules/unit plans will be developed targeting children 12–18 years of age, which will be available on the IGCP 591 website. These modules will consist of educational activities, background notes, and lists of supplementary reading. As part of this project, we will also include a form on the website, to enable individuals to ask questions of experts about their work and to give us feedback on the modules. We will also host a workshop for secondary teachers to expose them to the science being discovered as a result of the project.

This is a call to action for all scientists involved in IGCP 591. The more scientists directly involved in the broader impacts, the better the information that goes out to the public. Please contact the author if interested in contributing to the education and outreach plan for IGCP 591.

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How to define the lower boundary of the Cambrian Stage 2: A biostratigraphic marker or a geochemical one?

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In the new subdivision of the Cambrian System, the Cambrian includes 4 series and 10 stages, and the pre-trilobitic Cambrian is approximately the Terreneuvian (Series 1), including the Fortunian stage and an unnamed Stage 2. How to define the base of Cambrian stage 2 is still an unresolved task. Most discussions on the GSSP definition of Cambrian Stage 2 were focusing on the use of the first appearance datum (FAD) of a fossil (e.g., Li et al. 2011; Parkhaev & Karlova 2011; Moczydlowska & Yin 2012). But recently, a geochemical marker was proposed for defining the base of Cambrian Stage 2 (Landing & Geyer 2012).

Small Shelly Fossils (SSFs) have been one of the important biostratigraphic tools for correlation and subdivision of the Terreneuvian. Although many SSFs are provincial and some of them are not applicable for interregional correlation, some taxa, such as *Watsonella crosbyi, Aldanella attleborensis*, *Purella squamulosa*, *Anabarella plana* and *Lapworthella* spp., may exhibit a worldwide distribution and enable a biostratigraphic correlation of the Terreneuvian sequences between different blocks. Amongst, the micromollusc *W. crosbyi* is a widely occurring fossil, and has been recovered from, for example, South China, Siberia, Mongolia, North America, France, South Australia. It mainly occurs in the late Terreneuvian (late Meishucunian in South China, Tommotian in the Siberian Platform, late Placentian in North America). Its wide occurrence in both carbonate and siliciclastic environments indicates that it is an important fossil for both regional and global correlation of the pre-trilobitic strata. The FAD of *W. crosbyi* has been proposed as a candidate GSSP marker for defining the Fortunian–Stage 2 boundary (Li et al. 2011). This potential GSSP candidate marker could be calibrated with other fossils. The FADs of *Anabarella plana* and *Purella* spp. are below this marker, while the FADs of *Lapworthella* spp. are usually above it (except in Mongolia). The FAD of *Aldanella attleborensis* approximates to or is a little above this marker. Thus, the FAD of *A. attleborensis* was also suggested as a potential marker for defining the base of the Cambrian Stage 2. But in South China, the occurrence of *A. attleborensis* is not widespread and its FAD is higher than that of *W. crosbyi* in eastern Yunnan.

Besides the SSFs, acritarchs are useful microfossils for the Cambrian biostratigraphy. The FAD of *Skiagia ornata* as a global recognizable level is a little higher than that of

Watsonella crosbyi (Moczydlowska & Zang 2006), and was suggested for defining the base of the Cambrian Stage 2 (Moczydlowska & Yin 2012).

The FADs of *W. crosbyi* and *A. attleborensis* could also be calibrated with carbon isotopic chemostratigraphic data. In northeastern Yunnan, South China, the FAD of *W. crosbyi* is near the base of the Dahai Member of the Zhujiaqing Formation, and it is below the major positive $\delta^{13}C$ excursion (dubbed ZHUCE by Zhu et al. 2006). Landing & Geyer (2012) doubt the use of the FAD of a fossil and propose to use the $\delta^{13}C$ ZHUCE positive peak for defining the base of Cambrian Stage 2. But it is sometimes difficult to recognize a $\delta^{13}C$ peak horizon within an excursion interval. It is much better to use $\delta^{13}C$ data as a supplementary marker.

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Review of the Ordovician acritarch genus *Rhopaliophora*

JUN LI[1], THOMAS SERVAIS[2] AND KUI YAN[1,3]

Among Ordovician acritarch genera *Rhopaliophora* Tappan & Loeblich 1971 emend. Playford & Martin 1984 is one of the most commonly recorded genus. Originally described in the early 1970s from Laurentia, it has subsequently been found on most other palaeocontinents with eight species attributed to the genus. The present paper is a revision of the genus based on the analyses of published literature and on observations of large populations of new material from the South Chinese Ordovician. Our review indicates that the following species belong to the genus: *Rhopaliophora brevituberculatum* (Kjellström 1971) Martin 1983, *R. florida* Yin et al. 1998, *R. foliatilis* Tappan & Loeblich 1971 (type species), *R. impexa* Tappan & Loeblich 1971, *R. mamiliformis* Lu 1987 emend. Tongiorgi et al. 1995, *R. membrana* Li 1987, *R. palmate* (Combaz & Peniguel 1972) emend. Playford & Martin 1984, *R. pilata* (Combaz & Peniguel 1972) emend. Playford & Martin 1984. The species *Rhopaliophora*? *assymetrica* Raevskaya et al. 2003 was tentatively placed into the genus. However, we consider that *Rhopaliophora granulata* Yin 1995 is a junior synonym of *Rhopaliophora pilata,* whereas *Rhopaliophora reticulata* Uutela & Tynni 1991 can be considered a junior synonym of *R. foliatilis.* Intraspecific variability is great and the boundaries between the individual species are sometimes not clear. At the genus level, *Rhopaliophora* shows some transitional forms with the genera *Peteinosphaeridium* Staplin et al. 1965 emend. Playford et al. 1995 and with some species of *Pachysphaeridium* Burmann 1970 emend. Ribecai & Tongiorgi 1999, whereas its relation to the morphologically similar genera *Asketopalla* Loeblich & Tappan 1969 emend. Loeblich & Tappan 1971, *Loeblichia* Playford & Wicander 1988, *Tenuirica* Playford & Wicander 1988 and *Papilliferum* Yin 1994 needs to be clarified. *Rhopaliophora* first appears, together with *Peteinosphaeridium*, in the middle Tremadocian (first stage of the Lower Ordovician). After its orginal description from Laurentia and later from Australia, in low latitude warmer water environments, it has subsequently been found also in intermediate latitudes in Baltica and South China, and a few findings are also reported from high latitude areas of Gondwana, indicating a pandemic distribution in warm and temperate water masses. In terms of palaeoecology, the genus is rarely found in nearshore palaeoenvironments, but it is a typical indicator of offshore marine habitats, being abundantly present on carbonate shelf platforms.

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Early Ordovician graptolites from South China

MING LI[1], LIXIA LI[2], HONGZHEN FENG[2] AND WENHUI WANG[2]

The Nanba section is located in Yiyang City, Hunan Province, China, and exposes a set of deep-water deposits. In this section, the graptolites usually yield in dark colored mudstones, rather than in silt-mudstones, which usually contain dynamic disturbance structures and tube-like trace fossils.

The Jiangnan Slope belt is one of the regions with rich Early Ordovician planktic graptolites of great diversity and abundance in China. In order to improve the precision of the study on the Early Ordovician graptolites and strata in China, the Nanba section in the Jiangnan stratigraphical region is selected as the key section for the Early Ordovician graptolite sequence.

In the duration of 2000–2012, we studied this section and collected numerous graptolite specimens. The Nanba section yields an Early Ordovician graptolite fauna that includes 57 species assigned to 27 genera. Based on the current graptolite materials, the correspondingly complete graptolite zones of Lower Ordovician in China are recognized as follows (in ascending order): the *Adelograptus tenellus* Zone, *Aorograptus victoriae* Zone, *Araneograptus murrayi* Zone, *Hunnegraptus copiosus* Zone, *Tetragraptus approximatus* Zone, *Pendeograptus fruticosus* Zone, *Didymograptellus bifidus* Zone and the *Corymbograptus deflexus* Zone (Fig. 1). In the Nanba section, the *T. approximatus* Zone directly overlies the *H. copiosus* Zone; there is no hiatus below the base of Floian. As a result, a consecutive graptolite succession of the Lower Ordovician could be established in the Yiyang area. This succession allows precise correlation of the Early Ordovician graptolite biostratigraphy between this area and elsewhere home and abroad.

The *Adelograputs tenellus* Zone is the lowest graptolite zone found in the Nanba section, and is approximately equivalent to the *A.* cf. *tenellus* Zone of Yukon, the *Adelograptus* sp. Zone of Bolivia, the *A. tenellus* Zone plus the *Bryograptus ramosus* Zone in Scandinavia, and the *Psigraptus jacksoni* Zone in Australia and North China. The *Bryograptus* Zone in Argentina is possibly equal to the upper part of the *A. tenellus* Zone in the Nanba section.

Aorograptus victoriae mainly occurs in the lower part of the *A. victoriae* Zone (about 3–4 m), but very scarcely in its upper part. The *A. victoriae* Zone in the Nanba section may approximate the same zone in Bolivia and Zhejiang, China, the *Kiaerograptus supremus* Zone plus the *A. victoriae* Zone in Scandinavia and Argentina, and the *Paradelograptus antiquus* Zone plus the lower part of the *K. prichardi* Zone in Yukon.

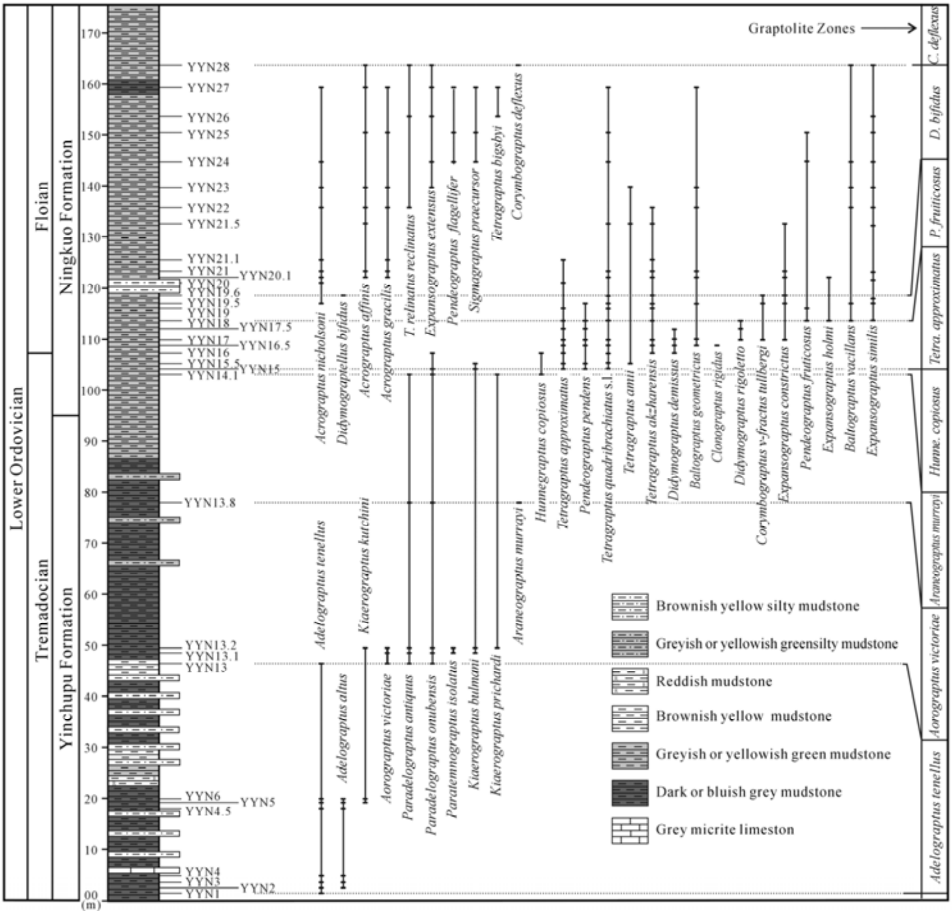

Fig. 1. Stratigraphic ranges of the graptolites at the Nanba section, Yiyang, Hunan, China.

The *Araneograptus murrayi* Zone here can be correlated with the same zone in Scandinavia, Bolivia, Britain, Argentina and Australia, and the upper part of the *Kiaerograptus pritchardi* Zone in Yukon, Canada. In North China, there is no report on the occurrence of *Araneograptus*.

The *Hunnegraptus copiosus* Zone here can be correlated to the same zone in Scandinavia, Bolivia, Argentina and the *H. copiosus* Zone plus the *Paradelograptus kinnegraptoides* Zone in Yukon. This zone can be correlated with the same zone in Sichuan Province of the South China.

The *Tetragraptus approximatus* Zone here can be correlated with the *phyllograptoides* Zone plus the *Expansograptus protobalticus* Zone in Scandinavia, the *T. approximatus*

Zone plus the *T. akzharensis* Zone in Nevada and Newfoundland, and the *T. phyllograptoides* Zone in Bolivia and Britain. It could be equal to the same zone in the Jiangnan and Yangzi regions of China.

The *Pendeograptus fruticosus* Zone here can be correlated with the same zone in Nevada, Newfoundland and the Sanshan area, Jiangnan region of China, the *Didymograptus balticus* Zone in Scandinavia, the *Expansograptus holmi* Zone in Bolivia, and the *Acrograptus filiformis* Zone in the Yangzi region of China.

The *Didymograptellus bifidus* Zone plus the *Corymbograptus deflexus* Zone here are approximately equal to the *D. bifidus* Zone in Nevada, Newfoundland and Quebec, the *Phllograptus densus* Zone in Scandinavia, the *Baltograptus minutus* Zone in Bolivia, and the *D. simulans* Zone in Britain.

The *Didymograptellus bifidus* Zone here is approximately equal to the *D. protobifidus* Zone in the Sanshan area, Jiangnan region of China, and the *D. eobifidus* Zone in the Yangzi region of China.

The *Corymbograptus deflexus* Zone here can be correlated with the *C. deflexus* Zone plus the *suecicus* Zone in the Jiangnan and Yangzi regions of China.

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Early Ordovician sponge-receptaculitid-microbial reefs on the Yangtze Platform margin of the South China Block

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The Ordovician witnessed a transition from microbial to metazoan-dominated reefs in a stepwise fashion (Webby 2002; Adachi et al. 2011). Skeletal reef-builders were already common in the Early Ordovician of the central Yangtze Platform, whilst microbial mounds prevailed on the southeastern margin (Li et al. 2004; Adachi et al. 2011) and elsewhere. We studied sponge-receptaculitid-microbial reefs from the Hunghuayuan Formation (late Tremadocian–early Floian) at Zhangzhai in southeastern Guizhou situated on the Yangtze Platform margin of the South China Block. Microbes and metazoans (e.g., lithistid sponges and the receptaculitid *Calathium*) build small patch reefs together, showing a broad spectrum in the proportion between skeletons and microbial fabrics. The reefs are generally domical or lenticular in shape, ranging in height from several tens of centimeters to several meters and in width from less than a meter to more than 10 meters. Based on the main reef-builders and their role in reef construction, we can distinguish three reef types: Stromatolite reefs, lithistid sponge-*Calathium*-calcimicrobial reefs and lithistid sponge-*Calathium* reefs. The first two types are both microbial-dominated (built mostly by laminated or unlaminated microbial fabrics), whereas lithistid sponge-*Calathium* reefs, occurring in the upper part of this formation, are metazoan-dominated and represent a rare example of metazoan-dominated reefs at the marginal belt. Lithistid sponges and *Calathium* are abundant (constituting over 50% in volume) and closely adjacent or even in contact to build a framework in the core facies. The microbial contribution to reef growth was far less important. The three types of reefs represent different communities controlled by environmental setting: stromatolites tended to develop in the shallow subtidal zone; unlaminated calcimicrobial mounds and metazoan-dominated reefs were flourishing at deeper depths with higher plankton availability and more suitable physical conditions for suspension feeders.

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The earliest known *Foliomena* fauna (Brachiopoda) from the Upper Ordovician Miaopo Formation at Jieling, Yichang, South China

YAN LIANG[1] AND RENBIN ZHAN[1]

As a unique and characteristic brachiopod fauna, the *Foliomena* fauna was studied by many experts on its occurrences, taxonomic composition, diversity, evolution patterns and palaeoecology after its first description by Sheehan (1973) from the Jerrestad Mudstone (early Ashgill, middle Katian), southern Sweden. In South China, the Upper Ordovician Miaopo Formation (mainly *Nemagraptus gracilis* Biozone, lower Sandbian) yields thousands of brachiopods belonging to 27 genera and 31 species, which are regarded as the oldest known record of the *Foliomena* fauna (Rong et al. 1999).

The 3-m-thick Miaopo Formation is marked by dark-gray or grayish brown mudstones or shales, interbedded with thin to medium bedded argillaceous limestones, yielding diverse and abundant fossils dominated by trilobites, graptolites, brachiopods and ostracodes, associated with fewer gastropods, conodonts and crinoid stems. This Upper Ordovician lithologic unit is confined to Chengkou of northern Chongqing District, Yichang of western Hubei Province and Hexian of Anhui Province (Chen & Qiu 1986; Chen et al. 2011), South China palaeoplate. Chen & Qiu (1986) suggested that the development of this formation is related to local depressions on the carbonate platform (the Yangtze Platform) during the early Late Ordovician. Within such a unit occurs the oldest known *Foliomena* fauna (Rong & Zhan 1995; Rong et al. 1999; Zhan et al. 2010), which requires a complete and deliberate systematic description.

In this study, the section of the Miaopo Formation is located at Jieling of northern Yichang, western Hubei (31°07'2.2" N, 111°24'13.7" E). Geologically, it is on the east side of the Huangling anticline. More than 2500 brachiopod specimens were collected, amongst which 910 complete brachiopod shells were measured for this study. The fauna appears to be a mixture of the core taxa of the *Foliomena* fauna such as *Christiania*, *Dedzetina*, *Leptestiina*, *Kassinella* and *Foliomena* itself, together with a number of other deep-water taxa such as *Skenidioides*, *Anisopleurella* and *Seriocoidea*, associated with some orthids such as *Dolerorthis, Glyptorthis, Taphrorthis, Nicoloidea, Chrustenopora, Drabovinella* and *Parisorthis*. Compared with Early and Middle Ordovician brachiopod faunas, which are normally dominated by orthids, the current fauna is composed mainly of strophomenids. Altogether, there are 27 brachiopod genera and 31 species (Fig. 1), amongst which 11 genera and species are plectambonitoids, comprising

37% of the fauna and 70% of the total 965 measured specimens, respectively. The orthoids include 5 genera and 6 species (about 18%), and the strophomenoids and inarticulates 6 and 4 genera and species, respectively. Other minorities are skenidioids, dalmanelloids and enteletoids. It is provisionally called the *Kassinella-Multiridgia-Anisopleurella* Association, and constitutes the oldest known *Foliomena* fauna in the world.

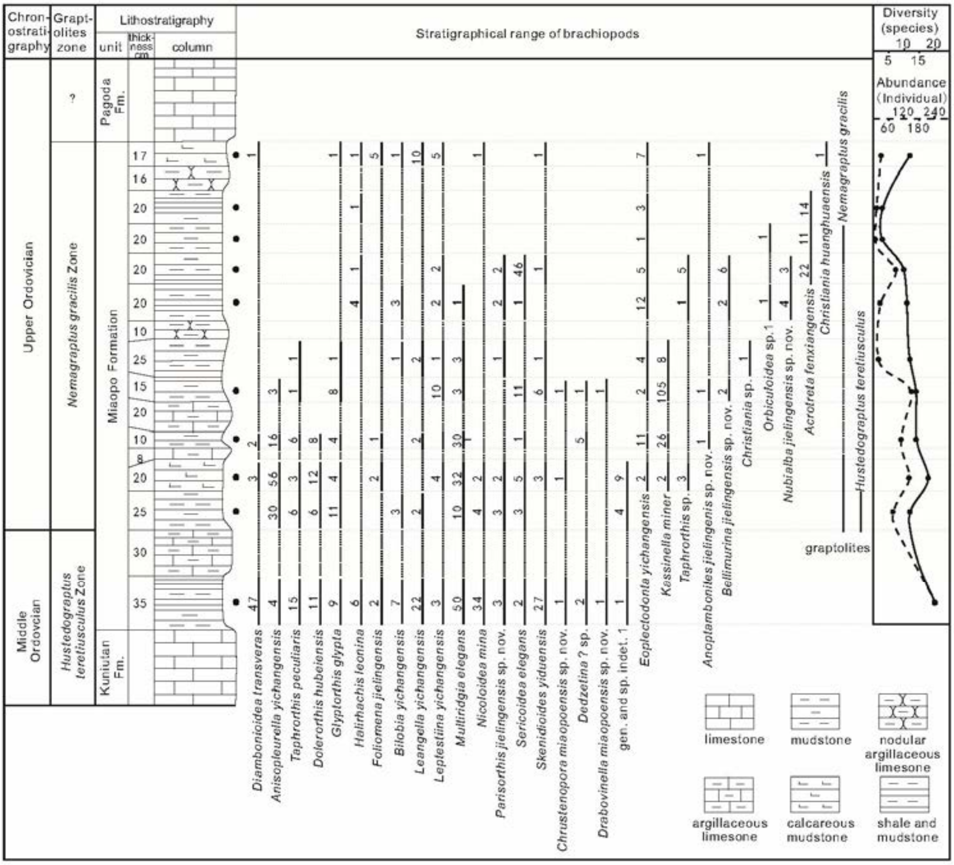

Fig. 1. Stratigraphical ranges of brachiopods in the Miaopo Formation at Jieling, Yichang, western Hubei Province. The graptolite biozones are from Chen et al. (2011). The numbers along the stratigraphical range of each species refer to the number of specimens at each particular collection respectively.

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The Darriwilian (Middle Ordovician) Holen Limestone at Kinnekulle, southern Sweden – with special focus on the 'Täljsten'

ANDERS LINDSKOG[1] AND MATS E. ERIKSSON[1]

Meridionally along Sweden, preserved Middle Ordovician deposits mainly consist of brown to red colored cool-water 'orthoceratite limestone' (e.g., Hadding 1958). In strata belonging to the Volkhov (Dapingian–lower Darriwilian) and Kunda (lower–middle Darriwilian) Baltoscandian stages, a conspicuous change to gray limestone is widely developed. The timing of this change varies somewhat. At Kinnekulle, Västergötland, these gray strata first appear in the lower part of the c. 14 m thick Holen Limestone, and span c. 1.5 m of lower to middle Kundan beds (e.g., Eriksson et al. 2012). Through local quarrying tradition, the gray beds are known as the 'Täljsten' (see Hadding 1958).

The entire Holen Limestone is exposed and accessible in the large abandoned Hällekis quarry, northwestern Kinnekulle, and the 'Täljsten' and c. 4.5 m of the overlying red limestone beds are exposed also in the smaller and still active Thorsberg quarry, southeastern Kinnekulle. In recent years, we have conducted fieldwork at these localities on several occasions. Studies have mainly focused on micropaleontologic and sedimentologic aspects of the Holen Limestone, and the 'Täljsten' and its immediately adjacent strata in particular.

The boundary between the Lanna Limestone and the Holen Limestone, which also marks the boundary between the Volkhov and Kunda stages, is situated within a series of closely spaced limonitic hardgrounds (cf. Jaanusson 1982), in an oolitic packstone interval c. 2.8–3 m below the base of the 'Täljsten'. The first appearance of typical Kundan trilobites has been recorded close to this level (Villumsen et al. 2001). Marly wackestone-packstone with poorly developed bedding then ensues and continues upwards c. 2 m. Relatively dense red wackestone-packstone, large parts of which appears to have formed during conditions of continuous sedimentation, underlies the 'Täljsten' and forms the quarry unit Arkeologen. The superjacent 'Täljsten' records successive change between different, increasingly coarse-grained facies, in stratigraphically ascending order:

1) Red-tinted gray wackestone-packstone with hematite-stained discontinuity surfaces (Golvsten quarry unit).
2) Clean gray packstone with well-developed phosphatic hardgrounds (Botten).

3) Glauconitic gray wackestone-packstone (Botten–Gråkarten).
4) Glauconitic dark gray marly limestone with poorly developed bedding (Blymåkka–Fjällbott).
5) Relatively clean, mottled and organic-rich gray packstone with numerous intraclasts and closely spaced phosphatic firmgrounds and hardgrounds (Likhall).
6) Red-tinted gray packstone strewn with limonitic grains, with well-developed phosphatic hardgrounds (Flora–Mumma), that gradually shifts into red wackestone-packstone (Rödkarten and other quarry units above the 'Täljsten').

These different facies are distinct and thus enable bed-by-bed correlation between the Hällekis and Thorsberg quarries, and sometimes also to sections elsewhere (see Dronov et al. 2001). In addition to the individual beds of the 'Täljsten', several other distinct beds are traceable (at least) between the two field localities. Approximately 2 m of relatively dense red wackestone-packstone overlie the 'Täljsten', and variably marly red wackestone-mudstone continue upwards until a flatly eroded discontinuity surface that marks the top of the Holen Limestone (see Holmer 1983), c. 9 m above the top of the 'Täljsten'. For the most part, the succession appears to record essentially continuous sedimentation and hardgrounds are rarely well developed. Many firmground and hardground surfaces in the topmost c. 3–4 m contain innumerable simple macroborings.

In addition to spectacular findings of abundant fossil meteorites and associated sediment-dispersed extraterrestrial chromite (e.g., Schmitz & Häggström 2006), the 'Täljsten' is associated with notable changes in the preserved fossil biota (e.g., Tinn & Meidla 2001; Mellgren & Eriksson 2010; Eriksson et al. 2012). Most conspicuously, some beds abound with relatively well-preserved cystoids. Overall, the fossil abundance is substantially higher in comparison to most of the enclosing red strata. In acid-insoluble residues from the 'Täljsten', particularly gastropods, ostracods and conodonts occur in exceptional numbers. Field studies also revealed a significant presence of microbialitic features, most notably well-developed oncoids. The Lanna–Holen Limestone/Volkhov–Kunda Stage boundary interval also appears anomalously fossiliferous. With regards to abundance, many taxonomic groups show similar patterns within their stratigraphic distribution, and at least in part these patterns reflect regional phenomena.

A common factor for the most fossiliferous stratigraphic intervals in the studied succession is that they are associated with sea-level lowstands. Both the Volkhov–Kunda transition and the 'Täljsten' are associated with variably extensive erosion in the more shallow-water parts of the Baltoscandian paleobasin (e.g., Nordlund 1989; Hints et al. 2012). The strata at Kinnekulle represent an essentially complete record of events during this time interval. With the exception of possible subaerial conditions during the formation of the discontinuity surface at the top of the Holen Limestone, the 'Täljsten' and its adjacent strata appear to record the most substantial lowstand in the entire Holen Limestone succession.

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Decrease in carbonate accumulation rate in Early Ordovician in south China: Insights into paleoceanographic changes

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The potential causal mechanisms of the "Great Ordovician Biodiversification Event" remain the subject of considerable debate. Although many causal factors are employed for promotion of the biodiversification, paleoceanographic effects (e.g., cooling trend through the Early Ordovician) are recently proposed to have played a forcing role in the unprecedented biodiversity increases (Trotter et al. 2008; Giles 2012). Shallow-marine carbonate systems are highly responsive to physical, chemical, and biological changes, e.g., biological/ecological, paleoceanographic conditions. The purpose of this study is to present an integrated synthesis of the Early Ordovician carbonate accumulation rates of the Yangtze platform, South China in order to highlight the paleoceanographic influences for the initial stage of the GOBE.

In the Tremadocian of the Early Ordovician, extensive shallow-marine carbonates (the Tongzhi, Nantsinkuan, Fenshiang and lower Hunghuayuan formations) prevailed in the offshore setting of the Yangtze Platform, with terrigenous clastics deposited in the inshore area. From the early Floian, the platform was deposited with mixed carbonate-siliciclastic sediments (the Meitan, Dawan, and Zitai formations) due to rapid sea level rise.

In this study, nine well-exposed sections from different palaeogeographical zones of the Upper Yangtze area were selected to document the temporal changes in the accumulation rates of carbonates. All the studied successions are well dated based on the conodont biozones. The carbonate accumulation rates are calculated from the stratigraphic thicknesses of conodont biozones in meters per million years (m/Ma), and are not corrected for compaction.

The observed rates of carbonate accumulation on the Upper Yangtze Platform various significantly between different biozones and sections, ranging from less than 1 to 100 m/Ma or more. However, total accumulation rates at the studied section are generally higher in the lower Tremadocian, and progressively decreases up to the base of the Floian. The mean rates are 37 or 29 m/Ma in the lower Tremadocian, 14 or 19 m/Ma in the upper Tremadocian, and 7 or 10 m/Ma at the base of Floian according to two time scales (Webby et al. 2004; Gradstein et al. 2012).

The bulk sediments of the Tremadocian and basal Floian in the Upper Yangtze Platform are mainly composed of shallow-subtidal grainstone/packstone with minor shale or wackestone intervals deposited in the deeper settings. Thus the generally decrease in the mean rates of the carbonate accumulation in the Early Ordovician cannot be entirely attributed to the fall of relative sea-level; whereas the growth potential of the carbonate system might have play a pivotal role on it. Previous studies documented a decline of ooid precipitation and a coeval gradual increase in skeletal mass from the upper Tremadocian of the platform (Liu et al. 2011). These changes indicate a transition from an abiotically controlled carbonate factory to a biotically controlled carbonate factory, and imply a decrease in the carbonate saturation of the seawater, chiefly due to a fall of atmospheric pCO_2 as well as the resultant global cooling. In summary, the decrease in the growth potential of the carbonate system in the Early Ordovician in South China was strongly influenced by the carbonate saturation state of the seawater in the gradually cooling ocean, which might have opened a window for the widespread taxonomic radiations of marine life.

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Palynology through the early Wenlock Ireviken Event

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The lower part of the Sheinwoodian (lower Wenlock, Silurian) is well known for its major positive carbon isotope excursion and extinction events, affecting in particular the graptolites and conodonts.

The temporal relationship between the isotope excursion, associated environmental change and the extinction events is the subject of much debate. The aim of this project is to conduct a high-resolution palynological study through the Sheinwoodian of Buttington Brick Pit, Wales, in order to establish the relative timing of the graptolite extinction with respect to the carbon isotope excursion and to establish the impact of the associated environmental changes on the microplankton.

The study focuses upon chitinozoans and acritarchs. The former will be used primarily (in combination with the existing graptolite biozonation) to constrain the age of the section biostratigraphically. Diversity changes will also be analysed to determine if the chitinozoans were affected by the environmental changes responsible for the graptolite extinction event. The second part of the study will focus upon quantitative analyses of the diversity and relative abundance of acritarch morphotypes, utilised successfully as palaeoenvironmental indicators in previous studies (e.g., Stricanne et al. 2006; Loydell et al. 2009). Acritarchs are particularly valuable in such palaeoenvironmental studies – different morphotypes reflect, in particular, relative distance from the shore and have been used successfully as proxies for sea-level change.

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The middle Rhuddanian (lower Silurian) ‘hot’ shale of North Africa and Arabia: An atypical hydrocarbon source rock

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An important hydrocarbon source rock (a ‘hot’ shale) has been identified from the middle Rhuddanian (Llandovery, lower Silurian) of a number of localities in North Africa and Arabia. It is unusual in having been deposited during a eustatic fall in sea-level. Evidence for the regression in Libya and Jordan is manifested in a wide variety of palynological proxy data (including reduced acritarch and chitinozoan total abundance, reduced acritarch diversity and changes in the relative abundances of various environmentally sensitive acritarch morphogroups) and from the presence of a minor positive $\delta^{13}C_{org}$ excursion at the same stratigraphical level as the ‘hot’ shale. The environment of deposition was anoxic before, during and after deposition of the ‘hot’ shale, except for some very brief incursions of more oxygenated water that enabled the development of a very limited burrowing benthos and graptolite preservation as three-dimensional pyrite internal moulds. Enhanced organic matter preservation within the ‘hot’ shale is attributed to greater productivity resulting from increased nutrient inputs particularly from wind-blown dust, more rapid descent through the water column of organic matter in post-bloom marine snow macroaggregates, development of geochemically sealing microbial mats at the sea floor and more rapid burial of organic material than had occurred earlier in the Rhuddanian.

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Silurian graptolite biostratigraphy of the Röstånga-1 drill core, Scania – a standard for southern Scandinavia

JÖRG MALETZ[1] AND PER AHLBERG[2]

The Lower Palaeozoic of Scania, southern Sweden, has long been a focus for research into the Ordovician and Silurian graptolite biostratigraphy of Scandinavia and provides the most complete successions available for the palaeo-continent of Baltica throughout this interval. The ratified Global Stratotype Section and Point (GSSP) for the Sandbian Stage of the Upper Ordovician Series is located in the Fågelsång area east of Lund, south-central Scania (Bergström et al. 2000; Bergström & Ahlberg 2004). The Silurian graptolitic strata of Scania are, however, less well known as little work has been done since the early investigations of Törnquist and Tullberg in the late 19th century, and hence additional research is sorely needed.

The Röstånga-1 core from west-central Scania, drilled in 1997 (Bergström et al. 1999), provides the most complete succession of the lower Upper Ordovician through lower Silurian (Llandovery, Telychian) of southern Scandinavia. The drilling was stopped at a depth of 132.59 m and penetrated a seemingly continuous succession with little tectonic disturbance. The sediments have a dip of ca. 35 degrees and the stratigraphic thickness of the sedimentary column was estimated to be about 96 m (Bergström et al. 1999). The core diameter is 71 mm (between 0 and 40.13 m) and 52 mm (between 40.13 and 132.59 m), thus providing enough sedimentological and palaeontological information for a detailed analysis.

The drill core has provided significant information on the Upper Ordovician–lower Silurian stratigraphy in Scania and serves as an important reference standard for this interval in southern Scandinavia. The lowermost part of the core comprises the upper part of the Sandbian Sularp Shale (?*Nemagraptus gracilis* to *Climacograptus bicornis* biozones), in which numerous K-bentonite beds were recorded (Bergström et al. 1999). The base of the Sularp Shale, with the Fågelsång Phosphorite Bed, and the base of the *Nemagraptus gracilis* Biozone ca. 1.4 m below (the base of the Sandbian Stage), was not reached. Above the Sularp Shale, the Skagen Formation, Mossen Shale, Fjäcka Shale and Lindegård Mudstone were differentiated in the Ordovician interval and a small number of graptolites of the *Pleurograptus linearis* and *Dicellograptus complanatus* biozones have been identified and support the estimated ages of the intervals (Pålsson 2002).

The Upper Ordovician (Katian–Hirnantian) Lindegård Mudstone grades into the Kallholn Formation, the base of which is Hirnantian in age and can be referred to the *Metabolograptus persculptus* Biozone. The sedimentology of the succession, unfortunately, has never been described in detail and a comparison with the Kallholn Formation of Dalarna (Llandovery, upper Rhuddanian to Telychian) is not possible at the moment. The mudstones of the Lindegård and Kallholn formations in the Röstånga-1 drill core include a variety of lithologies, predominantly black to dark brown, reddish and greenish mudstone and shale with intercalations of 1–15 mm thick siltstone layers in certain intervals. Lamination, cross bedding and bioturbation is common, except in some of the coarser sediment types. The upper part of the Kallholn Formation is dominated by dark to light greenish shale with lamination; coarser layers are usually lighter in colour. Some bioturbation can be found. Fossils are largely restricted to graptolites, but a few phosphatic and calcitic brachiopods and even trilobite fragments have also been encountered. Beds crowded with current-oriented graptolites are common in the lower, darker part of the Kallholn Formation, where graptolites are often preserved in full relief, filled with pyrite. The *Metabolograptus persculptus* Biozone (58.50–?52.70 m) can be recognized in the Hirnantian. The Rhuddanian, (Llandovery) *Akidograptus ascensus* (52.70–50.50 m), *Parakidograptus acuminatus* (50.50–46.70 m), *Cystograptus vesiculosus* (46.60–37.30 m) and *Monograptus revolutus* (37.30–35.40 m) biozones are preliminarily differentiated. A considerable gap may be present here comprising the lower Aeronian, as the oldest graptolite fauna of the Aeronian interval belongs to the *Lituigraptus convolutus* Biozone (35.40–31.05 m). It is followed by the *Monograptus sedgwicki* Biozone (31.5–28.45 m). The *Rastrites linnei* (28.45–24.12 m), *Spirograptus turriculatus* (24.12–21.70 m) and *Streptograptus crispus* (21.70–11.16 m) biozones belong to the Telychian interval. A finer subdivision of these biozones may be possible.

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Preliminary revision of the sequence stratigraphy and nomenclature of the upper Maysvillian–lower Richmondian strata exposed in Kentucky

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Late Ordovician (Katian) strata of Kentucky, in the Cincinnati Arch region, display a regional change in lithologic and faunal gradients corresponding to a southeast-shallowing epicontinental ramp. While a detailed sequence stratigraphic framework has been established for the lower Cincinnatian, that of the upper Maysvillian–lower Richmondian succession of northern and central Kentucky has not been studied in detail. Moreover, locally and inconsistently applied lithostratigraphic terms reflecting facies changes along the ramp have complicated precise subdivisions of sequences into component cycles and inhibited recognition of regionally consistent patterns.

This study uses high resolution facies analysis and tracing of distinctive stratigraphic markers including biostromal horizons, rhythmic intervals, erosion and flooding surfaces, and distinctive fossil epiboles across lithofacies and nomenclatorial boundaries to reveal stratigraphic consistencies largely overlooked by previous researchers.

The present study focuses on the lower portion of the Richmond Group and its transition with the underlying Maysville Group. Previous work by Holland & Patzkowsky (1996) recognized a single third order depositional sequence in this interval, C4, approximately coincident with the Arnheim Formation of Ohio and with lower portion of the Bull Fork Formation of Kentucky usage. The underlying C3 succession (Corryville-Mount Auburn has been modified to some extent as a result detailed field study of Schramm (2011). In particular, the Mount Auburn nodular packstones, skeletal grainstones and stromatoporoid biostromes, as well as shallow subtidal/lagoonal facies ("Sunset Member" *sensu stricto*), at least in part, appear to overlie a regional disconformity and form the base (early transgressive systems tract) of sequence C4. Recent fieldwork has shown that these beds pass laterally into southeastwardly thickening shaly dolomicrites with desiccation cracks and a sparse fauna suggesting complementary deposition of muddy peritidal facies (Terrill Member) during lowstand to early transgression. The overlying Arnheim succession records a third highstand/falling stage order contains at least two smaller (4th order) cycles separated by a thin grainstone/packstone bed which locally yields the distinctive brachiopod *Retrorsirostra carleyi*. The C4 upper boundary in Kentucky is formed by a regional discontinuity beneath a thin package of coarse skeletal beds, locally with corals and stromatoporoids (Fisherville Coral bed), and their shoreward equivalents, which also pass southward into peritidal micritic facies. These beds may be laterally equivalent to a condensed phosphatic limestone (herein termed Southgate Bed) that forms the base of Holland & Patzkowsky's (1996) C5 sequence in Ohio-Indiana.

Much of the past terminology can be retained and defined objectively, allowing the use of one unified set of names on the member scale level that will be integrated into formations. This will allow easier correlations along the Cincinnati arch. Moreover, this will lead to a refined and consistent sequence stratigraphic framework for a better understating of depositional environments and changes in faunal gradients. Because these sequences span offshore to peritidal facies they provide the possibility of testing for changes in sequences and their component systems tracts across a proximal–distal gradient. Finally, the beds record the onset of the Richmondian Invasion, an influx of taxa, including corals, stromatoporoids and a distinctive brachiopod assemblage from the more tropical areas of NW Laurentia associated with a period of late Katian warming (Holland 1997; Holland & Patzkowsky 2007) and the "Waynesville carbon isotopic excursion" (Bergström et al. 2010). High-resolution stratigraphy will provide a framework to examine the details of this important ecological-evolutionary event. Our preliminary results indicate that the effects of this warming event were manifest earlier in shallow water facies than in offshore biofacies, with the reappearance of stromatoporoids and the coral *Tetradium* in carbonate shoal-lagoonal facies as early as the late C3 sequence (late Maysvillian).

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Evolution of the late Ludlow and early Lochkovian benthic communities of the Prague Basin and their link to global carbon cycle

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During the last two decades it became evident that the Silurian was a period of major climatic changes (e.g., Calner 2008). The Prague Basin was in the late Silurian located in mid southern latitudes (e.g., Cocks & Torsvik 2002). The Prague Basin represents a relative restricted and shallow rift basin with a complex tectonic history (Kříž 1991). Here we present new data on evolution of the late Silurian and early Lochkovian benthic communities of the Prague Basin from the *S. linearis–M. uniformis* graptolite zones and their link to eustatic oscillations and to global carbon cycle inferred from new $\delta^{13}C$ data. Special attention is paid to an influence of several earlier recognized late Silurian bioevents on evolution of the benthic communities.

More than 30 benthic communities were recognised as result of recent study, which was focused on synthesizing all published data (e.g., Havlíček & Štorch 1990; Kříž 1999) as well as on new detailed palaeoecological analyses of late Silurian to Early Devonian strata of the Prague Basin. Each community is defined on the base of quantitative palaecological/taphonomic analyses and its stratigraphic range is also re-evaluated. Links among palaecological data, eustatic oscillations, and the $\delta^{13}C$ record were also analysed. Results of our analyses revealed that some of the benthic communities have rather high potential for correlation within the Prague Basin, as well as in different peri-Gondwanan basins. It is noteworthy that the stratigraphic ranges of vast majority benthic communities of the Prague Basin regardless of their facies correspond well with both the graptolite biozonation as well as chemostratigraphic zonation.

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Age and environmental setting of the Fezouata Biota (Lower Ordovician, Morocco)

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The recent discovery of several Early Ordovician Konservat-Lagerstätten in the Central Anti-Atlas of Morocco offers new insights into the initial animal biodiversifications during Early Palaeozoic times. Indeed, the new Moroccan Konservat-Lagerstätten are critical in unraveling the progressive settlement of primary marine ecosystems, after the Cambrian bioradiation events. Exceptionally preserved soft-bodied faunas are particularly abundant in the Cambrian (e.g., Sirius Passet, Chengjiang, Emu Bay Shale, Burgess Shale, Orsten), but far less common and associated to restricted environmental conditions (e.g., anoxic sea floors, shallow brackish estuarine embayment) in the Ordovician. The Fezouata Biota, from the Outer Feijas Group (Lower Ordovician…) of Zagora area partly fills in this lacuna. Description of the new Moroccan Konservat-Lagerstätten is in progress, and will permit to assess precisely Early Ordovician marine biodiversity for the first time but also, to compare marine assemblages with comparable preservational modes from the early-mid Cambrian and the Early Ordovician.

In the Ternata plain, north of Zagora, the Lower Ordovician succession lies unconformably over the middle Cambrian sandstones of the Tabanite Group, and consists of an extremely thick series of more or less silty and micaceous argillites (ca. 700 m; Lower and Upper Fezouata Formations) overlain by the sandstones of the Zini Formation. Since the early 2000s, several fossiliferous horizons within the Lower Fezouata Formation (Tremadocian) and the conformably overlying Upper Fezouata (Floian) have yielded extremely abundant and diverse remains of fully marine assemblages. Fossils comprise numerous exquisitely preserved remains of shelly taxa typical of post-Cambrian faunas: e.g., machaeridians, articulate brachiopods, bivalves, gastropods, nautiloid cephalopods, trilobites, ostracods, graptolites, glyptocystitid rhombiferans, mitrate stylophorans, asterozoans, and crinoids. However, the Fezouata Biota also contains abundant and diverse remains of non-biomineralized organisms with several representatives of the Palaeozoic Evolutionary Fauna (most previously known only from younger deposits): e.g., aglaspidid and cheloniellid arthropods, cirripedian crustaceans, xiphosurans. The fauna also contains non-biomineralized taxa typical of early to middle Cambrian Konservat-Lagerstätten: e.g., anomalocaridids, halkieriids, marrellomorphs, naraoiids, palaeoscolecids. This clearly shows that some Cambrian key faunal elements stepped into the Ordovician. This important information challenges current evolutionary models favouring abrupt changes during the Cambrian–Ordovician transition.

However, the different Lower Ordovician fossiliferous horizons around Zagora needed to be placed in a spatio-temporal framework. Indeed, studies on the Fezouata biota have been focusing on faunal elements but lack accurate data on the age and environmental setting of the fossil localities. In the last two years, under the auspices of the ANR project RALI and two French-Moroccan CNRS-CNRST projects (SDU 05/09 & SDU 02/13), two field campaigns logged in detail the whole Lower Fezouata Formation and the lower half of the Upper Fezouata Formation. The precise stratigraphic position of all fossiliferous levels yielding exceptional preservation was also identified. The occurrence of mm- to cm-thick silty layers displaying storm-wave influence (wave ripples) points to relatively shallow offshore depositional settings. Principles of sequence stratigraphy applied to the logs also permitted to reconstruct sea-level fluctuations, which were compared with the changes in composition of some taxa (e.g., graptolites, echinoderms, trilobites) in association with the soft-bodied faunas.

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Comparative analysis of changes in taxonomic structure and biodiversity dynamics of brachiopods in Ordovician palaeobasins of Siberian Platform and Baltoscandia

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The most large-scale biodiversification of Phanerozoic marine biota took place in the Ordovician period, where brachiopods became one of the dominating groups (Kanygin 2001; Achab & Paris 2007). The Siberian Platform and Baltoscandia belong to the most extensively studied regions by paleontological and stratigraphical methods. In the Ordovician, they were far spatially isolated and located in different climate zones, so the comparison of data according to the stratigraphical distribution of brachiopods is important for the evaluation of their role in interregional correlation.

The author made an inventory of the taxonomic structure of brachiopod complexes and graphically showed changes in dynamics of their biodiversity at the generic and relating to species levels (Fig. 1), based on published data (Roomusoks 1968; Yadrenkina 1974; Hints 1990; Paškevičius 1997) about the distribution of brachiopods in the two largest epicontinental basins. Two stages are distinguished in the evolution of Ordovician brachiopods: Early Ordovician and Middle–Late Ordovician. Early Ordovician brachiopods in both basins are characterized by a rather poor genus and species composition. A similarity of communities is observed in genus compositions of inarticulates, that are *Obolus* and *Lingulella* brachiopods. In this interval (Varangu time and Nyai time), there is one common species – *Apheoorthis*. In the Dapingian (Kimaian and Volkhov time), an increase of brachiopod complexes diversity is observed; new genera and species appeared. An abrupt reduction in the brachiopod communities is noted in the early Darriwilian in Baltoscandia (early Kunda time) and especially within the Siberian Platform (Vikhorevian time), where an extensive regression took place at that time. The most sudden changes in the brachiopod communities occurred in the mid-Darriwilian, which corresponds to Volginian time on the Siberian Platform and Lasnamägi time in Baltoscandia. It was a time when new communities appeared and genus/species composition was completely renewed. The diversity of brachiopods in the Siberian Platform is reduced again during the Kyrenian–Kudrinian regressive cycle, brachiopods of the order Lingulida are mostly distributed. At the same time in Baltoscandia (that corresponds to the late Darriwilian) five new brachiopods genera

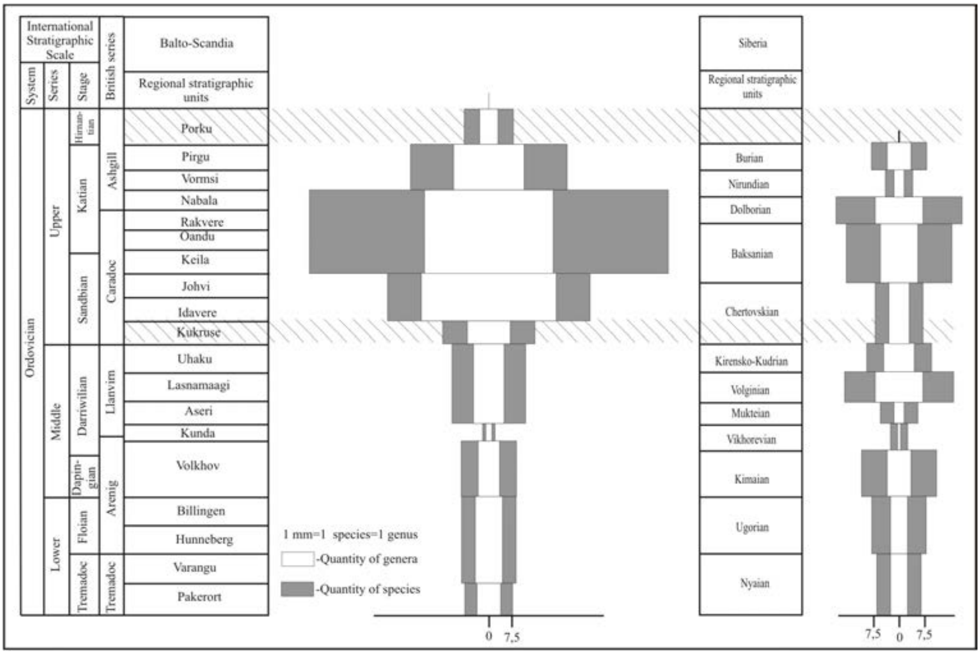

Fig. 1. Taxonomic diversity dynamics of brachiopods in Ordovician of Baltoscandia and the Siberian Platform.

have appeared: *Sowerbiella*, *Glassorthis*, *Leptestia*, *Leptelloidea* and *Porambonites*. The clearest correlation level in both paleobasins was established at the base of the Sandbian Stage. Within the Siberian Platform it corresponds to the base of the Chertovskian Regional Stage, which is reliably correlated with sections of the Verkhoyansk-Chukotka folded area on benthic fauna complexes. In this folded area graptolites of the *N. gracilis* Zone have been found at the same level. The Chertovskian time is characterized by the appearance of new genera and species; articulate brachiopods still dominate. The increase of diversity in Baltoscandia (Kukruse time) continues; 10 new species appear. At this level, as in Baltoscandia, representatives of the genera *Strophomena* and *Oepikina* arise first. In the Baksanian–Dolborian time (late Sandbian–early Katian) communities of brachiopods in the Siberian Platform reach their maximum diversity of species and genera. At the same time, seven common genera appear in Baltoscandia (Idavere–Nabala time): *Strophomena*, *Oepikina*, *Hesperorthis*, *Boreadorthis*, *Glyptorthis*, *Triplesia*, *Glyptorthis*. Genera *Dalmanella*, *Mendacella*, *Rafinesquina*, *Zygospira* and *Sowerbyella* appear in Sandbian and Early Katian ages in Baltoscandia. The same genera are determined on the Siberian Platform, but they appear here in the Silurian. A notable reduction of brachiopod complexes takes place in the late Katian within the Siberian Platform (Nirundian time). Similar changes occur slightly later (Vormsi and Pirgu time) in Baltoscandia. The brachiopod diversity in Baltoscandia is even more reduced in the

Latest Ordovician (Hirnantian); the *Hirnantia* fauna (Bergström 1968) dominates. This stratigraphic interval corresponds to a break within the Siberian Platform.

Comparative analysis has shown that along with high endemicity of brachiopod communities of the two considered paleobasins, they had common elements at the genus level in certain time frames. In the Early Ordovician (Baltoscandian paleobasin) other families of brachiopods developed in parallel, but the changes in the biodiversity dynamics occurred almost simultaneously with that in Siberian paleobasin. The important result of the work is the confirmation of close relationship of the taxonomic diversity dynamics with transgressions and regressions (Dronov et al. 2009). During the largest transgression (Darriwilian–early Sandbian), brachiopods reached their maximum diversity. During regression (early Darriwilian and late Katian), their variety was abruptly reduced. It is important to note that these changes occurred simultaneously in different climatic zones.

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Influences of imaging and morphological knowledge of species on phylogeny reconstruction: A case study in pliomerid trilobites

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Many invertebrate paleontological phylogenetic analyses rely on images of specimens from the published literature as coding sources. Species are typically represented by a handful of specimens, which were imaged at low magnification in plan view. New digital technology enables publication of highly resolved images of numerous specimens. Here we use silicified Lower Ordovician pliomerid trilobites from the Great Basin to investigate whether the quality of information conveyed in traditional versus current illustrations affects phylogenetic precision or accuracy. These trilobites were originally described in mid-20th century publications (Ross 1951; Hintze 1953) which were widely regarded as excellent, but our field-based revision of these faunas indicates that only about 1/3 of the common species were described (Adrain et al. 2009), and that species which initially appeared well-known were often composites of sclerites from several poorly known species.

Simulations have shown that phylogenetic accuracy and resolution are reduced by the inability to code characters for all taxa, not just the percentage of missing entries in any incomplete taxa (Wiens 2003), and this is consistent with the results of our analyses. Our primary dataset includes 29 species coded for 69 characters from our photographs of specimens we collected at the type localities. Most characters are coded for all taxa. A second dataset consists of the 20 species now known to be represented in the literature (even if they were unrecognized at the time; only nine of the 20 were previously named). This second dataset was coded only from the original illustrations of the sclerites, which are now correctly assigned to each species. Dataset 2 is incomplete due to species that were known from few exoskeletal elements (poorly known species, or former composite 'species'), or because the original illustrations did not show all relevant morphology. Twenty-five uncodable, or uninformative or autapomorphic characters (the latter two because excluded taxa or codings also removed the phylogenetic signal) were deleted from it, and it contains no characters coded for all taxa. We analyzed both datasets using parsimony.

Analysis of Dataset 1 resulted in six well-resolved, well-supported trees (CI 0.64, RI 0.89, average GC [groups supported/groups contradicted; Goloboff et al. 2003] bootstrap support of 74.6). Analysis of Dataset 2 resulted in nearly 1500 poorly resolved, poorly supported trees (CI 0.77, RI 0.88, average GC bootstrap support of 35.2). The strict consenses reflect similar broad relationships between genera, but the low resolution of the second analysis obscures relationships within genera. These preliminary data suggest that much greater species-level phylogenetic precision is possible with wider application of modern imaging techniques.

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Linking upper Silurian terrestrial and marine successions

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Several localities exposing Silurian sediments occur in Sweden and many of them are situated in Skåne, southern Sweden. The exposed successions range in age from Llandovery to Přídolí but many of the outcrop sections are inaccessible today. Whilst there are a vast number of studies on different groups of marine organisms, no or very little data exist on the late Silurian terrestrial biota of Sweden. This investigation aims to shed light on the previously poorly investigated Silurian spore assemblages from Sweden and to correlate subsurface samples with exposed Silurian strata. This study further comprises the first correlation between marine and terrestrial biostratigraphical schemes of upper Silurian strata for Scandinavia.

We have performed a palynostratigraphic study on miospore assemblages from near shore marine Silurian sedimentary rocks of Skåne, southern Sweden. The material includes both drillcore samples (from Klintaborrningen 1 and Bjärsjölagårdborrningen 2) and samples from exposures from various localities in Skåne. Well-preserved spore assemblages were identified and 36 spore species were identified. The cryptospores (produced by now extinct, primitive land plants) and trilete spores (produced by vascular plants) are represented by 18 species each. The organic matter is highly dominated by spores and plant debris but marine microfossils, such as prasinophytes, acritarchs, chitinozoans and scolecodont elements occur in some samples. We further identified fungal spores and hyphae in a few samples, together with tubular structures of an uncertain affinity.

Long ranging species with a global distribution dominate the spore assemblages, complemented with key taxa including *Synorisporites tripapillatus*, *Emphanisporites neglectus*, *Hispanaediscus verrucatus*, *Synorisporites lybicus*, *Hispanaedisucs lamontii* and *Scylaspora scripta*. Based on biostratigraphical schemes for early land plant spores, the studied sediments of the cores Klintaborrningen 1 and Bjärsjölagårdborrningen 2 are of Ludlow to Přídolí age. The spore assemblages are compared and correlated to marine fossil schemes including those of conodonts, chitionozoans, graptolites and tentaculitides. Relative abundance data of specific spore taxa for intra-basin correlation between the drillcores and the outcrops have further been applied.

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Geochemical comparison of Silurian sandstones from the Mora 001 core of the Siljan Ring structure with the Mesoproterozoic Dala Sandstone Formation of central Sweden

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The Mora 001 drill core gives new insight into the early Palaeozoic succession preserved in the Siljan impact structure of central Sweden (Lehnert et al. 2012). The lower part of the core consists of Proterozoic basement covered by a 21.57 m thick sedimentary package of Lower to Middle Ordovician limestone and unconformably overlain by an 224 m thick siliciclastic succession of Silurian (Llandovery–Wenlock) age which has been subdivided into six members (Lehnert et al. 2012). One of them is a 27 m thick sandstone unit. The goal of our study is to detect the origin of its detrital material. A potential source is the Dala Sandstone Formation, which was petrographically and geochemically described, for instance, by Aldahan & Morad (1986) and crops out west of the Siljan area. To test that hypothesis, four samples from the Silurian sandstone member were geochemically compared with six samples from the Dala Sandstone Formation collected near Mångsbodarne and Risberg. The bulk-rock geochemical composition (major elements, trace elements, and rare earth elements) of all samples was determined by XRF and ICP-MS at the Geoscience Center of Göttingen University. For simplification, we use the terms Silurian sandstone for the sandstone member of the Mora 001 core and Mesoproterozoic sandstone for the Dala Sandstone Formation.

Using the SiO_2/Al_2O_3 versus FeO/K_2O discriminant diagram of Herron (1988), the Mesoproterozoic and Silurian sandstones can be chemically classified as subarkoses. The Mesoproterozoic sandstones display high SiO_2 content (89–93 wt.%), low Al_2O_3 content (2.7–5.3 wt.%), very low TiO_2 content (≤0.12 wt.%), very low Fe_2O_3 content (≤0.5 wt.%), and variable K_2O content (1.4–3.2 wt.%). Very low values of CaO (≤0.14 wt.%) and LOI (≤0.35 wt.%) indicate the absence of carbonate-bearing minerals. Trace element concentrations are consistently low. The Silurian sandstones can be subdivided into two groups. Group 1, the two lowermost samples, displays moderate SiO_2 content (70–72 wt.%), very low Al_2O_3 content (2.1–2.6 wt.%), very low TiO_2 content (≤0.06 wt.%), very low Fe_2O_3 content (≤0.38 wt.%), and low K_2O content (1.0–1.2 wt.%). High values of CaO (~13 wt.%) and LOI (~10 wt.%) indicate the presence of carbonate-bearing minerals, in this case calcite cement, as evidenced by petrographic observations. Group 2, the two uppermost samples, displays high SiO_2 content (~91 wt.%), low Al_2O_3 content (3.3–3.6 wt.%), very low TiO_2 content (≤0.11 wt.%), very low Fe_2O_3 content (≤0.46 wt.%), low K_2O content (1.5–1.6 wt.%), and very low CaO content (<0.9 wt.%). In the Silurian sandstones, concentrations of trace elements are consistently low.

The upper continental crust-normalised multi-element diagram shows depletion in trace elements for both the Mesoproterozoic and Silurian sandstones, with a strong depletion in Th, U, Ti, Cr and Ni (Fig. 1). Taken collectively, petrography and geochemistry clearly point to a source area of felsic composition for all samples. Based on bulk-rock geochemistry, the Mesoproterozoic sandstones could be the source for the Silurian sandstones in the Mora 001 core. However, further investigations (e.g., U–Pb geochronology of detrital zircon grains) are necessary to clarify this assumption.

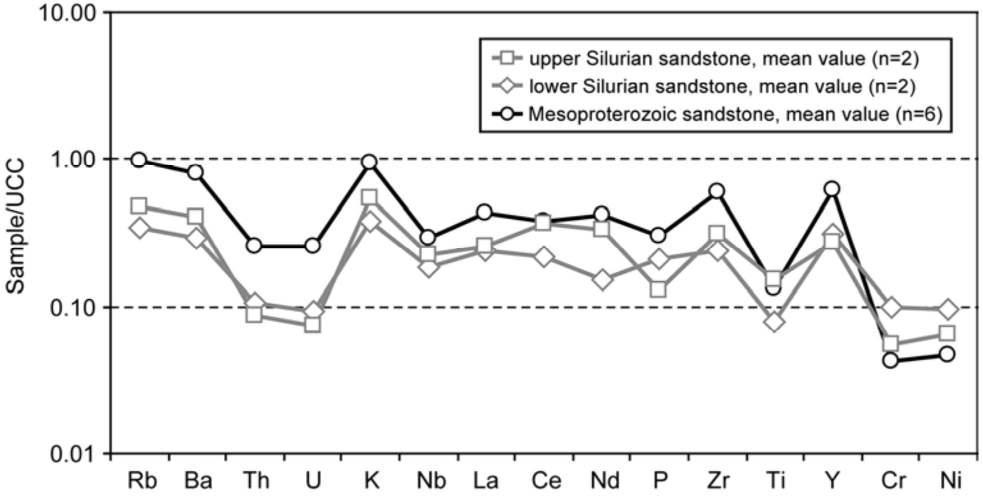

Fig. Multi-element diagram for studied sandstone samples from central Sweden. Concentrations are normalised against the upper continental crust composition (UCC; Rudnick & Gao 2003).

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A view of the Rhuddanian–Aeronian boundary from Arctic Canada

MICHAEL MELCHIN[1]

Since it was formally defined, the base of the Aeronian Stage was considered to coincide with the globally recognizable base of the *Demirastrites triangulatus* Biozone. However, recent studies indicate that the GSSP actually correlates to a level within the *D. triangulatus* Biozone (Davies et al. 2013). This level is biostratigraphically marked only by the first appearance of *Monograptus austerus sequens*, as species not known to occur outside of northern Europe.

Since the documentation of biostratigraphy of the Rhuddanian–Aeronian succession on Cornwallis Island, Nunavut, was documented by Melchin (1989) and Lukasik & Melchin (1997), significant new information has become available, including carbon isotope data (Melchin & Holmden 2006), conodont biostratigraphic data (Zhang et al. 2006), and new, unpublished graptolite data. The following observations can be made based on these new data. 1) The level of the current GSSP cannot be precisely recognized in the Arctic Canadian succession. 2) A biostratigraphic level corresponding to the base of the *D. triangulatus* Biozone can be recognized based on the succession of closely spaced FADs of *Pristiograptus concinnus*, *D. triangulatus separatus*, and *Petalolithus* sp. Each of these taxa is very rare in the succession. 3) The base of the *D. triangulatus* Biozone corresponds closely with the level of a weak (≈0.8‰) positive shift in $\delta^{13}C_{org}$ values, which was also observed at Dob's Linn, Scotland (Heath 1998), at the same biostratigraphic level. Data from Estonia also suggest that a weak positive shift in $\delta^{13}C_{carb}$ values occurs at or near the base of Aeronian, although the signal is somewhat less clear (e.g., Kaljo & Martma 2000) and less precisely biostratigraphically defined. 4) The interval in the Cornwallis Island succession that spans the latest Rhuddanian–early Aeronian interval is not marked by any significant biostratigraphic appearance datums within conodonts. This is consistent with conodont records in many other parts of the world through this interval.

These data support the observations made in many other parts of the world that the base of the *D. triangulatus* Biozone is a readily recognizable biostratigraphic level in graptolite successions in many parts of the world, based on the closely spaced FADs of several readily recognizable taxa, including the genera *Demirastrites* and *Petalolithus*. Unfortunately, thus far this biostratigraphic level cannot be precisely identified within a conodont or chitinozoan biostratigraphic framework. However, a weak positive shift in $\delta^{13}C$ values through this interval may prove to have potential for international correlation, although this remains to be rigorously tested.

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Carbon and nitrogen isotopic analysis of Rhuddanian–Aeronian graptolites from Arctic Canada: Implications for chemostratigraphic and paleoecologic studies

MICHAEL MELCHIN[1], PETER BULLOCK[1] AND CHRIS HOLMDEN[2]

LaPorte et al. (2009) reported the first study in which carbon isotope analyses were conducted specifically on graptolite rhabdosome wall material. That study showed that the $\delta^{13}C_{grap}$ values closely paralleled those of the $\delta^{13}C_{org}$, although the graptolite values tended to be slightly heavier, likely the result of different trophic levels represented by the graptolites and the organisms responsible for production of the bulk organic matter (likely mostly algal phytoplankton and bacteria). They also noted that the degree of difference between the $\delta^{13}C_{grap}$ and $\delta^{13}C_{org}$ varied through the section, which may have been the result of variation is the degree to which graptolites contributed to the bulk organic matter, or else differences in the composition of different graptolite species occurring at different stratigraphic levels. In that study, no effort was made to identify the species isolated for isotopic analysis. The LaPorte et al. (2009) study was also the first to identify the potential for nitrogen isotope analysis to gain insights into environmental/paleoecological changes in late Ordovician–early Silurian successions.

The objective of the present study is to further investigate the relationship between C and N isotopic composition of graptolite and bulk organic matter, how these vary stratigraphically, and also how isotopic values vary between species. We report the results of 138 $\delta^{13}C$ and $\delta^{15}N$ analyses of selected graptolite species from 32 samples spanning the upper Rhuddanian–mid Aeronian succession at Cape Manning, Cornwallis Island, Canada. The graptolites were isolated by dissolution of calcite concretions. Wherever possible, multiple analyses (2–5) of the same species from the same sample were conducted to determine the range of intraspecific variation within samples. In the vast majority of cases, the range of intraspecific/intrasample variation in both $\delta^{13}C$ and $\delta^{15}N$ was ≈0.6‰ or less – only three samples showed intraspecific variations greater than 1‰, which is a range of intraspecific variation commonly seen in analyses of modern zooplankton. The three cases of anomalously high intraspecific/intrasample variation may be the result of sample contamination, although we also note that modern studies show that there can be significant seasonal to decadal variation in the isotopic values of zooplankton and that the calcite concretions represent substantially time-averaged samples.

The following observations can be made based on the data in our study. 1) As observed in the LaPorte et al. (2009) study, but not that of Snelling et al. (2011), there is a relatively consistent pattern of stratigraphic covariation between $\delta^{13}C_{grap}$ and $\delta^{13}C_{org}$ (from Melchin & Holmden 2006), in which the $\delta^{13}C_{grap}$ values are generally ca. 0.2–1.0‰ higher than those of $\delta^{13}C_{org}$. A similar pattern is seen in comparison of $\delta^{15}N_{grap}$ and $\delta^{15}N_{tot}$ values, although in the lower part of the studied section, the $\delta^{15}N_{grap}$ and $\delta^{15}N_{tot}$ values often differ by even less than 0.2‰. Although some of the difference between the graptolite and bulk organic matter values may be the result of differences in trophic levels represented in the different sample sets, this does not appear to be the complete explanation. If this were the main cause, the difference between the $\delta^{15}N_{grap}$ and $\delta^{15}N_{tot}$ should be significantly greater than the difference between the $\delta^{13}C_{grap}$ and $\delta^{13}C_{org}$ values. 2) Pairwise comparison of species that coexist in successions of samples indicate that there is no consistent, significant pattern of interspecific variation in $\delta^{13}C$ or $\delta^{15}N$ values that would clearly indicate differences in trophic level, food source or habitat between species.

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Archaeocyathan fauna from Los Navalucillos Limestone Formation, Toledo Mountains, Central Iberian Zone, Spain

SILVIA MENÉNDEZ[1], ELENA MORENO-EIRIS[2] AND ANTONIO PEREJÓN[2]

The archaeocyathan fauna from Toledo Mountains (Spain) belongs to the Los Navalucillos Limestone Formation, which is formed by alternating carbonate and siliciclastic materials. They record a considerably high diverse archaeocyathan assemblage in the Lower Cambrian successions from the Central Iberian Zone (Julivert et al. 1972). Despite the importance of these successions almost no new meticulous research has been done on the region since the 1970s. This reason has lead the authors to research and revise the five series studied previously, as well as to analyze the carbonate materials outcropping in ten other localities that are previouslyt unexplored (Menéndez 2012).

The Urda locality is one of the most exceptional examples of the latter case. The study of this location have allowed us to confirm the presence of a significantly high diverse archaeocyathan assemblage composed of thirty five species and thirteen genera: *Afiacyathus*, *Dokidocyathus*, *Sibirecyathus*, *Dictyocyathus*, *Taylorcyathus*, *Protopharetra*, *Erismacoscinus*, *Nochoroicyathus*, *Rotundocyathus*, *Rasetticyathus*, *Coscinocyathus*, *Inessocyathus* and *Agyrekocyathus*. Archaeocyaths occur mainly in carbonate nodules embedded in siltstones as well as in cherts massive archaeocyath-rich orange limestone. The main facies are bioclastic and archaeocyathan wackestones and packstones. *Agyrekocyathus*, *Dokidocyathus* and *Taylorcyathus* had not been previously cited in the Toledo Mountains. Cerro Tejoneras is another new locality that recorded an interesting archaeocyathan assemblage. It is composed of eight species and five genera: *Cordobicyathus*, *Erismacoscinus*, *Nochoroicyathus*, *Rotundocyathus* and *Coscinocyathus.* It is the first time the presence of *Cordobicyathus* is recorded in the Central Iberian Zone. Recrystallized pink limestones bearing fossils, the facies are archaeocyathan wackestones.

Among the other new areas studied we were only able to verify the presence of the genera *Coscinocyathus,* in Cuartel de Barrancones. They occur in recrystallized grey limestones bearing archaeocyaths and the main facies are archaeocyathan wackestones. Unfortunately, although complete calices are observed, most fossils are skeletal fragments. They are all affected by strong recrystallization, which makes their recognition and taxonomic assignment very difficult, like the remains of the Cryptoporocyathidae family in El Lavadero and Finca Higueruela sections. It is even impossible to recognize them in some cases, like the samples from La Estrella or Casa Rosalejo localities, so they could only be classified as Ajacicyathina gen. indet.

Between the previously studied localities, only Los Navalucillos and Los Campillos list a rich and interesting group of archaeocyathan taxa. Six species and five genera composed the archaeocyathan assemblage of Los Navalucillos. These five genera are *Anthomorpha*, *Cordobicyathus*, *Dictyocyathus*, *Protopharetra* and *Rotundocyathus*. However, a more diverse assemblage is present in Los Campillos, twenty species and eleven genera: *Afiacyathus*, *Sibirecyathus*, *Dictyocyathus*, *Okulitchicyathus*, *Protopharetra*, *Erismacoscinus*, *Nochoroicyathus*, *Rotundocyathus*, *Coscinocyathus*, *Rasetticyathus* and *Anthomorpha*. The main facies observed are bioclastic and archaeocyathan wackestones.

Archaeocyathan zones VI and VII (Perejón & Moreno-Eiris 2006), late Ovetian Spanish age or early Botomian Siberian age, presently Stage 3 was previously assigned for these materials of the Los Navalucillos Limestone Formation. The presence of *Anthomorpha,* characteristic for zones VI and VII, has confirmed this fact. However, the study of all the newly collected taxa has confirmed that the assemblages from the different localities can correspond exclusively to Zone VI or Zone VII or both of them. The assemblage recorded at the Cerro Tejoneras locality corresponds exclusively to Zone VI because of the presence of *Cordobicyathus*, that is exclusive to Zone VI in Spain. Nevertheless, the Urda assemblage clearly corresponds exclusively to Zone VII and *Agyrekocyathus* and *Dokidocyathus* extend their distribution range to this zone. The archaeocyathan assemblages from the localities of Los Navalucillos and Los Campillos correspond to zones VI and VII.

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The conodont *Iapetognathus* and its value for defining the base of the Ordovician System

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Nicoll et al. (1999) published on the taxonomy of the conodont *Iapetognathus* and its ancestor, *Iapetonudus*. Cooper et al. (2000) used the FAD of the previous authors' new species *Iapetognathus fluctivagus* to mark the GSSP for the base of the Ordovician System at Green Point, Newfoundland. Terfelt et al. (2012) re-evaluated *Iapetognathus* at Green Point. They proposed that Nicoll et al. (1999) misoriented and misinterpreted *Iapetognathus*. For example, Terfelt et al. (2012) used the plane of compression of the cusp for orientation of *Iapetognathus* elements instead of using the direction of curvature of the cusp, which for decades has been the standard criterion for orientation. Terfelt et al. (2012) claimed that *Iapetognathus fluctivagus* is not really present at the level of the GSSP at Green Point but begins higher, above the lowest planktonic graptolites. However, Cooper et al. (2000), in their documentation paper on the GSSP, reported and illustrated several correctly identified *Iapetognathus fluctivagus* from Bed 23 at the stratotype section. Likewise, other workers who have collected samples from Green Point, e.g., Anita Harris (U.S. Geological Survey), also have recovered *Iapetognathus fluctivagus* in Bed 23. We disagree with the taxonomic interpretations and stratigraphic conclusions of Terfelt et al. (2012).

Terfelt et al. (2012) stated that they attempted to study *Iapetognathus* specimens illustrated by Nicoll et al. (1999) and by Cooper et al. (2000), but that the specimens were not available for loan. The material from the former paper is available from the U.S. National Museum. Of the material illustrated by Cooper et al. (2000), only two of the figured *Iapetognathus* specimens appear to be lost, and the others are reposited with the Geological Survey of Canada.

Cooper et al. (2000) reported *Clavohamulus* and *Hirsutodontus* slightly above the GSSP and identified them as shallow-water taxa occurring in deep-water, continental-slope strata at Green Point. That paper recommended that those genera be used for correlation only very carefully because they may be redeposited from older strata. *Clavohamulus* occurs in shallow platform and cratonic strata in Greenland, Newfoundland, Australia, Siberia, and many areas in Laurentia, including in nearshore sandstones and in stromatolite reefs. The homotaxial succession of Upper Cambrian euconodonts documented in Laurentia is reproduced in very shallow marine strata at Black Mountain, Australia, including occurrences of *Clavohamulus* and *Hirsutodontus*. Much of the homotaxial succession is also reproduced in deep-water strata in Kazakhstan and Hunan Province, China. However, *Clavohamulus* does not occur in those deep-water facies, although *Hirsutodontus* occurs in Kazakhstan. The only occurrences of both of these shallow-water genera in deep-water strata are in the Cow Head Group, but they are higher than the normal position in a homotaxial succession. The obvious conclusion is that they are redeposited from shallow facies in turbidites, the problem implied by Cooper et al. (2000).

Terfelt et al. (2012) considered elements of *Clavohamulus* and *Hirsutodontus* in the Cow Head Group to be *in situ*, and they interpreted ranges of co-occurring specimens of *Iapetognathus* as extending down section to the lower stratigraphic positions where those two genera occur in other parts of the world. Then, they interpreted species of *Iapetognathus* as occurring earlier at Green Point than elsewhere in the world, near the base of the *Cordylodus intermedius* Zone. In interpreting the Green Point *Clavohamulus* and *Hirsutodontus* as *in situ*, the Terfelt et al. (2012) re-evaluation did what Cooper et al. (2000) recommended should not be done because these two genera should be regarded as redeposited taxa.

Terfelt et al. (2012) also asserted that *Iapetognathus* is too rare and too geographically restricted to be used to characterize the GSSP. *Iapetognathus* is widespread in the United States and occurs in eastern and western Canada, Argentina, Scandinavia, Kazakhstan, Australia, and several provinces in China. These occurrences are in facies that include a variety of cratonic, platform, aulacogen, miogeoclinal carbonate platform, and slope deposits. The assertions and conclusions of Terfelt et al. (2012) do not appear to be supported by available data.

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The proposed GSSP for the base of the Lawsonian Stage (Cambrian Stage 10) at the First Appearance Datum of the conodont *Eoconodontus notchpeakensis* (Miller, 1969) in the House Range, Utah, USA

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Guidelines for choosing GSSPs encourage choosing horizons that are characterized using multiple criteria; this is a strong point of the base of the proposed Lawsonian Stage, which is characterized by several biological and non-biological correlation tools. The proposed horizon is at the evolutionary appearance of the coniform euconodont *Eoconodontus notchpeakensis* Miller 1969, part of the well-documented lineage *Proconodontus—Eoconodontus—Cambrooistodus*. The three zones below the proposed horizon are named for successive species in the evolution of *Proconodontus*. The FAD of *Eoconodontus notchpeakensis* marks the base of the *Eoconodontus notchpeakensis* Subzone of the *Eoconodontus* Zone; the FAD of *Cambrooistodus minutus* marks the base of the overlying *Cambrooistodus minutus* Subzone of that zone. Species of *Cambrooistodus* occur only in the *Eoconodontus* Zone; the next higher zone is the globally recognized *Cordylodus proavus* Zone.

The appearance of *Eoconodontus notchpeakensis* is an evolutionary event that is recorded in nearshore siliciclastic strata and in carbonate strata that include cratonic, platform, aulacogen, miogeocline, and slope environments. Conodonts diagnostic of the *Eoconodontus notchpeakensis* Zone are cosmopolitan and are known in many parts of Laurentia and China, in Greenland, Sweden, Estonia, Siberia, Korea, Kazakhstan, Iran, Turkey, Australia, and Argentina. Lowest occurrences of *Cambrooistodus* are at or slightly above the proposed boundary and occur in many geographic areas and facies, including open-ocean radiolarian cherts in Kazakhstan (identified in thin sections). Species diagnostic of the *Eoconodontus* Zone have been recovered from drill cores in the USA and Canada. *Eoconodontus alisonae* Landing 1982 apparently occurs only in the *Eoconodontus* Zone, mostly in deep marine facies.

Trilobites and brachiopods also characterize the proposed horizon. In western North America this horizon is slightly below the top of the *Illaenurus* trilobite Zone. In areas east of the Rocky Mountains the horizon is within the lower part of the *Saukiella junia* Subzone of the *Saukia* Zone in platform successions. This horizon appears to lie close to the boundary between the *Keithia subclavata* and *K. schucherti* faunas at the top of the Sunwaptan Stage in deep-water deposits in eastern North America. Rapid evolution of numerous ptychaspid, plethopeltid, eurekiid, and saukiid genera (among others) through the proposed stage interval offers great potential for placement and correlation of this horizon between the varied biofacies distributed across Laurentia during the late Cambrian.

The proposed horizon is near the lowest occurrence of the calcitic brachiopod *Finkelnburgia*, which occurs on several continents. Phosphatic-shelled brachiopods are abundant in insoluble residues of conodont samples, and the fauna is characterized by species of *Quadrisonia*, *Lingulella*, *Wahwahlingula*, *Zhanatella*, and *Stittia*. This horizon is near the highest occurrence of *Quadrisonia*, which is replaced with *Eurytreta* in slightly higher strata in both the Great Basin and Kazakhstan. The lowest occurrence of *Eurytreta* is also at a similar position in Oaxaquia, Mexico.

The proposed GSSP is within the thin Red Tops Member of the Notch Peak Formation, which includes trilobite, ooid, peloid, and flat-pebble lime grainstones. Conodonts are abundant in these lithologies, and all Red Tops samples produce conodonts. Faunas include tens of thousands of conodont elements distributed among many species. Two non-biological tools are useful for correlating these strata, which comprise the Red Tops Lowstand, a sequence-stratigraphic unit. The proposed GSSP is within Sequence 5A, and there is considerable potential for global correlation using sequence stratigraphy.

Carbon-isotope correlations utilize the HERB Event, a high-amplitude negative carbon-isotope excursion that occurs in the relatively thin *Eoconodontus notchpeakensis* Subzone. The FAD of *E. notchpeakensis* is slightly below the level on carbon-isotope profiles where values begin to shift rapidly toward a negative peak. Above this sharp peak, values shift toward positive and then reverse to form a secondary negative peak. The combined HERB Event peak and the slightly higher negative peak are very distinctive and have been identified in Utah, Texas, Australia, Tarim Basin and Jilin, China. At Green Point, Newfoundland, these peaks are identified in strata with very few fossils, so the proposed GSSP can be correlated into poorly fossiliferous carbonates.

The base of the *Eoconodontus* Zone is identified in seven sections in three mountain ranges in west-central Utah; three sections in the House Range are adequate to serve as a GSSP. Exposures are extensive within a huge area of public land (not privately owned) with unrestricted access. Paved and gravel roads and dirt tracks provide access to the many measured sections that comprise the type areas of the Laurentian Millardan and Ibexian Series. Detailed topographic and geologic maps are available for the area.

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An alternative international correlation of the latest Ordovician (late Katian and Hirnantian) chemostratigraphy, biostratigraphy, sequence stratigraphy and temperature history

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Excursions in the carbon isotopic records through the late Katian and Hirnantian differ substantially among sites around the globe in the magnitude of the excursions, the duration of the events and the precise timing of the peak or minimum values. These differences reflect the interaction of local and global drivers of the carbon system and require precise independent calibrations of the $\delta^{13}C$ chemostratigraphy for use in global correlation and paleoenvironmental inference. Sequence stratigraphic analysis of periglacial deposits in North Africa demonstrate that the Hirnantian glacial episode comprised two major cycles of ice cap growth separated by a substantial interglacial interval, which bears *Metabolograptus ojsuensis*. Likewise, the Silurian GSSP section at Dob's Linn contains sedimentological evidence of a lower glacial interval between Anceps Band D (uppermost *P. pacificus* Zone), and Band E (*M. extraordinarius* Zone), which is followed by a brief interglacial (Band E itself) and a return to glacial conditions that persisted through the uppermost Hartfell Shale (lower to mid *M. persculptus* Zone age).

These previously published observations combined with new ε_{Nd} data from late Katian and Hirnantian strata in Nevada and Yukon that also bear diverse graptolite faunas and detailed $\delta^{13}C_{org}$ and $\delta^{13}C_{carb}$ records, lead us to reconsider correlations in this interval. The post-Eureka Ordovician succession in Nevada comprises six stratigraphic sequences (O1–O6). Graptolite and chemostratigraphic evidence indicates that O5–O6 encompass the Hirnantian HICE excursion, which, in this region, exhibits a strong double peak in $\delta^{13}C_{org}$ values: one that commences in the uppermost *P. pacificus* Zone (following a brief deepening early in the *Diceratograptus mirus* Subzone interval) and reaches peak values in the basal Hirnantian, O5 strata (lower *M. extraordinarius* Zone) and a second in mid Hirnantian, O6 strata (upper *M. extraordinarius* Zone to mid *M. persculptus* Zone). ε_{Nd} data from the interval in the upper *M. extraordinarius* Zone between these two C excursions suggest a brief relative sea level rise and also coincides with a recurrence of many species from the *P. pacificus* Zone fauna. Thus, the first glacial interval appears to be latest Katian to earliest Hirnantian, the Hirnantian interglacial is securely dated as late *M. extraordinarius* Zone age, and the second, more extensive glacial advance reached its peak in the mid *M. persculptus* Zone interval.

These relations fit precisely with those recently demonstrated at the well known Mirny Creek section in Siberia, which also exhibits two distinct HICE peaks, and with the glacio-eustatic history inferred at both tropical sites, such as Anticosti Island, and peri-glacial sites in North Africa. In the Anticosti succession, as at Dob's Linn and the Hirnantian GSSP at Wangjiawan, the early Hirnantian peak is weakly developed and the typical large $\delta^{13}C_{carb}$ excursion, the so-called "Hirnantian Isotopic Carbon Excursion" (HICE), is present in the Laframboise Mbr (at Anticosti) and in the upper Hartfell Shale (Dob's Linn) and Kuanyinchiao Beds (Wangjiawan). At these sites the HICE represents only the mid Hirnantian-*M. persculptus* Zone peak. Graptolites are exceedingly rare in the Ellis Bay Formation on Anticosti Island, but rare specimens of *Metabolograptus parvulus* (elsewhere restricted to *M. persculptus* Zone and younger strata) occur there in association with the rising limb of the HICE, as expected under the correlations we advocate here.

The early Hirnantian peak appears to be manifested in the Laurentian midcontinent by the Elkhorn $\delta^{13}C_{carb}$ excursion. In the Baltic succession, chitinozoan correlations suggest that the basal Hirnantian-Elkhorn excursion is either missing in the unconformity below the Porkuni Stage or is weakly developed within the *B. gamachiana* Zone strata in the uppermost Pirgu Stage. Again, graptolites are exceedingly rare in the late Katian and Hirnantian Baltic shelf succession but a specimen of *Appendispinograptus supernus* is known within the *B. gamachiana* Zone interval and above a minor $\delta^{13}C_{carb}$ excursion in the Kaugatuma core that may correspond to the basal Hirnantian-Elkhorn excursion. We interpret this graptolite occurrence to be yet another manifestation of the Hirnantian interglacial episode.

In graptolite-bearing sections, core members of the *Hirnantia* fauna are very rare or absent in strata of the *M. extraordinarius* Zone. Rather, they are most common in strata that bear the mid Hirnantian HICE peak and are generally bracketed both above and below by *M. persculptus* Zone graptolite faunas. These relations also support our suggestion that the main glacial events and deepest climatic cooling took place during the *M. persculptus* Zone. Finally, sea surface temperatures inferred recently from carbonate clumped isotope paleothermometry suggest separate minima in the early and mid Hirnantian when replotted based on our revised correlations.

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Diversification of Ordovician and Silurian tabulate corals in Baltoscandia and Podolia

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Ordovician and Silurian tabulate corals from the Baltic region and Podolia are rather well studied, but a broader discussion on their diversification history in this area is still missing. The aim of this study is to fill this gap by creating a database of the distribution of Ordovician and Silurian tabulates from Estonia, Sweden, Norway and Podolia. This allows us to compile diversity curves and contribute to a better understanding of the development of regional tabulate coral faunas, their radiations and extinctions.

Altogether approximately 300 species of tabulate corals have been described in Baltoscandia and Podolia. Their taxonomy and distribution is documented in over 30 monographs and other publications (see Mõtus 2005, and references therein), which form the basis for our study. The Baltic regional stages were chosen as the common stratigraphical framework and data from all regions were fitted to that scale, inevitably resulting in some bias. Another obvious limitation of such literature-based data arises from inconsistent taxonomy. For instance, the favositids, which are particularly diverse in the Llandovery of Estonia, most likely have been taxonomically oversplit. However, it appears that the diversity trends, which combine all possible synonyms with overlapping characters, are not significantly different from those, which consider all species. The diversity patterns were described using various measures of taxonomic diversity and turnover, including total diversity, normalized diversity, taxa per million years, taxon appearances and disappearances, and turnover ratios, at species and genus levels. The normalized diversity measure is considered to be a good approximation of standing diversity, and is mostly referred to below. The patterns for individual regions may differ considerably, but here we discuss the combined data and trends.

The oldest tabulate corals in Baltoscandia and Podolia appear in the Oandu Stage (early Katian) forming the first diversity peak of six species and four genera. This is followed by an interval with virtually no tabulates and new faunas arise starting from the Vormsi Stage. Thereafter the species richness reveals continuous increase until the maximum diversity of nearly 60 species in the Adavere to Jaagarahu stages (Telychian to Homerian). The genus diversity is generally similar, but smoother, showing a plateau in the Pirgu to Juuru stages, and maximum values of nearly 30 in the Jaani to Rootsiküla stages (Sheinwoodian to Homerian). After the Silurian diversity peak, almost continuous diversity decline occurs.

Species and genus-level originations exceed extinctions up to the Jaagarahu Stage from where the extinctions dominate over the originations. The genus level disappearances are higher than appearances in the Porkuni Stage whereas the species turnover is the same. The end-Ordovician mass extinction did not have severe influence on tabulate corals, as many taxa crossed the Ordovician–Silurian boundary and a rapid innovation took place in the Juuru Stage (Rhuddanian). Similar results of coral genus-level high origination rates in early Silurian, high extinction rates in late Silurian and highest diversity in Wenlock were shown by Kaljo et al. (1996).

Sepkoski's database (Sepkoski 2002) of 166 Ordovician and Silurian tabulate coral genera shows the highest diversity peaks in late Katian (mid Ashgill) and in Wenlock. The late Katian peak in the Sepkoski's diversity curve is more prominent than revealed in Baltocandia and Podolia. However, the general correspondence between our data and the global compilation suggests that the regional pattern has evolutionary significance. On the other hand, the evolution of the paleobasin and availability of suitable habitats have played important roles in the development of tabulate coral faunas in Baltoscandia and Podolia.

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The Paleozoic microproblematicum *Wetheredella* is a wastebasket taxon

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Wetheredella Wood 1948 is an encrusting microproblematicum commonly observed in thin sections of rocks throughout Cambrian to Permian. It is characterized by vesicle to funnel-shaped tubes encrusting a foreign body, with their outer surface convex and the inner surface coiled around the encrusted grain. The tubes branch irregularly and, in many cases, exhibit double-layered walls, with the inner layer penetrated by rounded pores (Wood 1948). The taxonomic affinity of *Wetheredella* is not resolved, but it commonly occurs together with *Rothpletzella* and *Girvanella*, organisms with widely accepted cyanobacterial affinity, in oncoids and microbial buildups. Based on this association and the morphological similarities, *Wetheredella* has been often counted among calcimicrobes, possibly cyanobacteria. Vachard and Cózar (2010) included *Wetheredella* in the *incertae sedis* class Algospongia, a likely polyphyletic group of sessile organisms exhibiting perforations of the wall and apical growth, but lacking functional apertures. The same characteristics were also tentatively used by Wilson & Taylor (2001) to delineate the problematic group of Paleozoic encrusting organisms known only from their surface aspect: *Allonema* Ulrich and Bassler 1904, *Ascodictyon* Nicholson and Etheridge 1889, *Eliasopora* Bassler 1952, *Ropalonaria* Ulrich 1879, *Vinella* Ulrich 1890, and *Condranema* Bassler 1952. These epibionts have been originally described as ctenostome bryozoans, but this taxonomic position has been excluded by Wilson & Taylor (2001) based on the presence of a calcified skeleton and lack of apertures large enough to accommodate a bryozoan lophophore.

We have extracted specimens of *Allonema moniliforme moniliforme* (Whiteaves 1891) and *Ascodictyon venustum* Kiepura 1965 from the Mulde Brick-clay Member (Wenlock, middle Silurian) in the Blåhäll 1 locality of western Gotland, Sweden (Laufeld 1974). The sampled unit represents an off-platform environment with a rich benthic fauna and a high proportion of pelagic and hemipelagic organisms such as graptolites and chitinozoans. Faunal composition and the absence of phototrophic organisms clearly indicate sedimentation in the open-marine realm below the photic zone. Encrusted grains (trilobite and bryozoan fragments) were embedded in epoxy resin and cut into several sections. In thin sections, accumulations of *Allonema* and *Ascodictyon* were undistinguishable from *Wetheredella*, and well-preserved specimens had walls penetrated by pores, a feature diagnostic for *Wetheredella*. Thus, it was possible to link the problematicum known from thin sections with the three-dimensional organisms responsible for producing this structure.

Our observations show that the algal, and generally phototrophic, character of *Wetheredella* can be excluded. Its cosmopolitan character corresponds well with the fact that *Wetheredella* structure can be observed in thin sections of more than one taxon, but the affinities and trophic mode of these taxa remain unclear. Common co-occurrence with cyanobacteria may indicate a symbiosis of heterotrophic "*Wetheredella* organisms" with *Rothpletzella* and *Girvanella*. It may also explain the increased abundance of this microproblematicum during periods of microbial expansion, associated with biotic crises during the Paleozoic (Copper 1976; Calner 2005a, 2005b; Ezaki 2009; Desrochers et al. 2010).

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Discovery of thelodont scales in the Upper Ordovician of the Moscow Basin, Baltica

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Thelodont scales were found in the Danilov-1 drill core section at the southern margin of the Rybinsk-Sukhonsky mega-swell in the central part of the Moscow Syneclise (hereafter, Moscow Basin). About 50 scales of *Sandivia melnikovi* Karatajūtė-Talimaa were collected from three samples. So far, the distribution of *Sandivia* with two species, *S. melnikovi* and *S. angusta*, is limited to the Ust'Zyb and Malaya Tavrota regional stages of the Timan-Pechora Region (Karatajūtė-Talimaa 1997), correlative with the Katian. Ordovician thelodonts are rare worldwide. Besides *Sandivia*, a few ?Middle–Upper Ordovician thelodonts have been reported from the Severnaya Zemlya Archipelago, Russia, and Algoma District, Ontario, Canada.

Deposits of the core interval that yielded thelodont scales are assigned to the upper part of the Varlygino Formation, represented by grey and reddish-grey, variously clayey and sandy pelitomorphic dolomites. The age of the Varlygino Formation is uncertain. Some specialists have considered the whole formation, or at least its middle and upper parts, to be of lower Silurian age (Aristova & Ostrovsky 1975). It has also been suggested that the formation is Ordovician in age, and only the overlying Poshehon Formation is of Silurian age (e.g., Dmitrovskaya 1989). In the stratigraphic scheme of the East European Platform, the Varlygino Formation was correlated with the upper Caradocian–lower Ashgillian strata of the East Baltic and Leningrad District. Later, in the regional stratigraphic scheme of the Moscow Syneclise, the Varlygino Formation was reassigned as lower Silurian and this age determination is used until now.

The Danilov-1 core section has been proposed as the hypostratotype of the Varlygino Formation. No fossil remains have earlier been found in this drill core interval. However, in other drill cores the conodont *Icriodella* sp. (Urdoma-1), ostracod *Bolbina* cf. *B. rakverensis*, graptolites *Medusaegraptus* sp. and *Rhadinograptus* sp. (Rostov-1), brachiopods and lingulids have been found in the upper part of the formation. Taxa reliably pointing to an Ordovician or Silurian age of the formation are absent.

The Moscow Basin is the easternmost area of the palaeobasin, encompassing the western and central parts of the Baltica palaeocontinent and formally set off from the Baltoscandian Basin by the late Vendian Lovat uplift. The study of benthic faunas suggests that during the Ordovician, a possibly periodic sea passage connected the Moscow Basin with the eastern margins of Baltica (Ural basin) and the Timan-Pechora Region

(Dmitrovskaya 1993). New data on conodonts also confirm the link between the Timan-Pechora and Moscow palaeobasins, at least at the end of the Middle Ordovician. Conodonts of the genus *Pectonognathus*, which are endemic in the Early and early Middle Ordovician in the Timan-Pechora Region, appear in the Moscow Basin at the end of the Middle Ordovician. The occurrence of thelodont *Sandivia melnikovi* both in the Moscow and Timan-Pechora palaeobasins indicates connection between these basins in the Late Ordovician.

In contrast to the western regions of the Russian part of the Baltoscandian Basin, where the upper Katian as well as Hirnantian deposits are absent, the Late Ordovician and Silurian sediments are preserved in the Moscow Basin. This suggests that land separated the Moscow Basin from the Baltoscandian Basin in the Late Ordovician. No fish have been found in the East Baltic Ordovician so far.

In summary, the discovery of thelodont scales is extremely important (1) in broadening our knowledge about spatial distribution of the group; (2) for the biostratigraphy of the Moscow Basin, allowing estimation of the age of the Varlygino Formation on the basis of *Sandivia melnikovi* as Upper Ordovician; (3) for the interregional correlations between the Moscow and Timan-Pechora basins and (4) for palaeogeography, indicating that in the Late Ordovician the Moscow Basin was connected with the Timan-Pechora Basin and separated from the Baltoscandian Basin.

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Alpha, beta, gamma: Where did all the diversity go during the Cambrian Explosion?

LIN NA[1] AND WOLFGANG KIESSLING[1]

The Cambrian is a unique period not only in the origin of modern animal phyla but also in the dramatic rise of marine biodiversity. However, the geographic and environmental partitioning of diversity trajectories from the Ediacaran to the Early Ordovician is largely unexplored. Traditionally, global biodiversity (gamma diversity) through the Cambrian has been given much more attention than the diversity within (alpha diversity) and between (beta diversity) assemblages. Solving the problem if the global diversification was driven by higher species richness in local communities or rather by an increase between communities may help deciphering some of the underlying processes of the Cambrian explosion. We analyzed a data set of 38296 faunal occurrences from the Paleobiology Database. After revising the stratigraphic assignments of every single collection based on current biostratigraphic correlations between China, Siberia and Laurentia we assessed how variations in alpha and beta diversity influenced global diversity during the Cambrian Explosion. Sampling-standardized analyses showed that global diversity rose sharply from the Fortunian to Stage 3 and then leveled off erratically through the rest of the Cambrian. Alpha diversity peaked earlier, in Stage 2, and then declined. Changes in beta diversity are well correlated with changes in gamma diversity, suggesting that the Cambrian Explosion was manifested more by an increase of between-community diversity than by higher species packing within communities. Beta diversity appears to be largely driven by differences among environment rather than large-scale geographic differences (faunal provinces), and the level-bottom biota probably made a greater contribution to beta diversity.

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Decomposition of organic remains in colloidal solutions: A model for Lagerstätten

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Herein, we report the first experimental observations on decomposition of organic remains in colloidal solutions of kaolinite. Modeling fossilization in clay colloids is one of the challenging issues for understanding the formation of Lagerstätten, which often occur in fine-grained rocks deposited under catastrophic conditions.

With this idea in mind, we buried nauplia of *Artemia salina* in non-sterile, fresh water/kaolinite dispersion for 4–6 months at room temperature. The visual observations of the morphological changes in colloidal matrix are favored by a contrast between the bright orange-colored nauplia and light-grey sediment. After the incubation period, we measured the pH in different layers of the systems and analyzed the mineral/chemical composition of the colloidal matrix and organic remains.

The decomposition of organic remains in a colloidal substrate proceeds significantly slower than those in aqueous solutions: the nauplia within the sediment remained clearly discernible during the experimental period, whereas *Artemia* on the surface of the sediment completely decomposed within 1–1.5 months. Moreover, the process induced dramatic changes in physicochemical characteristics of the system. The entire sediment rapidly darkened due to the progressive release of H_2S from the decomposing organics and related formation of dark-colored sulfides. In the darkened matrix, colorless circular regions harboring each nauplius were formed within two weeks after the beginning of the experiment. Similar circular zones with fossilized organisms separated from the surrounding matrix have been found in different types of Lagerstätten.

Based on our data, we suggested a mechanism that might underlie this phenomenon. The anaerobic bacterial decomposition of bioorganic objects results in the natural excretion of organic acids. The acidic media enhances the aggregation of mineral particles through dissolution of the kaolinite surface. This process leads to the formation of diffusion gradients, which results in the accumulation of acids within the comparatively small portions of surrounding matrix. The pH value measured in the close proximity to the nauplia was about 3.4–3.8, whereas the pH measured above the nauplia-enriched layer was 6.5–7.0, and increased up to 7.4 near the surface of the sediment. The local increase in the acidity has important consequences: 1) The already formed sulfides dissolve under acidic conditions and that results in discoloration around the nauplia, the difference in acidity produces chemical heterogeneity between sediment matrix and nauplia-adjusted area. 2) The accumulated acids, in particular lactic acid, inhibit the growth of bacteria and therefore act as a preservative for organic remains. 3) The acid-induced kaolinite dissolution results in the release of silicates, aluminium complexes and other ions. Among those, aluminium cations are well-known coagulation promoters and decomposition inhibitors. Such release was corroborated by the qualitative chemical reactions, and mineralogical analysis showed the *de novo* synthesis of amorphous allophane and gibbsite.

The kaolinite-produced compounds serve as mineralizing agents during further diagenesis. We found heterogeneous chemical composition of fossilized shells presenting the amorphous allophane and silicates on the surface. The mineralogical analysis of the organic-enriched layer showed that the mineral matrix recrystallized into larger particles presenting almost ideal structure compared to that of the non-modified kaolinite. Similar distribution of crystal morphology is well-known for the Spanish Lagerstätten (Vintaned et al. 2011).

We also found gibbsite in the top layer of the sediment, which was of the highest value of pH. The mineral was most likely produced by a surface-catalyzed reaction between kaolinite and H_2S diffusing throughout the colloid solution. The addition of $CaCl_2$ to the probe resulted in the precipitation of calcite on the surface, however calcite did not form in the more acidic middle portion of sediment. This pH-dependent calcite formation strikingly resembles the layered distribution of calcite in some localities in Burgess Shale (Gaines et al. 2012). Moreover, the pH gradients evolving from the decomposition of organics should influence the entire pattern of fossiliferous layers initially formed in mineral colloids.

We believe that our modeling system provide a deeper insight into several aspects of the structure and origin of Lagerstätten such as the morphological differences between the rock matrix and the fossils, the structural heterogeneity along the fossil-bearing layers, and the self-conservation of ancient fossil objects within Lagerstätten.

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Experimental fossils: Fast mineralization in clay colloids

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Modeling fossilization is important for comprehensive understanding of the mechanisms of Lagerstätten formation. The common strategy is to use saline aqueous solutions with a concentration of salts that is considerably higher than the average concentration in seawater. This method is based on the reasonable assumption that salts play a key role in the mineralizing of biological organisms. The method, however, neglects the effect of spatial confinement of decomposing remains as well as that of the morphology of mineral matrix on the fossilization process. For the first time, we reported the in-lab fossilization of macroobjects under experimental conditions that are close to those in the natural environment. Experimental fossilization highlighted the important features of the Lagerstätten specificity: the fine-grained morphology of mineral matrix, mineralization of a body including the preservation of fine details, the heterogeneity in Al/Si ratio and non-uniform distribution of other cations along a fossil, and the spot-like bacterial presence. By modeling fossilization in clay colloidal solutions, we demonstrate that the structural morphology of the matrix is of fundamental importance for rapid mineralization and further diagenesis in the organic/mineral system.

We buried the nauplia of *Artemia salina* in finely dispersed non-saline aqueous colloids of kaolinite and montmorillonite for 2–5 months at room temperature. The fossilization of the nauplia, which occurred over the course of the experiment under these conditions, was confirmed by a SEM elemental analysis. Unlike the non-fossillized *Artemia*, which were evaporated under the SEM beam, the fossilized nauplia remained stable during the scanning (Fig. 1). Some of the nauplia were completely fossilized during the experiment, while eggs and empty egg-envelopes fossilized only on the surface. The most remarkable aspect of modeled fossilization in clay colloids is the conservation of the fine-structure elements of incubated organisms, including antennas with numerous chaetas. We believe that a rapid increase in local acidity, which occurs due to the decomposition-induced excretion of organic acids as well as protein coagulation promoted by aluminum cations, is responsible for the observed inhibition of the decomposition of the nauplia.

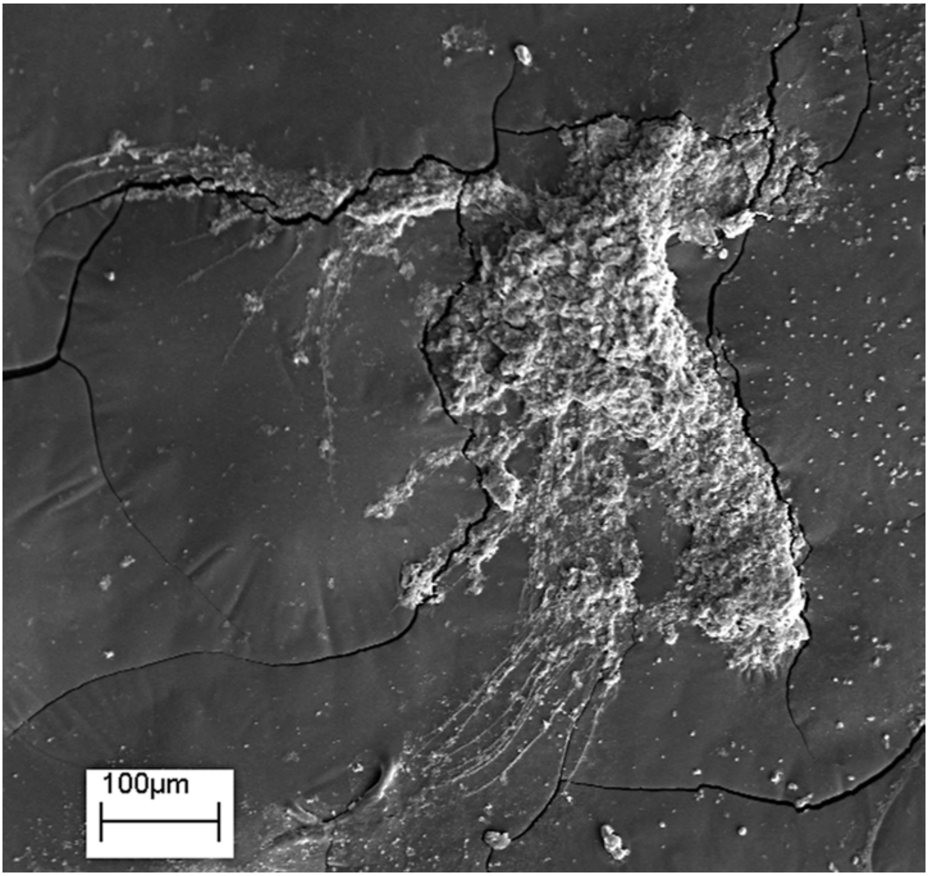

Fig. 1 Nauplius *Artemia salina* after 75 days of incubation in unconsolidated kaolinite sediment: two antennas, consisted of Na^+ and Cl^- compounding with organics, are clearly visible.

The fossilization pathway in the colloid system involves an orchestra of various chemicals comprising organic and inorganic acids, amorphous alumosilicate and complex inorganic ions, which are released from the surface of colloidal particles. The colloidal nature of the mineral matrix should also be taken into account because of the large surface area available for the interactions with the organic mixture in the acidic media; the fossilization in the colloidal system can therefore be considered as a surface-catalyzed process. This complex interplay among physicochemical factors manifests itself in the chain of consecutive events including early-stage decomposition, local acidification, and enhanced aggregation of colloidal matrix, surface modification and recrystallization, and, finally, mineralization and formation of the organomineral layer on the surface of buried remains.

The elemental analysis revealed local heterogeneities on the surfaces of the nauplia shells, although the entire composition corresponded to that of the surrounding kaolinite or montmorillonite matrices. Some fossilized regions were enriched with Al, though in several samples the presence of Si was more pronounced. The antennas of the nauplia were predominantly composed of Na^+ and Cl^- in combination with organics; the source of these ions was the inner media of the nauplia, as we did not add Na^+ and Cl^- compounds to the experimental solution. For some regions of shells, a remarkably increased concentration of Ca was observed. The shell-associated mineralized particle exhibited various chemistries: recrystallized clay, platelet calcite, sodium chloride, amorphous silica and allophane, and various oxidized sulfur compounds. The morphology of minerals varied from amorphous and crystal/amorphous heterostructures to almost ideal crystals. These results suggest a decomposition of the colloidal matrix in the presence of decaying biological organics, rapid elemental redistribution of clay minerals and a heterogeneous character of matrix–organism interactions. Another important finding was the presence of bacteria, which were associated with the body of a fossilized organism as well as on the surface of egg-envelopes. Exopolymer films were found on the clay particles in the clusters of bacteria. However, we did not observe bacteria in the vicinity of the antennas. This observation indicates that the presence of bacteria might not be necessary to initiate mineralization under certain conditions. However, for non-sterile systems, this presence is unavoidable in the largest portion of the sediment, since the lower Archean Eon. Bacteria initiate the decomposition and excretion of organic acids and may accelerate fossilization by forming organomineral complexes.

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Is the early Palaeozoic $\delta^{18}O$ isotope signal reflecting the geologically registered climate changes?

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General rises in carbonate shell $\delta^{18}O$ (Veizer et al. 1999) and biogenic apatite $\delta^{18}O$ (Trotter et al. 2008) have reasserted the long Ordovician cooling trend followed by the Hirnantian–Llandovery glaciation, suggested earlier by a general increase in the pole to equator climatic gradient, punctual glaciological markers, and long-term numerical modelling studies (see review in Nardin et al. 2011). At least five glacial periods have been identified in the sedimentological record through the Hirnantian–Sheinwoodian period (Ghienne et al. 2007). Three cold periods are supposed to occur in the early Katian, the early Sheinwoodian and the mid Ludfordian, mainly based on sea-level falls and positive $\delta^{13}C_{carb}$ excursions (Saltzman & Young 2005; Cramer & Saltzman 2007). In addition, major lithologic change on the peri-Gondwanan platforms and massive faunal migrations from tropical to higher latitude areas suggest a warm episode in the late Katian (Boda Event; Fortey & Cocks 2005). Finally, recent stratigraphic studies emphasized two possible colder periods in the late Floian and in the middle Darriwilian (Turner et al. 2012). Beside the large databases (Veizer et al. 1999 and Trotter et al. 2008), published $\delta^{18}O$ measurements have increased incredibly in the last few years, for the Ordovician–Silurian period. The next challenges are to compile and homogenise $\delta^{18}O$ measurements on biogenic carbonate and apatite and to confront their periods of instability to the supposed cold episodes. Expected outcomes are 1) the distinction between local and global climatic events, 2) the refinement of their timing (when did the icehouse period start and stop?), and 3) the improvement of the understanding of the early Palaeozoic climate.

After inventory of isotopic ($\delta^{13}C_{carb}$), stratigraphical and sedimentological climate markers, exhaustive databases of $\delta^{18}O$ measurements on carbonate (articulate brachiopod shells) and on phosphate (conodont and inarticulate brachiopod shell) were constructed from independent published studies. All data were temporally situated at the biozone scale and recalibrated according to the last used geochemical standards. Temperatures were calculated from the $\delta^{18}O$ measurements of our compilations and from the major databases using specific palaeothermometers. Four different hypotheses on the $\delta^{18}O_{seawater}$ have been considered in this study because $\delta^{18}O_{seawater}$ has likely varied through the geological time (Jaffrés et al. 2007).

Addendum

Insight into the systematic position and functional morphology of lentilform columnals from the Billingen and Volkhov regional stages (Floian–Lower Dapingian, Ordovician) of the Baltic

SERGEY V. ROZHNOV[1]

Numerous isolated lenticular columnals, described in the 19th century by Eichwald (1860) as *Haplocrinus monile*, are the most abundant fossils in some beds of Billingen and Volkhov stages of the Baltic. Despite the mass occurrence in many localities, their systematic position among the other pelmatozoan echinoderms is unclear. Yeltyshewa (1964) referred these columnals to the formal genus *Pentagonocyclicus*. The findings of stems, formed by lenticular columnals articulated with crowns, allow us surely to put them into iocrinids (Disparida, Crinoidea) and require the allocation of a new genus in this family. The structure of cups, with five basal plates, five radial plates and one upper radianal plate located within the cup and which originates in the upper radial C confirms this. The anal tube joins to the left side of the radianal plate, and the arm joins to the right side of the plate. Arms branch isotomously at least two times. The crown is typically iocrinid-like, with some differences compared to the other described genera. The proxistele is composed of pentagonal or star-shaped columnals, separated by radially arranged pentamers, as is typical for iocrinids. But the mesistele, isolated columnals that are the most common, is very different from the proxistele and mesistele of other iocrinids. The seven or eight most proximal columnals of the proxistele are very low and have stellate shape with rays beneath the sutures between the radial plates. They are characterized by a wide rounded-pentagonal axial channel and a narrow articular surface with two or three weakly expressed ridges in each pentamer. Proxistele columnals, located more distally to the cup, become gradually higher and increasingly bulbous in the middle part, then become turbinate. The mesistele is built by columnals of three, sometimes four orders, sharply differing in diameter, and with very narrow axial channel. Columnals of the last, third or fourth order differ greatly from lenticular columnals of the other orders by their small size (they are narrow and low) and pentagonal, rarely stellate, shape. They connect other columnals, ranging in slightly depth facet of a neighboring columnal. Sometimes they are almost invisible from the side, as they are nearly completely covered by the adjacent columnals. Columnals of other orders are similar to each lenticular shape with a sharp or smooth bend at the equator, but differ in size and dominant sculpture at the equatorial rim of the

Preliminary results on the compiled databases confirm the $\delta^{18}O$ increase, from the Tremadocian to the Dapingian for the $\delta^{18}O_{phos}$ signal and to the late Katian for the $\delta^{18}O_{carb}$ signal. Both signals reach a plateau to the Ludfordian, interrupted by positive peaks in the Hirnantian–low Rhuddanian, the early Sheinwoodian, the middle Homerian and the early Ludfordian for both signals. The global trend and the identified peaks seem to confirm most of the inferred glacial or cold periods, even those with no sedimentological record. However, the initial long increase of both signals does not reflect the hypothetic cold episodes in the late Floian and the early Darriwilian, as well as the warm Boda Event.

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The SPICE Event and its correlation to the base of the Paibian Stage (lower Furongian Series), Cambrian, in eastern North China

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The global correlation between North China craton and other paleo-continents at the base of the Paibian Stage has always been a challenge. Primarily due to the shallow-water endemic nature of the fossil materials, a precise biostratigraphic global correlation on this craton at this particular boundary is difficult. The study of the traditional Middle to Upper Cambrian rocks of the North China craton was first documented by Willis (1907) and Blackwelder (1907). Walcott (1905, 1911, 1913) studied their fossil collections and provided the first comprehensive Cambrian fossil record of North China. Sun (1924, 1935) studied the traditional Upper Cambrian of North China and established the basic stratigraphy. Despite the efforts by different scholars, a precise biostratigraphic correlation scheme within and beyond North China is still far from ideal.

The Steptoean Positive Isotope Carbon Excursion (SPICE) event is a useful phenomenon for global correlation, and helped to establish the GSSP for the Paibian Stage and Furongian Series (Peng et al. 2004). New data from Laiwu, Shandong, showed an obvious SPICE curve, and the onset of this curve could be correlated to the base of the Paibian Stage (Fig. 1). Comparing to the published carbonate carbon isotope data within the eastern North China (Zhu et al. 2004; Du et al. 2007), the presence of the SPICE curve is definite and clear, but they all displayed a generally lower peak value (2‰–~4‰) with smaller magnitude (<1‰–~3‰) than the other paleo-continents, where they all showed relatively higher peak value (3‰–~5‰) with larger magnitude (on average about 4‰). This may indicate certain regional variation(s) or effect(s) within the North China craton.

According to Peng (2009a, 2009b), the base of the Paibian Stage in North China should be positioned inside the *Prochuangia-Paracoosia* Zone. The base of the *Chuangia* Zone had been used to indicate the same horizon in some previous studies, or where the *Prochuangia-Paracoosia* Zone is absent. We concur with Peng, the onset of SPICE should be best indicated by the *Prochuangia-Paracoosia* biozone. The FAD of the *Chuangia* Zone could be a useful proxy of the base of the Paibian Stage, i.e., FAD of *Glyptagnostus reticulatus*, but its position is actually slightly higher (Peng 2009a, p. 443). The precise position within the *Prochuangia-Paracoosia* Zone that could correlate to the base of the Paibian Stage is still unclear at the moment.

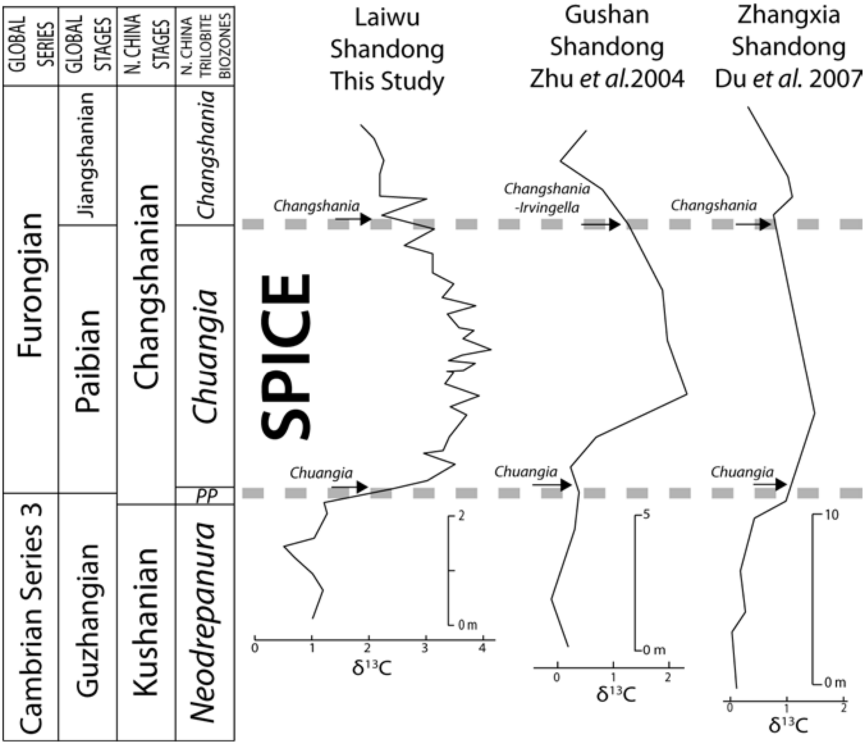

Fig. 1. Tentative correlation between different eastern North China sections based on the occurrence of the SPICE event. *PP = Prochuangia-Paracoosia* Zone.

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The Cambro-Ordovician Alum Shale revisited: Depositional environment, sea-level changes and transient isostatic disturbances

ARNE T. NIELSEN[1] AND NIELS H. SCHOVSBO[2]

The Alum Shale Formation (ASF) is a highly organic-rich unit (up to 25% TOC) deposited in an epicontinental sea on the western fringe of Baltica. The formation is mostly non-bioturbated, finely laminated and pyrite-rich and obviously deposited under oxygen-depleted conditions. This depositional regime lasted for nearly 30 million years through Cambrian Series 3 (CS-3) into the Early Ordovician and the facies originally covered >1 million km^2. The ASF ranges in thickness from 15–25 m across much of Sweden and up to 80–180 m in southwestern Scandinavia.

The ASF was deposited on the outer shelf from about the storm wave base and further outboard. The wide inner shelf was a zone of net sedimentary by-pass; sandstone was deposited close to the shore. The sea was exceptionally flat and the outer shelf bottom environment was generally dysoxic, maybe occasionally anoxic. The sediment itself was anoxic from just below the sea floor, which likely was covered by bacterial mats. Limestone occurs commonly as concretions and beds that may constitute more than 50% of the formational thickness in central Sweden vs. only 5–10% in southwestern Scandinavia. This distribution reflects recurrent erosion on the mid shelf caused by lowering of the storm wave base during sea level falls. Storm driven erosion recycled the unconsolidated Alum Shale mud and transported it outboard and left behind limestone and limestone conglomerates; many limestone beds consist of more or less crushed trilobite skeletons winnowed from the mud. Erosion was often stopped by resistant limestone beds.

Where the ASF is thickest the average accumulation rate was only up to 4–6 mm per 1000 years (compacted thickness). The profound sediment starvation reflects the pervasive late Precambrian peneplanisation of Baltica in combination with the extensive flooding of the craton (small land area, no topography).

The long-lasting dysoxic conditions in the depositional environment were likely due to globally reduced oxygen levels in the Cambrian, locally amplified by silled basin conditions. The general oxygen level in the Alum Shale Sea decreased during CS-3 with a major hike in dysoxia from the SPICE onwards (Fig. 1). The oxygen level in the depositional environment gradually rose again in the latest Furongian–Tremadocian, unrelated to changes in general depth of deposition. The progressive ventilation was possibly caused by gradual lowering of the sill along the western margin of Baltica.

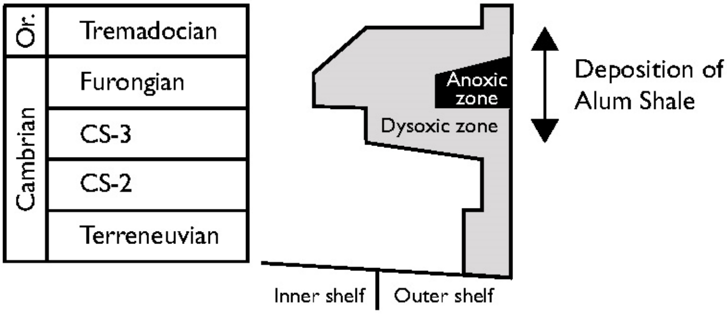

Fig. 1. Variations in dysoxia on the Baltoscandian shelf during the Cambrian–earliest Ordovician.

Changing isostatic movements affected different parts of Baltoscandia during deposition of the ASF (both uplift and local subsidence). The so-called Hawke Bay Event was associated with uplift of all of Scandinavia; the uplift subsided progressively and differentially during CS-3 and as a result the Hawke Bay unconformity is diachronous. Sub-regional uplift events took place in medial CS-3 and again in the latest Furongian, in both cases lasting for several million years. The intra-plate movements seemingly reflect isostatic responses triggered by concurrent plate tectonic changes.

A Cambrian–Tremadocian sea level curve is reconstructed and a preliminary sequence stratigraphy is outlined for the ASF comprising 20 third-order sequences forming two second-order supersequences. The sea level was low early in CS-3 and clastic supply from the east was high. Progradation shifted the coastline westwards almost reaching mainland Sweden. Alum Shale low in organic matter was at the same time deposited in westernmost Scandinavia with clastics supplied from the west and maybe also from uplifted parts of southern Scandinavia. A major sea level rise in mid CS-3 displaced the coastline far eastwards and deposition of Alum Shale spread across the greater part of Scandinavia as the Hawke Bay uplift concomitantly abated. The sea level rose strongly towards the close of CS-3 to drop again in the early Furongian, which constitutes a second order lowstand interval. The sea level rose once more in the late half of the Furongian with a highstand peak during the *P. minor* "Superzone". Following a transient latest Furongian lowstand a strong sea level rise characterized the earliest Ordovician, at which stage deposition of Alum Shale reached its greatest extent. The eastwards spreading of Alum Shale deposition was, however, also the result of local subsidence. After a mid Tremadocian moderate lowstand a new sea level rise took place in the late Tremadocian. Deposition of Alum Shale was eventually terminated by the late Tremadocian sea level fall referred to as the Ceratopyge Regressive Event and which likely coincided with disappearance of the uplifted western margin of Baltica.

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The uppermost Furongian on Kinnekulle, Västergötland, Sweden: New trilobite and conodont data

ARNE THORSHØJ NIELSEN[1], THOMAS WEIDNER[2], SVEND STOUGE[1] AND GABRIELLA BAGNOLI[3]

The youngest Furongian, traditionally assigned to the *Acerocare* Zone, is generally absent in south central Sweden, except for an isolated occurrence on Kinnekulle, Västergötland. Here the level has been known from two drill-cores and a couple of poor outcrops on the western slope of the mountain. A recently discovered section, 1.4 m thick, in the abandoned Dagbrottet Alum Shale quarry, on the eastern side of Kinnekulle, is much better exposed and has been investigated in detail (Weidner & Nielsen in press). Another section, at least 0.5 m thick, in the Trolmen quarry on the western slope of Kinnekulle has been studied cursorily. This section is more limestone-rich than at Dagbrottet and contains conglomerates.

The Dagbrottet section yielded the trilobites *Parabolina* (*P.*) *heres heres*, *Peltura transiens, Peltura costata*, *Peltura scarabaeoides westergaardi* and *Sphaerophthalmus alatus* (Fig. 1). Additionally, *Pelturina punctifera*, *Acerocarina granulata* and *Leptoplastides*? sp. were collected from loose boulders on the western side of Kinnekulle; the fossil assemblage of these boulders shows that they represent the same stratigraphic horizon. The trilobite assemblage comprises species hitherto considered characteristic of five different Furongian biozones, viz. the *Ctenopyge tumida* Zone, the *Parabolina lobata* Zone, the *Peltura transiens* Zone, the *Peltura costata* Zone and the *Westergaardia scanica* Zone. The mixed assemblage may in theory reflect that some of the species have longer ranges than previously recognized or that older faunal elements have been reworked (or both). The discussed strata are assigned to the *P. costata* Zone and the material of *P. transiens, P. scarabaeoides westergaardi* and *S. alatus* is assumed reworked, whereas *P. punctifera* seemingly appears one zone earlier than in Norway. The succession is resting on the *P. lobata* Zone, and the *Peltura paradoxa* and *P. transiens* zones are missing in the local succession. The presence of reworked trilobites indicates that successively older strata were eroded somewhere in Central Sweden during deposition of the youngest Furongian in the Kinnekulle area. We note that a veneer of Tremadocian Alum Shale is resting directly on the *C. tumida* Zone in nearby Hunneberg and several late Furongian zones are thus missing.

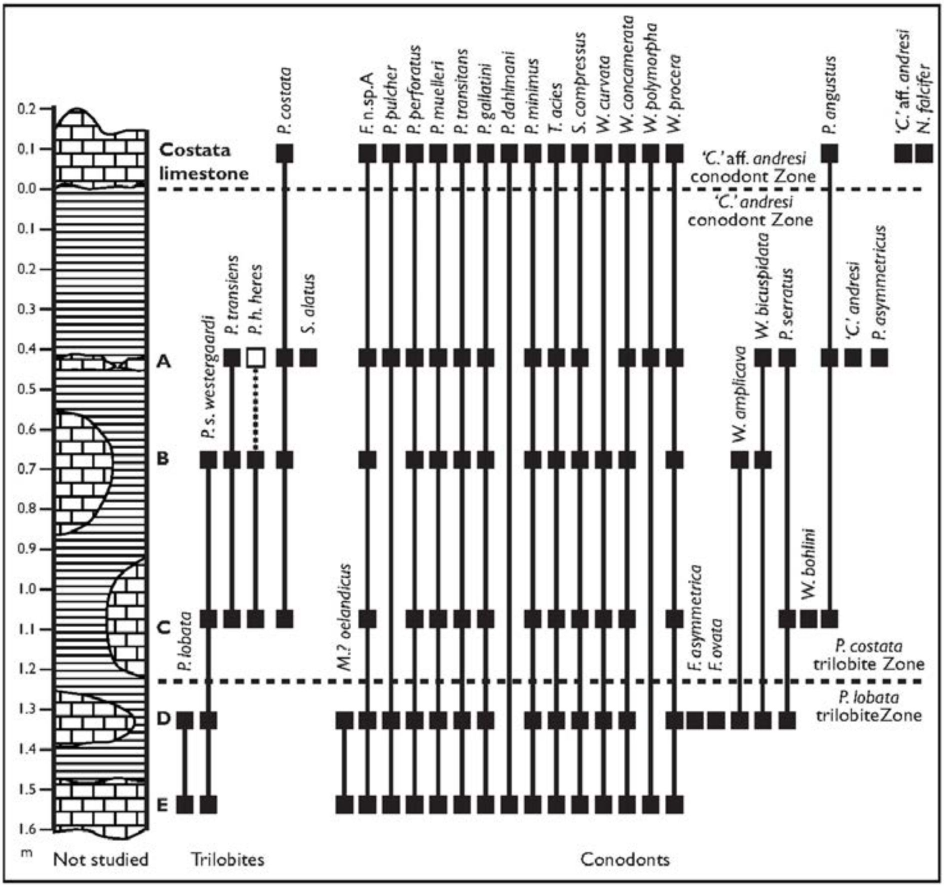

Fig. 1. The investigated upper strata at Dagbrottet, eastern Kinnekulle, Sweden. Ranges of trilobites and conodonts shown. The underlying strata are currently being investigated.

All limestone beds (E to Costata Limestone; Fig. 1) yielded well-preserved conodonts, phosphatocopinids and sponge spicules. The spicules are especially abundant in bed E and the Costata Limestone. The rich and diverse conodont fauna comprises proto-, para- and euconodonts; most of the species have been described by Viira et al. (1987), Müller & Hinz (1991) and Szaniawski & Bengtson (1998).

The paraconodont fauna includes *Furnishina* with four species, and *Westergaardodina* with seven species. *Westergaardodina polymorpha* is extremely abundant in bed A, in association with pellets. Other paraconodont taxa are *Prooneotodus gallatini*, *Problematoconites* spp. and *Prosagittodontus minimus*. The euconodonts *Proconodontus muelleri*, *P. transitans* and *Stenodontus compressus* are common, whereas *Proconodontus serratus* is infrequently present.

Most conodont species range through the investigated interval. *Muellerodus*? *oelandicus* has its last occurrence in bed D, probably representing the LAD of the species. '*Cordylodus*' *andresi* is present in bed A and is followed by its successor '*Cordylodus*' aff. *andresi* in the Costata Limestone. The interval from bed E to bed A is assigned to the '*Cordylodus*' *andresi* Zone (see Kaljo et al. 1986; Bagnoli & Stouge submitted). The LAD of '*C.*' *andresi* and the FAD of '*C.*' aff. *andresi* thus both occur in the *Peltura costata* Zone.

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Ontogeny of the eocrinoid genus *Akadocrinus* from Cambrian of the Barrandian area, Czech Republic

MARTINA NOHEJLOVÁ[1] AND OLDŘICH FATKA[1]

Eocrinoidea, an ancient echinoderm class ranges stratigraphically from early Cambrian to Silurian. Eocrinoids commonly belong to a dominant echinoderm group in Cambrian (Sprinkle 1973; Zamora et al. in press).

This study is focused on the ontogeny and the associated morphological changes of the genus *Akadocrinus* Prokop 1962 from the "Middle Cambrian" of the Barrandian area (Fig. 1). Material used for this study is deposited in the collections of the National Museum in Prague and in the Czech Geological Survey in Prague. Well to excellently preserved material originates from several outcrops of the Jince Formation in the Příbram-Jince Basin, namely from the *Paradoxides* (*P.*) *paradoxissimus gracilis* Zone of Drumian age. Comparable eocrinoid material has been studied only from the Balang and Kaili formations of South China.

The body of *Akadocrinus* consists of three parts: theca, brachioles and stalk. The theca is elongate and composed of irregular polygonal plates. The size of thecal plates is variable. Earlier formed plates are usually larger than later intercalated plates, similar to what has been described in other Cambrian eocrinoids (Parsley 2012). Brachioles are straight with biserially arranged plates. The stalk is composed of wide low columnals.

During the ontogeny of eocrinoids three ontogenetic stages can be distinguished: juvenile stage (early, middle and late substages), mature stage (early, middle and late substages) and gerontic stage. This ontogenetic sequence was established using thecal height (= distance between the top of the ambulacrum and the bottom of the basal "series" of thecal plates; see Parsley & Zhao 2006; Parsley 2012). Photographs of latex casts whitened by NH_4Cl were used for detailed study of each specimen. The aim of this study is to document changes during ontogeny of *Akadocrinus*.

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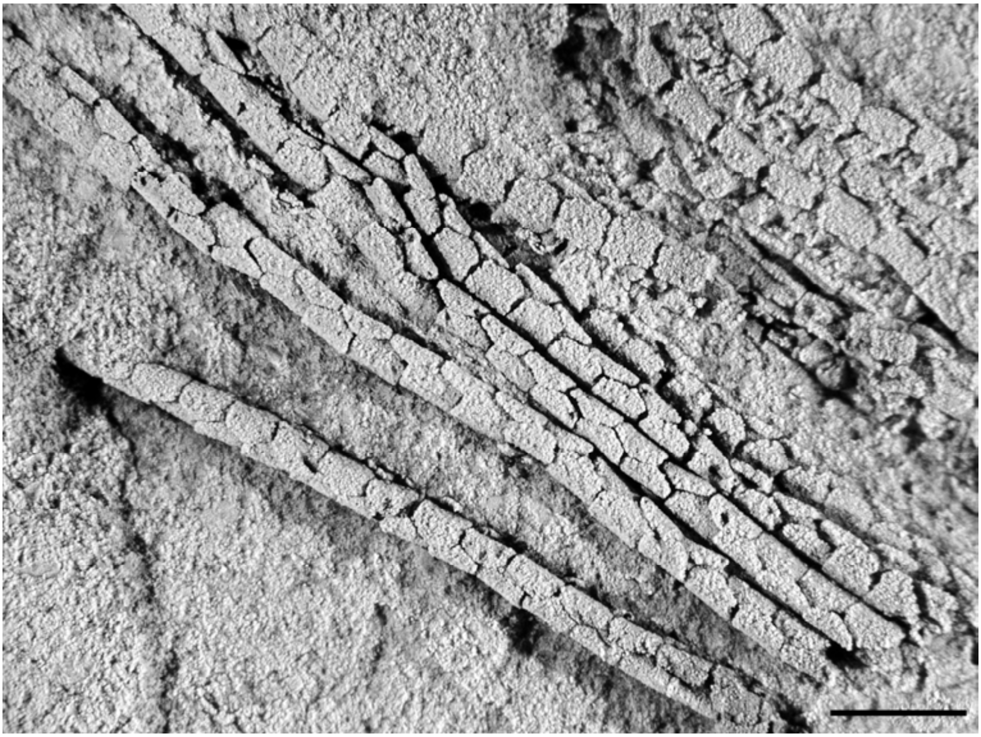

Fig. 1. Akadocrinus. Latex cast whitened with NH_4Cl. Detail of structure brachioles. Scale bar 1 mm.

Paleobiodiversity of Silurian chitinozoans in the eastern Baltic: A quantitative stratigraphic approach with CONOP

LIINA PALUVEER[1], VIIU NESTOR[1] AND OLLE HINTS[1]

Chitinozoans are common and diverse microfossils in early Paleozoic rocks. With excellent preservation, abundance and well-constrained stratigraphic ranges they comprise some of the most useful index fossils in the Silurian of the Baltic region, as well as globally. The diversity patterns of Silurian chitinozoans have been discussed in a number of publications (Nestor 2009; Grahn & Paris 2011; and references therein). However, studies based on different time bins are difficult to compare and the temporal resolution of most previous approaches may be insufficient for intervals of rapid changes.

In order to tackle these limitations we compiled a Baltic regional occurrence-level database for quantitative stratigraphic analysis. It currently holds data on 188 Silurian chitinozoan species (including those not formally described) from 15 drill cores from Estonia, Latvia and the Kaliningrad region (altogether 2359 productive samples). The studied localities characterise different settings within the Baltoscandian basin and cover the entire Silurian Period. The database was carefully checked for errors and taxonomic inconsistencies, and a best-fit composite correlation model and diversity curve were created using constrained optimisation (CONOP; see Sadler & Cooper 2003 for methodological details). The latter method and software has proven to be efficient not only for high-resolution biostratigraphy, but also for drawing diversity curves, which are devoid of binning problems (Sadler & Cooper 2003).

The modeled composite range chart turned out to be rather well constrained, especially in the more thoroughly sampled Llandovery and Wenlock strata, and without major contradictions with the empirically known distribution pattern. The modeled diversity curve is interpreted here to be a close approximation of the standing diversity.

Following the end-Ordovician extinction, the earliest Silurian was characterised by very low diversity of chitinozoans, as is the case with most other groups of organisms. The recovery started only in the late Rhuddanian and Aeronian, when the number of species reached about 10. A conspicuous diversification took place in the Telychian when a Silurian regional threshold of 25–30 species was first achieved. A major crisis and loss of more than half of the species richness occurred prior to, and during, the Ireviken Event. By the Homerian high diversity was regained, followed by series of low and high diversity intervals. A declining trend towards the end of the Silurian prevailed from the mid Ludfordian. However, since we lack Devonian data, the latest Silurian diversity drop is likely exaggerated.

Alongside with CONOP analysis, the same database was used for calculation of total and normalised diversity per Baltic regional stage. As expected, the total diversity strongly overestimates the CONOP-derived trend. This difference is particularly large in the Adavere, Jaagarahu and Paadla stages, where the number of species per regional stage exceeds 50, although the standing diversity probably stayed below 30. The normalised diversity provides much closer match with the CONOP curve and can be considered as an appropriate estimate for standing diversity in most cases.

Comparison with previous zone-based diversity analysis of Baltic Silurian chitinozoans (Nestor 2009) shows relatively good correspondence with the CONOP-derived curve, but many rapid changes and their amplitude and timing remain hidden in the conventional approach. Our results from the Llandovery and Wenlock are, however, very close to the quantitative stratigraphic analysis of similar, and partly overlapping, dataset discussed by Sadler (2012). The threshold for chitinozoan standing diversity in the Baltic Silurian seems to have been somewhat lower, perhaps by 10 species, than reported from the Ordovician using the same methodological approach (Hints et al. 2011). The Silurian diversity curve is more fluctuating and corroborates the idea that the period was a highly dynamic interval in the history of life and environments.

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Late Ordovician shelly deep-water faunas from Raheen, Waterford Harbour, Ireland

MATTHEW A. PARKES[1], DAVID A. T. HARPER[2] AND RENBIN ZHAN[3]

The Raheen Formation at Newtown Head in Waterford Harbour is a small isolated section of Ordovician rocks, dominated by volcanics of the Duncannon Group, but with interbedded fossiliferous shales. Although a brachiopod and trilobite dominated fauna has been known since the mid 19th century only the trilobites have been assessed in modern times. This paper describes the brachiopod fauna for the first time. The assemblage from Raheen is dominated by the dalmanelloid *Onniella*, with the small plectambonitoid *Sericoidea* comprising the second most numerous species. This revision has also identified a wide range of other genera, but all in very small numbers. These include a lingulid, a paterulid, *Paracraniops* and *Orthisocrania divaricata* amongst the non articulated brachiopods. Articulated genera present include the orthoids *Nicolella*, *Ptychopleurella, Sulevorthis*, *Skenidioides* and the plectambonitoids *Leptestiina* and *Sowerbyella.* Very rare forms include *Idiospira* and *Palaeostrophomena*? The brachiopod revision supports the late Caradoc age indicated by the trilobite fauna. Although the trilobite fauna generally indicated probable deeper water, the brachiopod assemblage confirms an outer shelf environment. Although elements of the assemblage indicate affinity with the well defined late Ordovician *Foliomena* fauna, it probably occupied a more shoreward position.

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Cambrian biostratigraphy and sedimentary evolution of the Siberian Platform

TATYANA V. PEGEL[1] AND SERGEI S. SUKHOV[1]

Interacting processes of different scale and genesis have been simultaneously reflected in stratigraphic sequences. There are local and global phenomena connected with inorganic nature development (including climate, tectonics, eustatic and other changes) and also with biotic functioning (especially significant for regions with predominating carbonate sedimentation, like the Siberian Platform in the Cambrian) and with the biosphere evolution as a whole. These interrelated processes formed stratigraphic and biofacies sequences at the concrete areas.

Stratigraphic investigations of the Siberian Platform throughout more than half a century have clearly shown that Cambrian deposits have distinct belt-like facies zonation (e.g., Pisarchik et al. 1975; Astashkin et al. 1984). This fact has been arisen from presence of giant structures: *shelves* with predominantly evaporites and *open seas,* or in morphostructural categories; *carbonate platforms* with reef rims and *basins.* However, the boundaries of these structures and their litho- and biocomplexes were not fixed spatially. The cause of litho- and biofacies changes and huge gradual spatial shifting (up to 500 km) during the Cambrian lies in the sea level fluctuations, the basin infilling, and regular extension of the carbonate platforms and pushing open marine basins to the craton periphery. As a result, it is almost impossible to find a single monofacies open marine section, or series thereof, suitable for global and inter-regional correlations within the region of the traditional stage stratotypes in the Siberian Platform (the basins of the middle courses of the Lena and Aldan Rivers). Shallow-water shelf deposits of the carbonate platform margin predomite in this territory. Under these circumstances additional sections in the peripheral NE and NW zones of the Siberian Platform with predominant open-marine deposits have to be used for the purpose of wide correlation. The shallow-water marginal zone of the open shelf was the most favourable area in the Cambrian basin for its inhabitants. It is precisely the area where the first small shale fossils, arheocyaths, algae, brachiopods, and trilobites appeared, but they were rather endemic. That is why in spite of abundance of fossils the stage stratotypes located in this facies area (especially at a stage of the most intensive reef-building without distinct layer structure) are of little use regarding the global subdivisions. First of all, it concerns the Amgan Stage stratotype of the traditional Middle Cambrian. Its replacement by the new *Molodian Stage* established practically in the same stratigraphic volume in the open-marine deposits of the Kuonamka Formation of the Molodo River section, NE of the Siberian Platform, is well-grounded. This section is among those expected to become the global Stage 5 stratotype (Shabanov et al. 2008).

Litho- and biofacies zones of the Cambrian deposits in the Siberian Platform corresponding to the inner shelf, outer shelf and open-marine basin have received own names, respectively: Turukhan-Irkutsk-Olekma, Anabar-Sinsk, and Yudoma-Olenek facies regions. Such zonation made it necessary to elaborate independent biostratigraphic scales for each of the main facies zones. Besides biostratigraphic zones and layers with archaeocyaths, brachiopods, and SSF (mainly in Anabar-Sinsk facies region) three parallel trilobite scales had been developed for each of the above-mentioned facies zones (Fig. 1; Astashkin et al. 1991). However, correlation of these scales still remains questionable in many respects.

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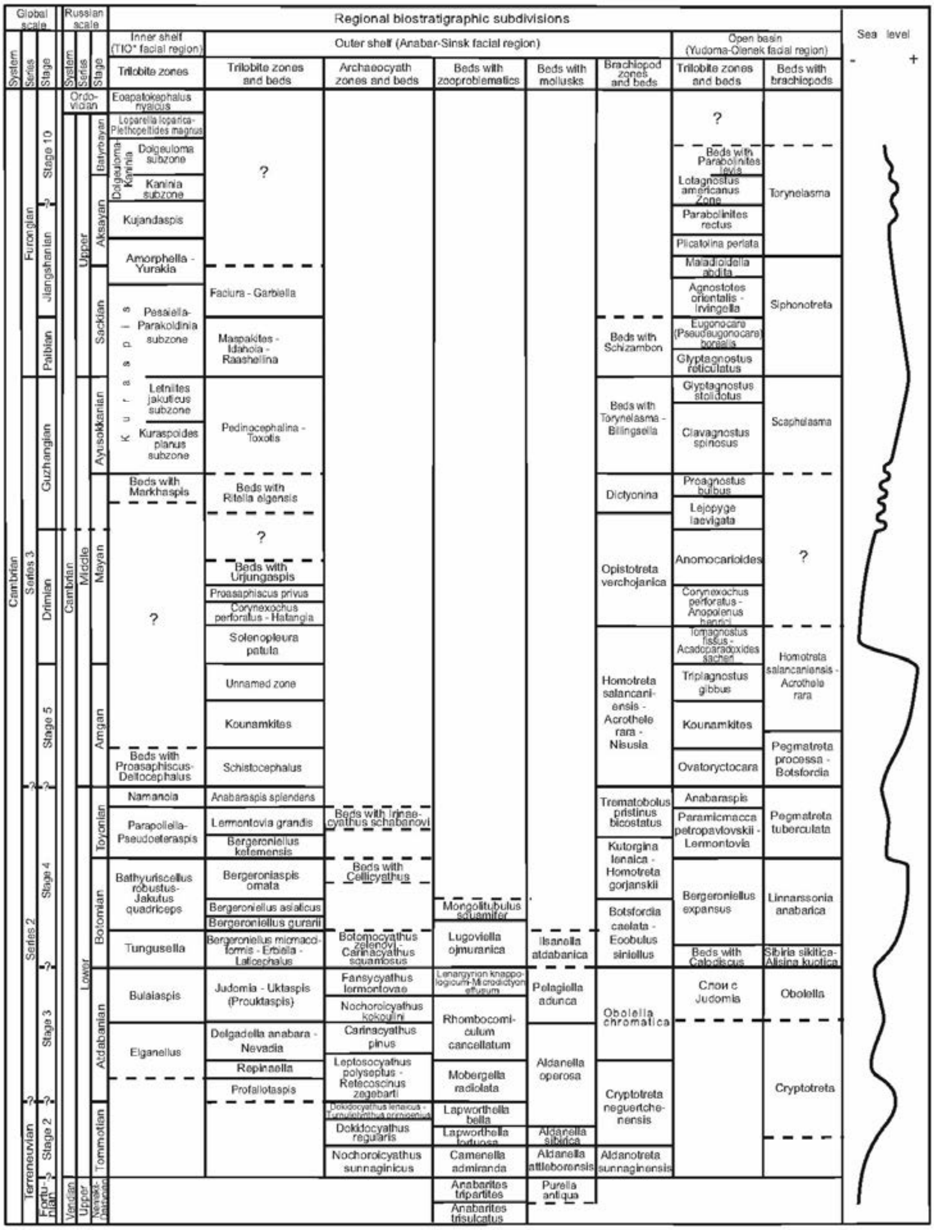

Fig. 1. Global and Russian series and stage nomenclature and current biostratigraphic subdivisions compared with the curve of the sea level fluctuations in the Cambrian of the Siberian Platform.

Trilobite *Bathynotus* from the uppermost Cambrian Series 2 of China and global precise correlation

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The Wuliu-Zengjiayan section of the Kaili Formation at Balang, Guizhou Province, China is a candidate boundary stratotype section base of Cambrian Series 3. It consists essentially of a monofacial succession of silty and calcareous mudrocks across the proposed Series 2–Series 3 interval. It overlays the Tsinghsutung Formation and is overlain by the Jialao Formation. The Kaili Formation contains 62 genus-level taxa of trilobites, including some that have been proposed as a guide fossil for the base of the unnamed Cambrian Series 3. Three trilobite biozones are recognized in the Kalii Formation (Zhao et al. 2012). In ascending order the zones are the *Ovatoryctocra* cf. *granulata-Bathynotus kueizhouensis* Assemblage Zone, the *Oryctcocephalus indicus* Zone, and *Peronopsis taijiangensis* Zone. *Batynotus kueichouensis* occurs in 0.8 m below *Oryctocephalus indicus* Zone, associated with representatives of *Redlichia*, *Oryctocephalops*, *Ovatoryctocara*, and *Protoryctocephalus*, as well as the ptychopariids *Probowmania*, *Nangaops*, *Chittidilla* and *Balangcunaspis*. In addition, this species also occurs in three other regions, eastern Guizhou, associated with trilobite assemblages similar to that of the Wuliu-Zengjiayan section. Therefore, *Bathynotus kueichouensis* is an important species to identify the top of Cambrian Series 2. *Bathynotus* has been found in Cambrian strata in many parts of the world, such as from Siberia of Russia, North American and Australia. Recently, new data of the genus from the Siberian Platform, North America and China indicate that the last appearance of *Bathynotus* can be of help to identify the uppermost part of Cambrian Series 2. The precise correlation of the level of *Bathynotus kueichouensis* occurrence in the world is significant for recognizing the top of the Cambrian Series 2.

In the western Siberian Platform, in the Lower-Imbak-219 well, *Bathynotus kueichouensis* was not only discovered but occurred with *B. elongates and B.* sp. and in association with *Dolichometopus perfidelis*, *Chondranomocare bucculentum*, *Ch. irbinica*, *Corynexochus grandis*, *Xingrenaspis xingrenensis* and *Gaphuraspis* sp. (Goryaeva et al. 2012). Above *Bathynotus* in the same well occur *Oryctocephalites incertus*, *Oryctocephalops frischenfeldi,* and specimens similar to *Oryctocephalus reticulatus* in morphological characteristics, and below *Bathynotus, Paradoxides* (e.g., *P. eopinus*, *P.* sp.). It is known that *Paradoxides* is an important index fossil for determining the base of the middle

Cambrian in Europe. According to the stratigraphic range of *Bathynotus* in the Siberian Platform (Goryaeva et al. 2012), the occurrence of *Paradoxides* below the level of *Bathynotus* means that the boundary of the traditional Middle Cambrian occurs lower in Siberia and Europe. The American scholar Mark Webster restudied *Bathynotus* from Laurentia and other regions (2009). He thought that *B. granulatus* is the most widespread species and *B. kueizhouensis* also occur in Australia. In fact, new data of *B, kueizhouensis* from Siberia indicate *B. kueizhouensis* should be the most widespread species. The study indicates a common co-occurence of *B. kueizhouensis* and *B. elongates* in China and Siberia. *B. holopygus* should be contemporaneous with *B. kueizhouensis.* The position of the species-level of *B. kueizhouensis* may precisely be correlated in Siberia, Australia, North America and China. It is known that *Bathynotus* has a short stratigraphic range. The boundary of the new definition of the Cambrian Series 3 should be located above the level of *Bathynotus*. If this view is accepted, the occurrence of *Paradoxides* may be recognized as the top of Cambrian Series 2 in Europe in reference to the stratigraphic range of *Bathynotus* in Siberia. As a result, correlation of the top of Cambrian Series 2 can be undertaken at a global scale.

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A potential GSSP for the base of the uppermost Cambrian stage (Furongian Series) coinciding with the first appearance of *Lotagnostus americanus* at Waergang, Hunan, China

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The well-documented Wa'ergang section in Taoyan, NW Hunan, China, contains a rich assemblage of Cambrian (Furongian Series) trilobites, which are well-characterised biostratigraphically (Peng 1984, 1990, 1992). The section has strong potential as a candidate for defining a GSSP marking the base of the uppermost stage of the Cambrian (provisionally termed Stage 10). The Wa'ergang section, which is exposed mainly in a roadcut in the village of Wa'ergang, reveals an interval from the upper Guzhangian Stage through the lowermost Ordovician. Palaeogeographically, it is situated in the Jiangnan Slope Belt of South China, where three other Cambrian GSSPs and one Ordovician GSSP have been erected. The section fulfills all the requirements for a GSSP.

A leading candidate horizon for the base of Cambrian Stage 10 is the first appearance datum (FAD) of the cosmopolitan agnostoid trilobite *Lotagnostus americanus*. The horizon is among the most readily recognizable levels in the Cambrian. Although *L. americanus* itself may be uncommon in some places globally, the horizon representing its first evolutionary appearance is constrained by multiple chronostratigraphic tools, and this ensures easy recognition on a global basis. Recently, Westrop et al. (2011) recommended splitting *L. americanus* into several species, each having narrow morphologic limits and limited geographic distributions. Subsequently, Babcock et al. (2012) and Peng et al. (2012) reported evidence contradicting that view. They demonstrated that populations referable to *L. americanus* have moderately wide morphologic variability, and that the species has a broad palaeogeographic distribution. Assuming that this is true, the horizon containing the FAD of *L. americanus* stands as perhaps the best horizon for defining the base of Cambrian Stage 10.

In the Wa'ergang section, the *Probilacunaspis nasalis-Peichashanian hunanensis* Zone through the lower part of the *Lotagnostus americanus* (= *L. punctatus*)-*Hedinaspis regalis* Zone has been studied in hopes of refining trilobite and conodont biostratigraphy, sequence stratigraphy and chemostratigraphy. So far as known the lowest occurrence of *L. americanus* is at a horizon of 29.65 m above the base of the Shenjiawan Formation.

The FAD of the conodont *Eoconodontus notchpeakensis*, which has been proposed as an alternative to mark the base of provisional Cambrian stage 10 (Landing et al. 2011), is also known from the Wa'ergang section (Dong et al. 2004). Its lowest occurrence is at a much higher level than the FAD of *L. americanus*. In the Wa'ergang section, as well as other sections in the world, *E. notchpeakensis* has a long stratigraphic range, extending from the *Eoconodontus* Zone (Furongian) through the upper part of the *Cordylodus lindstromi* (*Iapetognathus fluctivagus*) Zone of the Lower Ordovician (Dong et al. 2004). If *E. notchpeakensis* were to be selected as the principal guide fossil marking the base of Cambrian Stage 10, it would range through the entire stage, as well as into the succeeding stage, series and system.

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Bacterial epibionts encrusting Silurian graptolites

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Ten years ago SEM studies of the graptolite genus *Pristiograptus* from Silurian units of Lithuania showed that microscopic filamentous and coccoidal objects occurred on the surfaces of numerous specimens, morphologically distinctive small objects that resembled filamentous and spheroidal bacteria. All of the objects were minute, less than a micron in diameter, the filaments being spiral and varying from straight to twisted and the spheroids occurring either singly or in short chains (Fig. 1).

SEM studies documented the morphology and distribution of these objects and revealed that some of the spiral filaments evidently penetrated into the outer surface of the rhabdosomes, strongly suggesting that they were indigenous to and syngenetic with the deposition of the fossiliferous deposit – microbe-like objects present on and penetrating into the graptolites rather than being modern surficial contaminants. Such studies also showed the spheroids to be present only on the outer surface of the graptolites, providing no clear evidence of indigenousness. The SEM work indicated a need for special precautions to avoid contamination (e.g., storage of graptolite specimens in glycerol) and the collection of additional specimens. At that time, the filaments and spheroids seemed likely to be microscopic fossil bacteria but their age and origin had not been firmly established.

Recently, at the University of California, Los Angeles, we have used Raman spectroscopy and confocal laser scanning microscopy (CLSM) to analyze these microscopic objects, techniques that have been used previously to establish the cellular anatomy and molecular carbonaceous structure of filamentous and coccoidal microscopic fossils similar to the minute objects studied here (e.g., Schopf & Kudryavtsev 2010). To accomplish this work, graptolite-containing rocks were obtained from drill cores (Kybartai-14, Milaičiai-103 and Vištytis-17) in southern Lithuania. The sampled units are from the Gorstian–Ludfordian boundary (Ludlow), a stratigraphic level at which in the middle Ludlow contains a mass occurrence of pristiograptids (Paškevičius et al. 2012), well known as the "*Leintwardinensis* Event" (Koren' 1987).

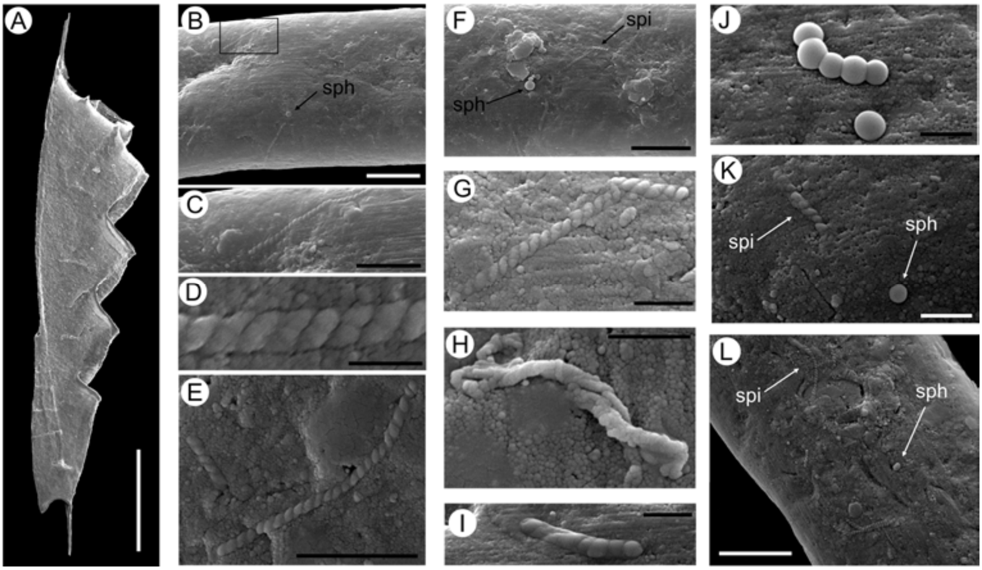

Fig 1. **A.** *Pristiograptus* sp., Ludfordian, depth 986.3 m, Kybartai-14 well (VU.P.K14-277). **B–D.** Spiral (SPI-KYB-14-01) and spherical stuctures. **C.** Larger image of spirally coiled bacteria. **D.** Spiral structure. **E.** Curved spirally coiled bacteria (SPI-KYB-14-02). **F.** Spherical structure and spirally coiled bacteria. **G.** Larger images of folded spirally coiled bacteria (SPI-KYB-14-03). **H.** Twisted spirally coiled bacteria (SPI-KYB-14-04). **I.** Small spirally coiled bacteria (SPI-KYB-14-05). **J.** Spherical stuctures. **K.** Spiral (SPI-KYB-14-06) and spherical stuctures. **L.** Spiral (SPI-KYB-14-07) and spherical stuctures. Abbrevations: spi = spirally coiled bacteria; sph = spherical stuctures. Scale bars: A = 1 mm; B, F, L = 10 μm; C, E = 5 μm; D = 1 μm; G–K = 2 μm.

Raman spectra and 2D-Raman images of the microscopic spiral filaments establish that they are composed entirely of kerogenous carbonaceous matter. Importantly, such data show that the filaments are identical in molecular-structural composition to the kerogen comprising the graptolite on which they are situated (being composed primarily of polycyclic aromatic hydrocarbons, PAHs), indicating that both the filaments and the graptolites have undergone the same degree of geochemical alteration – a firm indicator that the surficial/penetrating minute filaments are fossils, not modern contaminants. These Raman data have been confirmed by use of CLSM, which detects the fluorescence signal derived from the kerogen-comprising PAHs of both the spiral filaments and the graptolites on which they occur. Taken together, SEM, Raman, and CLSM establish that the minute spiral filaments are ancient graptolite-encrusting microscopic fossils.

Of the many types of modern spiral bacteria, the most likely analogue of these minute epibionts is *Oceanospirillum* and related gram-negative members of the proteobacterial order Oceanospirilles, most of which are halotolerant or halophilic. *Oceanospirillum*, a filamentous marine aerobe having diameters ranging from 0.3 to 1.2 μm, is essentially identical in morphology and size range to the graptolite-encrusting spiral filaments. Given current evidence, we regard it likely that the fossil filamentous bacteria are epibionts related to the Oceanospiralles. Nevertheless, morphology alone is an insufficient indicator of physiology for fossil bacteria, and these Silurian microbes could be members of a bacterial lineage now extinct. At present, we intend to propose a new genus name for these minute filaments – evidently the first such microbial epibionts described from the fossil record – and, in the absence of data that better define their phylogenic position, to refer them taxonomically to the *Bacteria incertae sedis*.

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Phylogeography of Ordovician–Silurian rhynchonelliformean brachiopods: Tracking phylogenies, radiations and extinctions in 4D

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The rhynchonelliformean brachiopods constitute the largest and most diverse sub-phylum within the Brachiopoda. Although it is rooted well down into the Cambrian Period, it was not until the early Mid Ordovician onset of the Great Ordovician Biodiversification Event (GOBE) that it rapidly diversified to become the main constituent within the Paleozoic Evolutionary Fauna (Sepkoski 1981; Harper 2006). Within a relatively short time span during the Middle Ordovician Darriwilian Stage – less than ten million years – the number of superfamilies more than doubled, as did the generic diversity. The GOBE facilitated the rise of several new clades, and the expansion of others, such as the Strophomenida, whose two superfamilies, the Plectambonitoidea and Strophomenoidea, by the early Late Ordovician suddenly accounted for almost half of the total generic diversity within the rhynchonelliformeans.

The current study has used a global database of rhynchonelliform brachiopods where every occurrence through the basal Ordovician (Tremadocian)–lower Silurian (Telychian) interval has been entered with high stratigraphical resolution and precisely georeferenced. From the Sandbian onwards all occurrences are further ecologically coded using the Benthic Assemblage Zones of Boucot (1975). This was done to incorporate a palaeobathymetrical component into the database and thus making it possible to track all the occurrences through time in three dimensions. Although originally constructed to track fluctuations in biodiversity and changing biogeographical assemblages throughout the interval (Rasmussen & Harper 2011a, 2011b; Harper et al. in press), the high resolution in space and time also makes it ideal to track and monitor the underlying phylogenetic dispersal at different taxonomical levels.

In the Early Ordovician, the high to low latitude, siliciclastic settings of Avalonia, Baltica and Gondwana were completely dominated by low diversity orthid faunas, which only contained a few other taxa that all belonged to the billingsellids. The tropical carbonate environments of Laurentia, Siberia and South China did contain a somewhat more heterogeneous faunal composition. In these settings, the pentamerid brachiopods – mainly fueled by an early Ordovician radiation within the Porambonitoidea – became at least as diverse, or, as in the case of Laurentia, even more diverse, than the orthids. South China stands out as a biodiversity epicenter. Already by the end of the

Tremadoc it contained nine different superfamilies – triple the amount of any other geographic entity at this point in time.

During the Middle Ordovician, the GOBE had a profound impact on the phylogeographic distribution all over the planet. The Orthida became less dominant. The Strophomenida now dominated the low to intermediate latitudes outside Gondwana. South China remained a diversity epicenter, being the place of origin for such important clades as the atrypids. It further now acted as a species pump, dispersing clades, such as the clitambonitoids, to the greater Iapetus region. This region began to contain a large number of clades and also acted as a cradle for new ones, such as the rhynchonellids and the triplesids in Laurentia.

The Late Ordovician saw even more new clades, notably towards the end of the Katian Stage. Important superfamilies, such as the Pentameroidea, originated in the tropical carbonate environments at this stage. However, the end-Ordovician crisis interval had a great impact on the total diversity, quickly removing more than 90 genera already at the start of the terminal-Ordovician Hirnantian Stage. This mainly hit the previously so dominant orthids and strophomenids, whereas the atrypids and pentamerids quickly took over the now vacated niches and thus diversified rapidly in the tropical shallow-water settings throughout the succeeding Llandovery Stage.

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Darriwilian (Middle Ordovician) cephalopod assemblages and palaeoenvironments across the Baltoscandian shelf

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Six localities representing different depositional settings across the Baltoscandian platform have been investigated with respect to their content of cephalopods. The localities Hällekis (Västergötland, Sweden), and Hälludden (Öland, Sweden) represent the Central Baltoscandian Confacies Belt of Jaanusson (1982), and Killeröd-Gislövshammar (Scania, Sweden) the Scanian Confacies Belt. The outcrops at Slemmestad (Oslo-Asker district) and Krekling (Eiker-Sandsvær district), both of the Oslo Region, Norway, represent the western part of the platform. The locality Røste is situated west of Lake Mjøsa, Norway, and belong to the Lower Allochthon of the Scandinavian Caledonides. It represents the most distal section encountered in this study.

The most common cephalopod taxa of the study area were described by Kröger (2012). A correspondence analysis based on the cephalopod taxa arranged in a sample-taxon matrix was carried out. Three distinct locality groups are seen (Fig. 1). Hällekis-Slemmestad-Krekling occur closely together in the lower left corner, Killeröd-Røste in the upper central part of the diagram and Hälludden in the lower right corner. Each of the three locality groups are typified by a distinct taxonomic content considered as biofacies. The three biofacies have been named the Orthocerid Biofacies, the *Proterovaginoceras* Biofacies and the *Anthoceras* Biofacies, named after their most characteristic taxa. The Orthocerid Biofacies is dominated by *Proterovaginoceras* and orthocerid cephalopods, the latter taxon group comprising more than 30% of the total cephalopod fauna. The *Proterovaginoceras* Biofacies comprises more than 85% *Proterovaginoceras*, and the *Anthoceras* Biofacies is dominated by *Proterovaginoceras* and *Anthoceras*, which together constitute more than 75% of the total cephalopod fauna.

The Orthocerid Biofacies is situated along the western and northwestern palaeomargin of Baltica facing the Iapetus Ocean and the Tornquist Sea. Although the cephalopod fauna from Killeröd-Gislövshammar is relatively sparse, it is clear that it shares characteristics with the faunas observed from Stein Formation at Røste, namely because orthocerids are much more common here than in the two other biofacies. A relatively deep-water palaeoenvironment occurring along the edge of the platform is supported by other faunas such as trilobites and conodonts (Nielsen 1995; Rasmussen & Stouge 1995).

The *Proterovaginoceras* Biofacies characterises the localities Slemmestad, Krekling and Hällekis. The Svartodden Member of the Huk Formation at Krekling was deposited at shallow depth close to the emerged Telemark land, and the equivalent deposits at Slemmestad and Hällekis in slightly deeper palaeoenvironments (Bockelie 1978; Rasmussen et al. 2011). The Hällekis section was located near the centre of the platform within the western part of the Central Baltoscandian Confacies Belt, while the two Norwegian localities have been referred to the Oslo belts (Jaanusson 1982). Cephalopods of the *Proterovaginoceras* Biofacies represent a relatively shallow-water fauna in the intermediate to outer proximal part of the shelf.

The *Anthoceras* Biofacies occurs at Hälludden, northern Öland. Both sedimentological characteristics from Hälludden and the conodont fauna of the closely situated Hagudden section (Stouge & Bagnoli 1990) indicate that the *Anthoceras* Biofacies typified the proximal shelf palaeoenvironment. The *Anthoceras* Biofacies probably represents the shallowest depositional palaeoenvironment encountered in the present study. The limestones of this biofacies were deposited in a shallow, open sea in the proximal part of the Central Baltoscandian Confacies Belt.

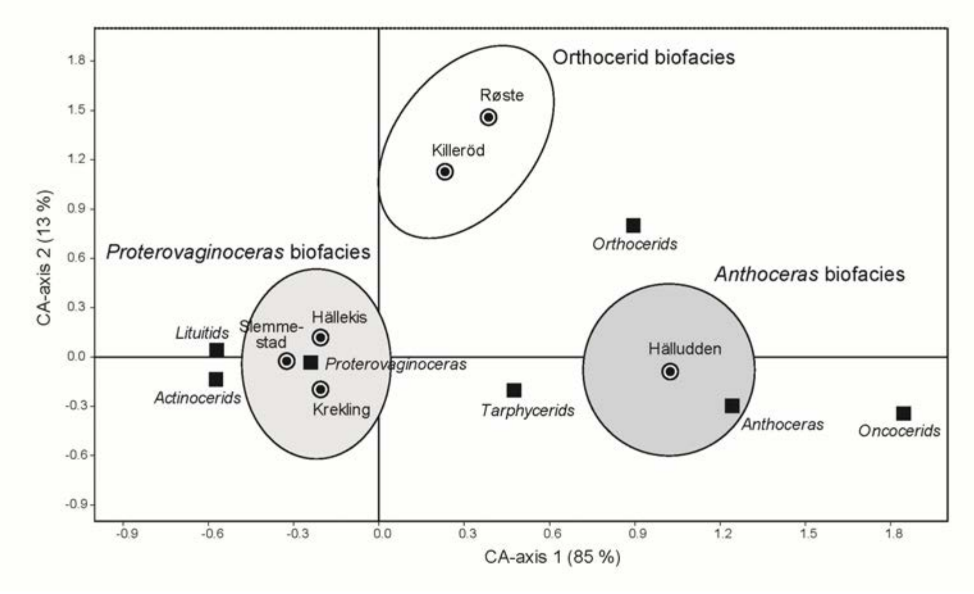

Fig. 1. Correspondence Analysis plot showing the distribution of localities, cephalopod taxa and biofacies.

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Building a better eustatic model: Comments on Cambrian to Silurian sea level change

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The establishment of a eustatic model of sea level (SL) change requires a global dataset rooted in a detailed knowledge of regional stratigraphy and built around key reference sections containing detailed age and relative SL information. Information on events affecting the biosphere, atmosphere and hydrosphere is also critical in the calibration of SL change between multiple palaeocontinents. The utilisation of such a global dataset is presented here and provides a clearer understanding of eustatic SL change and associated events during the early Palaeozoic.

By an evaluation of 97 key sections from 23 countries, augmented by primary fieldwork, 9 second-order and 27 third-order sequence stratigraphic cycles have been identified from the Cambrian, Ordovician and Silurian systems (541 to 419 million years ago). In establishing our record of SL change only sections that are biostratigraphically well constrained, show an unambiguous sedimentological expression of relative SL change and are associated with tectonically stable regions have been used. Furthermore, attention has been given to sections exhibiting isotope excursions, biotic events, glaciogenic sediments and palaeobathymetric indicators. The long-term SL trend shows a broad rise through the Cambrian to Late Ordovician, with second-order SL lows during Series 3, Furongian and Middle Ordovician times. Following the Late Ordovician SL high, pronounced SL fluctuations are observed until the mid-Silurian, after which SL broadly falls until the Early Devonian. During Cambrian to Silurian times, SL change varies in magnitude from a few tens of meters to a little over one hundred meters, with the largest changes broadly coeval with glacial-interglacial intervals. Episodes of regionally developed sea floor anoxia, biotic change and carbon isotopic excursions also appear closely linked to second and third order SL change.

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Darriwilian acritarchs and conodonts from the Källa Limestone, Öland, Sweden

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Upper Middle Ordovician limestones are poorly exposed on Öland, as old exposures and abandoned quarries are overgrown. The regional Middle (Viruan Series = upper Middle to lower Upper Ordovician global Series) Ordovician succession on southern Öland includes, in ascending order, the Segerstad, Skärlöv and Seby limestones, overlain by the Furudal Limestone and the Dalby Limestone, which forms the youngest preserved unit on Öland (Jaanusson 1960). On northern Öland the succession is different and comprises the Källa and Persnäs limestones. The Källa Limestone (2 m) represents a northern extension of the Furudal Limestone.

The abandoned quarry south-west of Källa church on Northern Öland is the type locality of the Källa Limestone. The quarry is today filled up by loose slabs and limestone blocks but small trenches in the quarry provide access to the bedrock and a section of about one meter has been accessed and collected for acritarchs and conodonts. The succession at Källa is composed of fossiliferous green to grey argillaceous limestone (wackestone) interbedded with green shaly marls. Macrofossils are rare but include trilobites (*Nileus* sp.) and articulate brachiopods (Jaanusson 1960).

Acritarchs are abundant and well preserved. The microflora is diverse but dominated by *Baltisphaeridium* and *Ordovicidium*. Associated common genera are *Pachysphaeridium, Ampullula* and *Polygonium*. *Peteinosphaeridium* is a minor component. Even though most of the identified taxa are long-ranging and are known from different palaeogeographic areas, the association is peculiar and has not been reported before.

The conodont fauna recovered from the same samples is typical for Baltoscandia and includes, among others, *Baltoniodus prevariabilis*, *Baltoplacognathus robustus*, *Oslodus semisymmetricus, Protopanderodus varicostatus and Pygodus serra*. The association indicates the *B. robustus* Subzone of the *Pygodus serra* Zone (Darriwilian; Bergström 1971). Therefore the acritarch association can be precisely assigned to Dw3.

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A stratigraphic profile of Ibexian (Early Ordovician) marine $\delta^{13}C$ variation from the type area in western Utah

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The Ibexian Series is the *de facto* standard for Early Ordovician chronostratigraphy in western North America. It is defined through type sections located in the Ibex area of western Utah, where a thick succession of fossiliferous marine carbonate is well exposed in the ranges bounding Tule Valley. The series has been divided into four stages – the Skullrockian, Stairsian, Tulean, and Blackhillsian, from oldest to youngest – that can be correlated throughout most of western North America and elsewhere. The internationally-recognized base of the Ordovician System occurs near the midpoint of the Skullrockian Stage, in the House Limestone. The paucity of biostratigraphically-useful graptolites found in the Ibex succession makes it impossible to identify precisely the boundary between the two internationally-recognized Early Ordovician stages (the Tremadocian and Floian), but it undoubtedly occurs near the base of the Tulean Stage.

The Ibexian $\delta^{13}C$ profile is dominated by the 'ELMO Low', an Extended Lower to Middle Ordovician interval of negative $\delta^{13}C$ values that is estimated to be at least 10 My in duration and encompasses most of the Ibexian Series. In the type region, $\delta^{13}C$ values during the ELMO Low remain consistently 2–3‰ lower than the ~+1‰ $\delta^{13}C$ values that are predominant in the Upper Cambrian. The ELMO Low begins with the Basal *Rossodus* Isotope Event (BRIE), a broad 2–3‰ negative shift through the upper half of the Skullrockian Stage, beginning just above the internationally-recognized base of the Ordovician System in the House Limestone. The BRIE Event is followed by the Basal Stairsian Positive Interval (BASPI), or 'Stairsian Step', a sharp and relatively brief (<1 My) rise of ~3‰ that reaches its maximum just above the base of the Stairsian Stage and ends within a few meters of the base of the Fillmore Formation.

Several secondary features of ~1‰ variation in $\delta^{13}C$ values are present within the Ibexian $\delta^{13}C$ profile. A trio of 1‰ oscillations in the lower half of the Skullrockian Stage have been reported previously by Ripperdan et al. (1992) and Ripperdan and Miller (1995). This interval of Cambrian–Ordovician Boundary Oscillation (the COBO Interval) merges into the ELMO Low and BRIE Event just below the base of the *Rossodus manitouensis* Zone. Within the ELMO Low, a rapid 1.5‰ decline is interrupted by a shorter-lived 1‰ rise in $\delta^{13}C$ values in the upper half of the (informal) basal ledge-forming member of the Fillmore Formation. Trilobite-based correlation to the El Paso Group in southern New Mexico and western Texas confirm that these short-lived $\delta^{13}C$ variations are undoubtedly a record of the 'Jose Event' of Taylor et al. (2004), which serves as a useful chronostratigraphic marker for the Stairsian-Tulean stadial boundary. A minor ~0.8‰ positive excursion is restricted to the third informal member of the Fillmore Formation. A short-lived negative excursion of 1‰ is restricted to the upper half of the (informal) brown slope and ledge member of the Fillmore, beginning just above the base of the Blackhillsian Stage. This negative excursion is followed by a 1‰ fall to $\delta^{13}C$ values of ~-2‰ that begins just below the base of the *Calathium* member, the uppermost informal member of the Fillmore Formation. $\delta^{13}C$ values rise to near -1‰ in the middle of the overlying Wah Wah Limestone, followed by a rapid ~1‰ negative excursion that ends in the lowermost Whiterockian, just below the base of the Juab Limestone.

The COBO interval, the BRIE Event, the 'Stairsian Step' and the Jose Event are readily identified in a coeval $\delta^{13}C$ profile from the Argentine Precordillera (Buggisch et al. 2003). The ELMO Low can be identified prior to the Jose Event, but in the Argentine profile, $\delta^{13}C$ values reach those of the COBO interval by the end of the Tulean Stage. Despite this difference, secondary features within the upper part of the ELMO Low can be recognized from both locales and show potential for international correlation, and raise important questions about the environmental mechanisms responsible for the ELMO Low.

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The HERB Event: A chemostratigraphic marker for the base of the proposed Lawsonian Stage (Cambrian Stage 10)

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The HERB Event is a unique, easily recognized Sunwaptan-aged (Upper Cambrian Stage 10) negative excursion in the carbon isotopic value ($\delta^{13}C$) of marine carbonates. It marks the end of an interval of predominantly positive $\delta^{13}C$ values that exhibit relatively minor variability following the dramatic positive $\delta^{13}C$ excursion of the Steptoean-aged SPICE Event (Jiangshanian Stage). The HERB Event allows identification of the base of the proposed Lawsonian Stage in barren or sparsely fossiliferous carbonate successions. The pattern of $\delta^{13}C$ variation within the HERB Event is remarkably consistent despite marked regional variability in the absolute magnitude of isotopic variation, and it provides an important constraint for identification and correlation of the base of the proposed Lawsonian Stage.

Ripperdan et al. (1992) first identified a rapidly changing and roughly symmetrical negative excursion of ~4‰ in $\delta^{13}C$ values within the uppermost Chatsworth Limestone at Black Mountain (Mt. Unbunmaroo) in western Queensland, Australia. Ripperdan & Miller (1995) found a temporally-equivalent negative $\delta^{13}C$ excursion of ~2‰ slightly above the base of the Red Tops Member of the Notch Peak Formation near the base of the Lawson Cove section in the Wah Wah Mountains, western Utah. Sial et al. (2008) found a negative excursion of >4‰ in the Sunwaptan-aged Flecha Formation at Quebrada de La Felcha in the Eastern Precordillera of Argentina and correlated it to the HERB Event at Black Mountain and Lawson Cove. Subsequent investigations have identified a ~5‰ negative excursion in the Martin Point Member of the Green Point Formation in the Cow Head Group, western Newfoundland. In western Utah and southern Nevada, at least six sections have coeval negative excursions of 1–2‰. A ~2‰ excursion was found in the Sunwaptan-aged Shoshone Canyon section near Cody, Wyoming, and an ~1‰ excursion was found at the Threadgill Creek section, central Texas. Others have suggested that the HERB Event is identifiable in the Tarim Basin and Jilin province, in China (Zhang et al. 2000; Jing et al. 2008).

In continuous sections with well-resolved conodont biostratigraphic data, the HERB Event begins slightly below the base of the *Eoconodontus* Zone (at Black Mountain, the HERB Event begins near the base of the *Hispidodontus resimus* Subzone, which has been previously identified as a useful proxy for the base of the *Eoconodontus* Zone). $\delta^{13}C$ values reach their nadir in the upper third of the thin *E. notchpeakensis* Subzone and eventually return to pre-HERB Event values at the base of the *Fryxellodontus inornatus* Subzone. Most sections preserve a minor (~0.5‰) positive excursion away from the longer post-nadir trend of rising $\delta^{13}C$, and this feature has proven to be reliably associated with the base of the *Cambrooistodus minutus* Subzone. The post-nadir trend of rising $\delta^{13}C$ values is also interrupted by a ~1‰ fall below the base of the *Hirsutus hirsutus* Subzone. This younger feature is not readily identified in all sections and appears to be controlled in part by strong regional differences in depositional rate. The HERB Event subsequently transitions into the ~1‰ oscillations of the basal Ibexian Series previously described in Ripperdan et al. (1992) and Ripperdan & Miller (1995).

The cause of the major carbon cycle perturbation evidenced by the HERB Event is not well understood. Strong regional differences exist in the absolute magnitude of the HERB Event, but the role of paleogeography – if any – is unknown. There appears to be no simple relationship between absolute magnitude and depositional environment; the most striking $\delta^{13}C$ records are from successions deposited in the shallowest (Black Mountain) and deepest (Green Point) water depths.

The HERB Event, in combination with conodont, trilobite, and brachiopod faunas, and sequence stratigraphy, provides a strong basis for correlating the base of the proposed Lawsonian Stage. The magnitude of change during the HERB Event yields a pattern of $\delta^{13}C$ variation that is unique within the interval between the Jingshanian-aged SPICE Event and the base of the Floian Stage, and can be used to identify the base of the Lawsonian Stage in barren or sparsely fossiliferous carbonate successions.

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An Early Paleozoic global change: Climate change to glaciations

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The purpose of this presentation is to analyze the Early Paleozoic global change for the cooling tendency for the climate between Early Cambrian and Late Ordovician. Regarding the different parameters involved in the quantity of solar energy received by the Earth (Pi), first the increase of the radius of the Earth through the episode induces a relative reduction of Pi from 0.01 to 0.04%, considered as not sufficient to explain the cooling tendency (Rousselle unpublished). Secondly, the increase of the solar constant through the episode implies a relative increase of Pi estimated to 0.4% (Rousselle unpublished). Consequently, the contribution of other physical agents should at least counter-balance this warming effect.

The application of Milankovitch theory with continuity of the actual factors should modulate the energy Pi from more or less 3.4% relatively, taking into account a variation of the distance Earth–Sun for more or less 2.5 million kilometers (Rousselle unpublished). This could explain the climate modulation with the different phases of the Ordovician glaciations but not explained sufficiently the entrance into these conditions. By these considerations about the distance Earth–Sun, it is supposed that there is no chaotic occurrence of strong disturbance of this distance due to the stabilizing influence of the Moon. Astronomers generally agree on this, but we have no complete evidence through the period, so doubt is remaining. Thus, we should introduce the four parameter for Pi, i.e., the factor (1 - A), as A is defined as the albedo. With the assumption of a value of 0.2 for the albedo A during the Early Cambrian and of 0.3 during the Late Ordovician when glaciations occurred (Rousselle unpublished), it is shown that the energy Pi decreases relatively to 12.5%. That means increase of albedo could be a significant factor for climate change towards more cooling climate conditions, even if absolute values of albedo are not well known through the episode. But a question is raised: which phenomena could modify the global albedo through the time of the episode? My answer to that question is consisting of the own theory I develop below and implicating during the episode the geodynamic regime of the continents, the oceanic currents and the green house gas in the atmosphere for climate change.

During the episode, the continents broke up and new oceans appeared and enlarged (Iapetus ocean, Rheic Ocean) and the geodynamic regime should mainly be in a rifting regime, even if some collisions and orogenies occurred. Consequently, during the episode, a larger number of oceans formed to the detriment of larger and older oceans. And more thermohaline currents should occur transferring more heat from low latitudes to more or less high latitudes. The link with albedo A is proposed to be the following: the existence, speed and flowrate of an oceanic current should be correlated to the albedo A. A more powerful oceanic current extracts more heat from the water oceanic mass by convection through the climatic processes at the surface between ocean and atmosphere and increase the albedo. A second phenomenon due to the rifting regime is the creation of more coasts so more area with oceanic climate with increased albedo, consequently. It induces a cooler climate as the first phenomena. A third phenomenon is an increase of the albedo as the surface of ice cap increases. It induces a cooler climate. A fourth phenomenon is regarding the greenhouse gases in the atmosphere. An increase of their content in the atmosphere can be considered as a reduction of the albedo A and an increase of the energy stored in the oceans and the continents. It induces a warmer climate.

During the episode, the four types of phenomena should result in an increase of the albedo and secondly in combination with the other main factors (solar constant and Earth astronomic parameters) could explain the cooling tendency.

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The Rheidol Gorge (central Wales) as potential stratotype for the Rhuddanian/Aeronian stage boundary: A progress report

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The type Llandovery area of Carmarthenshire, Wales, following work by Cocks et al. (1984), was accepted as the global standard by the International Subcommission on Silurian Stratigraphy (ISSS). Within this, the GSSP of the Aeronian Stage has its base in the Trefawr track section [SN83803953], within the Trefawr Formation at a level reported by Cocks et al. (1984) to lie at the base of the *triangulatus* Biozone. Subsequent revision of the stratigraphy and facies architecture of the Llandovery type area (Davies et al. 2013) uncovered serious issues with the type Llandovery sections. The Aeronian GSSP, in a shelf setting, is very sparsely fossiliferous, with further collecting and new micropalaeontological analysis having yielded insufficient data for precise correlation. The validity of this stratotype is questionable, and an alternative stratotype might be needed. The Rheidol Gorge section near Pont-Erwyd in central Wales, in a correlative basinal setting, has been long studied (Jones 1909; Sudbury 1958; Cullum & Loydell 2011) and might serve as alternative stratotype section for the base of the Aeronian. With support from the Paleontological Association, the section has been logged and recollected.

The Rheidol section in central Wales, though overgrown since Jones's and Sudbury's time, still represents a more or less continuously graptolitic section (in a basinal setting) from Rhuddanian to Aeronian strata, albeit with significant non-graptolitic intervals originally identified by Jones, contrasting with the stratigraphy to the east in the Rhayader district (Davies et al. 1997) where a continuously anoxic, graptolite-bearing succession has been recorded. Correlation of the stratigraphic logs produced by Jones (1909), Sudbury (1958) and Cullum & Loydell (2011) has allowed unequivocal identification of the boundary interval, located by identification of graptolites (the incoming of triangulate monograptids; cf. Zalasiewicz et al. 2009). The boundary interval was mechanically excavated to clear it of substantial amounts of gravel, mud and vegetation, and the boundary ~1 m portion logged at cm- and (via thin sections) mm-scale. A detailed and previously unrecognised event stratigraphy comprises alternations of seemingly oxic (bioturbated? and largely graptolite-free) and anoxic (carbon-rich, laminated, graptolite-bearing) strata. These occur as alternating centimetre- to decimetre-scale packets around the boundary, seen as an increase in the proportion of dark, laminated graptolitic strata that may correlate with a marine flooding surface identified in the type Llandovery area by Davies et al. (2013). Individual turbidite units punctuate the succession, while new graptolite-bearing levels have been identified. Stratigraphically useful chitinozoan assemblages from the boundary interval, indicating the *Spinachitina maennili* Biozone, can be directly correlated to the original type Llandovery area.

The Rheidol Gorge section thus has potential as a candidate stratotype for the Rhuddanian/Aeronian boundary, being more precisely correlatable than the existing type section in the Llandovery area. It is accessible, and possesses abundant and well-preserved graptolites and chitinozoans, a detailed event- and lithostratigraphy, and chemostratigraphic potential within a moderately expanded and seemingly continuous section.

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Traces of global and regional sedimentary and biotic events in the middle–late Ordovician and early Silurian Gorny Altai and Salair sections (Siberia)

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Studies of the Early Ordovician terrigenous sequences in the Gorny Altai (SW Siberia) reveled presence of global sedimentary events (Sennikov et al. 2011a). Beginning in the Middle Ordovician, within the Altai-Salair paleobasins, conditions of terrigenous sedimentation were followed by a general trend towards an increase of carbonate content in the sequences, attaining several peaks of reef systems in Katian, Hirnantian, Telychian, Sheinwoodian, and a following reduction of carbonates towards the terminal Silurian can be observed (Sennikov et al. 2008).

Regional late Dapingian regressive event

In the Uymen'-Lebed' paleobasin, NE Altai, a regressive "Karasu" sedimentary event is traced at boundary beds between the *caduceus imitatus* and *sinodentatus/Cardiograptus* subzones of the *hirundo* graptolite Zone. This sedimentary event is documented in the Karasu Formation as a basal bed of bar-generated coarse-grained yellowish-grey sandstones overlain by deep-water dark-grey mudstones of Tuloi Formation.

Regional late Darriwilian regressive event

In the Charysh-Chuya paleobasin, west Altai, a regional regressive "Bugryshikha" sedimentary event is defined through a basal conglomerate bed overlain by deep-water black mudstones of the Voskresenka Formation, at the boundary level between the *balchashensis/kirgisicus* and *geminus/jakovlevi/coelatatus* graptolite zones.

Regional late Katian–early Hirnantian transgressive event

In the terminal Ordovician (late Katian–early Hirnantian) in the Charysh-Chuya paleobasin, a large-scale regional transgression spike is observed. In one group of sections it is documented by the fast growth of reefs within the Tekhten' Formation, and in another group of sections by the appearance of radiolarites in siliceous-terrigenous sequences (Sennikov et al. 2011b). This was due to intensive warping of the Charysh-Chuya paleobasin, exceeded by a quick general reduction of the global ocean level in connection with the Late Ordovician glaciation.

Global terminal Ordovician regressive event

During the Late Ordovician glaciation and mass extinction of paleobiota, this event is marked in the Uymen'-Lebed' paleobasin by the abrupt change of grey-colored carbonates and fine-terrigenous sediments of the Guryanovka Formation to red-colored terrigenous (sandstone and gravelstones), extremely shallow-water sequences of the Cheborka Formation. In the NW Gorny Altai, in dalmanitina limestones, the middle HICE excursion has been established (Sennikov & Ainsaar 2012).

Global early Sheinwoodian biotic event

In the lower Silurian Charysh-Chuya paleobasin, the Early Sheinwoodian biotic event has been defined. From black mudstones of Chesnokovka Formation, graptolites of the *insectus* and *centrifugus* zones were found. Directly over the relatively deep-water terrigenous sequences, massive light grey reef limestones of Chagyrka Formation occur.

Global late Wenlockian biotic *lundgreni* event

In the lower Silurian Altai (Charysh-Chuya paleobasin) and Salair (Gurievsk-Eltsovka paleobasin) sections, a lithological manifestation of the late Wenlockian *Cyrtograptus lundgreni* global extinction event was found. In the Gorny Altai, it is marked by thin (1–2 m) nodular clayey limestones in the upper Chagyrka Formation massive limestones, which are overlain by the yellow-grey mudstones and sandy limestones of the Kuimov Formation. In the other Altai sections, in dark-grey and yellow-grey mudstones of the Kuimov Formation, the earlymost Homerian (*lundgreni*/*testis* Zone) graptolites *Testograptus testis*, *Monograptus* cf. *flemingi* and *Cyrtograptus* sp. have been obtained. In Salair, transitional forms of the graptolites *Monograptus priodon–Monograptus flemingi*, defining the early Homerian age (*lundgreni*/*testis* Zone), were found in yellow and grey mudstones of the Potapovka Formation. Yellow-light-brown sandstones found in Altai and Salair sequences dated to graptolites of *lundgreni* Zone could be regarded as a marker bed for this event on the south of Siberia. They are identical to light-brown-yellow limestones that form a marker bed for the *lundgreni* biotic event in Tadzhikistan sections (Koren 2000).

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Palaeogeography, palaeobiogeography, surface water currents and upwelling zones in the Lower Palaeozoic

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The Lower Palaeozoic experienced a significant rise in marine biodiversity and an increase in the biocomplexity of marine life representing one of the two significant radiation events in the history of marine life. This Lower Palaeozoic radiation (that extends into the Devonian), includes both the 'Cambrian Explosion' and 'The Great Ordovician Biodiversification Event' and it has been associated with important palaeoecological changes, such as the 'Cambrian substrate revolution', the 'Ordovician plankton revolution' and the 'Devonian nekton revolution'. The unusual environments of the Lower Palaeozoic were associated with extensive epicontinental seas, which developed during periods of high sea level and limited land areas; these were probably represented by occasionally emergent archipelagos. Sea levels were most probably the highest of the Palaeozoic and possibly the highest of the entire Phanerozoic; there are no modern analogues to the epicontinental seas of the Lower Palaeozoic. Magmatic and tectonic activity was intense and persistent, and associated with rapid plate movements and widespread volcanic activity. The continents were widely dispersed favouring the provincialism of most benthic, nektic and planktic fossil groups, especially in the southern hemisphere, where most of the continental plates were gathered. Since 1990 major advances in the taxonomy of Early Palaeozoic groups have been achieved in parallel with improved stratigraphic correlations of Lower Paleozoic rocks and quantitative analysis of the stratigraphic and biogeographic fossil record. Moreover, and most significantly, there has been a quantum leap in the accuracy and precision of palaeogeographic reconstructions, reconciling in many cases palaeomagnetic data and the distribution of fossil organisms. Available global pre-drift maps for the Early Palaeozoic can now be used to plot and analyse fossil distribution data and further attempts to place major biotic events, such as extinctions and radiations, in a paleobiogeographic scenario. As global reconstructions for the Lower Palaeozoic are now becoming more reliable, ancient atmospheric and oceanic circulation patterns can now be modeled with some confidence. In the present paper, we examine previous studies on Lower Palaeozoic surface water currents. It can be assumed that past circulation patterns were governed by the same factors that govern them today. The distribution of organic-rich rocks and sili-

ceous biogenic sediments (e.g., radiolarites) are indicators of paleoceanographic conditions. Based on a number of palaeogeographic maps for the Lower Palaeozoic we take a fresh look at the pattern and dynamics of surface currents and attempt to understand the loci of upwelling zones during the Early Palaeozoic.

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The palaeogeographical spreading of the acritarch genus *Veryhachium* during the Ordovician

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The acritarch genus *Veryhachium* Deunff 1954, originally described from the Ordovician of Britanny, western France, is one of the most frequently recorded organic-walled microphytoplankton genera. Over 250 specific and subspecific taxa are recorded from the Cambrian to the Oligocene, and the genus is generally abundant and widespread throughout the Phanerozoic.

The detailed analyses of the first occurrences of *Veryhachium* in different localities from different palaeocontinents provided precise first appearance data (Servais et al. 2007). In addition, it is also possible to describe the palaeobiogeographical radiation of the genus from the South Pole to all Ordovician palaeocontinents: first *Veryhachium* specimens appeared in the middle part of the Tremadocian (Early Ordovician), and possibly earlier in the early Tremadocian, at levels where graptolites of the *R. flabelliformis* group occur, in localities from North Africa, which was located at the South Pole during the earliest Ordovician. Subsequently, *Veryhachium* is also present in the late Tremadocian in localities of the Gondwanan margin in North Africa and Avalonia (English Lake District and Rügen Island, Germany), which are all considered to have been located at high latitudes (>60°) in the southern hemisphere. In China, located at intermediate latitudes (between 30° and 60°S), *Veryhachium* has not been recorded below the lowermost Floian (lowermost Arenig), and in Argentina, located at similar latitudes, not below the middle Floian (lower–middle Arenig). *Veryhachium* has not been recorded outside of peri-Gondwana during the Tremadocian. The first occurrence on another palaeocontinent, Baltica, is recorded in the lower Floian, but the genus did not become common until the Darriwilian (Middle Ordovician). This suggests that *Veryhachium* first appeared in the Tremadocian at high latitudes before it radiated to lower latitudes of the Gondwanan margin (China and Argentina) and Baltica during the Floian, to become cosmopolitan by the end of the Middle Ordovician.

After the Middle Ordovician, the genus became a major component of most open marine acritarch assemblages throughout the Palaeozoic. For instance, in the Permian, it is the most frequently recorded microphytoplankton taxon. *Veryhachium* dominates most open marine acritarch assemblages with numerous taxa belonging to the '*Veryhachium-Micrhystridium* complex.'

The relatively slow expansion of *Veryhachium* in the Ordovician, over some 20 million years from a regional distribution in high latitudes in the early–middle Tremadocian to a cosmopolitan distribution in the Upper Ordovician, raises the question of the usefulness of the genus *Veryhachium* for biostratigraphical correlations. Although of significant importance for regional stratigraphical correlations in the earliest Ordovician, intercontinental correlations using the genus should be analysed with greatest care.

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What happened in north–east Gondwana during the IGCP 591 interval?

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Most of the activity relating to northeast Gondwana during the interval covered by IGCP 591 is situated within the Lachlan Orogen/Fold Belt (Gray & Foster 2004), also known collectively as the Tasmanides (Glen 2005). This orogenic belt, which includes also the poorly defined Thomson Orogen (Burton 2010), is situated in the eastern margin of the modern Australian continent. There are extensive Ordovician and inferred Siluro-Devonian sediments in the centre and west of the continent, in particular the Larapinta rift zone, but much is in areas of poor outcrop and known only from drill cores. The best-known and probably most complete sequences are in Victoria and New South Wales.

Middle Ordovician to early Silurian

Around the Middle to Late Ordovician boundary (Darriwilian–Sandbian, or Darriwilian–Gisbornian to use Australasian units) there was a marked change in sedimentation in the eastern part of what is now the Australian plate. The turbiditic sand and silt, which characterised the Early Ordovician Adaminaby Group, was replaced by black shale deposition with extensive quartz sandstone fans of the Bendoc Group. In central New South Wales there was extensive shoshonitic volcanism, associated with monzodioritic intrusives around the Ordovician–Silurian boundary. In shallower areas there was widespread carbonate sedimentation on weathered Early Ordovician or older basaltic volcanics. There is no obvious break in deep water sequences between the Ordovician and Silurian, although recognition of the boundary is difficult in structurally complex sequences with patchy fossil control.

Mid to late Silurian

In central Victoria there is apparent continuity of sedimentation throughout the Silurian, although there are gaps in the recognised graptolite zonation. In central New South Wales there are no obvious breaks in the largely black shale Cotton Formation which has graptolites ranging from Late Ordovician (Bolindian) to early Silurian (late Llandovery), although not all European zones can be recognised. However, it is questionable how relevant an essentially European zonation scheme is for seas surrounding the Gondwana continent. There is a widespread hiatus from the late Llandovery to early Wenlock throughout the Lachlan Orogen. In shallow water sequences of central New South Wales there is an even longer break indicated where weathered Late Ordovician volcanics are overlain by limestone of Wenlock age. European Silurian bioevents tend to correlate with graptolite zonal hiatuses or even angular unconformities in the Lachlan Orogen (Sherwin 2010). Silurian volcanism, particularly in New South Wales, is notably felsic in composition in comparison with the shoshonitic Late Ordovician volcanics. There was also considerable granitic intrusion in the southern Lachlan Orogen (Glen et al. 2007). Away from the Lachlan Orogen in central and Western Australia the Silurian consists of poorly fossiliferous sandstone and evaporates with even the period boundaries in doubt (Walley et al. 1990).

Late Silurian to Early Devonian

By late Silurian (Ludlow) there are distinct tectonic histories across the Lachlan Orogen. In the east, within New South Wales, the Hill End Trough is a rift feature which commenced in the late Wenlock (Pickett et al. 1996) and terminated with inversion in about the late Emsian. Immediattely west of this trough, particularly in the Yass district, there is an hiatus in the early Lochkovian, followed by a largely shallow water calcareous sequence terminating with a polymictic conglomerate and quartzose sandstone close to the Emsian–Eifelian boundary (Young 2011). On both sides of the Hill End Trough the Lochkovian is marked by considerable felsic volcanism. In the central and western divisions of the Lachlan Orogen there is a diachronous hiatus ranging from latest Ludlow to Pridoli, followed by a mostly conglomeratic to sandy series of formations with only minor limestone and felsic volcanics. The sandstone in particular is commonly reddish and analogous with the Old Red Sandstone of northwest Europe. These largely siliciclastic sequences were deposited in basins of variable depth but shallower basins have a distinct mid Lochkovian break marked by small granitic intrusives. Succeeding formations are likewise dominated by lithic quartz sandstone and terminate by the early Emsian (Sherwin 1996). It is also possible that the thick sandstone formations in the terminal Larapintine rift zone of central Australia persisted into the Early Devonian but reliable fossil dating is wanting.

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Ludlow Series in the Prague Synform – a progress in biostratigraphic correlation

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The Ludlow Series in the Prague Synform is marked by general transition from shale-dominated Gorstian to largely carbonate sedimentation in the Ludfordian. The facies distribution and changes reflect a regressive-transgressive eustatic regime combined with tectonically unstable basin settings and synsedimentary alkaline basalt volcanism. Accordingly, shallow carbonate facies that first developed near the volcanic centers are very diverse, whereas the deeper environment is rather monotonous. In the past years a progress was made to enhance biostratigraphic correlation among local facies of the Prague Synform and the global correlation of the Ludlow strata by integration of new biostratigraphic data on graptolites, conodonts and additional pelagic and benthic faunal groups.

The conodont zonation of the lower Ludlow (Gorstian) remains unchanged due to limited conodont occurrence in the shale-dominated succession. The late Gorstian time is characterized by *K. variabilis* Interval Zone and *A. ploeckensis* Zone that may even straddle the Gorstian/Ludfordian boundary. The graptolite zonation includes three biozones: *N. nilssoni, L. progenitor,* and *L. scanicus/S. chimaera.* The limestone-dominated Ludfordian strata allowed much finer biozonal subdivision of the Stage. It consists of six conodont biozones and faunal intervals: *P. siluricus* Zone, *Delotaxis* fauna interval, *P. plodowskii*, *Ped. latialatus*, "*Oz.*" *parasnajdri* and "*Oz.*" *crispa* biozones (Slavík & Carls 2012). Six biozones are recognized among graptolites (*S. leintwardinensis*, *B. tenuis*, *N. inexpectatus*, *N. kozlowskii*, *P. latilobus/S. balticus* and *P. fragmentalis* zones), although for the most part in the offshore, shale-dominated facies. Systematic sampling in selected sections suggested a tentative, but so far the most accurate juxtaposition of conodont and graptolite biozones. The integration of conodont-graptolite biostratigraphy substantially improved also the correlation of the global extinction bioevents of Ludlow Series.

The lower Ludfordian graptolite fauna suffered from the *leintwardinensis* Event, which is characterized by extinction of spinose *Saetograptus*, last plectograptids and subsequent demise of cucullograptids. Also, nautiloid cephalopods of Baltic provenience temporarily vanished from the Prague Synform fossil record, whereas straight-shelled pelagic orthocerid cephalopods remained intact. The extinction interval appears to coincide with rising sea level, although no marked change in $\delta^{13}C$ has been recorded worldwide. The pronounced mid-Ludfordian Lau/Kozlowskii Event was characterized by extinction among pelagic faunas, with particular reference to planktonic graptolites. Selective coeval extinction of several little phylogenetically related taxa with ventrally curved rhabdosomes (*Bohemograptus, Polonograptus, Neocucullograptus*) was recorded at the top of the *kozlowskii* Biozone (Manda et al. 2012). Also common and widespread pelagic ostracods of the genus *Entomis* became extinct whereas orthocerid cephalopods and nektonic crustacean *Ceratiocaris* passed unaffected through the extinction interval. Conodont fauna suffered less extinction than suggested by earlier data from Gotland – the type area of the Lau Event (Slavík et al. 2010). In the Prague Synform, sediments of the critical interval are dominated by minute elements of long-ranging stock of *Delotaxis*. The faunal extinctions coincided with major fluctuations in sea level, as indicated by local unconformities associated with debree-flows slumped from the adjacent carbonate platform. A prominent positive excursion of $\delta^{13}C$ commenced in the same level. New data demonstrated the coincidence of the graptolite crisis with benthic faunal changes and a fall in sea level manifested by facies change and the carbon isotope excursion.

A distinct constraint for quantification of the true impact of the respective events on all the pelagic and benthic faunal groups arise from a combined eustatic and tectonic control on local sea-level fluctuations, recorded by abrupt and commonly local facies changes and gaps.

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The origination of the early dicellograptids based on biostratigraphy and cladistic analysis

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The abrupt appearance of early dicellograptids in the Late Darriwilian to Early Sandbian is one of the most important events in graptolite evolution. As early dicellograplids had a worldwide distribution, the crucial significance is that they can be used for the correlation of the concerned interval among regions within and outside China. How is the origination and early evolution of such world-wide graptolite group and what is the relation between jiangxigraptids (the representative clade of dicellograptids) and undulograptids (the earliest biserial graptolites)? Herein some new information on the structures (especially proximal structures) of early dicellograptids are described from exquisite, pyritic material, mostly from the Upper Hulo Shale of western Zhejiang Province and northern Jiangxi Province, SE China. The information together with previous descriptions provides the basis for a cladistic analysis of some nine taxa, which have been involved in previous discussions on the origin of early dicellograptids. Seventeen characters and their coding are briefly discussed.

Archiclimacograptus caelatus and *Expansograptus extensus* are chosen as the outgroups, while the ingroups include *Jiangxigraptus mui*, *J. wuningensis Dicellograptus sextans*, *D. vagus*, *D. gurleyi*, *Dicranograptus brevicaulis*, *Undulograptus*? *praesextans*. All of them, except the last species, are present in the upper Hulo Formation of western Zhejiang. Among the species for cladistic analysis, *E. extensus* first occurs in significantly lower horizons within the Ningkuo Formation. *Undulograptus*? *praesextans*, which was assigned to *Dicellograptus* in the light of its seemingly identical morphology to the other species of the genus, appears in the early Darriwilian in Chilianshan Mts., northwest China. Seventeen characters and nine species have been chosen, and coded to form a 9×17 matrix. The running cladistic analysis containing biostratigraphic character by PAUP 4.0 for PC turned out to be four most parsimonious cladograms. Alternatively, another analysis excluding the biostratigraphic character turned out only one cladogram.

The results show that the early dicellograptids fall into two clearly-separated groups: (1) *Jiangxigraptus wuningensis*, *Dicellograptus gurleyi*, *Dicellograptus sextans* and *Jiangxigraptus mui* with almost the same characteristic of possessing prothecal folds. (2) *Dicellograptus vagus*, *Undulograptus*? *praesextans* and *Dicranograptus brevicaulis* with almost the same characteristic of the the first some pairs of scandent thecae in the proximal end. Moreover, the analysis also shows that *Jiangxigraptus wunningensis* and *Dicellograptus gurleyi* form a sister group, implying that they are closer to each other than to others. These results suggest that the definition of the genus *Dicellograptus*, which has been widely used across the world, needs to be redefined. Meanwhile, by a comparison of the FADs of the early dicellograptids globally, it was found out herein that the interval of Middle Darriwilian is almost devoid of dicellograptids, whereas the likely earliest representative (*Undulograptus*? *praesextans*, or the likes) has been reported to appear in the early Darriwilian. There are two interpretations for this phenomenon: either the dicellograptids originated independently in the latest Darriwilian in the major regions across the world, or they did exist in the middle Darriwilian but left no records, or the records have not yet been discovered.

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Integrated upper Homerian (Silurian) biostratigraphy and chemostratigraphy of the Viduklė-61 well, Lithuania

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The type section of the Gėluva regional stage is in the Jakšiai-104 borehole 813–776.9 m interval (Paškevičius et al. 1994). The lower boundary of the Gėluva regional stage is marked by the upper boundary of the *lundgreni* Biozone and the upper boundary is marked by the lower boundary of the *nilssoni* Biozone. Based on this the Gėluva regional stage covers the upper part of Homerian. The lower part of Gėluva is marked by one of the biggest Silurian graptolite and conodont extinction episodes. This extinction is well known all over the world and called the Big Crisis (Große Krise), the *lundgreni* or/and Mulde event. The purpose of this report is to integrate graptolite and conodont biozones with the $\delta^{13}C$ excursions in the Viduklė-61 well in order to better understand the extent of the Gėluva regional stage and the timing of Mulde Event.

In the Gėluva regional Stage in the Viduklė-61 well, we identified the following graptolite biozones: *parvus* (1309.9–1302.8 m), *nassa* (1302.8–1298.5 m), *praedeubeli* (1298.5–1289.9 m), *deubeli* (1289.9–1282.6 m) and *ludensis* (1282.6–1275.1 m). The lower boundary of the Gėluva stage is marked by the *lundgreni* event. Graptolites are absent from the last occurrence of *lundgreni* Biozone graptolites to the first appearance of *P. parvus* and *G. nassa* (1309.9–1308.4 m). The upper boundary of the *ludensis* Biozone and Gėluva regional stage (Wenlock/Ludlow boundary) is marked by the appearance of new graptolites, typical for Ludlow. It is important to note that *Colonograptus gerhardi* (Kühne) appear in upper part of the *ludensis* Biozone and disappear in the lower part of the *nilssoni* Biozone.

In the analyzed part of the Viduklė-61 section, two conodont biozones were identified: the *Oulodus siluricus* Biozone, and the *Ozarkodina* cf. *bohemica* Biozone, which is almost coincident with the *Kockelella ortus absidata* Biozone. Due to the great depth of the basin during the analyzed time interval at the given location, there was recovered quite a low diversity and abundance of conodonts in the samples. The only find of *Oulodus siluricus* is at depth of 1297.1 m, so the full extent of the Biozone could not be determined with precision. Elements of the Biozone species *Ozarkodina* cf. *bohemica* (including *Ozarkodina* cf. *b. bohemica*) are found from 1282.3 m up until 1267 m. The *Kockelella ortus absidata* Biozone coincides almost precisely with *Ozarkodina* cf. *bohemica* (it spans from 1283 m up to 1267 m). In addition, we identified element of the

Ctenognathodus murchisoni species. The only find of it in Viduklė-61 occurred at a depth of 1302 m, i.e., 19.7 m lower than the first occurence of the *K. o. absidata* Biozone species. This observation is at odds with the interpretation that this species belongs to biozones that span after the *K. o. absidata* Biozone (Calner & Jeppsson 2003).

The carbon isotopic trends in the Gėluva regional Stage were investigated in the Viduklė-61 well by Martma et al. (2005). According to the new graptolite data, the first small positive excursion is observed in the graptolite-free interval (lower part of the *parvus* Biozone). A second, slightly greater, excursion was recorded near the upper boundary of the *nassa* Biozone. A third, still greater, $\delta^{13}C$ excursion was recognized near the upper boundary of the *deubeli* Biozone. In the following (upper) part of the section, the $\delta^{13}C$ values dropped and reached negative values in the middle part of *ludensis* Biozone. The stabilization of the negative $\delta^{13}C$ values probably is at the same level with the first appearance of *C. gerhardi*.

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Chemostratigraphy versus biostratigraphy for a chronostratigraphic subdivision of the traditional "Lower Cambrian"

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The Cambrian System is one of the last systems with numerous undefined stages and series, and here especially the traditional "Lower Cambrian" Series raises many open questions for an internationally applicable chronostratigraphic subdivision. The classical application of biostratigraphic tools faces the problems of a general lack of typical Palaeozoic faunas in the Terreneuvian, a strong faunal provincialism, uncertain biological assignments, poor international fossil distribution, and a partial facies dependence of earliest faunas. This may be due to a rarely developed pelagic lifestyle and larval dispersal of the majority of metazoans during this time interval. Especially faunal assemblages of small shelly fossils (SSFs), acritachs, trace fossils, archaeocyatha, and trilobites played an important role for the biostratigraphic subdivision of the traditional "Lower Cambrian", whereas some species of SSFs and acritarchs have a great potential for representing possible index fossils.

Some recent chemostratigraphic investigations have cast doubts on the general applicability of biostratigraphy for chronostratigraphic purposes in the early Cambrian. Claims that all SSFs have worldwide diachronous FADs were mostly based on independent chemostratigraphic correlations of carbon isotopic curves. These results require a serious and critical illumination of both biostratigraphic and chemostratigraphic tools.

In particular, carbon and strontium isotope stratigraphy has been developed into a widely applied stratigraphic correlation tool during past decades. This method has the great advantage that also unfossiliferous sections or strata can be assigned. However, carbon isotope stratigraphy has the drawback that no single values of single samples can be correlated, but only isotopic trends, which are assigned as the consequence of a basic interpretation of strata. The peaks and partial sequences of peaks are themselves not specific enough to allow undisputed correlation. This makes the method prone to misinterpretation if unrecognized or recognized hiati exist. A good example of this is the chemostratigraphy-based definition of the Pc–C boundary in Mongolia. Here peak correlation led to the proposal that strata of Upper Tsagaan Oloom Fm with a profoundly negative C isotopic shift and SSFs typical of a basal Cambrian aspect are correlative with the terminal Ediacaran. However, the chemostratigraphic studies also reported that this interval is truncated by two disconformities (above and below peak NP2). It is therefore possible that part of an isotope trend with an even more negative C isotopic excursion at the transition between middle and upper Tsagaan Oloom Fm is missing. If so, the upper Tsagaan Oloom sequence could still be regarded as Cambrian, which would prevent the conflict that typical Cambrian SSFs appear in the Neoproterozoic.

Other unresolved questions on carbon isotope stratigraphy include diverging isotopic trends in part of the studied sections, e.g. in South China and Siberia. In China the terminal Ediacaran mostly indicates a slightly positive C isotope signature, whereas in Siberia the pre-Nemakit Daldynian shows quite negative values (with the exceptions of some peaks). Therefore, the question needs to be addressed whether these isotopic trends reflect true primary and global signals. Another challenge for the application of chemostratigraphic tools in the Cambrian is the proper recognition of diagenetic alterations. However, a general challenge for both biostratigraphy and chemostratigraphy of early Cambrian strata lies in the availability of suitable complete and undisturbed sections, because the majority of the hitherto well-studied sequences are situated on shallow carbonate platfoms.

In conclusion, we propose to complement the biostratigraphy-based definition of new stages by chemostratigraphic tools such as carbon isotope excursions, although a chronostratigraphic subdivision cannot solely be based on isotope stratigraphy.

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Relating environmental change and species stability in Late Ordovician seas

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The stratigraphic record documents a series of constantly shifting environments and life forms. The continuous evolution (and eventual extinction) of species provides the framework against which geologic history can be assessed, but equally critical is the fact that species maintain morphological integrity during their lifespan. Thus, each species evolved, persisted with relatively little change, and then became extinct. The primary driver of evolutionary innovation and extinction is environmental change, including both biotic and abiotic components of the environment. Understanding the mechanisms that control when a species does and does not demonstrate adaptive response is, therefore, a critical component of understanding the Earth system. In this contribution, we examine the relative impacts of changes in the abiotic and biotic environment of a diverse suite of marine invertebrates from the Late Ordovician of Laurentia.

This study focuses on taxa that occupied a shallow marine basin centered on present day Cincinnati, OH, USA during the C3, C4, and C5 sequences of the Katian. A high-resolution sequence stratigraphic framework has previously been developed for these strata which allows investigation of time slices that are approximately 250 000 years in duration. Fine temporal intervals, such as these, are necessary for assessing direct causal relationships between environmental causes and ecological effects. The C3 to C5 sequence interval includes both abiotic environmental changes in relative sea level and significant changes in the biotic environment following the Richmondian Invasion, which facilitated the movement of extra-basinal species into the Cincinnati Basin. Using spatial distribution modeling (SDM), we reconstructed the fundamental niche for twenty-one taxa including articulated brachiopods, bryozoa, trilobites, crinoids, rugose corals, bivalves, and gastropods across nine temporal intervals. Brachiopod taxa were analyzed at the species level, whereas other taxa were modeled at the genus level. The relative degree of niche stability that taxa exhibited between time slices was assessed in both geographic and environmental space.

Niche stability varied through time. During the pre-invasion interval, taxa exhibited niche stability (= no adaptive response) to environmental changes. Instead, these taxa maintained their ecological niche and tracked their preferred environment laterally to accommodate gradual sea-level fall. Adaptive response, as indicated by increased niche evolution, became more common during the Richmondian Invasion interval. During

this interval, species adjusted to the new suite of competitor species by altering aspects of their ecological niche. Notably, surviving taxa contracted their niche into a subset of their previous niche parameters. This represents an adaptive response, and it was employed most successfully by generalist taxa. Notably, patterns of niche evolution were congruent between clades and at both the specific and generic level. These patterns indicate that adaptive response (stability vs. evolution) is related to the tempo, mode, or a combination of both aspects of environmental change. Biotic interactions played a key role in driving biotic divergence at the species level within this case study.

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Candidate sections for new international boundary stratotypes of the lower Silurian Aeronian and Homerian stages in the Prague Synform, Czech Republic

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In response to ISSS's efforts to replace unsatisfactory international boundary stratotypes of several Silurian stages and series, close attention was paid to two prospective candidate sections available in the Barrandian area of the Czech Republic.

Natural outcrop on a steep slope east of Hlásná Třebaň exhibits an unmetamorphosed middle Hirnantian through upper Aeronian siliciclastic sedimentary succession (Fig. 1; Štorch 2006), almost unaffected by tectonics. Rhuddanian and Aeronian stages are developed in form of moderately condensed black shales rich in well-preserved graptolites. Eighteen graptolite species have been recorded by Štorch (1991) in the upper Rhuddanian *Coronograptus cyphus* and lower Aeronian *Demirastrites triangulatus* biozones. Monograptid diversification across the Rhuddanian/Aeronian boundary involved *C. cyphus* and *C. gregarius*, lowest occurrences of the zonal index taxa *Monograptus austerus vulgaris* and *Dem. triangulatus*, as well as the earliest representatives of the Aeronian genera *Petalolithus*, *Rastrites* and *Campograptus*. Chitinozoan preservation is less favourable but previous studies, which recorded 15 taxa, were confined to the latest Hirnantian through earliest Aeronian strata (Dufka & Fatka 1993). Carbon isotope sampling revealed only minor and gradual positive shift in $\delta^{13}C$ from -30.4‰ in the middle *cyphus* Zone to 29.7‰ in the upper *triangulatus* Zone. The Hlásná Třebaň section, proposed as a new boundary stratotype of the Aeronian Stage, is protected by State Law as a part of the Bohemian Karst Protected Landscape.

Sheinwoodian/Homerian boundary strata, unmetamorhosed and undisturbed by tectonics, are well exposed in the lower part of large abandoned Kosov quarry, southwest of Beroun (Turek 1990). The upper Sheinwoodian through lower Homerian succession is formed by a continuous sequence of black, slightly calcareous shales with scattered nodules of micritic limestone and several thin tuffitic-carbonate intercalations slumped from a carbonate platform that fringed adjacent volcanic highs. The black-shale succession is rich in both graptolites (18 species recorded by Štorch 1991) and moderately to poorly preserved chitinozoans (16 species recognized by Dufka 1995). The upper *Cyrtograptus rigidus* graptolite Biozone, *Cyrt. ramosus-Cyrt. ellesae* Zone and

Cyrt. lundgreni Zone are involved in the section proposed as boundary stratotype of the Homerian Stage. The base of the Homerian is marked by the lowest occurrence of *Cyrt. lundgreni*, which is coincident with the highest occurrence of *Gotlandochitina martinssoni* (Dufka 1995). Other faunal elements, such as flattened shells of pelagic cephalopods, epibenthic bivalves and crinoids are rare and of limited stratigraphic significance. Preservation of the section is guaranteed by the private owner of the quarry until supposed ratification and protection through State Law.

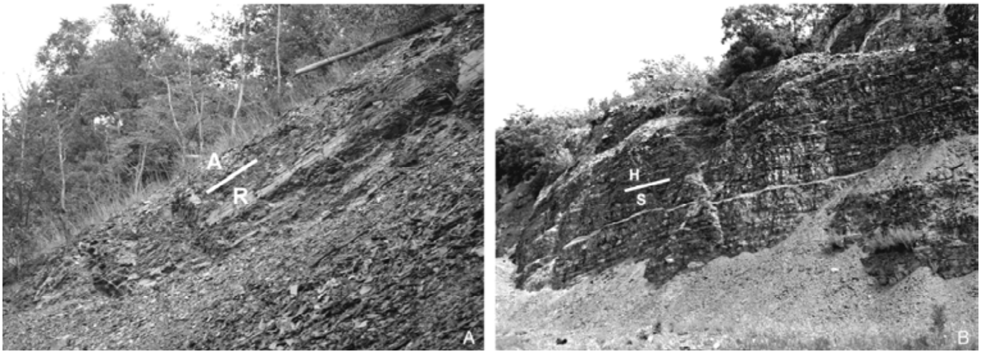

Fig. 1. **A**. View of Rhuddanian (R)/Aeronian (A) boundary exposure at Hlásná Třebaň. **B**. Sheinwoodian (S)/Homerian (H) boundary interval in the Kosov quarry. White bars indicate position of biostratigraphically dated stage boundaries.

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Constraints on the age and correlation of two problematic Telychian (Llandovery; Silurian) stratigraphic units in Ohio and Kentucky: Synthesizing biostratigraphy, $\delta^{13}C_{carb}$ chemostratigraphy and sequence stratigraphy

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Regional correlation of lower Silurian rock units in the eastern United States has been hindered by many factors, despite numerous outcrops and over a century of detailed study. However, new analytical tools and recent improvements to existing methods, such as $\delta^{13}C_{carb}$ chemostratigraphy, conodont biostratigraphy, and sequence stratigraphy, greatly expand the potential for confident correlation at regional and global scales. These techniques are utilized herein to resolve the stratigraphic relationships of two problematic Telychian (upper Llandovery) rock units: the Waco Member (Alger Shale Formation) of east Kentucky, and the Dayton Formation of Ohio. These units have several lithologic characteristics in common, they are of roughly similar age, they both overlie a major unconformity, and they had not been identified together in outcrops. The presumed equivalence of these units has been an important regional tie linking the various depositional regimes on the Cincinnati Arch and Appalachian Foreland Basin of eastern North America. However, new and published data from these stratigraphic units have cast serious doubt on this correlation. These results are synthesized here, and a refined Telychian stratigraphic framework for this succession is proposed.

Comparative studies of the sedimentological and lithologic characteristics of the Waco Member and the Dayton Formation suggest that these are genetically distinct units, representing subtly different facies. In its type area, the Waco Member is composed primarily of fossiliferous green grey shale that overlies a meter-thick basal carbonate bed containing abundant glauconite, pyrite, and frame-building organisms. To the north of its type area, the Waco becomes increasingly calcareous; here the unit is divisible into a lower "white" division that is glauconitic and highly fossiliferous, and an upper "orange" division characterized by burrowed firmgrounds and ferruginous dolostones. The Dayton Formation in its type area is sparsely fossiliferous, composed primarily of stacked, light-colored dolostone beds with numerous hardgrounds. However, it should be noted that a stratigraphic unit found in southern Ohio (Adams, Brown, and Highland counties), historically referred to “Dayton”, bears stronger lithologic and faunal similarities with the Waco of Kentucky than it does with the dolostone unit found in the vicinity of Dayton, Ohio.

Previous workers have recognized conodonts indicative of the lower Telychian in the Waco of Kentucky; similar conodont assemblages have been recognized in the “Dayton” of southern Ohio. These findings are corroborated by new and published $\delta^{13}C_{carb}$ data collected from these successions that show a positive excursion in this unit, consistent with the lower Telychian Valgu Excursion. In contrast, biostratigraphic studies from the type area of the Dayton Formation in western Ohio have reported upper Telychian conodonts from beds near the top of the unit, indicating that it is substantially younger. At these sections, $\delta^{13}C_{carb}$ values rise steadily through the Dayton, into the overlying Osgood. Interpretation of this trend is problematic, though previous workers have argued that this represents an upper Telychian interval of rising $\delta^{13}C_{carb}$ values that occurred just below the onset of the Sheinwoodian Ireviken Excursion.

The depositional history of these units may be interpreted as the result of prolonged sea-level rise during the Telychian, which onlapped the proto-Cincinnati Arch in a time-transgressive manner. Sea-level rise began during the early Telychian, inundating the lower parts of the depositional basin, where Waco strata and equivalent units were deposited. The complete flooding of the proto-Cincinnati Arch followed in the middle to late Telychian, depositing Dayton and overlying strata on topographic high points. During this later transgression, the deeper parts of the basin were marked by the deposition of the Estill Formation, a succession of green, red, and maroon mudstone that overlies the Waco. The relationship between the Dayton and the Estill is difficult to establish at a high level of precision. However, the lower part of the Estill becomes progressively more phosphatic and calcareous toward the type area of the Dayton Formation. This transition is highlighted by geologic cores taken from a transition zone between these depositional regimes, which show successions interpreted as the Dayton Formation overlying the Waco Member. While existing biostratigraphic data indicates a substantial temporal break (1–2 Ma) between the Waco Member and the Dayton Formation, no sedimentological evidence for a discontinuity in the stratigraphic record is known at this time. Though many questions remain, the data presented here may bring the goal of a high-resolution Silurian stratigraphic framework one step closer.

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Late Katian *Paraorthograptus pacificus* Graptolite Biozone from Xing'an, Northern Guangxi, China

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Ordovician–Silurian (lowest Llandovery) strata in Northern Guangxi, China is characterized by a slightly metamorphosed clastic deposit bearing a low diversity graptolite fauna. The Huang'ai-Shengping-Tianlingkou section is recognized as an Ordovician to lowest Silurian reference section in the Zhujiang Basin since the 1960s. Very recently, graptolites were discovered in the Upper Tailingkou Formation near the top of the Ordovician in the section with *Paraorthograptus pacificus* (Ruedemann), *Dicellograptus ornanus* Elles & Wood, *D. minor* Toghill, *Amplexograptus latus* (Elles & Wood), *Appendispinograptus venustus* (Hsü), *A. supernus* (Elles & Wood), *A. leptothecalis* (Mu & Ge), *Rectograptus abbreviatus* Elles & Wood, *R. socialis* (Lapworth), *R. songtaoensis* Li, *R.* cf. *songtaoensis* Li, *R.* sp. and *Yinograptus disjunctus* Yin & Mu. It clearly indicates the *Paraorthograptus pacificus* Biozone and easily to be correlated with that of the same biozone in the Wufeng Formation of the Yangtze region.

Lowest Silurian graptolites have also been found in the same section, as a low diversity but characteristic *Neodiplograptus modestus* graptolite fauna, including *Neodiplograptus modestus* (Lapworth), *Neodiplograptus anhuiensis* Li, *Normalograptus guantangyuanensis* (Fang et al.), *Paramplexograptus madernii* (Koren & Mikhailova), *Normalograptus angustus* (Perner), *N. laciniosus* (Churkin & Carter), *N. normalis* (Lapworth), *Sudburigraptus angustifolius* (Chen & Lin in press). This fauna implies the *Akidograptus ascensus-Parakidograptus acuminatus* Zone of the early Rhuddanian. Unfortunately, the Hirnantian strata were not possible to examine completely, due to limited outcrops and an absence of the Hirnantian fauna. It might be controlled by a deeper flysch-like deposit which is certainly unsuitable to the shelly *Hirnantia* fauna.

The *Paraorthograptus pacificus* Biozone in the Yangtze region bears a very high diversity graptolite fauna. It seems that the Yangtze region experienced high and stable organic productivity during this time interval.

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Chitinozoan records through Late Ordovician (Katian) to early Silurian (Rhuddanian) in China

PENG TANG[1] AND YAN LIANG[1]

Outcrops with a continuous, fossiliferous Upper Ordovician–lower Silurian succession are developed in South China. Particularly, the Hirnantian GSSP was established in Yichang, Hubei Province of China. Thus, the Yangtze Platform of South China is well known for providing excellent exposures Ordovician–Silurian boundary, and is a one of the best regions in the world for Ordovician–Silurian boundary research.

Chitinozoa is a kind of marine microfossil group, which has great potential for widespread geological correlation. The Wangjiawan North section is the GSSP section of Hirnantian. It has been shown to have a complete Ordovician–Silurian succession (Chen et al. 2006). However, due to serious weathering, no chitinozoans were obtained from there. Only a few poorly preserved specimens were found from the *P. pacificus* graptolite interval in the nearby Wangjiawan River section. This situation even made chitinozoan specialist draw a conclusion that it is impossible to identify the base of the Hirnantian by using chitinozoans in the GSSP type section (Vandenbroucke et al. 2005). It is true that weathering is sometimes very serious in the Ordovician–Silurian boundary interval in South China. 92 samples were collected from three sections, i.e., the Yanrui section of Jiangxi Province, the Wenchang section of Zhejiang Province and the Dawangou section of the Xinjiang Autonomous Region.

From the the Dakengwu section in Chun'an County, Zhejiang Province, abundant and well-preserved shelly fossils were found near the base of the Anji Formation. On the contrary, chitinozoans are poorly preserved and of low abundance and low diversity from the same interval. The chitinozoan assemblage there is composed of *Ancyrochitina* sp., *Belonechitina* cf. *postrobusta*, *Belonechitina* sp. and *Spinachitina verniersi* (Peng et al. 2012). Recently, a comparable chitinozoan assemblage, which mainly consists of *S.* cf. *verniersi*, was observed in the Anji formation from the Wenchang section, Zhejiang Province by one of the present author (P.T.) According to Zhang et al. (2007), the Anji Formation yields, e.g., *Normalograptus mirnyensis, N. jerini*, indicating the *Akidograptus acensus* graptolite Zone.

In the Tarim Basin, two chitionozoan biozones, *Belonechitina dawangouensis* and *Armoricochitina yinganensis*, are defined from the Tierekawti Formation of the Dawangou section. These chitinozoan assemblages are local ones and quite different from other chitinozoan assemblages around the world. Due to a lack of other fossil groups, the age of the Tierekawti Formation has been debated for years. Recently, in samples collected at the Yanrui section, which is 3800 km away from the Dawangou section, *B. dawangouensis* and *A. yinganensis* are observed in the Xiazhen and Hongjiawu formations, which are of Katian age, probably earliest Hirnantian (Munnecke et al. 2010). This means the Tierekawti Formation is synchronous with the Xiazhen and Hongjiawu formations. This find solves the age problem of Tierekawti Formation and confirms the opinion that the Ordovician–Silurian boundary in the Kalpin area of the Tarim Basin is located between the Tierekawti Formation and the Kalpintake Formation. Definite Hirnantian sediments are not found and may be absent from both sites.

Up to now, the earliest Silurian chitinozoan in China are recorded from the Anji Formation. More work has to be done in the future to understand chitinozoan assemblages throughout the Late Ordovician (Katian) to early Silurian (Rhuddanian) in China. The appearance of the same chitinozoan assemblages in different plates confirms that chitinozoans provide a very good stratigraphic tool for long distance correlation. In addition, they may be of palaeogeographic significance, as well.

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Gorstian palaeoposition and geotectonic setting of Suchomasty volcanic centre (Prague Synform, Bohemia)

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Undercooled lavas associated with proximal facies of pyroclastic fallout and surge deposits produced by a phreato-strombolian eruption were excavated by test pits in the vicinity of Vysoká skála Hill, SE of Suchomasty, in SW-closure and SE-flank of the Prague Synform. Effusions of basaltic magma gave origin to lava flows sinking down to hemipelagic muddy succession of Kopanina Fm., in which basalts moved ahead in the form of shallow, near-water/sediment interface sills. Present-day preservation of effusive basalts in test pits of the Vinařice section is restricted to the lower–middle *S. chimaera* Biozone and basalt sill of the Bykoš section is placed within the upper *L. progenitor* Biozone. Besides that, the pyroclastic precursors of the magma eruption appeared as early in the sedimentary succession as within *N. nilssoni* (surge deposits) and lower *L. progenitor* (fallout deposits) graptolite biozones.

The basaltic lavas have alkaline character with relatively steep REE patterns with LREE enrichment (La_N/Yb_N ~3.8–4.6), no Eu anomalies, high LILE abundances, low Zr/Nb ratios (8.5–8.6) and positive Ti anomalies in NMORB-normalized spiderplots (Sun & McDonough 1989). The whole-rock chemical signatures with fairly positive $\varepsilon_{Nd}^{423\ Ma}$ values (+6.0 to +5.3) point to a character transitional between EMORB and OIB. A high degree of REE fractionation and low HREE abundances in the Vinařice and Bykoš basalts suggest that they could have originated from a low-degree partial melting of garnet peridotite source. Their incompatible element ratios (Agrawal et al. 2008) and Nd isotopic signatures correspond to a within-plate (oceanic island or intracontinental rift) setting. Given the geochemical variation in basalts and the well-documented existence of Neoproterozoic continental basement, the geotectonic setting for the Suchomasty volcanic centre can be characterized by progressive attenuation and rifting of continental lithosphere connected with asthenospheric mantle upwelling.

Palaeomagnetic analyses performed on basalts, their contact aureoles and surrounding rocks at Vinařice section involved: (1) progressive thermal demagnetization using the MAVACS (Magnetic Vacuum Control System; Příhoda et al. (1989) equipment with step intervals of 60 to 40°C; (2) demagnetization by Alternating Field (AF) technique using Superconducting Rock Magnetometer type 755 4 K with steps every 5 to 20 mT; and (3) separation of the remanent magnetization (RM) components with the help of the multi-component analysis (Kirschvink 1980; Man 2003). Magnetite and Ti-magnetite RM components were established at temperature intervals (400–520°C) and/or AF range (25–100 mT). Tilt-corrected mean direction of RM (D = 201°, I = -40°) fits well the Silurian direction of the Bohemian Massif and palaeolatitude calculated from palaeomagnetic direction for the Suchomasty volcanic centre in Gorstian is 22°S.

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Anatomy of an epibole: Microstratigraphy of the 'bead bed' interval in the lower Silurian Brassfield Formation of central Kentucky

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The lower Silurian (Llandovery, Rhuddanian–Aeronian) Brassfield Formation is a widespread and prominent carbonate unit that crops out throughout the Cincinnati Arch region of eastern Laurentia, exposing a variety of shoal to shallow shelf facies. The uppermost member of the Brassfield Formation, known as the Rose Run or upper massive member, is a distinctive unit comprising cross-bedded, intraclastic, oolitic, hematitic ironstone and ferruginous grainstone that is associated with dense accumulations of large, cogwheel-shaped crinoid columnals that have long been known informally as "beads." Although the taxonomic affinity of the bead-producing crinoid is currently unknown, beads can be identified as the columnal morphogenus *Floricolumnus*, known from similar-aged strata of Wales and Scotland. The sudden occurrence of large numbers of these columnals represents an epibole, valuable for regional stratigraphic correlation. Detailed stratigraphic measurements of the Brassfield Formation were made of four closely spaced outcrops in central Kentucky known to contain abundant *Floricolumnus*. This microstratigraphic approach clearly permitted recognition of the erosive basal contact of the Rose Run, interpreted as a third-order sequence boundary, as well as several surfaces within the lower Rose Run. The lowest occurrence of *Floricolumnus* occurs at a calcareous tempestite in the middle portion of the "middle shaley" member of the Brassfield, underlying the Rose Run. The highest occurrence of *Floricolumnus* occurs in the lower portion of the Rose Run and these columnals are never found at the top of this unit. Taphonomic observations provide suggestive evidence that columnals in the Rose Run might be re-worked bioclasts derived from the underlying shaley member, which contains more abundant and better preserved specimens of *Floricolumnus*. At least two discrete erosive surfaces within the Rose Run contribute to stratigraphic complexity and complicate precise bed-by-bed correlation even within a relatively restricted area, in contrast to other Silurian intervals that are characterized by widespread, microstratigraphic consistency.

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New look into Ordovician stratigraphy of the Moscow Basin, inferred from conodont and carbon isotope data of the Gavrilov Jam-1 drill core

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The Ordovician rocks of the epicontinental Moscow Basin, embracing the central part of the East European Platform, are much less studied than the contemporary deposits of Baltoscandia, located on the western margins of Baltica. These rocks are known only in the subsurface, at depths from 1500 to 2400 m in numerous deep boreholes that were drilled mainly 30–40 or more years ago. The small amount of rock material recovered from the major part of the drill cores has resulted in poor palaeontological collections and finally in controversial biostratigraphical age determinations of local stratigraphic units (Prokofiev & Kuznetsov 1982). The subdivisions of lithostratigraphical units that have been dated by acritarchs, brachiopods, ostracods, bryozoans and trilobites and their correlations are based mainly on well logging. Rare graptolites are informative mostly in the lower and middle Ordovician. One of the most complete and recently studied drill cores, the Gavrilov Jam-1 drill core, is located in the south-eastern part of the Moscow Basin. Melnikova & Dmitrovskaya (1997) identified ostracods from this drill core and provided its lithological description.

A new study of conodonts from the Gavrilov Jam-1 drill core was aimed to refine the old biostratigraphic subdivision of the Ordovician in the Moscow Basin. Conodonts are numerous in the Darriwilian and lower Sandbian, so the collection is satisfactory despite the restricted amount of rock material. Carbon isotope analyses ($\delta^{13}C$) were made to have an independent control of conodont-based ages of the lithostratigraphical units. Traditional laboratory equipment and methods were applied to study 73 whole-rock samples. The $\delta^{13}C$ curve obtained shows some specifics in shape and generally 1‰ lower values than expected, but still some excursions are recognizable. The trend seems to be affected by local environmental conditions.

The conodonts indicate that the Middle Ordovician part of the section is younger than previously thought. The Nefedovo Formation that was assigned to the Volkhov regional Stage (Melnikova & Dmitrovskaya 1997) contains conodonts of the Kunda and Aseri stages. This correlation is supported by isotope data, revealing the mid-Darriwilian excursion recorded worldwide (Ainsaar et al. 2010). The upper Darriwilian and lower Sandbian conodont assemblages contain several typical representatives of the

Uhaku and Kukruse stages (Männik & Viira 2012), but the dominance of *Phragmodus polonicus* hampers a precise correlation of these stages. The base of the Upper Ordovician was recognized in the uppermost part of the Skalino Formation by the first appearance of rare elements of *Amorphognathus* and lower values of $\delta^{13}C$ (the so-called Kukruse low). The upper part of the Kubena and Mitino formations yielded extremely poor conodont assemblages with *Pectinognathus khoreyvericus*, earlier known only from the Timan-Pechora region. This interval of the section cannot be recognized in the isotope curve. A potential position of the GICE might be in the Mitino Formation, most likely in the top just below the appearance of *Icriodella superba* also known from the Oandu Formation. The lower part of the Varlygino Formation, which was considered to be Silurian (Melnikova & Dmitrovskaya 1997), contains Katian conodonts. The Silurian conodont *Ozarkodina oldhamensis* was found in the overlying Poshekhonie Formation in the Mar'ino-1 drill core.

In general, the Middle and Late Ordovician conodont assemblages identified in the Gavrilov Jam-1 core consist mainly of species widespread in Baltoscandia, except those from the upper Kubena and Mitino formations where elements of the Timan-Pechora palaeobasin assemblage appeared.

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Scolecodonts across the Llandovery–Wenlock boundary in Estonia and Sweden: Assessing the impact of the Ireviken Event on polychaete faunas

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The Silurian Ireviken Event (IE) represents a short period of severe global climatic and environmental perturbations spanning the Llandovery–Wenlock boundary. It is associated with a prominent carbon isotope excursion and extinctions in many groups of marine organisms, with conodonts suffering most severely; approximately 80% of the species disappeared globally (Jeppsson 1998). The effects of the IE on benthic faunas are less well documented and this concerns also the polychaete worms (represented by scolecodonts), which constituted a diverse component of the Silurian benthic communities. In this study we describe changes in the polychaete faunas below and across the IE in the Viki drill core, Saaremaa Island, Estonia, and compare these with previous records from Gotland, Sweden (Eriksson 2006) and the Paatsalu drill core, Estonia (Hints et al. 2006), in order to more fully assess the impact of the IE on Silurian polychaetes.

The Viki drill core is the reference section for the IE in Estonia, and it is precisely tied to the Gotland succession based on conodont biostratigraphy (Jeppsson & Männik 1993). The interval sampled for scolecodonts includes Telychian (Rumba and Velise formations) to early Sheinwoodian (Jaani Formation) limestones and marls, which were formed in open marine conditions in the eastern part of the Baltoscandian basin. Compared to Gotland, the IE interval is more condensed in the Viki drill core, but without major stratigraphic gaps.

Altogether more than 60 species were identified from the sampled interval, including those yet to be formally described. In taxonomic composition the fauna is very similar to those reported previously from Gotland (Eriksson 2006) and the Paatsalu drill core (Hints et al. 2006), and dominated by polychaetaspids, paulinitids and mochtyellids. The abundance of scolecodonts shows a generally increasing trend throughout the upper Telychian, reaching 1000 specimens per kg just below the IE in the Viki drill core. Coinciding with the start of the IE, the abundance drops rapidly, with minimum values recorded between the IE datum points 3–6. This change is reflected also in a reorganized assemblage structure. Most strikingly the polychaetaspids temporarily disappear close to datum 4 in the Viki succession. The same pattern was observed on Gotland, where all polychaetaspid taxa show a major crisis near datum points 4–5 (Eriksson 2006). The frequency changes recorded in the Paatsalu section (Hints et al. 2006) in general reflect the same pattern. Eriksson (2006) reported the disappearance of at least 20% of lineages within the IE interval on Gotland. Based on the Estonian sections the disappearance rate seems to be slightly lower. There are also indications for the occurrence of "Lazarus taxa" rather than extinctions. For example, *Mochtyella pragensis* is common throughout the upper Telychian, and disappears just below datum 3. However, the same species is known from Ludlow strata of the Prague Basin, suggesting that it could reappear during suitable environmental conditions. A few species also have their first appearance within or immediately above the IE interval.

Our new data corroborate the previous studies from Gotland and the Paatsalu section, showing that the IE affected benthic jaw-bearing polychaete faunas and caused a short-lived crisis for several taxa. Polychaetaspids seem to have been most severely affected and the restructuring of assemblages occurred especially between the IE datum points 2–6. However, relatively few species seem to have gone extinct and the global trends of changes in the polychaete faunas tied to the IE remain to be assessed by data from regions outside Baltica.

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Tracking Silurian climate change with conodont paleothermometry

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Much has been learned in recent years about changes and events in Early Paleozoic paleoclimates and paleoceans, particularly from isotope studies of Sr, Nd, C and O, and climate modeling. Temperature is a key factor, with particular added importance in interpreting changes in the paleoecology and paleobiogeography of marine faunas. Much of the temperature data has been determined from brachiopod carbonate, however considerable efforts have also been made at some laboratories to secure quantitative paleotemperatures of seawater using oxygen isotope compositions of conodonts (phosphatic microfossils), believed to be less susceptible to diagenetic alteration. Conventional $\delta^{18}O$ phosphate analyses require tens to hundreds of conodonts, whereas recent technical advances have enabled high spatial resolution *in-situ* analysis within single specimens (Trotter et al. 2008). This not only allows multiple analyses of individual conodont elements but can also target specific mineralized tissues and features to avoid contaminants and limit potential variables. We have used this method to expand our initial work that documented paleotemperature trends from equatorial paleoplates through the Ordovician. As part of a larger-scale conodont paleothermometry project funded by the Australian Research Council (Trotter as Chief Investigator), here we report Silurian paleoseawater temperatures determined from conodont $\delta^{18}O$ compositions using the SHRIMP II ion microprobe at The Australian National University. Specimens were selected from extensive conodont collections taken previously from long stratigraphic sections or cores having little tectonic or thermal alteration and providing good biostratigraphic and age control. The sampled collections were representative of several paleoplates, mainly from equatorial to mid paleolatitudes and from shelf to upper slope paleoenvironments, including Laurentia (Cornwallis Island, Canadian Arctic and Anticosti Island, Quebec), Avalonia (Welsh Borderlands, UK), and Baltica (Estonia and Latvia). Oxygen isotope compositions were determined on >650 conodonts from 158 samples (>2000 spot analyses) through the Silurian which gave sufficient stratigraphic resolution to determine both long-term trends and short-term excursions. The data show that following the terminal Ordovician glaciation, there was an overall warming trend during the Llandovery, cooling during the Wenlock, returning to warmer conditions through the Ludlow and Pridoli. This primary trend is punctuated by numerous short term climate cycles. Overall, equatorial seawater temperatures varied by ~12°C throughout the Silurian but did not reach the excessively high temperatures reported for the Early Ordovician in our earlier study. Some of the isotope data can be used to complement other studies of conodont community patterns and sea level changes from some of the regions sampled, and to document the effects of paleoceanographic changes such as the closure of the Iapetus Ocean.

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Cladistics and mass extinction events: Conulariids and the End Ordovician extinctions

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Assessing the causes and consequences of mass extinctions may be facilitated by analysis of the phylogenetic relationships among species or genera in relevant clades. In turn, extinction/survival patterns of well-resolved clades may shed additional light on the paleobiology of those clades. Conulariids, an extinct (?Ediacaran–Triassic) order of benthic marine invertebrates now generally classified as scyphozoan cnidarians, survived the End Ordovician Extinction Event (EOE) with little reduction in diversity or disparity. Of the 11 known Late Ordovician genera (*Anaconularia*, *Archaeoconularia*, *Climacoconus*, *Conularia*, *Conularina*, *Ctenoconularia*, *Eoconularia*, *Exoconularia*, *Glyptoconularia*, *Metaconularia* and *Pseudoconularia*), all but two (*Anaconularia* and *Glyptoconularia*) occur in early Silurian or younger strata. Moreover, *Anaconularia* may have gone extinct well before the EOE. No new genera appear to have originated during early Silurian times, and previously available data suggest that following the EOE total species diversity was recovered. Nearly all of the supra-generic clades generated in our cladistic parsimony analysis survived the EOE. However, nearly all genera that are not known from post-EOE strata lack transverse ribs and are derived relative to most genera that survived. Interestingly, all known genera that originated after the Ordovician Period, including *Notoconularia*, *Paraconularia* and *Reticulaconularia*, belonged to a single clade that included *Climacoconus* and that was characterized by a unique configuration of the transverse ribs in the corner sulcus. Nearly all discrete anatomical features collectively present in Ordovician conulariids survived the EOE: All but one of the 36 generally recognized character states for conulariids were each retained in at least one of the surviving genera. Finally, nearly all discrete anatomical features of conulariids appeared before the EOE. Following the EOE, conulariids generated only one new evolutionary novelty (the median ridge in the corner sulcus of *Notoconularia*).

In addition to similarity in taxonomic composition at the level of genera, Late Ordovician and early Silurian conulariids also are similar in diversity at the scale of individual faunas. Both in Upper Ordovician and lower Silurian strata, many conulariid-bearing invertebrate bottom faunas contained only one species of conulariid, usually a *Conularia* (Ordovician and Silurian faunas) or a *Metaconularia* (Silurian faunas). At least in cratonic North America, the first conulariid faunas to appear following the

EOE, in relatively restricted bottom environments, generally consisted of a single species of *Metaconularia*. Although many Late Ordovician conulariid faunas contained multiple genera, the frequency of conulariid faunas of early Silurian age containing multiple conulariid genera appears to have been substantially lower.

Two additional factors that must be considered are sample size and paleogeographical/paleoenvironmental distribution. The two conulariid genera that currently are not known from post-Ordovician strata appear to have been rare and/or to have exhibited restricted paleogeographical ranges. This raises the possibility that the apparent absence of these genera in post-Ordovician strata is an artifact of sampling. Among the nine surviving genera are those represented by the highest numbers of collected specimens and having the broadest paleogeographical and paleoenvironmental ranges. *Archaeoconularia*, *Conularia*, *Metaconularia* and *Pseudoconularia* were cosmopolitan, ranging from low to high paleolatitudes and occurring on multiple terranes, including Laurentia, Baltica and various peri-Gondwanan terranes. These four genera also inhabited a broad range of bottom environments, including open carbonate and siliciclastic shelves and restricted shelf slopes and shale basins. Following the EOE, Silurian conulariids reprised the broad paleogeographical and paleoecological distributions of the major Ordovician genera, but there was a marked reduction in the degree of endemism. As in Late Ordovician times, *Archaeoconularia*, *Conularia* and *Pseudoconularia* were among the dominant genera, though *Metaconularia* appears to have become relatively more abundant.

Overall, the EOE resulted in catastrophic declines in species diversity but relatively little loss of higher taxa. This pattern may also hold true for conulariids, but the impact of the EOE on conulariid species requires additional assessment. There is little evidence that any particular character state of the periderm, save possibly the absence of transverse ribs, conferred reduced fitness on any conulariid genera. Coupled with the broad distribution of Ordovician conulariids, the observation that nearly all genera and character states survived the EOE suggests that conulariids were eurytopic organisms that collectively were well adapted to the kinds of environmental perturbations, including rapid changes in sea level, ocean temperature and dissolved oxygen levels, generally thought to have been associated with the EOE.

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Dynamics of placoderm distribution in the Prague Basin (Czech Republic)

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Placoderms represent early jawed fish-like vertebrates inhabiting the Early Paleozoic seas since their appearance in the early Silurian. They reached their maximum diversity during the Devonian and were extinct in the Late Devonian. Placoderms also occurred in the Prague Basin (Barrandian area, central Bohemia, Czech Republic) as shown by many discovered specimens. This basin was situated in peri-Gondwana and existed from the Early Ordovician (Tremadocian) to the late Middle Devonian (Givetian). The relict of its marine volcano-sedimentary infill displays a trend of a gradual replacement of predominant clastic sediments by carbonates during the Silurian. The upper Silurian to early Middle Devonian succession is dominated by limestone that was formed in a warm climate, and is terminated by terrigenous deposits reflecting progressive movements of the Variscan Orogeny.

The distribution of vertebrates in the Prague Basin has only been occasionally studied due to the low abundance and low diversity of fish-like vertebrates in the sediments of this peri-Gondwanan structure. Historical and modern collections, however, provided a lot of specimens displaying their local and stratigraphical distribution patterns. Although much material was collected in the 19th century, it can be considered as a relevant database for analyses because vertebrate fossil remains are quite rare and their appearance is striking, thus we assume that all identified fragments have been collected. In that time, the limestones and other rocks in the Barrandian area were quarried by hand and much attention was paid to fossil collecting. Therefore, the historical collections are considered as non selective, covering the stratigraphical range and facies of vertebrate distribution well. They illustrate a lack of agnathans, domination of placoderms together with acanthodians, and absence of placoderms in the Silurian sediments of the Prague Basin.

Occurrences and abundances of placoderms at the localities clearly show a very unsteady distribution of placoderms in space and time. They are known from all corners of the relict basin and are not related exclusively to any facies, neither typical shallow water, nor deeper. They also occur in white to very dark limestones, and from micritic to bioclastic. One specimen is known from clastic sediment. However, some trends can be traced in the stratigraphic distribution. The most abundant specimens are in the Lochkovian and through a decrease in the Pragian they become uncommon to rare in the Eifelian and Givetian. Thus, they were most common in the time of their appearance in the Lower Devonian and gradually disappeared in the Middle Devonian. The other trend is taxonomic: acanthothoracans dominating the Lower Devonian are completely replaced by atrhrodires at the beginning of the Emsian. This peculiar change is caused by a delayed migration of arthodires into the Prague Basin, despite of a common occurrence of this group in the neighbouring paleogeographic areas in the Lochkovian and Pragian.

Fluctuations of body size depending on facies and stratigraphy are also noted. The Lochkovian placoderms occurring in the dark limestones are average sized. In the Pragian they are known almost only from reef limestones, in smaller dimensions, very often found inside the orthocone cephalopod shells. Placoderms of the overlying units are larger in general. This can be related to the above-mentioned taxonomic overturn. There seem to be differences between facies as well, but they cannot be reliably described at the time because of low number of specimens.

All placoderms in the Prague Basin, without any regard to their dimensions, had untoothed jaws. Some of them, including the largest species known from the Prague Basin (its length is estimated to 2 m), probably possessed a subterminal mouth. It may manifest that they were bottom feeders rather than predators, the trophic level probably occupied by acanthodians and cephalopods.

It would be speculative to elucidate the placoderm distribution dynamics and its patterns in the Prague Basin for the time being. However, ecological factors such as food supply and competition with other similar trophic types of invertebrates can be considered as controlling factors. The location of the basin far on the Gondwanan wide sea shelf apparently also influenced and controlled the distribution of placoderms. The appearance of these gnathostomes represented a revolution in the trophic webs, ecological relations and evolutionary novelties, but had probably only a marginal influence on the communities in the Prague Basin.

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Ordovician brachiopods from Peru and the persistence of a Gondwanan faunal signal in Avalonia during the late Sandbian

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The Avalonian affinity of South American Lower and Middle Ordovician brachiopods is well known from the Central Andean Basin, especially for some localities placed in Peru (Hughes et al. 1980; Gutiérrez-Marco & Villas 2007), Bolivia (Havlíček & Branisa 1980) and in the Argentinian Puna and Famatina (Benedetto 1998, 2003). The strong faunal links between Avalonia and Baltica during the Sandbian commonly result in palaeogeographical reconstructions depicting Avalonia very close to Baltica and already far apart from Gondwana. However, the scarcity of data from the Upper Ordovician of South America has made it impossible to precisely know how far from Gondwana Avalonia had drifted by that time. The study of a brachiopod association from the Peruvian Altiplano, northwest from the Titicaca Lake, allows confirmation that by the late Sandbian (early Late Ordovician), faunal exchange between Gondwana and Avalonia was still possible, even to the species level.

The following brachiopods have been identified from the Calapuja Formation: *Colaptomena expansa expansa* (J. de C. Sowerby), *Dinorthis* cf. *flabellulum* (J. de C. Sowerby), *Heterorthis retrorsistria* (M'Coy), *Eorhipidomella*? *cardocanalis* Havlíček & Branisa 1980, as well as new species of the genera *Onnizetina*, *Horderleyella* and *Drabovinella*. *Colaptomena expansa expansa* and *Heterorthis retrorsistria* are well known from the Burrellian British stage (Williams 1963; Cocks 2008), making possible and indirect correlation with the late Sandbian global stage. The occurrence of *Eorhipidomella*? *cardocanalis* besides the former species, also constrains its early Caradocian age in Bolivia (Havlíček & Branisa 1980). The new species of *Onnizetina*, *Drabovinella* and *Horderleyella* are unknown outside Peru, pointing to a certain isolation of the region, although the Gondwanan links of these genera are clear. The Welsh *C. expansa expansa* and *H. retrorsistria*, restudied by Williams (1963), can be considered as typical representatives of the Avalonian faunas, although *H. retrorsistria* has also been recorded from Morocco (Havlíček 1971). The occurrence of both taxa in Peru, besides typical Mediterranean brachiopods, allows envisaging them also as Gondwanan, remarking the strong faunal links between the continent and Avalonia still during the early Late Ordovician. Havlíček & Branisa (1980) identified in Bolivia another Welsh species of

Sandbian age, *Dinorthis flabellulum* (J. de C. Sowerby), pointing out their surprise in view of the supposed palaeogeographical distance between both regions. This species could also be present in the studied Peruvian association, as well as in northwest Argentina (Benedetto 2002).

Considering the low dispersal potential of the rhynchonelliformean lecitotrophic larvae, and the co-occurrence of the same brachiopod species in Avalonia and the proto-Andean margin of Gondwana, it can be concluded that during the early Late Ordovician the drifting of Avalonia away from Gondwana was still limited.

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Aeronian patch reefs, northern Guizhou Province, China: Early Silurian reefs formed during reef recovery from the end-Ordovician extinction

GUAN WANG[1], STEVE KERSHAW[2] AND YUE LI[1]

A wide northward-sloping epicontinental ramp covered northern Guizhou, Upper Yangtze Platform, South China Block, during the Llandovery, Silurian. Patch reefs of the Shihniulan Member, Shihniulan Formation are especially concentrated near Shuibatang Town, N. Tongzi County, covering an area about 10 km^2. Two layers of reef-building are recognized. The first reef unit is generally several meters thick and tens of meters in diameter. Patch reefs of the second unit have obvious mound shapes and reef flanks are tens of meters thick and from tens to ca. 100 m laterally. The biotic structures of both reef units are rich in algae, stromatoporoids, bryozoans and tabulate and colonial rugose corals with potential for frameworks. Solitary rugose corals, brachiopods, trilobites, nautioloids and crinoids are reef-associated and abundant in reef flanks, in more muddy facies. Factors of depth and clarity of the marine water can be considered as major controls on reef distribution spatially. Due to short-term regression with northward expansion of the Qianzhong Land, the sea floor in the Shuibatang area was exposed, ending the reef-building realm. Onward transgression with much turbid shallow marine environment of the Hanchiatien Formation was unfavourable for growth of big reefs, so the reef phase ended.

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Earliest known Silurian rugose corals from Meitan, SW China

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Early Rhuddanian (Llandovery, Silurian) rugose corals are rarely recorded worldwide. South China is one of the regions where the coral-bearing rocks of this interval have developed and are well exposed. However, the oldest record of Silurian rugose corals was from the basal Xiangshuyuan Formation of Shiqian, eastern Guizhou, which was dated as late Rhuddanian age approximately corresponding to the *Conronograptus cyphus* graptolite Zone (Rong & Zhan 2004).

A newly discovered small rugose coral fauna from the Wulipo Bed in Meitan, northern Guizhou, SW China, has been studied for the first time (Fig. 1). The age may be dated as early Rhuddanian approximately corresponding to the *Parakidograptus acuminatus* zone and the *Cystograptus vesiculosus* Zone (Rong Jiayu pers. comm. 2012). These corals are *Streptelasma* sp. 1, *S.* sp. 2, *Crassilasma* sp. and *Meitanolasma muratum* gen. et sp. nov., amongst which *M. muratum* is dominant. Species referred to *Streptelasma* and its relevant genera recorded in China are revised under the modern taxonomic framework (e.g., Neuman 1969, 2003). The new genus *Meitanolasma*, with *M. muratum* as its type, is characterized by the presence of fossula *sensu stricto*, slightly to moderately dilated septa and an open axial region in its late growth stages. The characteristic features of this small rugose coral fauna can be summarized as: all solitary, low diversity, small in sizes, and lack of dissepiments. The maximum preserved length of the corallum is 36.3 mm and the maximum diameter less than 20 mm. It is proposed that these corals might have grown under unfavorable circumstances, i.e., an ecological adversity.

The Wulipo coral assemblage is quite distinct from the Hirnantian coral fauna of South China, which is dominated by streptelasmatid species characteristic of having comparatively large coralla, fossulate structures and strongly dilated septa (He et al. 2007). In addition, there are no associated tabulate corals in the Hirnantian assemblage. The faunal change from Hirnantian to early–mid Rhuddanian probably indicates the earliest Silurian deglaciation, associated with sea level rise and the spread of anoxic water. It also differs markedly from a stratigraphically higher typical Silurian assemblage from the basal Xiangshuyuan Formation by having much lower diversity and lacking typical Silurian forms (Chen et al. 2006). Concerning also information from sedimentology and other fossil groups, we can tentatively conclude that the Wulipo assemblage could represent the survival interval after the end-Ordovician mass extinction. The recovery of rugose corals in South China may occur much later, in the late Rhuddanian.

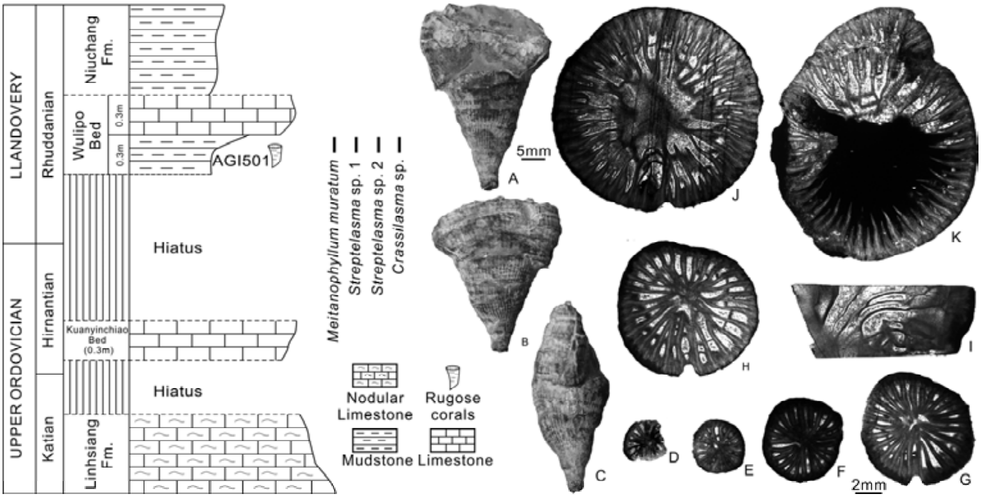

Fig. 1. Left part: Composite stratigraphic section and the horizon of solitary rugose corals at Gaojiang, Meitan County, northern Guizhou Province. Right part: Pictures of the holotype of *Meitanolasma muratum* gen. et sp. nov., and selected serial thin sections of this new species. **A.** Counter view. **B.** Cardinal view. **C.** Alar view (cardinal side left). **D–H, J, K.** Transverse sections. **I.** Part of a longitudinal section. 5 mm scale bar for A–C; 2 mm scale bar for D–K.

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Preliminary study of upper Llandovery and lower Wenlock graptolite fauna of Ziyang and Langao sections, Shaanxi Province, China

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Ziyang and Langao counties are located in southern Shaanxi province, china (Fig. 1). The regions of Ziyang and Langao belong to the northwestern margin of the Yangtze plate (Rong 2003). There are much Silurian works, mainly about the lower Llandovery and a few about the upper Llandovery (Fu 1985, 2006). In recent years, we also found many the upper Llandovery and lower Wenlock sections in this area. Such as, Ziyang Bajiakou section (2nd), Ziyang Gonglu section (1st) and Langao Qiaoxi section (4th), Langao Qiaodong section (5th) and Langao Laopa section (3rd). Litho-units of these sections belong to Doushangou Formation and Wuxiahe Formation according to reports of China Geological Survey. Doushangou Formation is composed of grey fine sandstone, grey siltstone and grey-yellow mudstone and Wuxiahe Formation is composed of grey siltstone, grey-yellow mudstone and carbonaceous slate. We have collected the upper Llandovery and the lower Wenlock graptolites (Boucek 1933; Lenz 1991; Loydell 1993; Storch 1994; Mu 2002) from these five sections.

Five sections about Telychian (upper Llandovery) and Sheinwoodian (lower Wenlock) strata have been examined bed by bed in Ziyang and Langao counties. After preliminary study, 28 graptolite taxa have been found in the *Stomatogratpus grandis*, *Cyrtograptus insectus*, *Cyrtograptus centrifugus*, *Cyrtograptus murchisoni,* and *Monograptus riccartonensis* Zones (Loydell 2011). As follows: *Cyrtograptus sakmaricus*, *Cyrtograptus* cf. *sakmaricus*, *Cyrtograptus* aff. *lapworthi*, *Cyrtograptus* cf. *insectus*, *Cyrtograptus* aff. *insectus*, *Cyrtograptus polyrameus*, *Cyrtograptus bohemicus*, *Cyrtograptus* aff. *bohemicus, Cyrtograptus* aff. *murchisoni*, *Cyrtograptus* sp. n., *Diversograptus* cf. *pergracilis*, *Diversogratus* cf. *ramosus*, *Monoclimacis* sp., *Monoclimacis* aff. *geinitzii*, *Monograptus riccartonensis, Monograptus priodon*, *Monograptus* sp. n., *Oktavites spiralis*, *Pristiograptus* cf. *meneghinii*, *Pristiograptus praedubius*, *Retiolites* cf. *australis*, *Retiolites geinitzianus*, *Retiolites* sp., *Streptograptus* aff. *anguinus*, *Streptograptsus* cf. *flexuosus*, *Streptograptus* cf. *anguinus, Streptograptus* cf. *kaljoi*, *Stomatograptus* cf. *imperfectus*. There are three new species in these species. Study of the fauna is important to sections through Llandovery–Wenlock boundary strata and all of the fossils beneficial complement for South China graptolites.

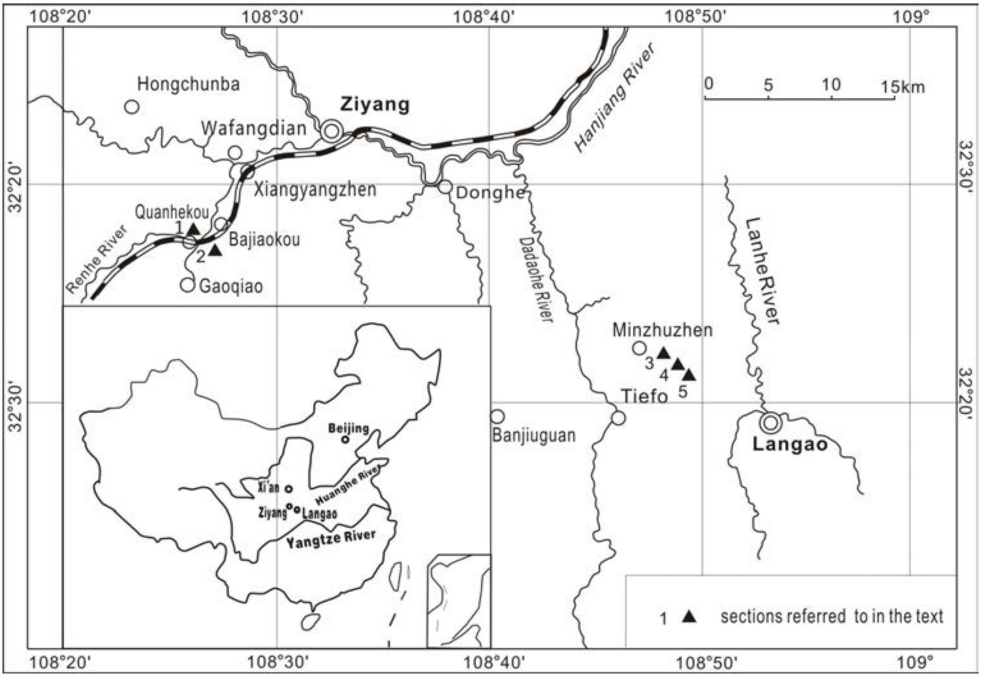

Fig. 1. Locations of the Ziyang and Langao sections.

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The fossil collections at the Geological Survey of Sweden

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The Geological Survey of Sweden (SGU) was founded by Axel Erdmann in 1858. The objectives for establishing the survey was to produce geological maps with full coverage of Sweden, since there was a pronounced need for geological information at the time of the industrial revolution and an increasing population.

From the very beginning, fossils were a part of the geological collections, since it was decided that a palaeontologist also should be included among the staff. The first palaeontologist, Gustaf Linnarsson, was employed in 1870. The fossils were collected in order to define and describe the younger sedimentary bedrock, which in Sweden mainly includes strata from the Lower Palaeozoic. On-shore Lower Palaeozoic strata is mainly present in the south of Sweden, in the Siljan area and along the Caledonides. Off-shore strata are present in the southern Baltic Sea, Bothnian Bay and Bothnian Sea. Most of the specimens kept at the SGU are from Sweden, since they originate from surveys undertaken in Sweden. There are, however, a few specimens from nearby countries such as Norway and Denmark.

The early detailed studies of the sedimentary strata by SGU palaeontologists resulted in many Survey publications and geological maps describing the bedrock in these areas. Quite a few of the publications in Sveriges Geologiska Undersökning Series C or Ca were also published in the journal of the Geological Society of Sweden, today named GFF. During the years, many of the palaeontologists at SGU have been working at the Geological Museum of the Survey (1871–1984), which could be one reason to the current large fossil collection. Estimates suggest that the fossil collection holds at least 100 000 specimens, probably even more. Some of the collectors that have made contributions to the fossil collection are J.G. Linnarsson, J.C. Moberg, G. Holm, N.O. Holst, S.A. Tullberg, G. von Schmalensee, A.H. Westergård, O. Kulling, B. Asklund and P. Thorslund.

The type and figured collection is the most precious part of the geological collections and requests about its content are made on a regular basis. In 2013, the type and figured collection contains approximately 9200 specimens. The oldest cited material is from Linnarsson 1866, in his thesis ”Om de Siluriska Bildningarne i Mellersta Westergötland” (“On the Silurian formations in the Middle of Westergötland”). Examples of specimens held at the SGU fossil collection is trilobite type material of the Swedish

Cambrian described by A.H. Westergård, graptolites from the GSSP Diabasbrottet at Hunneberg described by J. Maletz and the only native Swedish crocodile described by Persson (it is from the Cretaceous, though).

Today, the fossil collection is mostly used by researchers from universities in Sweden and worldwide. Approximately 200 fossils are on circulation every year, mainly used for research, but also for display in exhibitions at different museums. The duration of a loan is normally six months and after that the specimen should be returned to SGU. An extension of a present loan may be given if it is requested by the researcher.

Currently, the fossil collection is undergoing digitization, with the aim to increase the availability of the collections by presenting them on the web. At present, 3200 specimens have been recorded in the database. The digitization process also includes scanning of old plates in the literature and the user should then be able to compare these with photographs of the specimen.

Over the years, SGU has noticed that there are specimens that have not been returned in due time or have been noted as “lost” in the records. Therefore, if you are in the possession of specimens that belong to SGU and the loan has expired, please return them as soon as possible. If you need an extension of the loan period, please contact SGU or Linda Wickström for details.

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Floian–Dapingian conodont biofacies in the marginal Yangtze Platform, South China

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The Hunghuayuan Formation, established by Chang & Sheng (1958), consists of a sequence of thick, grey to white grainstone, and is latest Tremadocian–mid Floian in age, and widely distributed on the vast area of the Upper and Lower Yangtze platform (Chen et al. 1995). The Zitai Formation, established by Mu et al. (Nanjing Institute of Geology and Palaeontology, 1974), is of late Floian–early Darriwilian age and characterized by reddish argillaceous limestone intercalated with a few yellowish-green shale beds, conformably underlain by the Hunghuayuan Formation and overlain by the Kuniutan Formation. Systematic and statistical study on conodonts from the uppermost Hunghuayuan and Zitai formations in Shitai County, Anhui Province, paleogeographically located in the margin of the Yangtze Platform, indicates that four conodont biofacies can be recognized, i.e., the *Diaphorodus* biofacies, *Oepikodus* biofacies, *Baltoniodus-Periodon* biofacies and the *Periodon-Protopanderodus* biofacies. The changes of the conodont fauna are related to sea-level changes. Replacement of the *Diaphorodus* biofacies by the *Oepikodus* biofacies, recorded across the uppermost Hunghuayuan Formation and lowermost Zitai Formation, represents a transgression during the late Floian. Another transgression can be distinguished in the upper Zitai Formation, showing the biofacies changing from the *Baltoniodus-Periodon* biofacies to the *Periodon-Protopanderodus* biofacies.

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Palaeoenvironmental implications of Early–Middle Ordovician acritarch assemblages in South China

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As primary producers, acritarchs represent the base of the food chain in the Paleozoic marine ecosystem, and are linked with the evolution of other fossil groups and palaeoenvironmental changes. Based on high precision quantitative research, much information about Paleozoic marine ecosystem is provided. In the present study, about 60 samples were collected from the Meitan Formation, Honghuayuan section (Tongzi, Guizhou), and the Dawan Formation, Huanghuachang section (Yichang, Hubei) in South China for quantitative analysis to understand the relationship between acritarch diversity and abundance changes and sea level changes (sea-level curves based on Liu 2006).

Yan et al. (2005) analysed the acritarch diversity and relative abundance in the Honghuayuan section, where four recognized diversity peaks and three drops can be approximately correlated to four sea-level peaks and three sea-level falls. Four peaks in the acritarch diversity curve in the Huanghuachang section appeared in the *suecicus*, lower *hirundo*, lower *clavus* and *austrodentatus* graptolite biozones. The acritarch diversity curves can be partly correlated to the sea-level curves.

We also analyzed relative abundance changes of several selected acritarch taxa to understand how sea-level changes affected acritarch assemblage changes. The genera *Baltisphaeridium*, *Leiosphaeridia*, *Polygonium*, *Peteinosphaeridium*, *Striatotheca*, *Veryhachium*, and the galeata and diacromorph groups were selected within the Meitan Formation in the Honghuayuan section (Tongzi, Guizhou) for relative abundance analysis. The galeata group includes the genera *Cymatiogalea* and *Stelliferidium*, and the diacromorph group includes the genera *Acanthodiacrodium*, *Arbusculidium* and *Dicrodiacrodium*.

The relative abundance trends of *Baltisphaeridium*, *Polygonium*, *Peteinosphaeridium* and the galeata and diacromorph groups are similar, and their relative abundance curves are paralleled to the Early–Middle Ordovician sea-level curves in the Honghuayuan section. When the relative abundances of *Baltisphaeridium*, *Polygonium* and *Peteinosphaeridium*, and the galeata and diacromorph groups were high, sea level was also high. When the relative abundances of *Baltisphaeridium*, *Polygonium* and *Peteinosphaeridium*, and the galeata and diacromorph groups were low, sea level was also low. On the contrary, the relative abundance changes of *Leiosphaeridia* and *Striatotheca* shows the opposite relationship to sea-level changes; when the relative abundances of *Leiosphaeridia* and *Striatotheca* were high, but sea level was low, and when the relative abundances of *Leiosphaeridia* and *Striatotheca* were low, sea level was high.

We also analyzed some acritarch relative abundance changes in the Huanghuachang section. Similar to the Honghuayuan section, relative abundance curves of *Baltisphaeridium* and *Polygonium* are more or less paralleled to sea-level curves and that of *Leiosphaeridia* is negatively correlated to sea-level curves. But in contrast to the Honghuayuan section, relative abundance curves of *Peteinosphaeridium*, *Rhopaliophora* and galeata group are similar to that of *Leiosphaeridia*.

This result implies that acritarch diversity changes and relative abundance changes of some important taxa would respond to which environmental facies the sections were located in. More studies are needed to understand how palaeoenvironmental changes affected the acritarch assemblages.

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Chert-hosted small shelly fossils: An expanded tool for establishing the early Cambrian biostratigraphy

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Biostratigraphy based on small shelly fossils (SSFs) from Terreneuvian carbonate sequences has been carried out for decades. It is generally accepted as the tool with the greatest potential for early Cambrian chronostratigraphy because many critical fossil groups had not yet appeared at that time, or were either endemic to specific faunal realms or too rare. For SSFs it has been discussed that many species are facies-limited to shallow-water carbonates or have a diachronous first appearance date (FAD) on different palaeo-continents. However, the assumed connection of SSFs to carbonate facies is likely biased by the applied investigation method. Most SSF studies only applied an approach by etching carbonates with weak organic acids. Although simple physical methods (rock cracking) also have generated data on SSFs from clastic rock sequences, these data are mostly not comparable in quality and quantity with results yielded by etching methods.

Here we use hydrofluoric acid (HF) to etch cherts of a Terreneuvian deeper-water section of the Yangtze Platform (Zhejiang Province, China) to compare SSF contents of the chert facies with the well-known record of carbonates. Our study retrieved considerable amounts of SSFs from early Cambrian siliceous rocks. The SSF assemblage reported here is well comparable with assemblages of other early Cambrian strata (SSF zones 1 to 5) of Kazakhstan and other regions of the Yangtze Platform. EDS analyses of recovered SSFs from cherts revealed a composition of carbon (often with considerable amounts of sulfur), calcium, phosphorus and fluorine. Therefore, it is concluded that the SSFs consisted of organic compounds and phosphate prior to the etching process and were partially replaced by fluorite during the chemical treatment. Even though some chemical replacement occurred during the etching process, it is evident that SSFs can be treated taxonomically and thus can contribute to a sound biostratigraphic assignment of comparably deeper water siliceous sediments of carbonate platforms or non-carbonate sequences. The study indicates that HF etching of early Cambrian siliceous rocks can provide valuable biostratigraphic data on early Cambrian SSFs that are complementary to standard methods.

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Cambrian sponges radiation from Guizhou, South China

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Sponges are phylogenetically the most primitive group of multicellular animals, and it is logical that they can be traced very far back in the fossil record (Carrerao & Botting 2008). In China, with ongoing extensive study of early animals, biotas such as the Niutitang and Kaili biotas of Guizhou and Chengjiang Biota of Yunnan, all with numerous sponges, have been important for basic sponge research.

The Niutitang Biota is found in the lower Cambrian Niutitang Formation black shales located at Zunyi (Zhao et al. 1999; Steiner et al. 2001), Jinsha and Danzhai, Guizhou. It is composed of 40 genera of sponges, cnidarians, arthropods, algae and mollusks. Sponges, represented by 22 genera, are the dominant group, accounting for 55% of the total generic diversity of the biota (Yang et al. 2012). *Triticispongia* sp. from the base of the Niutitang Formation at Jinsha may represent the earliest record of sponge body fossils in the Cambrian (Yang et al. 2005). The Niutitang Formation is thus a window into the initial radiation of sponges and the sponges likewise exhibit facies-related variation, with Demospongea being dominant in shallow water facies and Hexactinellida dominant in deep water facies of Guizhou Province, China. These well-preserved sponge fossils have been reported from early Cambrian black shales, not only in the Guizhou Province, but also in western Zhejiang and southern Anhui, south China.

The Kaili Biota is of earliest middle Cambrian age and is preserved in the gray-green shale of the middle-upper part of the Kaili Formation in Balang Village, Gedong Town, Jianhe County, Guizhou Province, SW China. There are serven genera, *Leptomitus*, *Choiaella*, *Halichondrites*, *Hazelia*, *Vauxia* and *Protospongia* and spongia gen. nov., but these taxa make up only six percent of the biota. Sponges in the Kaili Biota are typically Demospongea, with six genera belonging to the Demospongea and only one genus representing Hexactinellida.

The numerous, well-preserved sponges from the Niutitang Formation suggest that the explosive radiation of sponges occurred during the Qiongzhusian stage, and indicate that the appearance of abundant sponges extends down closer to the Precambrian–Cambrian boundary. Study of sponges in the Kaili Biota increases our knowledge of early sponge composition and provides an important record of sponges from the middle

Cambrian of China. Moreover, all Cambrian sponges of Guizhou provide important materials and evidence for research into the more detailed processes of the “Cambrian Explosion” and the early radiation of sponges, by giving us a “slow-motion movie” of the real evolutionary story.

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Oryctocephalus indicus (Reed, 1910) from the lower part of the Kaili Formation at Wangjiayuan, near Tongren City, eastern Guizhou and its biostratigraphic significance

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Oryctocephalus indicus (Reed 1910) occurring at Wangjiayuan, near Tongren City comes from the dark-grey thin bedded to medium bedded limestone intercalated with dark-grey mudstone. This fauna is composed of oryctocephalids, eodiscoids and ptychopariids. Oryctocephalids includes *Oryctocephalus indicus* (Reed 1910), *Oryctocephalus* cf. *americanus* Sundberg et McCollum (2003a) and *Euarthricocephalus taijiangensis* Zhou et Yuan (*in* Yuan et al. 2002); eodiscids have *Pagetia significans* (Etheridge 1902), *Pagetia* cf. *edura* Jell (1975), *Pagetia taijiangensis* Yuan et Zhao (*in* Yuan et al. 1997); ptychopariids consist of *Taijiangocephalus gedongensis* Yuan et Zhao (*in* Yuan et al. 2002), *Nyella* cf. *rara* (Rasetti 1951), *Kuetsingocephalus wangjiayuanensis* sp. nov., *Parasolenopleura* spp. *Oryctocephalus indicus* (Reed 1910) is widely distributed in India, South China, USA, Korea, Greenland and perhaps Siberia (Egorova et al. 1976, pl. 43, fig. 14; Jell & Hughes 1997; Sundberg et al. 2011); *Oryctocephalus americanus* Sundberg et McCollum (2003a) and *Euarthricocephalus* occur both in USA and South China; *Pagetia significans* (Etheridge 1902) is widely distributed in Australia of *Xystridura templetonensis* Zone, as well as in India, South China of *Oryctocephalus indicus* Zone; *Pagetia edura* Jell (1975) occurs both in Australia of *Xystridura templetonensis* Zone and in South China of *Oryctocephalus indicus* Zone; *Nyella* cf. *rara* (Rasetti 1951) is quite similar to *Nyella rara* (Rasetti 1951; Sundberg & McCollum 2003b, p. 349, fig. 14.14) from the *Amecephalus arrojosensis* Zone. Therefore, the *Oryctocephalus indicus* Zone of South China can be correlated with the *Oryctocephalus indicus* Zone and underlying *Amecephalus arrojosensis* Zone of USA, as well as with the *Xystridura templetonensis* Zone of Australia.

Parasolenopleura Westergård (1953) with *Calymene aculeata* Angelin 1851 as the type species (Westergård 1953, p. 23, pl. 5, figs. 6–10; pl. 6, figs. 1–4) is quite similar to *Pseudosolenoparia* Zhou (*in* Lu et al. 1974) with *P. yankongensis* Zhou as the type species (Zhang et al. 1980, p. 369, 370, pl. 131, figs. 1–7) in general outline of cranidium, glabella and pygidium, both genera are synonymous. *Parasolenopleura* is first recorded in *Oryctocephalus indicus* Zone of South China, but it is quite common in

Sweden and Newfoundland in traditional lower Middle Cambrian, detailed study on phylogeny of *Parasolenopleura* will provide the basis for the precise correlation between South China and North Europe.

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New stratigraphic data on the Ordovician from the Pestovo-1 drill core (the Moscow Syneclise, East-European Platform)

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The Pestovo borehole was drilled in the Novgorod region, 20 km west-south-west from the small town Pestovo. It is a single drill core located in the most western part of the Moscow Syneclise, in a transition zone between the Baltic and the central part of the Moscow Basin. The Ordovician in the core is 350 m thick and spans the interval from 852.15 to 1201.4 m. First data on the stratigraphic subdivision of the Pestovo drill core were published in 1961 by L.I. Stankevich, who recognized there the Estonian regional stages (Stankevich 1961). According to this subdivision the Ordovician deposits occupy the interval from 921.0 to 1225.5 m whereas the overlying dolomites (852.15–921.0 m) are Middle Devonian (Narva or Aruküla Regional Stage). Later the litho- and biostratigraphic subdivision of the Pestovo drill core was revised by Y.E. Dmitrovskaya in her unpublished doctoral thesis. New data on conodonts, acritarchs and carbon isotopes from the Pestovo drill core allow to evaluate the adopted Ordovician stratigraphy in the region and to refine the ages of proposed stratigraphic units.

The lower boundary of the Ordovician in the Pestovo drill core is considered at a depth of 1225.5 m, at the base of dolomitic quartz sandstones yielding lingulid brachiopods *Obolus appolinis*. This position of the Ordovician base is supported by new data on acritarchs. Acritarch assemblage from the interval 1201.3–1210.32 m is very diverse and contains more than 30 taxa. Presence of *Dasydiacrodium palmatilobum*, *Izhoria angulata*, *Acanthodiacrodium angustum*, *Nelia acifera*, and some other characteristic species indicates a late Furongian age corresponding to the latest part of the *Peltura* trilobite Zone (possibly *P. scarabaeoides* subzone)–earliest *Acerocare* Zone. Tremadocian–lower Darriwilian strata (up to the *Didymograptus bifidus* Zone) in the Pestovo drill core was well dated earlier by graptolites (Sennikov & Obut 2002). Acritarchs from this stratigraphic interval have not been studied before. Occurrence of *Pachysphaeridium balticum* and *P. robustum*, accompanied by various *Baltisphaeridium*, in the interval 1126.0–1152.85 m (Obukhovo Formation) suggests an early Darriwillian (Kunda) age for the enclosing strata. Subdivision of the overlying sediments by acritachs is difficult due to gradual reduction in acritarch number and diversity.

Conodonts are relatively numerous and diverse through the studied Ordovician with the exception of the upper Meglino–Ratynia formations composed of sandy dolomites. Conodont assemblages are dominated by *Semiacontiodus* and *Drepanoistodus* elements. The distribution of conodonts showed that biostratigraphic subdivision of the Lower and Middle Ordovician proposed earlier is correct in general. The most significant change we propose is the position of the lower boundary of the Upper Ordovician that is shown to be stratigraphically higher by the appearance of *Amorphognathus* in the middle part of Berezaika Formation. Before our studies it was placed at the base of the Berezaika Formation due to the brachiopod data. Conodonts from the top of the Khrevitsa Formation show older (Idavere–Jõhvi regional stages) ages of the strata than previously thought (upper Jõhvi Regional Stage). This may indicate diachronic boundaries of the East Baltic lithostratigraphic units identified in Pestovo drill core, or errors in the lithostratigraphic subdivisions. *Icriodella superba* and *Amorphognathus* found in the samples from the interval 852.0–884.0 m (lower part of the Varlygino Formation) prove that it is of late Katian age, instead of Middle Devonian age, as previously was considered (Stankevich 1961).

Excursions of the carbon isotope curve of the Pestovo drill core do not contradict with the new biostratigraphic data. Eight Baltoscandian chemostratigraphic zones (Ainsaar et al. 2010), corresponding to the interval of Volkhov–Rakvere regional stages, were recognized. Minor variations in the isotopic composition of oxygen suggest a negligible impact by secondary processes on the isotopic composition of the bulk samples. One of the most pronounced isotopic excursions marking the lower half of the undifferentiated interval of the Aseri–Uhaku regional stages is considered to be the middle Darriwilian isotopic event.

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Pulses of the Early Ordovician brachiopod radiation in South China

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Led by the early studies of Ordovician biotic radiation (Sepkoski 1979, 1981) and faunal diversification (e.g., Droser & Bottjer 1989; Droser & Sheehan 1995, 1997; Miller & Mao 1995, 1998; Miller & Foote 1996; Miller 1997a, 1997b, 1997c; Miller et al. 1998) and facilitated by the IGCP project 410 (the Great Ordovician Biodiversification), the study on the Ordovician biotic radiation in China has been extensive and intensive, based on integrated taxonomic and biostratigraphic investigations of more than 50,000 fossil specimens of various fossil groups (e.g., graptolites, brachiopods, trilobites, bivalves, and acritarchs; see Zhan & Rong 2003, 2006; Chen et al. 2006; Fang 2006; Li & Yan 2006; Zhang & Chen 2006; Zhou et al. 2006). The diversity change could now be assessed against different graptolite biozones, and diachroneity is known as a common feature of the radiation (Zhan & Harper 2006).

The Ordovician brachiopod radiation of South China includes three diversity acmes which occurred, progressively, in early Floian (late Early Ordovician), middle-late Darriwilian (late Middle Ordovician) and late Katian (late Late Ordovician) (Zhan & Jin 2008a), and manifested respectively by the diversification and ecological expansion of three regional brachiopod faunas, i.e. the *Sinorthis* Fauna (Zhan & Jin 2008b), the *Saucrorthis* Fauna (Zhan et al. 2007) and the *Altaethyrella* Fauna (Rong & Zhan 2004). Detailed palaeontological and biostratigraphical investigations on six classic Lower to Middle Ordovician sections from the Jiangnan Slope to the Upper Yangtze Platform show that the Ordovician brachiopod radiation commenced during the earliest Ordovician and the first radiation acme had an episodic character from off shore, deep water to near shore, shallow water benthic regimes (Fig. 1). The first brachiopod diversity acme was achieved in the upper Jiangnan Slope, Sandu, southeastern Guizhou (Zhan & Jin 2008c). This fauna comprised three brachiopod dominated associations in deep water environments (~BA 4) and contained several precursors that later invaded the shallow Yangtze Platform to become predominant taxa (Zhan & Jin 2008c). The main pulse of radiation occurred in the central area of the Upper Yangtze Platform. It was characterized by a very high brachiopod α- and β-diversities with more than 50 genera and species, and over 20 brachiopod-dominated associations and communities (collectively known as the *Sinorthis* Fauna) that thrived from near-shore to offshore platform settings (Zhan & Rong 2006; Zhan & Jin 2008b). After the flourishing *Sinorthis*

Fauna, some associations, e.g., the *Paralenorthis* Association (Zhan et al. 2006), expanded their benthic regimes to nearer-shore localities, where they combined with some lingulids and the earliest known strophomenoids to mark another diversity acme. This time in a shallow water environment.

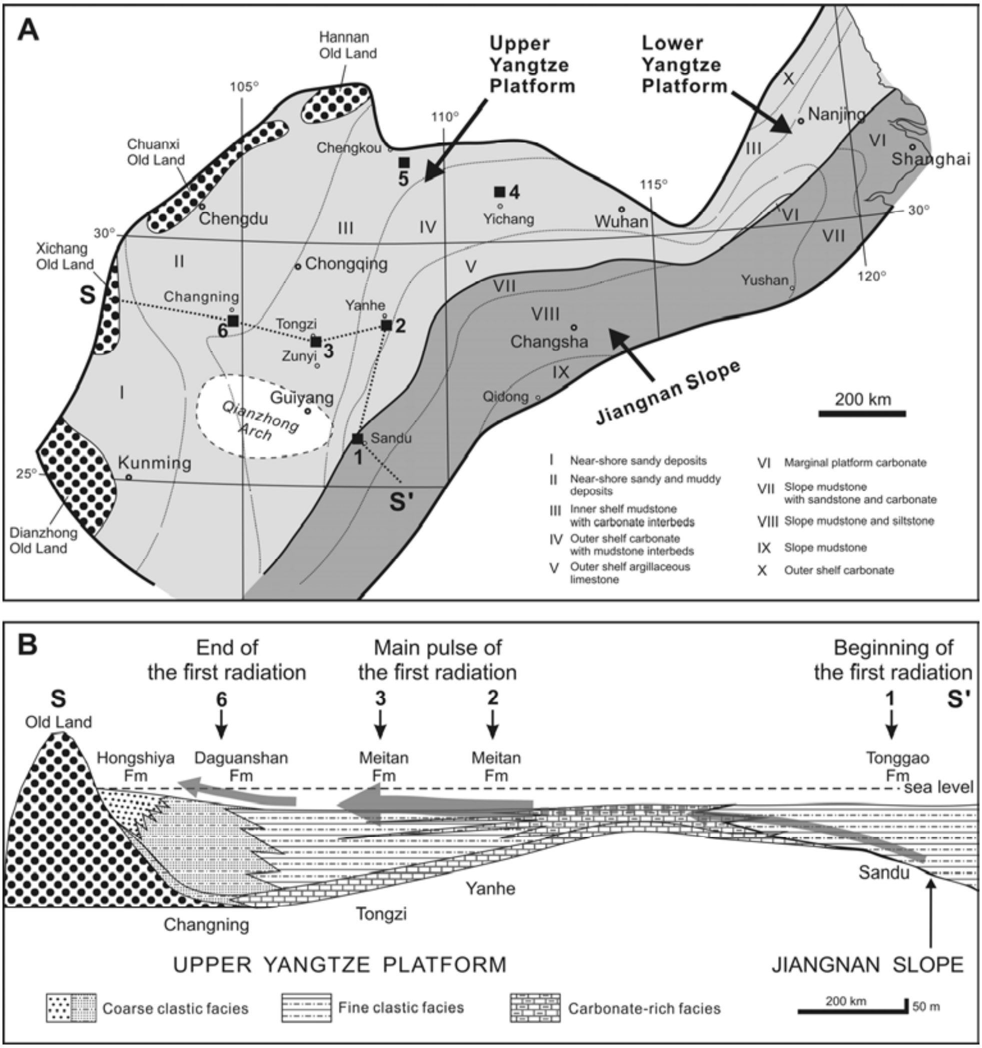

Fig. 1. **A.** Palaeogeographical positions of six Lower–Middle Ordovician sections investigated particularly for the case study in South China. **B.** Stratigraphical cross section (S–S') from the Upper Yangtze Platform to the upper Jiangnan Slope showing deposits of mainly Floian age in different palaeogeographical settings. The transparent arrows indicate the stepwise pulses of diversity acmes during the first radiation of the brachiopod GOBE in South China.

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Paleobiogeographic patterns of the graptolite evolution during the Late Ordovician extinction in South China

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Here we employed species distribution models (SDMs), a numerical method widely adopted in modern ecological research, to study the paleobiogeographic changes of graptolite species during the Late Ordovician mass extinction. This method, based on the habitat requirements of species, can establish the link between the observed distributions of species with the environmental data in the known distribution area, and therefore predict the potential geographic distribution of the species and its dynamic changes. The Geobiodiversity Database (GBDB, www.geobiodiversity.com) was used to prepare the dataset for the present study, including the biostratigraphic data, species occurrences and environmental data. The time interval of late Katian to Hirnantian, i.e., from the *Dicellograptus complexus* Biozone to the *Metabolograptus persculptus* Biozone was divided into four time slices. Nine long-ranging graptolite species were chosen as the study objects, six of which belong to the Diplograptina and three to the Neograptina. Twenty-seven potential geographic distribution maps of the graptolites species were generated by using Maxent, a powerful program for SDM analyses, and the ArcGIS software.

By investigating the dynamics of the potential distributions of each graptolite species during the successive time slices, we found that the graptolite species of different clades exhibit different paleobiogeographic patterns while facing the Late Ordovician mass extinction. The geographical ranges of the Diplograptina decreased during the extinction event, while those of the Neograptina remained stable or increased from the *Paraorthograptus pacificus* Biozone (e.g., *Korenograptus laciniosus*) or the *Metabolograptus extraordinarius* Biozone to the *M. persculptus* Biozone, showing a significant influx and spread in the Hirnantian.

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New evidence for the Silurian/Devonian boundary in the Changwantang section, Guangxi Province, South China

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Southern Guangxi is one of important areas for the study of the Silurian/Devonian boundary (SDB) in China. Some biostratigraphic attempts were made to define the exact level of the SDB in Yulin and Qinzhou regions (Wang 1977; Mu et al. 1983, 1988), however no consensus has been reached because the indicative fossils (graptolite *Monograptus uniformis*, conodont *Icriodus woschmidti* and trilobite *Warburgella rugulosa*) are not coexistent in South China (Zhao et al. 2010, 2011). Since Mann et al. (2001) reported the first isotope curve based on organic carbon for the SDB at Klonk in the Czech Republic (GSSP), comparable curves of $\delta^{13}C_{org}$ across the SDB have been provided at several locations, including sections from Turkey and China (Buggisch & Mann 2004; Herten et al. 2004; Kranendonck 2004; Zhao et al. 2010, 2011). Previous studies suggested that a distinct positive excursion of $\delta^{13}C_{org}$ from the uppermost Silurian to the lowermost Devonian represents a global bioproductivity event (Mann et al. 2001). This distinct trend from the isotopic composition of organic carbon across the SDB seems to provide a chemostratigraphic reference for a worldwide correlation of the SDB (Zhao et al. 2010). Recently, we applied organic geochemistry (including several indexes, such as $\delta^{13}C_{org}$, Ph/nC_{18}, Pr/nC_{17}) together with graptolite biostratigraphy as a tool to identify the SDB in the Changwantang section of Yulin, South Guangxi, and set up a renewed late Silurian–Lower Devonian sequence framework in the region. Our results suggest that the variations of some indexes of organic geochemistry can be correlated to the representative curve of the SDB at the Klonk and Fetlika sections. In spite of the absence of some index fossils, including the conodont *I. woschmidti* and the trilobite *W. rugulosa*, the exact level of the SDB in the Changwentang section can be located in the upper part of the Fangcheng Formation, which is consistent with available paleontological data.

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Comments on some important issues about the GSSP establishment of the Cambrian Stage 5

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The FAD of *Oryctocephalus indicus* was originally proposed as the lower boundary of Cambrian Stage 5 in 1999 and was accepted as a potential biomarker by the ISCS. There have been more than ten years since the Working Group on Stage 5 was established in 2001. It also has been ten years since Fletcher first proposed the FAD of *Ovatoryctocara granulata* as another potential boundary marker of the Cambrian Stage 5. Several field excursions have been organized to explore these and other potential boundary levels, resulting in a delayed establishment of a GSSP for Cambrian Stage 5 through the two competing views on FAD proposals of *Oryctocephalus indicus* in the Wuliu-Zengjiayan section and *Ovatoryctocara granulata* in the Molodo section. Some important factors or arguing points affecting the establishment of the GSSP for Stage 5 are summarized as follows.

Geographic distribution of potential FADs for Stage 5

Oryctocephalus indicus was first described from the Himalayan region and is widely distributed in Korea, South China, Greenland, United States and Siberia. *Oryctocephalus reticulatus* from Siberia is significantly distinguished from *O. indicus* by the undeveloped second and third pairs of transglabellar furrows. However, many specimens of *O. reticulatus* from the Molodo River show developed second and third transglabellar furrows. As for the specimens with poorly developed transglabellar furrows, this may result from intense compression, since some of them also have very shallow transglabellar furrows. Hence, many specimens of *O. reticulatus* should be reassigned to *O. indicus*. Some scholars have long argued whether *O. reticulatus* is the synonym of *O. indicus*.

Recently, some new localities of *O. indicus* have been recognized in South China, such as the Kaili Formation at Sanwan section in Nangao, Danzhai County, Guizhou Province. The Tianpeng Formation in Mengzi, Yunnan Province, deposited in shallow water platform facies, also yields *O. indicus* at the bottom of this formation. *Ovatoryctocara granulata* is mainly distributed in Siberia and Greenland, as well as Newfoundland with only three specimens. In South China, specimens originally assigned to *Ovatoryctocara granulata* have been reassigned as *Ovatoryctocara* cf. *granulata.* As of yet, *Ovatoryctocara granulata* has not been confirmed from China.

The Wuliu-Zengjiayan section in Balang, Jianhe County, Guizhou Province, China – a candidate for the GSSP for Stage 5

A majority of scholars hold the view that the *Bathynotus holopygus* or *Bathynotus guichowensis-Ovatoryctocara* cf. *granulata* Zone beneath *O. indicus* at the Wuliu-Zengjiayan section can be correlated with the *Ovatoryctocara* Zone at the Molodo River section, because the trilobite *Oryctocephalops*, *Protoryctocephalus* in the *Ovatoryctocara* Zone is widely distributed in China. The Wuliu-Zengjiayan section can thus be correlated to the Mediterranean region through the Molodo River section. It must be pointed out that the Mediterranean sections belong to platform facies during the interval between Cambrian Stage 4 and 5. In addition, the Mediterranean trilobites are regional fossils and, together with lacuna, result in difficulty of correlation outside this region. Despite this, there are certain advantages for the correlation of the boundary of Cambrian Stage 3 and Stage 4 in both the Mediterranean region and South China with its widely distributed occurrence of *Redlichia*.

Some suggestions on the study of Molodo River section in Siberia: (1) the upper boundary of *Ovatoryctocara* Zone is difficult to determine since *Ovatoryctocara* has expanded to the lower–middle part of the *Kounamkites* Zone; (2) *Kounamkites* are regional ptychopariids with restricted distribution and correlation difficulties. It is suggested to use *Oryctocephalus indicus* or *Oryctocephalus reticulatus* to define the upper boundary.

Principles for the GSSP establishment and the GSSP establishment of Stage 5

The International Commission on Stratigraphy (ICS) has introduced detailed requirements for establishing GSSPs (Remane et al. 1996). Recently, these requirements have been restated again (Gaines et al. 2011), including geological and other requirements, which are directly related with the GSSP establishment for Stage 5. Required is an adequate thickness of sediments and that a candidate section can be easily accessed. The Molodo River section fails both of these requirements. The section is highly condensed, containing six trilobite zones in the Kuonamka Formation over an interval of only 44.4 m. The section is located above the Arctic Circle (~69°N) and difficult to access. Both of these aspects of the Molodo River section do not meet the recommendations for a GSSP. In contrast, the Wuliu-Zengjiayan section contains three trilobite zones in the Kaili Formation over an interval of 214 m. It is also easily accessible with ordinary vehicles and can be connected with the whole world through expressways, railways and airlines. Access to the outcrop at the Wuliu-Zengjiayan section is unrestricted throughout all seasons.

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Geochemistry of dental bioapatite, the key to palaeoclimate

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Chemical and isotopic compositions of dental bioapatites have gained wide recognition as paleoenvironmental proxies, first demonstrated on modern fish teeth (Longinelli & Nuti 1973a, 1973b; Kolodny et al. 1983) establishing a major link between bioapatite oxygen isotopic compositions and climate (e.g., Trotter et al. 2008; Joachimski et al. 2009; Zigaite et al. 2010; Barham et al. 2012). Advances in analytical techniques and methods (Dettman et al. 2011; Zigaite et al. 2012), as well as most recent experimental work on seabreams (*Sparus aurata*) by Pucéat et al. (2010) clearly defines the potential of aquatic vertebrate dental biomineral in palaeoenvironmental research.

Plesiosaur teeth and lungfish tooth plates from the Lower Cretaceous high-latitude sequences of SE Australia, representing temperate to cold and seasonally freezing environment, were analysed for stable oxygen isotope compositions. Two methods for obtaining $^{18}O/^{16}O$ ratios have been applied: (1) *in-situ* $\delta^{18}O$ measurements of all the fluorapatite oxygen components within the enamel, enameloid and dentine have been carried out using a secondary ion microprobe, and (2) bulk $\delta^{18}O$ values of the separate phosphatic component of bioapatite have been measured through silver phosphate precipitation and high-temperature reduction mass-spectrometry. Dentine proved to be diagenetically susceptible, showing moderate variations in isotopic values, particularly those obtained by secondary ion microprobe. In contrast, both methods provided highly adequate and repeatable isotopic ratios within the enamel and enameloid in all the examined sequences, independently suggesting freezing climatic conditions, which confirm the existing sedimentological data for permafrost. The rare earth element (REE) abundances, analysed *in situ* using laser ablation inductively coupled plasma mass-spectrometry, supported the selective geochemical resilience of tissues, favouring enamel as the most reliable biomineral proxy for palaeoclimate research.

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Stable oxygen isotope compositions in shark enameloid as a proxy to seawater chemistry

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Dental tissues of modern shark species, Blacktip Reef shark (*Carcharhinus melanopterus*) and Sand Tiger shark (*Carcharias taurus*), have been analysed for oxygen isotopic compositions using a Cameca 1280 secondary ion microprobe at the NORDSIM facility (Naturhistoriska Riksmuseet, Stockholm). The sharks were growing their teeth in monitored environment of constant temperature and salinity of the tropical ocean tank at the Blackpool Sea Life Center (UK), where after being shedded they were collected from the substrate. The high spatial resolution of the ion microprobe as well as the triple-layered enameloid organization of the teeth (Andreev & Cuny 2012) allowed to target two layers of enameloid (parallel-bundled enameloid (PBE), and tangle-bundled enameloid (TBE), as well as the dentine. The resulting $\delta^{18}O$ values were replicable within each of the separate tissues of the tooth (PBE in particular) and within each species. The monitored ocean tank temperatures were reproduced using the bioapatite fractionation equation by Pucéat et al. (2010). However, the $\delta^{18}O$ values appeared to be species-specific, resulting in a 2‰ average difference. This offset between two species can be related to the 2.5‰ to 2.9‰ taxonomic offsets observed in fossil vertebrate bioapatite (Zigaite et al. 2010; Barham et al. 2012). The resulting discrepancy provides unique insight to possible 'vital effects' and species-specific dental biomineralization patterns in sharks.

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The Early to Middle Paleozoic Revolution

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Addendum

Insight into the systematic position and functional morphology of lentilform columnals from the Billingen and Volkhov regional stages (Floian–Lower Dapingian, Ordovician) of the Baltic

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Numerous isolated lenticular columnals, described in the 19th century by Eichwald (1860) as *Haplocrinus monile*, are the most abundant fossils in some beds of Billingen and Volkhov stages of the Baltic. Despite the mass occurrence in many localities, their systematic position among the other pelmatozoan echinoderms is unclear. Yeltyshewa (1964) referred these columnals to the formal genus *Pentagonocyclicus*. The findings of stems, formed by lenticular columnals articulated with crowns, allow us surely to put them into iocrinids (Disparida, Crinoidea) and require the allocation of a new genus in this family. The structure of cups, with five basal plates, five radial plates and one upper radianal plate located within the cup and which originates in the upper radial C confirms this. The anal tube joins to the left side of the radianal plate, and the arm joins to the right side of the plate. Arms branch isotomously at least two times. The crown is typically iocrinid-like, with some differences compared to the other described genera. The proxistele is composed of pentagonal or star-shaped columnals, separated by radially arranged pentamers, as is typical for iocrinids. But the mesistele, isolated columnals that are the most common, is very different from the proxistele and mesistele of other iocrinids. The seven or eight most proximal columnals of the proxistele are very low and have stellate shape with rays beneath the sutures between the radial plates. They are characterized by a wide rounded-pentagonal axial channel and a narrow articular surface with two or three weakly expressed ridges in each pentamer. Proxistele columnals, located more distally to the cup, become gradually higher and increasingly bulbous in the middle part, then become turbinate. The mesistele is built by columnals of three, sometimes four orders, sharply differing in diameter, and with very narrow axial channel. Columnals of the last, third or fourth order differ greatly from lenticular columnals of the other orders by their small size (they are narrow and low) and pentagonal, rarely stellate, shape. They connect other columnals, ranging in slightly depth facet of a neighboring columnal. Sometimes they are almost invisible from the side, as they are nearly completely covered by the adjacent columnals. Columnals of other orders are similar to each lenticular shape with a sharp or smooth bend at the equator, but differ in size and dominant sculpture at the equatorial rim of the columnal. Sculpture on the equatorial bend is formed by spines, blades, and continuous sharpened or fringed rim. Sometimes the sculpture at different pentamers of one columnal has its own peculiarities. The crown was large enough for disparids and the maximal diameter of the stem columnal it is quite consistent and was also quite typical for disparids. But in terms of physical loads that the stem was able to withstand, this diameter was indicative only for the proxistele. In the mesistele, the diameter of the smallest columnals, that link larger columnals of other orders, defines the withstand load. Diameters of the columnals of the highest order, linking the mesistele, are usually no more than one-third of the proxistele diameter. As a result, only the smallest columnals are functionally significant for the stem strength. This could promote a good bending of the theca, but the functional role of the thickened lenticular columnals is questionable. It could be, for example, an excess in the organism calcium carbonate depot. But usually, a massive carbonate skeleton and pronounced rough sculpture are characteristic for warm-water, high-carbonate environments, but the Billingen Sea at the time of the echinoderm invasion was a cool-water and low-carbonate environment. The weakness of the joints of the stem is supported by complete disintegration into separate columnals and the rarity of even small articulated fossil fragments. The specific gravity of the stem should be close to the specific gravity of water, because of weak collagen articulation joints of the stem columnals and a relatively large branching crown. The high porosity of the stereom skeleton common to all echinoderms, with partial filling by gas, contributed to this. Several columnals with an overgrown axial channel and without articular facets on one side could indicate on the possibility of living for some time by hovering in the water in case of stem breakage.

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