PALAEOZOIC CLIMATES

International Congress – Congrès international
August 22-31, 2008, Lille, France

Abstracts

Edited by Björn Kröger & Thomas Servais

Palaeozoic Climates – International Congress
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Ordovician Palaeogeography and Palaeoclimate

An event of the **International Year of Planet Earth**, an initiative of UNESCO and IUGS aiming to raise public awareness of Earth Sciences. This is a contribution to the to the scientific topic: Earth & Life – the origins of diversity and Climate Change.

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FOREWORD

The International Congress on PALAEOZOIC CLIMATES, organized by the CNRS research unit *Géosystèmes*, that integrates the palaeontologists from both the University of Lille 1 and the Catholic University of Lille, brings together over 120 scientists from over 20 countries, presenting their results in about 90 scientifical contributions in form of keynote lectures, talks and posters, of which the abstracts are assembled in this volume.

The International Congress on PALAEOZOIC CLIMATES serves as the Closing Meeting of the International Geoscience Programme (IGCP) n° 503 'Ordovician Palaeogeography and Palaeoclimate', that runs from 2004 to 2008 (and possibly on extended term in 2009). As such, the meeting in Lille is the main annual meeting of IGCP 503, following the meetings in Erlangen, Germany (2004), Milwaukee, Wisconsin, USA (2005), Glasgow, Scotland, UK (2006) and Nanjing, China (2007). IGCP 503 was and is not limited to the Ordovician, and naturally the programme of the Lille meeting also include specialists from the Cambrian and Silurian. In addition, at Lille, two days of the meeting are dedicated to the Upper Palaeozoic (Devonian to Permian), so that the meeting fills the entire week from Monday to Friday, August, 25th to 29th.

We would like to use this foreword to acknowledge our sponsors and the different organizing bodies that provided us support :

First of all, we thank the *Université Catholique de Lille* (UCL), and in particular the *Institut Supérieur d'Agriculture* (ISA) for providing their lecture halls for the scientifical sessions.
We also thank the *Université de Lille 1* (USTL) for providing support that includes the printing of this issue and the invitation of keynote speakers.
The *Institut National des Sciences de l'Univers* (INSU) of the *Centre National de Recherche Scientifique* (CNRS) and the *Palaeontological Association* provided support that allowed the invitation of keynote speakers from overseas.
The *Association Paléontologique Française* (APF), the *Société Géologique de France* (SGF), the *Société Géologique du Nord* (SGN), and the *Groupe Français du Paléozoïque* (GFP) also supported our meeting, while IGCP 503 supported the participation of several scientists from developing countries and of young scientists, including students.

We also wish to thank the members of the scientifical committee, including office members of the different Palaeozoic stratigraphical subcommissions and the French Committee of the International Year of Planet Earth, to which this meeting is a contribution.

We would also like to acknowledge the members of the organizing committee, the organizers of the field trips, as well as our students and technical staff, who help to make the meeting running smoothly.

Lastly, thanks to all participants and contributors to this meeting, in particular the keynote speakers, to make this congress a major event in the understanding of Palaeozoic geology and palaeontology.

Thomas Servais (organizing chair)
Björn Kröger (organizing secretary)

CONTENTS

REVISITING THE UPPER ORDOVICIAN CHITINOZOAN ASSEMBLAGES FROM ANTICOSTI ISLAND: IMPLICATION FOR LOCAL, REGIONAL AND GLOBAL CORRELATIONS

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The Upper Ordovician – Lower Silurian chitinozoan biozonation of Laurentia is based essentially on assemblages from the Vauréal, Ellis Bay and the basal Becscie formations of Anticosti Island. These units form a ~200-km long, east-west trending outcrop carbonate belt, with some nearshore siliciclastics in the eastern part of the island. These sediments were deposited on a storm-influenced, equatorial carbonate ramp. Lateral facies, changes and variations in thickness have made correlations difficult between the thicker distal sections in the western part of the island and the thinner and more proximal sections in the eastern part. The Laframboise Member, a widespread oncolitic-reefal carbonate unit at the top of the Ellis Bay, serves as an important stratigraphic marker for regional correlations.

Recent sequence stratigraphy studies have led to the recognition of major transgressive-regressive sequences that can be followed from the western to the eastern ends of the island. These studies have also revealed the presence of discontinuity surfaces in a sequence hitherto believed to be more or less continuous. Two of these surfaces bound the Laframboise Member near the O/S boundary. 50 samples from two sections at each end of the island were analyzed in order to re-evaluate the chitinozoan distribution in the interval containing the two discontinuities. Results from our past studies have also been used to correlate the older numbered seven members of the Ellis Bay Formation to the recent members named after localities on the eastern part of the island (the Grindstone, Vellada, Prinsta, Lousy Cove, and Laframboise members).

The western section at Pointe Laframboise has yielded the more productive samples. These have led to the recognition of the *B. gamachiana* and the *S. taugourdeaui* zones below the oncolitic bed. No chitinozoans were recovered from the Laframboise Member itself. A microfauna belonging to the *A. ellisabayensis* Zone has been identified, above the bioherm, in strata belonging to the Becscie Formation, and not the Ellis Bay Formation, as previously assumed.

Chitinozoans are less abundant in the eastern section at Pointe Renard. No chitinozoan have been recovered from the Laframboise Member and the lower part of the Becscie Formation. The chitinozoan assemblage from the Lousy Cove Member, below the oncolitic bed, is older than that recognized at the same position at Pointe Laframboise. It contains rare specimens of *B. gamachiana* associated with *T. laurentiana* that suggest a comparison with levels in members 3 and 4 of the Ellis Bay Formation in the western part of the island. More importantly, the chitinozoan assemblages from the Velleda and Prinsta members, assumed to belong to the Ellis Bay Formation, contain H. crickmayi a species diagnostic of the Vaureal Formation. Moreover, the presence of *H. crickmay*, *H. normalis*, *C. baculata* in the Grindstone Member and in the underlying Schmitt Creek and Mill Bay members of the Vaureal Formation suggests comparison with levels of the Vaureal Formation older than those cropping out in the Pointe Laframboise area.

These findings, corroborated by sequence stratigraphy analysis and acritarch do not support the previously proposed east-west correlation scheme and appeal for a new stratigraphic framework.

Comparison of the biostratigraphic and chemostratigraphic data from the uppermost Ordovician strata of the Anticosti succession (i.e. the interval spanning the *gamachiana* - *ellisbayensis* biozones) with those of Nevada, Arctic Canada, Dob's Linn and Estonia offers potential for global correlations.

MIDDLE AND UPPER ORDOVICIAN CARBON ISOTOPE STRATIGRAPHY IN BALTOSCANDIA: TOWARDS A REGIONAL CHEMOSTRATIGRAPHIC STANDARD

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Fluctuations in the oceanic dissolved inorganic carbon (DIC) stable isotope composition ($\delta^{13}C$) are considered to be indicators of global or regional environmental changes. Unless the marine carbonates are diagenetically altered, their carbon isotope composition is expected to reflect original composition of DIC in seawater. Secular variations of $\delta^{13}C$ in marine carbonates have become an important tool in stratigraphy, especially in correlation of sections from facies formed in different biotic and sedimentary environments. Relatively good preservation of the Middle and Upper Ordovician carbonate rocks in Baltoscandia makes this region unique for chemostratigraphical and palaeoenvironmental isotopic studies of this period.

Previous stratigraphic studies suggested a relatively slow but constant carbonate deposition in the Baltoscandian epeiric sea from Middle Ordovician to Silurian. Detailed biostratigraphic investigation of the succession demonstrates relatively continuous deposition in the Livonian Basin but shows also numerous local and regional sedimentary gaps in the Estonian Shelf facies. Therefore, the core sections from the Livonian Basin (southern Estonia, Latvia) are keys for stratigraphic subdivision of the Ordovician strata in the region.

The main goal of previous studies on Early Palaeozoic carbon isotope stratigraphy in Baltoscandia has been the correlation of isotope excursions. Seven positive and one negative Ordovician isotope excursion are described in the Baltic sections. The studies have demonstrated that the isotopic events can be correlated across the different lithologies over the Baltoscandian palaeobasin and some of them (Hirnantian Excursion, Guttenberg Excursion) even between different continents.

The goal of present study is subdivision of the Middle and Upper Ordovician succession into chemostratigraphic zones. The analysis is based on $\delta^{13}C$ data from 21 drillcore sections and outcrops, published by different authors in 1999-2007, and on new data from outcrops of Russia and Sweden. These sections represent the Livonian Basin (southern Estonia, Latvia), Estonian Shelf facies (northern Estonia, northwestern Russia), and Scandinavian Basin facies (Sweden). All isotope analyses have been made from whole-rock samples.

Carbon isotope zones described here are generally consistent with available biostratigraphic data. Some difficulties are met in correlation of thin units bounded by sedimentary gaps. The correlation of $\delta^{13}C$ curves can be compared with distribution of biostratigraphically important conodont, chitinozoan, and ostracode data. As a result of this analysis, we present a composite carbon isotope succession for Baltoscandian region, which can be used as a regional standard and a base for comparing the region with other basins. The composite curve also reflects history of oceanographic changes in the region, serving as a good base for understanding the global environmental history during a considerable part of the Ordovician.

SHORT-LIVED EPISODES OF CARBONATE PRODUCTIVITY ASSOCIATED WITH THE EFFUSION OF SUBMARINE LAVA FLOWS IN THE MIDDLE CAMBRIAN OF THE COASTAL MESETA, MOROCCO

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To the NW of the Moroccan High Atlas, a thick lower Palaeozoic succession is known from exposure, along the Oum-Rbia oued and its SE prolongation (the Rehamna jbel), and from core drilling under the Mesozoic-Cenozoic cover in the Doukkala Plateau. There, the middle Cambrian 'Schistes à Paradoxides', more than 1000 m thick, consists of homogeneous green shales and greywackes, locally interrupted by volcanosedimentary units.

In the Sidi-Saïd-Maâchou area, located along the Oum-Rbia oued, a volcanosedimentary complex embedded in homogeneous shales forms a broad lenticular sedimentary body, up to 10 km across and ca. 16 m thick. It consists of lava flows, dike intrusions, volcaniclastic conglomeratic and breccia lenses, and limestone beds embedded in a green and purple, shale-dominated succession that display interbedded tuffs and tuffites decreasing in abundance upsection (Gigout, 1951, 1956; El Attari, 2001). Although Gigout (1956) named this volcanosedimentary complex the 'Sidi-Saïd-Maâchou volcano', it does not preserve the typical conical shape of volcanoes, and can better be described as a 'flood basalt field', characterized by spreads of lava flows, erupted from scattered monogenic fissures vents, which flooded the seafloor generating a new substrate. From a geochemical point of view, the volcanic products of Sidi-Saïd-Maâchou show a within-plate alkaline nature (Ouali et al., 2000) and its emplacement fits well with the northward migration of the Atlas rift that began during the late Neoproterozoic and aborted during late Cambrian times.

The episodic development of carbonate productivity in this volcanosedimentary complex is directly associated with the effusion of submarine lava flows. Carbonate factories are both shelly and microbial in character. The biodiversity displayed by trilobites (conocoryphids, solenopleurids, and paradoxidids) and linguliformean brachiopods (*Almahadella*, *Eothele* and other acrotretids) is similar to that reported in coeval strata from the Anti-Atlas. This suggests normal marine and not stressful conditions, so that the fossil community cannot be envisaged as a chemotrophic-dominated hydrothermal vent ecosystem (sensu Van Dover, 2000). Degradation of microbial mats was primarily responsible for the development of sheet cavities, up to 30 cm thick, subsequently occluded by sediment infill and banded calcite cements. Carbon and oxygen analysis of the calcite cements points to depleted values representative of the degradation of organic matter.

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ROLE OF CLIMATE IN DROWNING OF THE UPPER ORDOVICIAN-LOWER DEVONIAN REEFS IN THE NORTHEAST EUROPEAN PLATFORM

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The Upper Ordovician-Lower Devonian stacked carbonate platform generations in the northeast European Platform show a mosaic of isolated reefs (middle Ashgillian, upper Hirnantian and upper Lochkovian), barrier and patch reefs (upper Aeronian) and large barrier reefs (Homerian-lower Ludfordian and Pragian-lower Emsian). The carbonate factory of the Middle Ordovician-Lower Devonian time scale without reef episodes was unable to aggrade to sea level during this period. The reef-builders that constructed the Late Ordovician reefs continued to be important in the Silurian and Lower Devonian reefs. This fact shows that the Late Ordovician and Late Silurian mass extinctions and others Silurian biotic events had comparably small ecologic impact on the shallow-marine ecosystem. The Ashgillian-Emsian is the enough short time period of the Phanerozoic (~ 455-397 Ma) but yields a significant record of ocean-atmospheric-biosphere changes.

The facies of the deep subtidal Yaptikshor Fm mark an abrupt sea level rise following emergence of the middle Ashgillian. The Ordovician reefs formation has finally stopped in the end of the Hirnantian at the Ordovician-Silurian boundary. This is marked by an abrupt change in facies reflecting a sea level rise with the massive reef shoal succession overlain by the deep slope succession. This sharp facies change is attributed to eustatic fluctuations caused by the demise of the Hirnantian ice sheet (Brenchley et al. 1994). The same sedimentological situation is observed with the Late Aeronian reefs in the Polar, Subpolar and Northern Urals which overlying by the deep subtidal and pelagic Marshrutnyj Fm facies at the base of the Telychian (post-glacial episode of Caputo, 1998). The Wenlock-Ludlow reefs were built at the edge of an incipient shelf margin after a drowned platform during Telychian time. The Homerian-early Ludfordian reefs growth was eventually terminated at the early-late Ludfordian (= Lau Event of Jeppsson, 1998) boundary because an abrupt sea level fall was replaced by a relatively abrupt sea level rise with forming of the Greben' Superformation in pelagic slope and deep subtidal environments. The growth of the Lower Devonian reefs was interrupted by an abrupt sea-level fall, first at the end of the Pragian and later in the middle Emsian. It is possible that the demise of the Lower Devonian reef growth corresponds to a global transgression in the mid-Emsian (= Daleje Event of House, 1985). It is well expressed by a rapid change from shallow-water reef carbonate platform deposits to pelagic slope deposits with significant terrigenous influx facies (Vyazov Fm).

Arid period (A-period of Bickert et al., 1997) was characterized by high $\delta^{13}C$ and $\delta^{18}O$ concentrations and, as a result, the climate at low latitudes was dry, and as a consequence, low rates of weathering and run-off promoted clear waters and prolific reef growth (the middle Ashgillian, late Hirnantian, late Aeronian, Homerian-lower Ludfordian, and late Lochkovian-early Emsian). During this time a back-reef basin often included lagoons with high salinity forming in the Pre-Urals Foredeep and the Pechora Syneclise areas carbonate-sulfate successions in ten and hundreds metres of thick. On the contrary, humid period (H-period) was shown low $\delta^{13}C$ and $\delta^{18}O$ concentrations, intensive weathering and wide distribution of clay limestones and marls on shallow-water shelf (early and late Ashgillian, Ruddanian-middle Aeronian, Telychian-Sheinwoodian, and late Ludfordian-early Lochkovian). Growth of reefs stopped during these periods, as a result of a distribution of the deep subtidal transgressive tracts of argillaceous limestones with various benthic faunas covering carbonate platforms in whole.

MICRO-SCALE SPATIAL VARIABILITY OF VISEAN BENTHIC FORAMINIFERA; IMPLICATION ON SAMPLE SIZE FOR PALEOECOLOGICAL INTERPRETATION

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The different taxa of benthic foraminifera are distributed on the sea floor following various parameters, including sea water characteristics, trophic relationships, and rock micro-facies... The understanding of these relationships is the base of the studies of foraminifera through time in order to understand climatic evolution, varying palaeogeography, and palaeoenvironmental changes in marine systems. The aim of the present study is to describe the micro-scale spatial variability of their distribution and the spatial range of the trophic relationships. A sample from the late Visean (lower Carboniferous) was selected for the study because of the reasonable richness and density of the fauna. Twenty four slides of a total 436 cm² surface were studied.

Eight foraminiferal families are observed with a heterogenic distribution in the sampled surface. This diversity is principally composed of the two dominant opportunistic families, Endothyridae (*Endothyra*) and Tuberitinidae (*Eotuberitina*). Tetrataxiidae (*Tetrataxis* and *Valvulinella*) and Archaediscidae (*Archediscus* and *Asteroarchaediscus*), are the families with the highest ecological significance. The range of the spatial variability depends on the recognition of families even if a medium to a high diversity and equitability reveal a quite stable environment.

This study emphasizes that a reasonable sample size should be sampled and studied before paleoecological descriptions and reconstitution can be put forward.

MID ORDOVICIAN FAUNAL ASSEMBLAGES AND EVENTS IN THE VILLICÚM RANGE, ARGENTINIAN PRECORDILLERA

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In the Villicúm Range, the eastern thrust belt of the Precordillera of San Juan Province, western Argentina, a warm carbonate platform that corresponds to the San Juan Formation (380 m thick) occurs. The upper part of the formation (*Eoplacognathus pseudoplanus* Zone) is composed of a lower nodular wackestones; a middle thick-bedded packstone-wackestone and upper fossiliferous wackestones and mudstones. Ash beds (k-bentonites) are intercalated with the uppermost beds. The record of these bentonites evidence the volcanism of the "Mid Ordovician mantle superplume event" (Barnes, 2003) in the Precordilliera. After this event a marked change occurs. A rhythmically bedded limestone-marlstone (12 m thick) with scarce breviconic orthocones, cyrtocones and trilobites overlies the limestones along a hardground surface. Widespread graptolite-rich deep water black shales of the Gualcamayo/Los Azules Formation cover the carbonates in many localities of the Precordillera basin. These intervals of black shales evidence a major transgressive event of the Middle Ordovician. In the uppermost unit of the carbonate sequence (9 m thick), burrowed bioclastic wackestones with a diversified fauna of trilobites, sponges, articulated brachiopods, gastropods, nautiloids, ramose bryozoans, algae and conodonts occurs immediately below and during the deposition of bentonites, during the early Darriwilian.

This fauna exhibits some degree of community succession. In this unit can be distinguished three characteristic assemblages, based on the percentages of fossil fauna (from bottom to top): **Assemblage I**: composed of trilobites (*Annamitela* and *Illaenus*), asaphids, articulated brachiopods (*Paralenortis*, *Tritoechia*, among others), gastropods (*Lophospira*, *Hormotoma*, *Helicotoma* and *Maclurites*), crinoids, ramose bryozoans and small-sized demosponges. **Assemblage II**: consists predominantly of lithistid sponges of dishes, domical, cup and bowl forms (*Psarodictyum*, *Patellispongia*, *Hudsonospongia* and *Calycocoelia*) comprising about 60% of the total biological volume. Calcified cyanobacteria (*Girvanella problematica*) and microproblematica (*Rothpletzella* sp., *Halysis monoliformis* and *Nuia sibirica*, Beresi) are present and are locally abundant. **Assemblage III**: dominated by a diversified and abundant nautiloid fauna of early Darriwilian orthoceroidans (*Braulioceras sanjuanense*, *Eosomichelinoceras baldisii*, *Gangshanoceras villicumense*, *Rhynchorthoceras minor*) and endocerids.

These faunas grow in shallow subtidal environments within the photic zone, where organic nutrients are most abundant and are situated below the fair-weather wave base.The presence of lithistids in life position implies a low-energy level environment in which this assemblage developed. The algae and cyanobacteria indicate deposition within the photic zone. The fauna suggests low-energy, subtidal conditions on an open carbonate platform under warm temperatures during this interval of the San Juan Formation deposition. So, during the Early and Middle Ordovician times the Precordillera should have been located at low latitudes under a warm temperate climate. At the top of the San Juan Formation there is a laterally persistent, crinoidal grainstone, representing a high-energy shallow carbonate setting. On the bedding planes, large orthoconids show a preferential alignment on the sea floor. The stop of the carbonate fabric and the change to graptolitic shales occur within the *E. pseudoplanus* Zone, in the Villicúm Range. In other places of the Precordillera, however, the cessation of the carbonate fabric was diachronic. Sea-level changes and epeirogenic subsidence were possibly the mechanisms responsible for producing the diachronic end of the carbonate fabric in the Precordillera basin.

CHANGES IN TRILOBITE ASSOCIATIONS DURING THE DEVONIAN IN THE ARDENNE MASSIF

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In the Devonian of the Ardenne Massif, trilobites present a high biodiversity but still remain poorly documented. Recent studies have been performed on systematical palaeontology and on the understanding of biodiversity trends and their response to environmental variations (Crônier and van Viersen, 2007).

The present work particularly focuses on the Givetian section of the Mont d'Haurs, from Givet (France). Three genera have been found and have been assigned to *Dechenella* (about 90% of all specimens), *Calycoscutellum* (9%) and *Nyterops* (1%). All specimens are disarticulated or fragmented. Microfacies studies (Hubert, 2008) indicate predominantly shallow, agitated, open marine environments that are often close to reefs.

Biodiversity indices (Shannon, Dominance) and a cluster analysis allow to show that this assemblage is close to the trilobite associations of the Eifelian-Givetian transition, defined by Crônier and van Viersen (2007). This analysis also precises the definition of the *Dechenella* and *Nyterops* association.

We were able to recognize six megaguilds (Bambach, 1983) among the Mont d'Haurs' organisms: pelagic carnivores, attached low suspension feeders, reclined suspension feeders, attached high suspension feeder, active deposit feeder and active suspension feeder. The replacements of the megaguilds precise the structural changes within the various ecosystems independently of taxonomic composition or dominance of some taxa. This approach is also useful to identify the environmental events of level 2 and 3 (Droser et al., 1997).

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WHAT ARE THE CAUSES AND PALAEOECOLOGICAL SIGNIFICANCE OF SMALL-SIZED SAMPLES OF MARINE INVERTEBRATES?

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For a long time, and more recently, some small-sized samples of marine invertebrates have been cited and described. They belong to all groups of marine invertebrates and geological periods. They have been recognized on all continents. In this paper we will examine, in two parts, the palaeoenvironnement, palaeoecological or palaeoclimatical conditions associated with small-sized samples of marine invertebrates (from the literature devoted to the palaeozoic faunas).

The first part deals with small-sized, rare specimens, belonging to one (1) or two orders (2) or one whole group (3) associated with normal-sized specimens:

(1) – rare specimens of spiriferid brachiopods from uppermost Famennian, France, Massif Central, NE Morvan (Legrand-Blain, 2000), small-sized cyrtospiriferids, late Frasnian, South China, Central Hunan, (Ma & Sun, 2001); micro-productid from Early Carboniferous, South China (Balinski & Sun, 2005).

(2) – orthid brachiopods from Tournaisian, Spain, Iberian Peninsula (Martinez-Chacon & Winkler Prins, 1993); orthid and spiriferid from Givetian, Poland, Holy Cross Mountains, Laskowa Hill (Racki et al., 1985).

(3) – small solitary conical rugose corals, D/C boundary, France, Montagne Noire, La Serre (Semenoff-Tian-Chansky, 1988), similar fauna from Famennian, Germany, Thuringian Mountains and from Upper Famennian, the former USSR, Omolon region (Poty, 1986).

The second part deals with three fossil assemblages for which all specimens are small-sized. The first assemblage concerns brachiopods, gastropods, crinoids from Late Givetian. The second one corresponds to the so-called “brachiopod bed” from Frasnien, France, Boulonnais, Ferques (Wallace, 1969). The third assemblage consists of ostracods, conodonts, brachiopods, gastropods, bryozoa from Early Carboniferous, South China, Guizhou Province, Muhua (Balinski, 1999).

First of all, we had to verify if the specimens concerned were adults, if their size was really different (dwarfed) from the adults, and, for the first part, if the whole small-sized specimens occurred together with normal-sized specimens in the same level. The causes of the presence of small-sized marine invertebrates are multiple and palaeoecological significance is relatively different for the examples cited in the two parts. Those of the first part being more connected than the second one with the nature of the group concerned. Among the causes are mainly shallow water, and/or near shore environment, temperature.

SILURIAN GLOBAL EVENTS: A REVIEW OF THE ASSOCIATED CHANGES IN SHALLOW-MARINE BENTHIC ECOSYSTEMS

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A wealth of stratigraphical data concerning the Silurian global events has been assembled by several research teams over the last few years. Although a great ecological significance of a few of these events can be questioned, there are at least three of them that without a doubt are significant on a global scale – the Early Silurian Ireviken Event, the Middle Silurian Mulde Event, and the Late Silurian Lau Event (Jeppsson 1998). The close relationship between the biodiversity changes of these events with substantial perturbations in the global carbon cycle and changing oceanography implies that they were intimately associated with changes in ocean circulation and in Earth's global climate. The most substantial extinctions have been documented in pelagic and nektonic groups of taxa and the misconception that the events only affected the oceanic realm may therefore arise. Nevertheless, studies over the past few years of the sedimentology and sequence stratigraphy of the carbonate platforms of Gotland (Sweden) have clearly shown that the events had great impact also on shallow-marine ecosystems although this has not been measured in terms of taxonomic loss. The bulk of these strata formed in shallow subtidal to intertidal environments and the most pronounced changes in their composition and temporal development are directly associated with the events, obviously due to a complex interaction of climate, sea-level and biotic changes. For the Mulde and Lau events it is strikingly that the platforms [i.e. carbonate production] are terminated during the biotic crisis and re-establish contemporaneously with the post-event improvement of microfossil assemblages and the falling limb of the associated carbon isotope anomalies. The peak of the biotic crises correlate with anomalous carbonate production, including increased formation of non-skeletal elements such as ooids and carbonate facies generally accepted as 'disaster forms', e.g. oncoids, sessile stromatolites, wrinkle structures, and other microbially mediated facies (Calner 2005). The contemporaneous changes in reef composition are very little studied but most notable is a reduction in both size, abundance and diversity of stromatoporoids, the common reef-builders in the Silurian. The ecological changes associated with bioevents are far more difficult to quantify than taxonomical and an attempt to develop a systematic method for identifying so called 'paleoecological levels' was made by Droser et al. (1997, 2000). In their scheme, they included microbial resurgence in normal marine environments as a characteristic signal of second-level paleoecological changes during mass extinctions. Hence, a rather significant ecological impact of the Silurian global events on shallow marine environments may have been decoupled from a less drastic taxonomic impact. Two conclusions can be made. First, from an ecological point of view, the Silurian global events stand as remarkable miniatures of the more devastating extinction events of the Phanerozoic. Secondly, the events had substantial impact on shallow-marine, benthic ecosystems.

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THE SIGNIFICANCE OF MIDDLE KATIAN PALAEOKARST IN BALTOSCANDIA FOR UPPER ORDOVICIAN GLOBAL CLIMATE

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The Upper Ordovician of Baltoscandia consists of a succession of temperate carbonates, dolomites and fine-grained clastic rocks that formed in widely different settings depending on proximity to the Caledonian Orogen. The units discussed here formed in the stable interiors of the craton, where strata are condensed and display good lateral continuity. One of the most drastic environmental changes of this time interval and region is associated with the Slandrom Limestone and Fjäcka Shale transition in the middle Katian (near the *Amorphognathus superbus-A. ordovicicu*s zonal boundary). The facies succession across this transition reflect a regression and lowstand, resulting in basin-regional cessation of carbonate production, followed by a major transgression and deposition of black, organic-rich shale over wide areas. A significant hiatus at this sequence boundary can be identified based on chitinozoan biostratigraphy in different parts of the basin and our preliminary results suggest that karst weathering is associated with it.

There are two main lithologies in the Slandrom Limestone. These are a beige-coloured, very dense (aphanitic) limestone that forms the framework rock, and a brown, porous matrix with a varying degree of skeletal grains. Both lithologies occur in a complex arrangement in which the aphanitic rock type form highly irregular bands or lithoclasts with angular forms. Primary bedding is not observed and the fabric rather suggests a collapse origin of clasts or in minor part a short transport. Conspicuous concavo-convex clast forms and circular cavities filled with exotic micro-facies suggest a karst origin for the Slandrom facies. The overlying Fjäcka Shale is a conspicuous and regionally important marker bed that is the source rock for petroleum in the Upper Ordovician mounds of the basin. This unit superimposes rocks of widely different facies in distinct parts of the basin, underlining the vast magnitude of the transgression. Similar pronounced facies changes occur in Dalarna, central Sweden, were the Kullsberg mounds are drowned by the Fjäcka Shale and in the East Baltic were the Slandrom-equivalent Sjauna Limestone is capped by an unconformity covered by the Fjäcka Shale.

Based on $\delta^{13}C$ data and a sequence stratigraphic analysis of strata in the Monitor and Antelope Ranges in Nevada, Saltzman & Young (2005) argued that global cooling and glaciation occurred already in the middle Katian, ca 10 Ma before the Hirnantian glaciation. They indirectly dated the Eureka Quartzite, a unit which cuts down into stratigraphically different levels in different areas, by the GICE event in the underlaying Antelope Valley Formation. It seems likely, however, that the vitreous part of the Eureka was deposited during a glacial at the Mohawkian/Cincinnatian transition. Our high-resolution carbon $\delta^{13}C$ record (Lehnert et al., this volume) and the profound sedimentary change across the Slandrom/Sjauna-Fjäcka boundary in Baltoscandia support such a scenario for the Caradoc/Ashgill transition (presumably time-equivalent to the upper Eureka in the western US) although the exact dating of this pre-Hirnantian glaciation remains uncertain.

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OSTRACODS AND THE ALLEGED *PUNCTATA* CRISIS IN THE TYPE-LOCALITY FOR THE DEFINITION OF THE FRASNIAN STAGE

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Recently, Yans et al. (2007) have demonstrated an abrupt and high-amplitude negative carbon isotopic excursion ($\delta^{13}C$ shift of -7‰) in the *punctata* Zone, corresponding probably to a world-wide perturbation in the earth-ocean system. Yans et al. suggest that this event is related to a catastrophic release of oceanic methane hydrate. They also estimate that among others an impact or a high-amplitude sea-level change may have contributed to that carbon isotopic excursion. Precisely, in the *punctata* Zone, the Alamo Event is responsible for the deposition of a huge megabreccia related to a pelagic marine impact in the eastern part of the Great Basin (Nevada) (Sandberg & Warme, 1993; Morrow et al., 2005).

Negative carbon isotopic excursions are frequently associated with biological crisis, eg during the Late Frasnian Event. To test if the isotopic event detected by Yans et al. may be related to a biological crisis, and as part of a program of the Belgian FNRS and of an other of the Polish KBN, we have undertook the study of ostracods close to the Early Frasnian / Middle Frasnian boundary, in Poland, Nevada and Belgium. The results of the two first studies (Poland, Nevada) have been recently reported in a special issue of Acta Palaeontologica Polonica (Casier et al., 2006; Gluchowski et al., 2006).

In the type region for the definition of the Frasnian Stage (Southern border of the Dinant Synclinorium), we have selected two classic sections. The access path to the Arche quarry (*transitans* Zone) and the Frasnes railway section (*punctata*, *hassi* and *jamieae* Zones). 825 ostracods belonging to 27 taxa and 25 species have been recorded in the first section, and 1400 ostracods belonging to 47 species in the second section. They appertain to the Eifelian Mega-Assemblage, and their distribution is mainly controlled by the energy of the environment principally related to sea level variations.

Seventeen species (18 if we count some doubtful specimens of *Punctomosea weyanti*) out of 25 present below the *punctata* Zone in the access path to the Arche quarry, are also present above that zone in the Frasnes railway section. Moreover, with the exception of a single species belonging to the genus Microcheilinella, all the others absent above the *punctata* Zone are scarce. Consequently we can state positively that ostracods are not touched by a crisis during the *punctata* Zone or close to the Early-Middle Frasnian boundary. A contradictory analysis of carbon isotopes across the *punctata* Zone in the type region for the definition of the Frasnian stage is desirable. The high-amplitude negative carbon isotopic excursion detected by Yans et al. (2007) on brachiopod valves has been maybe amplified by a short hiatus or may be related to the collection of brachiopods. These one has been collected in the Ermitage path at Boussu-en-Fagne, a section inaccessible since several tens of years.

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PALEOECOLOGICAL INTERPRETATION OF VISEAN MICRO-FACIES BASED ON FORAMINIFERAL HORIZONTAL MICRO-REPARTITION

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Benthic foraminifera respond rapidly to fast environmental changes. The different taxa of these protists are spread on sea floor according to sea water characteristics. This biological capacity is the base of studying foraminifera through the time in order to understand climatic evolution, palaeogeography, and palaeoenvironments in marine systems. Paleozoic foraminiferal micro-distribution is not very well known in northern France. The aim of this study is to describe palaeoenvironemental data through foraminiferal fauna analysis, from late Visean (lower Carboniferous). It emphasized on horizontal foraminiferal micro-distribution, depth and environmental activity through the observation of 24 slides from horizontal sampling (436 cm²).

Eight foraminiferal families are observed with a heterogenic distribution in the sampled surface. A medium to a high diversity and equitability reveal a quite stable environment. This diversity is principally composed of the two dominant opportunistic families, Endothyridae (genus Endothyra) and Tuberitinidae (*Eotuberitina*). Tetrataxiidae (*Tetrataxis* and *Valvulinella*) and Archaediscidae (*Archediscus* and *Asteroarchaediscus*), which are the families with the most ecological significance. The absence of photophile algae and the presence of the worm Spirorbis and numerous ichnites in the quarry, reveal a water depth between 20 and 25 m. Moreover, the numerous crinoids found in the sample and the foraminiferal association confirms the location on a middle carbonate ramp (under the fair weather wave base). Local high foraminiferal density may be explained by bioturbations filling with a muddy sediment and storm deposit, shown by observation of terrestrial plants in marine systems

GEOBIODIVERSITY DATABASE

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The Geobiodiversity Database (GBD) Project (http://www.geobiodiversity.com) is facilitating regional and global collaboration based on large-scale fossil and sedimentary rock database, enabling a greater understanding of the life, sediment and geography of our planet during the Earth history. The key elements of GBD are data, analyzing tools and web services.

The database of GBD is structured around three subsets or tables: reference, taxonomy and collection. Each record of the three subsets can be linked to the record or records in other subsets. For example, once user input a reference record, he can use it in taxonomy or collection record by giving the reference number or by searching in the reference subset. And the database provides compatibility with Endnotes and also the function of uploading standardized reference list. In the taxonomy subset, user can input general taxonomy information from phylum to species or subspecies, synonym list and images. In the collection subset, user can input geographic, chronostratigraphic, lithostratigraphic, taxonomic information as well as the isotopic age and paleogeographic information of any fossil collection. User can easily link a collection record to related reference or taxonomy records by using the reference or taxonomy numbers or by searching in those two subsets.

The GBD provides a powerful text-searching engine. For example, user can search collection subset by using any combination of 22 fields, such as fossil name, locality or biozone. Results are viewable on present-day maps now. The statistical tools and related functions, such as data visualization (e.g., rangechart), diversity statistics (e.g., diversity curve, origination and extinction rates), will be available sooner. The server of GBD, which is hosted in the State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, is supported by the institute and the laboratory, and will provide stable and long-term service.

EARLY PALAEOZOIC COOLING EVENTS: EVIDENCE AND PERIODICITY

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The end-Ordovician (Hirnantian) Gondwanan glaciation had a short-lived glacial maximum associated with marine mass extinction(s). Global sea level fall of 50-100m correlates with large C and O stable isotope excursions, and with widespread evidence of glacial deposits and erosional geomorphology in Gondwana. Recent work suggests that this glaciation was the culmination of much longer drawn out climatic cooling. Less severe cooling events both earlier and later (late Ordovician–early Silurian) have been interpreted from isotope records, corroborated by the direct evidence of glacial deposits in Gondwana. The distributions of some basinal and shelf sedimentary facies, and faunal migrations, have been proposed as providing indirect evidence of climatic shifts and changing oceanographic conditions through this period. However, we review here the various strands of facies and faunal evidence, and isotope data, which indicate periodic cooling events over a much longer time scale, from at least mid Cambrian through to late Silurian times. Through the early–mid Ordovician, reduced stratigraphical and facies evidence for sea level changes may represent a relative lull in glacial development. We consider the periodicity and controls promoting early Palaeozoic climate cooling, in particular the possible interface with orbitally controlled rhythms as opposed to intrinsic factors such as evolving palaeobiogeography, changes in global sea level and in pCO_2.

ORDOVICIAN AND SILURIAN GEOGRAPHY

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Lower Palaeozoic geography was dominated by the vast Panthalassic Ocean and the supercontinent of Gondwana, the latter stretching from over the South Pole to more than 30º N. However, there were other very substantial terranes at the start of the Ordovician; notably Laurentia, Baltica, Siberia and South China, as well as numerous smaller terranes, mid-oceanic islands and island arcs. The Turkey to New Guinea and western South American margins of Gondwana were largely passive but between them the European and Australian margins were active, resulting in the progressive accretion of the Australian area island arcs and the separation of Avalonia from north-western Gondwana in the early Ordovician, closely followed by Perunica (Bohemia). However, Armorica did not become independent of Gondwana until the late Silurian or early Devonian with the opening of the Palaeotethys Ocean. Siberia and Baltica were both inverted at the end of the Cambrian, with Siberia drifting northwards across the equator to remain one of the few large continents in the northern hemisphere, to which various Altai-Sayan and Mongolian terranes progressively accreted. Baltica rotated quickly and moved from high to intermediate southern latitudes, so that by the end Ordovician it was in today's orientation before colliding obliquely with Avalonia at about Ordovician-Silurian boundary times. The combined Avalonia-Baltica collided more dramatically with Laurentia (which remained equatorial during the whole Lower Palaeozoic) in the middle Silurian in the Caledonian and Scandian orogenies, following the closure of the Iapetus Ocean. Within the Iapetus there had been various mid-ocean islands and island arcs which became progressively accreted to Laurentia, Baltica or Avalonia as the ocean closed: many of those islands had formed important faunal staging points. Because the major terranes were widely separated at the beginning of the Ordovician, substantial faunal provinces were more obvious then than at any other time in the Lower Palaeozoic: indeed, the mid to late Silurian marine benthic faunas were largely cosmopolitan apart from the endemic *Clarkeia* Fauna in the Gondwanan high latitudes and the *Tuvaella* Fauna in Siberia and the peri-Siberian Mongolian terranes to the then north of it. We have constructed revised palaeomagnetic APW paths for the major continents; outline global maps for the whole period and more detailed palaeogeographical reconstructions for Baltica, Siberia, and the north and north-eastern Gondwanan active and passive margins. The climates varied greatly: the most notable event was the relatively brief end-Ordovician Hirnantian glacial episode, but in both the Ordovician and Silurian there were identifiable warming and relatively cooler events which can be recognised by analysis of both sediments and faunas.

THE LATE ORDOVICIAN GLACIATION IN VALONGO ANTICLINE: EVIDENCES OF EUSTATIC SEA-LEVEL CHANGES

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The basal Upper Ordovician is represented by massive quartzites with evidences of an unconformity in the base and in the transition to the overlaying glacial deposits. Some of the late presents rapid lateral facies changes. In some places the basal glacial deposits consist of a thinly laminated mudstone with alternating black and white layers interpreted as varves. To the top of this deposit a thin milimetric shelly bed appears. The mudstones are overlained by diamictites bearing dropstones, either massive or sometimes evidencing stratification (lamination, slump, convolute bedding). In some places and at different levels, particularly in the base of the glacial sequence Mn-rich crusts occur interbedded within the diamictites resulting from sedimentation in basins isolated from the open ocean. Usually the Mn oxides occur in oolitic horizons, concretions or laminae.

The diamictites consist of a dominant fine grained sandstone, siltstone or mudstone matrix usually with disseminated rocks fragments. These dropstones may exhibit angular to rounded forms, with different lithologies (quartz, quatzites, slates, sitstones, sometimes remobilized fossils) ranging in size from microscopic (25-250µ) to about half a meter. Usually these rocks are dark grey turning to light grey, beije or reddish evidencing banded weathering. The diamictites are widespread.

Conglomeratic deposits occur sometimes within the diamictites, bearing quartz and quartzite clasts of centimetric size in a phylitic dark grey matrix. They might be interpreted as terminoglacials fans canalized deposits.

To the top these glacial deposits contact with Silurian schists.

The isolated basins were Mn deposited were the result of a low glacio-eustatic sea-level on the North Gondwana platform that consequently allowed the drainage of fresh water from continent creating oxidizing conditions with the formation of Mn with vast terrigenous input. This fact and the presence of varves support the idea that part of these glacial deposits was formed in a near-shore environment, not far from the ice sheet (ice-proximal).

BRINGING THE LOWER PALEOZOIC INTO THE 21ST CENTURY: A CASE STUDY OF METHODS, OBJECTIVES, PITFALLS, AND POTENTIAL OF HIGH-RESOLUTION (<500,000YRS) INTEGRATED GLOBAL CHRONOSTRATIGRAPHIC CORRELATION IN THE SILURIAN

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The fidelity and resolution of global chronostratigraphic correlation largely depends on the time period of interest. Through the use of astrochronology and deep-ocean cores, the Cenozoic and Mesozoic communities have the ability to correlate on the scale of thousands to hundreds of thousands of years. For most of the Paleozoic, chronostratigraphic control better than one million years is considered ‘high-resolution’, and much of the timescale carries error bars longer than 1myr. For too long, the difficulty added to intercontinental correlation by the general lack of Paleozoic deep-sea strata has been considered an insurmountable hurdle in our efforts towards a Paleozoic chronostratigraphy that approaches the resolution of younger eras. Although difficult, recent investigations have begun to show that this is neither impossible nor impractical.

Seven of the biostratigraphically best-constrained Silurian regions, outcrops and cores have been studied for integrated conodont, graptolite, and carbon isotope $\delta^{13}C_{carb}$ stratigraphy providing three independent methods of chronostratigraphic correlation from the same strata. The result is an improved chronostratigraphy that allows global correlation on the scale of a few hundred thousand years and much less in the interval near the Llandovery-Wenlock boundary. The improved resolution puts this interval of the Silurian on par with what is currently achievable in younger eras, however this level of detail has taken over a decade to accomplish for this small time-slice alone. A staggering amount of basic stratigraphic research will be required to complete the Silurian at this resolution, and with few exceptions, there is a similar prognosis for the Paleozoic as a whole.

'PALEOZOIC STRATIGRAPHY HAS ALL BEEN DONE BEFORE': AN OPPOSING VIEW FROM SILURIAN HIGH-RESOLUTION STRATIGRAPHY ACROSS THE CINCINNATI ARCH

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Silurian strata of the Cincinnati Arch region (Ohio, Indiana, Kentucky; USA) have been studied for over 200 years. The last major investigations into the regional and global correlation of these strata took place almost 40 years ago, and since then, only a handful of studies have been conducted. Even to the casual observer, it would appear as though the details had been worked out long-ago. The unfortunate reality was that in one sense this was true. We knew (or at least thought we knew) the age of the units in the area down to the stage level in most cases and this was considered sufficient. The age of basic Paleozoic stratigraphic research had clearly come to an end.

The discovery of dramatic global climate events during the Silurian over the past decade however has begun to change this viewpoint and has improved our ability to chronostratigraphically correlate global strata in the process. In an effort to investigate short-term changes in the global climate system, a high-resolution (<500,000yrs) Silurian chronostratigraphy has been developed. By combining high-resolution conodont biostratigraphy, carbon isotope stratigraphy, bed-by-bed section and core logging, sequence pattern analysis, and faunal composition analysis, together with improved global chronostratigraphy, we can demonstrate the level of stratigraphic resolution now achievable in the Lower Paleozoic, as well as the overwhelming amount of work that still needs to be done.

This investigation represents two years (truly hundreds of years) of preparation for a field trip run by the Geological Society of America (GSA) held in April, 2008. A stratigraphic overview of the field trip will be presented highlighting the need for major revisions to both the stratigraphic nomenclature of the region as well as the chronostratigraphic correlation of Cincinnati Arch strata, together with the global implications of these changes. The field guide for this meeting is available online through GSA (McLaughlin et al. 2008).

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LATE HIRNANTIAN (ORDOVICIAN) SEDIMENTARY AND FAUNAL EVENTS IN THE WELSH BASIN (UK): A RECORD OF RAPID POST-GLACIAL, CLIMATIC AND OCEANIC CHANGE

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Research into the causes, patterns and timing of the end-Ordovician extinction has largely focused on the climatic-oceanographic processes which accompanied the growth and subsequent collapse of an extensive Gondwanan ice sheet. However, a critical requirement for the evaluation of any deep-time palaeoclimate event is a well constrained stratigraphy. New discoveries from the peri-Gondwanan Welsh Basin provide a secure basis for global comparisons of late Hirnantian strata deposited during the c.0.5 m.y. period of rapid, but episodic sea level rise and environmental change that followed the glacial maximum (c. 444.5 Ma).

In peri-basinal shelfal settings, landward of the glacial shoreline, the onset of post-glacial maximum deepening (Garth House-Brynglas Event) is recorded by an unfossiliferous, transgressive shoreface facies overlying a newly recognised unconformity. On the seaward side, this facies succeeds regressive sandstones containing the distinctive, cool water '*Hirnantia* fauna'. In the deeper central parts of the basin, this same sequence boundary is now recognised as the contact between barren, re-sedimented mudstones and an underlying regressive unit of conglomeratic turbidite sandstones.

New correlations reveal that a second deepening episode in younger Hirnantian strata (Ystradwalter-Mottled Mudstone Event), led to an abrupt post-glacial re-colonisation of the sea bed by a soft-bodied, bioturbating infauna and re-population of the water column by planktonic, persculptus Biozone graptolites. This coincided with the re-establishment of shelly communities in shallower shelf settings, including local re-colonisation by elements of the '*Hirnantia* fauna'. Further deepening (Cwmere-Chwefri Event) established a stratified water column, concomitant with the imposition of anoxic bottom water conditions and the loss of the 'Hirnantia fauna' components from shelly shelfal communities.

The evidence of these deepening events is widespread and points to their eustatic origin, suggesting that the associated faunal changes were linked to the shifts in global climatic-oceanic belts that accompanied the orbitally forced decay of the Gondwanan ice-sheet. The initial, post-glacial demise of thermohaline circulation, and the spread of warm, nutrient-poor waters, was marked by a widespread biotic minimum (Garth House-Brynglas Event). Subsequent changes in oceanic circulation, which coincided with renewed deepening (Ystradwalter-Mottled Mudstone Event), promoted the basin's faunal re-colonisation. The succeeding transgression (Cwmere-Chwefri Event) introduced warmer waters that finally expelled the '*Hirnantia* fauna' and signalled the final resetting of the Earth-climate system to a new, post-glacial maximum 'Silurian' regime.

PALAEOBIOGEOGRAPHY OF EARLY CAMBRIAN ARCHAEOCYATHS

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Global distribution of archaeocyaths (a group of Cambrian calcified sponges) was fundamentally governed by the availability and mutual proximity of normal-marine carbonate depositional tracts, in conjunction with the distribution of constituent environments now recognised as discrete facies. Resulting biogeographic patterns were further influenced by rapid tectonic changes accompanying rifting, as well as by evolution within the group, leading to the frequent appearance of short-lived, specialised endemic taxa. Among global palaeogeographic reconstructions proposed for the Early Cambrian, those which best fit the archaeocyathan distribution portray a post-supercontinental world (Rodinian or Pannotian) with the major epeiric seas within the tropical belt. The pathways of archaeocyathan migration inferred from Jaccard similarity coefficient analysis of both archaeocyaths and total Cambrian faunas suggest the Early Cambrian existence of East and West Gondwana, the rifting of Laurentia from the Australian-Antarctic margin, and the drift of suspect Altay Sayan and Mongolia terranes toward Siberia. Cluster analysis of generic distribution data has recognised two major archaeocyathan realms, Eurasian and Lauraustral, the former embracing Siberia-Mongolia, Central-East Asia and Europe-Morocco, the latter, Australia-Antarctica and North America-Koryakia.

Archaeocyaths appeared within the transitional Anabar-Sinsk tract of the Siberian Platform at the beginning of the Tommotian Stage and had dispersed to the Altay Sayan and Russian Far East only by the very end of this stage. Other regions, with phosphate-rich sedimentation, extensive evaporite basins or fluviatile and deltaic siliciclastic sediments, were not suitable for archaeocyathan colonisation.

During the early Atdababian Stage, marine transgression generated widespread carbonate sedimentation. Archaeocyaths of Siberian affinity reached westernEurope and Morocco, where a new centre of diversification developed and endemic forms appeared. By the terminal Atdabanian and initial Botoman stages, continued transgression had initiated carbonate accumulation and archaeocyathan proliferation on Yangzi, Australia and Laurentia. By the end of the Botoman Stage, archaeocyaths had dispersed from Australia to Antarctica. Early Cambrian transgression attained its maximum in the Botoman Stage, leading to the relative isolation of the various regions and a maximal diversity of mostly endemic archaeocyaths. The medial Botoman transgressive peak was marked by extensive accumulation of black shale, thin-bedded limestone in low latitudes, and an anoxic/dysoxic event affecting the archaeocyaths which thereafter survived only as low-diversity communities in certain localised refugia. Subsequent late Botoman-Toyonian regression substantially reduced shallow marine platform areas and thereby decimated the archaeocyaths, leading to their virtual extinction by the beginning of the Middle Cambrian. Due to counter-clockwise rotation of Gondwana, Antarctica alone remained in low latitudes, so furnishing both known species of post-Early Cambrian archaeocyaths.

DISRUPTION INTO THE PALAEOPHYTOPLANKTON REALM ACROSS THE ORDOVICIAN-SILURIAN BOUNDARY: TIMING AND SCENARIO

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The Late Ordovician was a icehouse period, culminating with the Hirnantian (latest Ordovician) glaciation which correlates in time with the second biggest mass extinction in Earth history. Acritarchs (palaeophytoplankton; Palaeozoic primary producers) had been previously considered to undergo an “abrupt terminal Ordovician extinction”. However, a gradual turn-over from typical Ordovician to Silurian microphytoplankton assemblages has been recently proposed in opposition to a mass extinction scenario. In fact, origination rates were still high during latest Ordovician times, as shown by the appearance of several taxa (e.g. *Evittia*, *Tylotopalla*, *Dilatisphaera*, *Oppilatala*) in Hirnantian strata. The present study, based on new palynological investigations of Upper Ordovician strata from Anticosti (Ellis Bay Fm) and southern Estonia (Valga-10 drillcore) supports the idea that diagenetic processes (e.g., dolomitization), hiatuses, and/or unfavourable environments for phytoplankton development and preservation (e.g., reefs) may be at the origin of the perceived drastic diversity reduction of the Hirnantian palynofloras, thus discounting a mass extinction event, and corroborating the "Hirnantian turn over" scenario.

In order to discuss our data within a coherent chronostratigraphic framework, we assume here that the HICE (Hirnantian Isotopic Curve Excursion), detected in the two study areas, occurred synchronously worldwide, being entirely bracketed within Hirnantian times. Well preserved and diversified acritarch assemblages occur in pre-HICE strata from the two study localities. HICE strata from Anticosti (Ellis Bay Formation, the reefal La Framboise Member) are almost barren, while the age equivalent sediments from southern Estonia (Kuldiga and Saldus Fms) yield a diversified and very well preserved palynoflora. Only the post-HICE sediments from Anticosti (base of the Becsie Fm; initial transgressive event) yielded a moderately well preserved, low diversity palynological assemblage composed of highly tolerant acritarchs like *Multiplicisphaeridium*, *Micrhystridium*, *Evittia*, *Hoegklintia*, in addition to prasynophytes and cryptospores. Typical Ordovician acritarchs (e.g., *Peteinosphaeridium*, *Ordovicidium*, *Orthosphaeridium*, *Baltisphaeridium*) are absent, like it is the case in post-HICE sediments worldwide. These data suggest a post-HICE crisis for typical Ordovician acritarchs rather than a Hirnantian one. In proximal carbonate platforms from low-middle palaeolatitudes (e.g. Anticosti and southern Estonia), a change in nutrient supply coupled with a probable decreasing light penetration into the water masses during the basal Silurian transgression might be the cause for this crisis.

The gradual Late Ordovician atmospheric cooling could have favoured productivity by increasing thermohaline circulation and water-masses oxygenation. Phytoplankton of K-type reproductive strategy would have adapted to the gradual environmental modifications. Phytoplankton of r-type reproductive strategy should have been also favoured in a slowly changing environment. The "Silurian-type" acritarchs would have radiated during the Hirnantian and survived the early Silurian transgression because of wider range of tolerance (r-type?) as opposed to the typical Ordovician taxa (K-type?) that went extinct.

A HIGH-RESOLUTION STRATIGRAPHIC MODEL TO RESOLVE THE LONGSTANDING ISSUES RELATIVE TO THE CORRELATION AND INTERPRETATION OF THE O/S BOUNDARY ON ANTICOSTI ISLAND

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The Upper Ordovician Ellis Bay Formation on Anticosti Island, Québec, Canada, provides an unique opportunity to study the stratigraphic architecture of mixed carbonate-siliciclastic deposits formed during a period of major glaciation on a subsiding, storm-influenced, tropical ramp. Our study integrates litho-, bio-, cyclo- and stable isotope chemostratigraphy with the aim of developing a high-resolution stratigraphic model near the O/S boundary on Anticosti.

The east-west trending, ~200 km long Ellis Bay outcrop belt, with superb coastal exposures at both ends, is slightly oblique to the paleoshoreline with nearshore siliciclastic-dominated facies restricted to the eastern part of the island and more offshore carbonate-dominated facies present along the central and western parts. Despite important lateral facies changes, five major transgressive-regressive (TR) sequences are recognized allowing for a precise correlation between the eastern and western sections. In the eastern sections, relatively thin TR sequences are bounded by unconformities and characterized by a modest thickness of their transgressive intervals. A typical sequence begins with a thin transgressive carbonate lag overlain by a maximum flooding calcareous shale grading up into regressive, storm-influenced, lower/middle shoreface sandstone/grainstone and shale and eventually fair-weather, upper shoreface sandstone/grainstone. In the central and western sections, the thicker TR sequences have more symmetrical transgressive-regressive components reflecting an increase in subsidence compensated by higher carbonate sediment supply. The tops of the TR-4 and TR-5 sequences are truncated from east to west by regional erosion surfaces corresponding to the base and the top of the distinctive Laframboise member, respectively. This stratal architecture style is compatible with that of icehouse sequences dominated by 400 ka Milankovitch climatic and eustatic changes with 50-100 m shifts.

Our sequence stratigraphic framework, when coupled with new high resolution chitinozoan biostratigraphic and stable isotope chemostratigraphic data, suggests the following scenario: 1) the current lithostratigraphic framework of the upper Vauréal and the Ellis Bay formations is incorrect; 2) the base of the Ellis Bay Formation (e.g. base of the Gamachian stage) is older than the base of Hirnantian stage; 3) the Hirnantian is restricted to the upper Ellis Bay Formation and the basal Becscie Formation; 4) the O/S boundary occurs in the basal Becscie Formation; 5) the profile of the Hirnantian Isotope Carbon Excursion (HICE) is offset by two hiatuses; 6) the Laframboise member (TR-5) displays a transgessive succession composed of nearshore, oncolitic gravels locally overlain by keep-up, calcimicrobial-coral biocontructions truncated by a regional, probably karstified, erosion surface with as much as 8 m in local relief; and 7) the Laframboise calcimicrobial-coral reefs are stratigraphic reefs built in small, incremental phases punctuated by high-frequency ecological crises.

This study shows that the Anticosti succession captured a high resolution record of physical, biological, and chemical events near the O/S boundary comparable to those of the O/S sections in Estonia, Dob's Lin, and Nevada.

MULTI-ORDER GLACIO-EUSTATIC FLUCTUATIONS RECORDED IN LOWER SILURIAN TROPICAL CARBONATE RAMP DEPOSITS, ANTICOSTI ISLAND, QUEBEC, CANADA

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The Lower Silurian (upper Llandovery) Chicotte Formation is a regional 80 m thick encrinite (crinoid-rich) deposit that accumulated on a slowly subsiding cratonic tropical carbonate ramp now exposed in superb coastal and river exposures on Anticosti Island. Chicotte encrinites represent extensive crinoid blankets formed at a modest depth below the fairweather wave base. These blankets were frequently reworked by storms resulting in the selective landward and seaward transport and rapid burial of various crinoidal skeletal elements (i.e., stem versus calyx and holdfast). Small coral-stromatoporoid and sponge-bryozoan buildups occurred locally. Vertical and lateral facies successions in the Chicotte encrinites record three distinct hierarchical cycles at sub-meter, meter, and decameter scales. The predominant depositional unit is a meter-scale subtidal cycle (3-8 m thick) typically characterized by upward coarsening, locally cross-bedded encrinitic debris capped sharply by an erosion surface. These surfaces display low scalloped relief but up section become more complex with a highly irregular relief similar to modern rocky shorelines. Several closely-spaced encrinitic sub-units (< 1 m thick) also capped by erosion surfaces are typically present in the upper part of individual meter-scale encrinitic cycles. At the larger scale, meter-scale encrinite cycles display an aggrading to prograding stacking pattern truncated locally by major incised paleovalleys (at least 1 km wide and 50 m deep) that developed during a long term sea level fall and subsequently were filled with encrinitic debris during the ensuing long term trangression. This complex but repetitive record of sea level changes preserved in the Lower Silurian Chicotte encrinites was likely forced by multi-order glacio-eustatic fluctuations associated with the South American Gondwanan ice sheet growth and melting.

ORDOVICIAN DEPOSITIONAL SEQUENCES OF THE SIBERIAN CRATON

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Eight depositional sequences bounded by regional unconformities or correlative conformities can be recognized in the Siberian Ordovician. They are as follows (from the base to the top): (1) Nya; (2) Ugry; (3) Kimai; (4) Baikit; (5) Krivaya Luka; (6) Mangazeya; (7) Dolbor; (8) Kety.
1. The Nya sequence coincides in scope with the Nyaian regional stage. An unconformity between the Cambrian and Ordovician deposits is poorly expressed in Siberia. Facies shift and signs of erosion were recorded only near the Yenisey Land. **2. The Ugry sequence** coincides with the Ugorian regional stage. In the Irkutsk basin (Angara and Lena river valleys) its base is marked by a regional unconformity and abrupt changes of facies from predominantly carbonate to siliciclastic. **3. The Kimai sequence** coincides with the Kimaian regional stage. Its base (the boundary interval between Ij and Badaranovo formations in the Angara river basin) is marked by beds enriched with glauconite. The lower boundary of these beds is interpreted as a transgressive surface. **4. The Baikit sequence** embraces the Vikhorevian and Mukteian regional stages. Its base coincides with the regional unconformity at the base of the Baikit Sandstone. The underlying Kimaian sequence is usually partly eroded. This unconformity is probably evidenced of the most extensive Ordovician regression in the Siberian craton. **5. The Krivaya Luka sequence** embraces the Volginian and Kirenskian-Kudrinian regional stages. A base coincides with well developed erosional surface at the base of the Volginian regional stage. The Volginian deposits seem to represent a transgressive systems tract while Kirenskian-Kudrinian deposits reflect regression and represent a highstand systems tract. **6. The Mangazeya sequence** is equal in scope to the Chertovskian and Baksian regional stages. Its base coincides with regional erosional surface at the base of the Chertovskian regional stage. The Chertovskian and Baksian deposits represent transgressive and highstand systems tracts respectively. **7. The Dolbor sequence** corresponds to the Dolborian regional stage. It is bounded by surfaces of erosion in the shallowest parts of the Tunguska basin and displays a full cycle of relative sea-level changes. **8. The Kety sequence** embraces the Nirundian and Burian regional stages. There is an unconformity at the base of the Nirundian stage near the Katanga Land. The deeper water facies of the Nirundian stage represent a transgressive systems tract and Burian deposits represent a higstand systems tract. The uppermost part of the Ordovician succession is eroded and the Burian deposits are directly overlapped by the Silurian ones.
The sequences reflect third-order sea-level fluctuations (in sense of Vail et al., 1977) 1-10 m.y. long and correspond to the Pakerort, Latorp, Volkhov, Kunda, Tallinn, Kegel, Wesenberg and Fjacka sequences of Baltoscandia respectively.

PALAEOGEOGRAPHIC PROXIMITY BETWEEN SOUTH CHINA AND EASTERN GONDWANA DURING THE EARLY DEVONIAN: THE EARLY VERTEBRATES DATA

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The study focuses on some basal arthrodire placoderms ("armoured fishes") from the Early Devonian of South China: *Gavinaspis convergens* Dupret & Zhu 2008, from the late Lochkovian (Lower Devonian) of Yunnan (South China); *Yiminaspis shenme* Dupret 2008 from the Pragian of Zhaotong (Yunnan); *Szelepis yunnanensis* (Liu 1979) from the Lochkovian of Qujing (Yunnan); and *Yujiangolepis liujingensis* Wang, Pan & Wang 1998 from the Pragian of Liujing (Guangxi). All these taxa are the most ancient occurrence of their respective groups. The Phyllolepida then occur in the Givetian—Frasnian of Gondwana, and the Famennian of Euramerica; the Wuttagoonaspididae occur in the Emsian—Eifelian of Eastern Gondwana only; the Antarctaspididae occur in the Emsian—Givetian of Eastern Gondwana only; the Actinolepididae occur in the Pragian—Givetian of Laurussia. A Chinese origin is hence proposed for these groups, and a first step of dispersal from South China to the North-Eastern margin of Gondwana is dated at the Pragian—Emsian boundary (E'Em bioevent) for all groups but the Actinolepididae. Indeed, after this bioevent, the endemism rate of Chinese vertebrate faunas drastically falls because of the invasion and subsequent competition with Gondwanan taxa. These data are consistent with those of other early vertebrates (i.e. Galeaspida, Sarcopterygii; Zhao & Zhu, 2007; Zhu, Wang & Wang, 2000) and of palaeobotany (Hao & Gensel, 1998; Wang, Hao & Liu, 2002). The models derived from the palaeontological data support a short distance between South China and the North-Eastern margin of Gondwana during the Early Emsian, contra a wider oceanic mass as suggested by palaeomagnetic data (e.g. Torsvik 2004, Cocks 2002, Cocks & Torsvik, 2002; Torsvik & Cocks, 2004). As for the family Actinolepididae, it is noteworthy that no Gondwanan occurrence has ever been reported (due to the poor Early Devonian record). One should consider either a trans-Panthalassic dispersal (most likely impossible for these sub-benthic organisms), or a more ancient origin for this family (possibly not Chinese).

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GRAPTOLITE RECOVERY AFTER THE LATE ORDOVICIAN EXTINCTION – WITH DATA FROM SOUTH CHINA

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The early Rhuddanian strata are widespread from the Upper Yangtze region to the Lower Yangtze region in South China. Recently, we investigated over 20 sections in South China and an abundant graptolite fauna, including 55 species assigned to 13 genera, occurs from the early Rhuddanian strata from this area. Two graptolitic biozones can be recognized and correlated globally, i.e., the lower, *Akidograptus ascensus* Biozone, and the upper, *Parakidograptus acuminatus* Biozone. The available evidence suggests that the *A. ascensus* Biozone is a globally distributed biostratigraphic unit. Its base, as well as the base of the Silurian System, can be recognized by the close co-occurrence of several species, including *A. ascensus*, *Sudburigraptus similaris*, *Normalograptus anjiensis* and *Paramplexograptus kiliani*. The *P. acuminatus* Biozone can be divided into three parts and correlated globally. Dynamic changes of the composition of graptolite fauna from Hirnantian to early Rhuddanian indicate a reorganization interval or survival-recovery interregnum (*Normalograptus persculptus* Biozone) after the major extinction and a recovery interval (*A. ascensus* to *Cystograptus vesiculosus* biozones). The present material also supports the graptolite faunal replacement from the *Ordovician* DDO fauna to the Silurian M fauna after the extinction event, with a transitional N fauna between them.

THE UPPER ZLICHOVIAN EVENT (EMSIAN) IN THE NERITIC FACIES OF THE CANTABRIAN ZONE AND ITS IMPACT ON TABULATE CORALS BIODIVERSITY

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In the Devonian rocks of the Cantabrian Zone (NW Spain) several events of diverse kinds and intensity have been identified by García-Alcalde (1997). Among them, the Upper Zlichovian Event (UZE, *Nowakia elegans* dacryoconarid biozone) is a small transgressive event, well identified in the offshore facies of the Cantabrian Zone by lithologic and faunistic evidence and also by MSEC anomalies. Nevertheless, in the neritic facies of this Zone this event is specially distinguished by faunistic turnovers, which include brachiopod fauna changes and the setting of an important coral association.

The main aim of this paper is to show the huge impact on the biodiversity of the tabulate corals induced by the beginning of this pelagic episode. Four sections have been studied to date: La Vid de Gordón, Adrados, Colle and Villayandre. In all of them, the UZE is recorded in La Pedrosa Formation (La Vid Group), its lithological evidence being the replacement of dolomitized argillaceous limestones by dark shales intercalated with packstone nodules and lenses. Tabulate corals occur in these carbonate beds either as mostly complete specimens or as bioclasts and they usually appear with rugose corals belonging to the so-called "*Cyathaxonia* fauna".

Specially because of the absolute lacking of tabulate faunas prior the UZE, the more strinking feature of the post-UZE tabulates is their taxonomic, morphological and ecological diversity. To date, the list of taxa includes two orders (Favositida and Auloporida) and five families (Parastriatoporidae, Micheliniidae, Favositidae, Pyrgiidae and Aulocystidae). The commonest taxa are *Parastriatopora cantabrica* Fernández-Martínez and Tourneur, *Saouraepora* sp. B *Plusquellec*, Tourneur and Lafuste., *Praemichelinia* Lafuste and Plusquellec, *Crenulipora* Le Maître, *Hamarilopora* Le Maître, *Bainbridgia* Ball and *Schluetherichonus* Byra. Bioclasts of the incertae sedis genus *Mejdoubia* Termier and Termier are very common.

Concerning morphological diversity, several types of colonies can be found in these beds, their study indicating a wide range of ecologial strategies. Massive cerioid colonies (such as *Crenulipora* ones) would live free on the muddy substrate. Robust branching colonies (such as those of *Parastriatopora* and *Saouraepora*) probably maintained a suprastratal growth but the presence of anchorage basis and opercula in the lower part of the main branches indicates than they grew partially buried. Delicate branching colonies (such as numerous striatoporids and probably also *Mejdoubia*) developed a constratal or slightly suprastratal growth, and thus worked the lowest level of the water column. A little upper level of tiering was also occupied by fairly numerous dendroid colonies, like those of *Schluetherichonus* and other auloporid taxa. Finally, several specimens belonging to two genera (*Cladochonus* and *Hamarilopora*) are featured by growing around a crinoid stem. This fact enabled them to reach a higher level of tiering.

The diversity of this fauna decreases some meters after the beginning of the Upper Zlichovian event and they finally disappear near the next transgressive event (Daleje-*Cancellata* event).

Jenaro García-Alcalde (Oviedo University) provided me with a large amount of data concerning the UZ Event. This paper is a contribution to the projects CGL2005-03715/BTE and IGCP nº 499.

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COOL- TO WARM- WATER CONDITIONS FOR EARLY CAMBRIAN REEFS?

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The study of Early Cambrian bioconstructions proves that they were mainly built by calcimicrobial - archaeocyathan communities. Most of the authors have agreed, besides some differences, on their effective contribution to form a framework construction that in some instances has all the prerequisites of true reefs and in analogy with recent equivalents, have ascribed them to tropical warm waters. But since temperatures of the water in a deep setting of the tropical zone may equate the temperatures of shallow water in higher latitudes, bioaccumulations developed in deeper tropical waters would show depositional features similar to those of shallower ones grown in cooler conditions. Thus, communities with disguised warm water composition might have lived in cool-waters either in deeper tropical settings or in shallower conditions in higher latitudinal zones.

Concerning the paleoecological behavior of Early Cambrian reef building organisms it is difficult to discriminate light-independent Heterozoan from light-dependent Photozoan Assemblages within bioconstructions built by low diversity communities apparently lacking climate sensible organisms. Since the taxonomic affinities of the dominant components of the calcimicrobial assemblages (*Renalcis* and *Epiphyton*) are largely unknown, we assume that they should correspond to the present day phototroph association which components appeared later in Ordovician times. Sponges, archaeocyaths and few other accessory taxa passively involved in the framebuilding (coralomorphs) or acting as commensal (chancelloriid, trilobites, hyolitids, molluscs, brachiopods) represent the heterotroph components of the communities. Most of the formerly studied Early Cambrian bioconstructions are characterized by a comparatively simple structure of the microbial-archaeocyath communities suggesting general low nutrient and prevailing low energy levels. The sedimentological analysis of the different styles of reef building and associated surrounding sediments and of the early diagenetic features provide informations on the spatial, latitudinal/climatic conditions of the primary depositional setting since the relative development of the main reef-building components, and their evolution within the reef communities, reflect the dominant physico-chemical factors of the environment. Buildups supported by well developed fibrous/bladed, high-Mg cements are indicative of high salinity and degassing/energy of the sea waters, hence of warm tropical conditions on oceanward shelf margins. Conversely reduction of marine cement volume evokes decreasing evaporation, lower salinity from cooler marine waters and intracontinental (epeiric) shelves. Abundant production of lime mud/automicrite and abiotic marine cements in stromatactis-like cavities suggests low energy and deeper/cooler depositional settings.

Therefore the biological/ecological relationships alone cannot provide satisfying responses to the interpretation of climatic/latitudinal variations. Adding to the data resulting from the biota distribution within the buildups, the facies patterns and the abiotic syn- and diagenetic processes, it is possible to recognize rather well diversified ecologic conditions of the microbial-archaeocyath communities involved in the different bioaccumulations scattered in the present day continents. Some of these features can be related to the influence of the morphology of the depositional shelf, while others can be equated to the entire range of physical, climate-related conditions affecting shelves spanning the tropical zone from North to South.

Thus the analysis of the depositional features and the different bioaccumulation styles provide informations on the primary settings of the microbial-archaeocyath communities and on their diversified ecologic conditions. They also bring elements to outline the latitudinal distribution of the buildups since the first appearance of reef communities in the Early Cambrian.

THE LATE ORDOVICIAN GLACIAL RECORD

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An outline of the North Gondwanan, Late Ordovician glacial record is proposed. The related palaeogeographic domain extended from southern high palaeo-latitudes (southeastern Mauritania, Niger) to northern lower palaeo-latitudes (Morocco, Turkey, Sardinia) and covered a more than 4000 km-wide section perpendicular to ice-flow lines. Glacial advances are spatially and stratigraphically evidenced by subglacial structures (tunnel valley, shear zones) delineating glacial erosion surfaces, while deglaciation periods and interglacial intervals are reflected in fluvio-deltaic, glaciomarine or shallow shelf successions. A major mid-Hirnantian deglaciation event subdividing the Hirnantian glaciation in two first-order cycles is recognised. Each cycle comprises 2-3 glacial phases separated by several hundreds kilometres ice-front retreats. From ice-proximal to ice-distal regions, the number of glacial surfaces differentiates *(i)* a continental interior with post-glacial reworking of the glacial surfaces, *(ii)* a glaciated continental shelf that is subdivided into inner (1-2 surfaces), middle (2-5 surfaces) and outer (a single surface related to the glacial maximum) glaciated shelves, and *(iii)* the non-glaciated shelf. Glaciomarine outwash diamictites are developed at or near the maximum position of the ice-front. During ice-sheet recession, a relatively thin sediment cover blankets the erosion surfaces in foredeepened ice-stream areas. Marine-terminating ice fronts then evolve later into more slowly retreating, land-terminating ice fronts. In adjacent areas (inter ice-stream) where a more gradual ice-sheet recession occurred, fluvio-glacial deposits prevailed. The progradation of a delta-shelf system, coeval with fluvial aggradation, characterises the late glacial retreat to interglacial conditions (Ghienne et al., 2007, The Late Ordovician glacial sedimentary system of the North Gondwana platform. Special Publication n°39, International Association of Sedimentologists, Blackwells, pp. 295-319).

This model for sequence stratigraphic interpretation of the North Gondwana glacial record allows other proxies of Late Ordovician environmental changes derived from low palaeolatitude settings (e.g. sea level change, isotopic excursions or biodiversity) to be confronted to the reconstructed ice-sheet evolution (timing, extent) throughout the Hirnantian. Of particular interest are the Moroccan successions that comprise in intermediate palaeolatitudes a full glacial record with, in addition, evidences for Katian (pre-Hirnantian) glacially-driven lowstands. The deglaciation of the North Gondwana resulted in a major, latest Ordovician transgression, which was followed during the Lower Silurian by an additional glacio-eustatic sea-level rise reflecting the final recession of the ice-sheet in the continental interior. However, glacier influences maintained throughout the Lower Silurian as shown by the South American glacial record. From an ice-free, pre-glacial status (resp. post-glacial) to full glacial conditions (Hirnantian glacial maximum), the cumulative amplitude of the inferred glacially driven sea-level fall (resp. rise) has probably been in the 150-250 m range. The Hirnantian event may have account for at least 100 m, depending on the growth and extent of pre-Hirnantian glaciers inside the Gondwana landmass.

CLIMATE HISTORY OF THE PHANEROZOIC IN RESPONSE TO CONTINENTAL DRIFT

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Large fluctuations in the continental configuration occur all along the Phanerozoic times. While it has long been recognized that paleogeography may potentially influence atmospheric CO_2 via the continental silicate weathering feedback, no numerical simulation have been done given the lack of a spatially resolved climate-carbon model. Indeed, all previous numerical models reconstructing past atmospheric CO_2 and climate link global air temperature and mean continental runoff to atmospheric CO_2 through simple parametric laws [1-3]. Those kind of models are blind to the continental configuration, and thus neglect the role of continental drift on the long term geochemical and climate evolution. However spectacular progresses have been made in the climate modelling area. In particular, owing to the ongoing improvement of supercomputers, we are now in position to use atmospheric general circulation model (GCM) to investigate the long term carbon cycle evolution in response to continental drift. Here a GCM has been coupled to a model of the biogeochemical cycles leading to the building up of the GEOCLIM model able to calculate simultaneously atmospheric CO_2 and the spatially resolved climate [4-6]. The climate module of the GEOCLIM model is the FOAM atmospheric general circulation model, allowing the calculation of the consumption of atmospheric CO_2 through continental silicate weathering with a spatial resolution of 7.5°longitude x 4.5°latitude. 20 time slices have been simulated, from 600 to 65 Ma.

Regarding the Mesozoic, we show that the break up of the Pangea supercontinent triggers an increase in continental runoff, resulting in enhanced atmospheric CO_2 consumption through silicate weathering. As a result, atmospheric CO_2 falls from values above 3000 ppmv during the Triassic, down to rather low levels during the Cretaceous (around 400 ppmv), resulting in a decrease in global mean annual continental temperatures from about 20°C to 10°C. In the super continent case, given the persisting aridity, the model generates high CO_2 values to produce very warm continental temperatures compensating for the lack of continental humidity. Conversely, in the fragmented case, the runoff becomes the most important contributor to the silicate weathering rate, hence, producing a CO_2 drawdown and a fall in continental temperatures. We also show that most of this global cooling occurs within a 20 Ma window at the end of the Triassic. New results for the Paleozoic shows the atmospheric CO_2 at rather high values in the latest Proterozoic and in the Cambrian (above 104 ppmv), mainly driven by the aridity persisting above the Gondwana, thus limiting the CO_2 consumption through silicate weathering. Then CO_2 decreases to reach 3000 ppmv in the latest Ordovician at the time of the Hirnantian glaciation, a decrease related to the drift of North America towards the humid and warm equatorial area where CO_2 consumption is optimized. The cimatic role of the land plants colonization will be also discussed.

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CORRELATION OF DARRIWILIAN SUCCESSIONS IN GONDWANAN (SEANATOLIAN AUTOCHTHON & TAURIDES) AND PERI-GONDWANAN (ISTANBUL & ZONGULDAK) TERRANES IN TURKEY

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Darriwilian successions, dated by conodonts, graptolites, chitinozoans and acritarchs are encountered in all main Paleozoic terranes of Turkey.

In the SE Anatolian Autochthon, which had been attached to the northern edge of the Arabian Platform all along its geological past and is hence a typical Gondwanan entity, early middle and late Darriwilian is represented by siltstone, shale, and subordinate sandstone beds. Based on chitinozoans Paris et al (2007) recognized a northern Gondwanan affinity. However, index species of the Ordovician chitinozoan biozones for Baltica are also identified.

In the Taurides, which was detached from Gondwana during the Late Permian, the Early Darriwilian is characterized by a 40m thick carbonate–dominated sequence. The early Darriwilian (*Baltoniodus norrlandicus* Biozone) conodont taxa in this unit are typical for Baltoscandia, but also described from N. Africa (Sarmiento et al (2003). In the southern Taurides, a single locality with mixed carbonate-siliciclastic tempestite-type deposition with Baltoscandian conodonts is dated as late Darriwilian (*P. anserinus* Zone).

Istanbul and Zonguldak terranes in N. Anatolia were considered as two separate Peri-Gondwanan (Avalonian) terranes, where Ordovician is generally represented by coarse clastics with rare fossils. Recently, early Darriwilian (*Undulograptus austrodentatus* Zone) was recognized in black shales with carbonate bands (Boncheva et al, in print) and late Darriwilian (*Eoplacognathus suecicus* Zone) in massive carbonates in the Zonguldak Terrane (Lakova et al, in prep).

To conclude, during the early Darriwilian the Istanbul, Zonguldak and Tauride terranes with their carbonate-dominated successions were in similar latitudes to the other Peri-Gondwanan terranes. During the Late Ordovician Istanbul and Zonguldak Terranes must have migrated towards lower latitudes, as they do not include evidence of the Late Ordovician glacial event, which is found both in the Taurides and the SE Anatolian Autochthon. Moreover, during the Middle Ordovician, the Turkish terranes must have been close enough to Baltoscandia for faunal exchange.

MIDDLE DEVONIAN "OOLITIC IRONSTONE" FORMATIONS WITHIN THE PALEOZOIC CARBONATE PLATFORM IN NW ANATOLIA

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In NW Anatolia, the Early Devonian deposition is characterized by brachiopod and crinoid–rich limestones alternating with mudstones and sandstones. Upwards they are followed by a shoaling-upward series with red conglomerates, red and green mudstones and sandstones with dolomite lenses and hardgrounds that grade into oolitic ironstones and chamositic mudstones (Ironstone Member of Kipman, 1974). The overlying marly limestones, nodular limestones and dolomitic limestones (Manastır Member of the Yilanli Formation) are characterized by the abundance of corals, brachiopods, bivalvia and echinoids. Recent conodont findings in these carbonates indicate the *ensensis* and *hemiansatus* zones of Lower Givetian (Boncheva et al, in review). The overlying thick succession of shallow-marine limestones and dolomitic limestones (Yilanli Formation) range from Frasnian to lower Tournaisian in age.

In the Camdag area, eleven separate bands of oolitic limestones/dolomites and oolitic ironstones were recognized. Mineralogically, the carbonate part is dominated by goethitized and chamositized Solenopora with rare chamositic oolites. The oolitic ore is made up of goethite, brown iron-silicates, chamosite, sideritic oolites, quartz clasts and some brachiopods.

The bioclastic grainstone (Dunham)/ biosparite (Folk) limestone facies displays partial iron precipitation within microborings around the bioclasts or total iron emplacement within whole bioclasts. Iron could not be observed within the sparry cement, therefore must be syncroniously precipitated with the sediments before cementation. Iron precipitation could be explained as precipitation of transported dissolved iron from terrestrial environment under the wet/subtropical climate within oxidizing and increased PH conditions, or dissolved iron transported by upwelling currents over the shelves and precipitated under oxidizing environment.

THE GREAT ORDOVICIAN BIODIVERSIFICATION EVENT (GOBE): FROM ANOXIA TO IMPACTS, ISLANDS AND NEW TROPHIC STRUCTURES

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The Ordovician Period (c. 488-444 Ma) witnessed profound changes in the biodiversity and biocomplexity of marine life, marked by the installation of a benthos dominated by suspension-feeding animals. Arguably these changes set the agenda for subsequent marine life on the planet. Whereas the Cambrian Explosion generated a range of spectacular new body plans, it was not until some 20 Myr later that biodiversity at the family, genus and species level began to climb. Over an interval of some 25 Myr, accelerating γ (inter-provincial), β (inter-community), and α (intra-community) diversity was initiated by high diversities amongst Early Ordovician benthic faunas, emerging from the widespread anoxia of the Furongian (late Cambrian), and associated with the dispersal of the continents and the high frequency of volcanic arcs and microcontinents (γ diversity) against a background of sustained sea level rise. The disparate and diverse assemblages belonging to the Celtic, peri-Gondwanan and Toquima-Table Head, peri-Laurentian marginal and oceanic provinces may have helped accelerate the event. Moreover, during the Early and Mid Ordovician, community types expanded particularly into deeper water and around carbonate platforms and mound structures (β diversity) and more animals were squeezed into communities by the canalization of ecological niches permitting more densely packed associations (α diversity). Other factors such as an abundance of phyto and zooplankton, planktotrophic larvae together with periodic meteorite showers, climatic and sea-level changes may have provided critical resources and stimuli to a rapidly diversifying marine invertebrate fauna, participating in new trophic structures that reached its Palaeozoic plateau during the Late Ordovician.

CHANGING BIOGEOGRAPHIC PATTERNS THROUGH THE ORDOVICIAN: RHYNCHONELLIFORM BRACHIOPODS RESPOND SPATIALLY TO DIVERSIFICATION AND EXTINCTION EVENTS

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The Ordovician Period (c. 488-444 Ma) witnessed profound changes in the biodiversity and biocomplexity of marine life, marked by an initial major diversification and concluded with a multiphase extinction event. During the period there was an overall reduction in the provinciality of its brachiopod faunas as the many of the major continental basins and shelves converged. Multivariate analyses of brachiopod-range data through the system indicate at least five temporal groups corresponding to the Tremadocian-lower Floian, upper Floian-Dapingian, Darriwilian-Sandbian, Katian and the Hirnantian. Over an interval of some 25 myr a recognizable set of brachiopod provinces was initiated by high diversities amongst the upper Floian-Dapingian benthic faunas associated with the dispersal of the continents and the high frequency of volcanic arcs and microcontinents. Assemblages belonging to the Celtic, peri-Gondwanan and the Toquima-Table Head, peri-Laurentian marginal and oceanic provinces may have helped kick-start the event the Great Ordovician Biodiversification Event. During the Darriwilian-Sandbian, biogeographic patterns are more diffuse and less easy to define against a background of fluctuating sea level; nevertheless, continental, marginal and oceanic faunas can be differentiated. The abundant and diverse faunas of the Katian show well-defined provincial patterns although modified during the Boda Warming Event, and although less diverse, the Hirnantian faunas, developed during transition from greenhouse-icehouse-greenhouse conditions, demonstrate a strong provincial polarity, with fewer recognizable provinces against a background of biotic extinction and recovery.

DEVONIAN GREEN ALGAL FLORA OF THE GRAZ PALAEOZOIC: STATE OF KNOWLEDGE

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The Lower to Middle Devonian (Emsian – Eifelian) calcareous green algal flora of the Graz Palaeozoic contains halimedalean representatives of *Pseudolitanaia*, *Pseudopalaeoporella*, *Zeapora*, *Maslovina* and a new lanciculoid taxon. Findings within the Graz thrust complex are restricted to four localities in the Rannach Nappe. Remains of algal thalli have been found in the Lower Devonian (Pragian?-Emsian) Flösserkogel Fm. and in the Middle Devonian (Eifelian) Plabutsch Fm. All these algal findings are monogeneric mass occurrences and therefore make up the majority of the rock. Consequently, they are interpreted as (par)autochthonous bafflestones. According to the literature profiles of the Flösserkogel Fm. contain “dasyclads” in the skeletal grains of the tidal flat-deposits (Pfaffenkogel). Although further investigations confirm the occurrence of reworked *Ortonella*-remains and pieces of Halimedales, algal thalli suitable for taxonomic determination have not been found so far. Well preserved, determinable algae have so far just been detected at the following four localities:

Locality 1: (Coordinates: 47°08’25’’N/15°15’27’’E) At a succession north of the monastery Rein (ca. 20 km North of Graz) an occurrence of little disarticulated lanciculoid algae were detected. This location is characterised by dark-grey to black, micritic to pelmicritic dolomites (equivalent to *Amphipora* meadows) and can be assigned to a slightly subtidal depositional environment.

Locality 2: (Coordinates: 47°03’40’’N/15°22’34’’E) The oldest known algal taxon of the Graz Palaeozoic, *Zeapora*, originates from the Plabutsch Fm. (formerly “Barrandeikalk”). Its occurrence is restricted to one single outcrop, the former Illite mine on the Southern slope of the Kollerkogel at the border to the urban area of Graz.

Locality 3: (Coordinates: 47°05’25’’N/15°22’11’’E) The occurrence of *Pseudopalaeoporella lummatonensis* and *Pseudolitanaia graecensis* is also located near the city of Graz (at a small path on the Southern slope of the Frauenkogel). The upper parts of the Plabutsch Fm. are characterised by alternating layers of clayey limestones, red mudstones and marls. In the clayey limestones of this alternating sequence, masses of *Pseudopalaeoporella lummatonensis* and only a subordinate number of *Pseudolitanaia graecensis* thalli occur.

Locality 4: (Coordinates: 47°08’01’’N/15°11’02’’E) The outcrop is situated along the road about 2 km South of St. Pankrazen (30 km NW of Graz). This succession contains in the lower parts of the Plabutsch Fm., in grey, clayey limestones a mass occurrence of *Maslovina*.

THE BRYOZOAN DISPERSION INTO THE NORTH GONDWANA MARGIN DURINGTHE PRE-GLACIAL LATE ORDOVICIAN

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Ordovician bryozoan palaeobiogeographical studies have been primarily focused on tropical palaeocontinents, because until recently only a few bryozoans were known from Ordovician temperate or cold regions. Previous palaeobiogeographical studies of temperate regions were based primarily on old lists of Ordovician Mediterranean bryozoans from the Montagne Noire, Carnic Alps and Bohemia, and a few genera recorded from Morocco or the Iberian Chains. These were insufficient for any statistical study. An addition problem for studies based on these lists was the uncertainty of the correlations of the Mediterranean Ordovician stratigraphic units. Using this rather limited data a bryozoan Mediterranean Province was recognized only in pre-Ashgillian times, and its scarce Ashgill bryozoan occurrences were included within the bryozoan Baltic Province. Over the last 18 years, detailed taxonomic studies have been undertaken of the mid Ashgill (late Katian) bryozoans from Sardinia and the Montagne Noire, and preliminary investigations made of those from Libya. There is also a comprehensive study of the mid Ashgill bryozoans from the Iberian Chains currently being carried out by the first author. This new data has been added to the bryozoan genera presence/absence database compiled for previous authors for Ashgill times and localities from the main Ordovician palaeocontinents. This has enabled the biogeographic affinities of mid Ashgill fossiliferous localities from the North Gondwana margin to be analyzed. Ordering multivariate statistical techniques, including principal coordinate analysis, detrended correspondence analysis, and non-metric multidimensional scaling, have been applied to a presence/absence matrix which includes 48 mid Ashgill localities and 138 bryozoan genera. The results are very similar for the main similarity coefficients considered: Dice, Jaccard and Simpson. In all cases the scatter plots display all the Mediterranean localities clearly grouped, and neatly separated from other sample point groups made up by Laurentian, Siberian and Baltic localities. Nevertheless, clustering analysis fails to cluster consistently Lybia, Morocco, Bohemia and the Carnic Alps, with the better known Montagne Noire, Sardinia and the Iberian Chains, this is probably due to smaller samples from the former localities. Our results support the existence of a temperate bryozoan Mediterranean Province during the pre-Hirnantian Late Ordovician, in spite of its associations being characterized mostly by genera which arrived from tropical palaeocontinents, mainly Baltica, Laurentia and Siberia. The first sign of the tropical bryozoan dispersion into the North Gondwana margin is recognised in the early Ashgill, in the Bohemian basin, prior to the development of its carbonate platforms. It is not until the mid Ashgill when the carbonate sedimentation was fully developed in North Gondwana, and the tropical bryozoans become widely dispersed into the area. In the multivariate analysis carried out, the bryozoan association from the Pin Formation, from India, clusters recurrently among the localities of the temperate Mediterranean Province, in spite of being associated to tropical fauna and flora. Perhaps the peculiarity of the Mediterranean bryozoan associations were not only latitudinally and climatically influenced, but also strongly geographically linked. The Mediterranean Province seems to have served as a refugium for several bryozoan genera during the late Katian. This is the case for *Amalgamoporus*, *Moorephylloporina*, *Nematotrypa*, *Orbipora*, *Prophyllodictya*, *Pseudostictoporella* and *Ralfinella*, whose first occurrences are known from the Middle and low Upper Ordovician of the tropical palaeocontinents, but are not recorded there in the upper Katian. This gives further evidence that the Late Ordovician pole-ward dispersion of tropical fauna was not only linked to local changes in the Gondwana margin. This could also have been associated with a global warming event, which made their original tropical environments inhospitable for some taxa.

LATE PALAEOZOIC CLIMATE HISTORY: INSIGHTS FROM CARBON AND OXYGEN ISOTOPES

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The latitude dependent distribution of climate-sensitive sediments like tropical carbonates, coals, evaporites, calcareous palaeosols or glacial sediments as well as of temperature–controlled faunal groups allow a qualitative reconstruction of the climatic history of the past. Stable isotopes represent another powerful proxy and have proven to give valuable information on the palaeoclimatic evolution. Carbon isotopes measured on well-preserved brachiopod shells, whole rock carbonate or organic matter were used to reconstruct changes in organic carbon burial rate. Inorganic and organic carbon isotope records were compared to speculate about variations in atmospheric pCO_2 that may be linked to global climatic changes. Finally, oxygen isotope ratios of brachiopod shell calcite and, more recently, of conodont apatite were used to reconstruct the palaeotemperature and ice volume history of the Palaeozoic.

The climatic evolution of the Late Palaeozoic is characterized by prominent changes from the Devonian greenhouse to the Permocarboniferous icehouse and the Late Permian warm mode. The Devonian, especially the Middle Devonian, is generally interpreted as a supergreenhouse, characterized by the maximum extent of Phanerozoic metazoan reef development. The oxygen isotope record of conodont apatite ($\delta^{18}O_{apatite}$) challenges this view. The isotope ratios suggest that the Early and Late Devonian (Famennian) were warm climatic periods whereas the Middle Devonian was characterized by relatively temperate climatic conditions. Interestingly, the warm climatic periods are characterized by sparse metazoan reefs (Early Devonian) or by the extinction of the metazoan reef ecosystem (Late Devonian). Instead, metazoan reefs flourished during the cooler Middle Devonian time interval.

The Carboniferous is marked by the transition from the Late Devonian greenhouse to the icehouse of the Permocarboniferous glaciation. The onset of the glaciation is generally dated around the Mississipian-Pennsylvanian boundary. However, analyses of oxygen isotopes of conodont apatite suggest that the initial onset of the glaciation occurred much earlier in the Tournaisian. We observe two positive shifts in $\delta^{18}O_{apatite}$ of 2‰ and 1.5‰ in the Tournaisian and Serpukhovian, respectively. Both positive shifts in $\delta^{18}O_{apatite}$ are interpreted to reflect climatic cooling and ice build-up at high latitudes. A first major glaciation event is interpreted to have occurred in the Tournaisian with ice masses persisting during the Visean. The second ice buildup event occurred in the Serpukhovian and early Bashkirian and culminated in the first glacial maximum of the Permocarboniferous glaciation. $\delta^{18}O_{apatite}$ values decrease in the Bashkirian and show cyclic variations during the Pennsylvanian as consequences of the waning and waxing of the high latitude ice caps. Both shifts in $\delta^{18}O_{apatite}$ coincide with major positive shifts in the carbon isotope composition of inorganic or organic carbon and suggest a causal link between enhanced organic carbon burial, lowering of atmospheric CO_2, climatic cooling, and ice build-up.

SUCCESSION OF HIRNANTIAN EVENTS BASED ON DATA FROM BALTICA: BRACHIOPODS, CHITINOZOANS, CONODONTS AND CARBON ISOTOPES

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The Hirnantian is an Ordovician time interval that has deserved much attention due to several highly important global events – large-scale glaciation (short-lived glaciation or the peak of a long-lasting one), great biodiversity change (mass extinction or a series of events), remarkable sea level drop (two or more events) and related regressions-transgressions on continents and changes in carbonate-platform weathering rates, a major positive carbon and oxygen isotope excursion. All these and many other less discussed processes are more or less interacting and clearly have implications into palaeogeography and palaeoclimatology.

It is understandable that a proper order of events (succession, overlapping) and their correct place in a time scale are extremely important in all interpretations of this many-sided and dynamic environmental complex. Underlining that the stratigraphical order of certain facts or proxies of processes may play a crucial role in deciphering the study items, we try to analyse some real situations using mainly the Baltic data set and brachiopod, chitinozoan and conodont biostratigraphy.

In general, we think that when discussing different Hirnantian events, many authors pay insufficient attention to the detailed time succession of different aspects of the phenomenon. This may partly be due to an inadequate stratigraphical framework in use, but more often due to the rather general approach where some crucial details may be left without notice. We are not going to criticize any particular paper, but our aim is to demonstrate how a study can be made more detailed.

Definitions of the boundaries of the Hirnantian Stage are given on the official IUGS ICS website with references to respective publications in Episodes. The principal correlative events listed at the definition of the lower limit are especially interesting in regard to our topic: "lowest occurrence of *Normalograptus extraordinarius*, base of major positive carbon-13 isotope excursion, and beginning of pronounced sea-level fall associated with onset of a major glaciation". This listing of events means that they all should be synchronous. Is it so?

The Porkuni Regional Stage is a nearly full equivalent of the Hirnantian Stage in the Baltic area. There are two facies belts in the Baltic – shallow water facies in Central Estonia (with a gap in the bottom and the missing upper Porkuni) and deep shelf facies in South Estonia and Latvia with lesser hiatuses in the very top. A reliable nearly complete carbon isotope trend was compiled using overlapping sections, especially those from the deeper sea area. Brachiopods of the Hirnantia community occur in the middle of the stage, the *Spinachitina taugourdeaui* chitinozoan Biozone is known from the bottom of the stage and the last occurrences of the conodont *Amorphognathus ordovicicus* are known nearly from the same bed, but its main range is much below. Above and below these markers different others, including carbon isotope ones, have been established, allowing a detailed dating of events.

Despite some progress we cannot be sure that the needed exactness in the dating of events has been achieved. Some problems exist with correlation of the stratotype in China and the sequence on the Anticosti Island, which means that an environmental history of the Hirnantian time remains a bit obscure. We do not think that this is at all surprising.

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PALAEOCLIMATE AND STABLE ISOTOPE ANALYSES OF PERMIAN-TRIASSIC CARBONATE RICH PALEOSOLS FROM THE SOUTHERN URALS, RUSSIA

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The Permian/Triassic (P/Tr) boundary is widely assumed to have been a time of extreme environmental upheaval and change. A possible record of this is a notable negative anomaly in both stable $\delta^{13}C$ and $\delta^{18}O$ isotope records at or near the P/Tr boundary recorded in multiple marine and terrestrial sections round the globe. In the terrestrial realm, this anomaly has been reported in organic carbon from the Transantarctic Mountains in Antarctica, Australia, India and Madagascar, and in carbonate from the Karoo Basin in South Africa which has been linked to several extinction mechanisms including the Siberian Traps and mass methane release. However these sections are all from southern palaeolatitudes.

Herein we describe the first analysis from the Permian - Triassic terrestrial sedimentary record of the South Urals, in Russia, comprising of many vertisol palaeosol horizons. These horizons include pedogenic carbonates at different stages of development, both above and below the P/Tr boundary. Analyses of the $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ signatures of these pedogenic carbonates have revealed a number of negative excursions in $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ in the Late Permian, including a negative excursion that begins in the latest Permian and continues into the Early Triassic. Associated with these excursions are indicators of increasing aridity, including pedogenic dolomite, which suggest a dramatic change in climate up to the P/Tr boundary. This data is being used to shed new light on the magnitude, timing and possible cause of the negative excursions in the northern palaeolatitudes.

ORDOVICIAN PALEOKARST, QUARTZ SAND, AND CLIMATE

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In western Laurentia (Nevada, California), a thick Paleozoic succession is exposed that shows repeated paleokarst development. Hitherto, more than 25 individual karst events have been identified in Cambrian through Devonian strata. They culminate within the Ordovician, and there towards the top of the Sauk megasequence (earliest Cincinnatian). The Ordovician paleokarst has been explained mainly as of tectonic origin.

Within the Ordovician paleokarst succession, there is a systematic increase in depth of erosion and intensity of weathering from the base of the system towards the Mohawkian. Many of the flooding surfaces following paleokarst development are overlain by reddish to light orange, fine-grained deposits (clay shales, marlstones, dolomitic marlstones). Much of the terrigenous component is interpreted to be the insoluble residue of karstification (“terra rossa”). After deposition of the Ninemile Shale as a typical example of these terrigenous deposits, the amount of this fine-grained detrital material is drastically reduced at the expense of quartz sand. In contrast, there is an apparent increase in the content of clean quartz sand within the individual karst units and as intercalated beds. Sand deposition culminated with the formation of the Eureka quartzite (Mohawkian /Cincinnatian). The Eureka is enigmatic in that, in the southern Great Basin, it is the only prominent (~ 150 m thick) pure quartz sand unit within a thick (several 1000 m) Cambrian through Devonian dominantly carbonate platform succession. The question is what caused the drastic changes in karst typology and the deposition of the Eureka? And why is the Eureka a quartz arenite at all?

First, the Eureka may be the product of recycling older quartz arenites. Second, it may have been the effect of intense chemical weathering. As pCO_2 was very high during the Ordovician and as Laurentia was in tropical latitudes it likely experienced high precipitation in a warm climate leading to intensive weathering and total break down of unstable minerals. Second, the clean vitrious quartzites of the Eureka are similar to widespread quartz arenites that where deposited during sea-level rise that followed the Hirnantian glaciation. They are the product of prolonged reworking and elimination of unstable minerals during transgression in a shallow-marine environment. As it is assumed that the late Ordovician glaciation already started during the Mohawkian, and that there were several pulses, the Eureka might be a depositional equivalent to these quartz sandstones. Although these processes by themselves could account for the presence of the Eureka, they do not explain the overall evolution of the karst system through time. An additional process is needed that is responsible for the change in karst typology and sand production.

We argue that this additional factor may be the increasing volcanic activity during the Ordovician which culminated during the Mohawkian with the deposition of the Deicke and Millbrig/ Kinnekulle K-bentonites in eastern Laurentia and Baltica. The additional input of corrosional volcanic gases may have sped up the karst processes so that destruction of carbonates per unit time increased considerably in comparison with other times. As a consequence, only relatively short times were needed to develop a mature karst system; in addition, more violent weathering would have led to the break down of unstable minerals and providing an increasing amount of quartz sand. Finally, the onset of glacial events during times of maximum volcanism apparently is no coincidence. The corresponding sea-level drawdown provided additional exposure for weathering, enhancing the production of quartz sand. During the ensuing sea-level rise, a further cleaning of these sands may have taken place in shallow-marine environments. Finally, we suggest that similar, earlier events might have been triggered by cooling-warming successions, which suggest glacial - non-glacial events through much of the Ordovician.

MICROBIALITES AND CLIMATE CHANGE: PERSPECTIVES FROM THE PALAEOZOIC

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Microbialites are sedimentary deposits containing evidence of microbial action, and are usually $CaCO_3$. They comprise a range of forms, dominated by thrombolite, stromatolite, dendrolite and leiolite; they generally form in shallow marine systems. Microbialites are common components of reef systems and dominated reef deposits in many Palaeozoic settings. Microbialites also occur in abundance after some mass extinctions, and are commonly perceived to be responses to mass extinction events. However, this is controversial, because microbialite abundances do not correlate to only mass extinctions (Kiessling, 2002, SEPM Spec.Pub. 72, 625-690; Riding, 2005, Revista Espanola de Micropaleontologia, 37, 23-39). In fact, microbialites are becoming recognised as more important components of reef systems than has been traditionally understood. For example, there is some circumstantial evidence that microbial components may be more important during some positive carbon isotope excursions, but much more work is needed to establish the role and importance of microbial processes in reef and non-reef carbonate systems.

The terms “anachronistic facies” and “disaster forms” are commonplace in the literature, relating unusual microbial and other biota to environmental shifts following mass extinctions. However, research has emphasised the important role of carbonate saturation in the formation of microbial deposits (Riding & Liang, 2005, Palaeogeography, Palaeoclimatology, Palaeoecology, 219, 101-115). For example, the abundance of Cambro-Ordovician thrombolites may be attributed to raised carbonate saturation state in warm climates, yet are not related to mass extinction. In contrast, abundance of a wide range of microbial types in the Permian-Triassic boundary extinction may be due to a number of potential reasons, of which some are: extinction and opening up of ecological space; loss of skeletal biota releasing carbonate for uptake by microbialites; raised temperatures (possibly related to Siberian Trap volcanics), ocean overturn bringing dissolved inorganic carbon up to surface waters raising carbonate saturation levels. The latter may be associated with the almost isolated setting of Tethys Ocean at the end of the Permian, so palaeogeographic configuration may play a role in microbialite abundance and distribution. In fact, after the end-Permian event, there is evidence of palaeogeographic separation of different types of microbialites, leading to the possibility of microbialite provinces (Kershaw et al. 2007, Facies, 53 (3), 409-425).

There is a bright future in the information that microbialites can reveal about environmental change in the Palaeozoic record, and more high-resolution studies are needed.

PHOSPHORUS DISTRIBUTION IN THE ORDOVICIAN BALTIC SHELF

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Phosphorus is an essential element for bioproductivity. P content in sedimentary rock can be a proxy for the once-been available phosphorus in seawater and primary bioproductivity. In the Baltic Ordovician rocks P is bound into carbonate-fluorapatite, francolite (Põlma, 1982). Usually the apatite is scattered in the sedimentary rock, or occurs as the constituent of faunal debris, ooids, crusts and impregnations.

Estonian Tremadoc contains obolus-phosphorite with the content of P_2O_5 in this easily enriched sand about 10%. During post-Tremadocian the north Estonian cores reveal a constant diminishing of P_2O_5 content pointing to the decline of reworking of underlying obolus-sandstone (Viira et al., 2004). In the west Latvian Aizpute-41 core the P_2O_5 content is up to 1% in several samples of the Hunneberg–Billingen stages, and diminishes thereafter during the Volkhov Stage. The redeposition of Tremadocian conodonts is recorded in covering sediments in the Łeba Elevation (Bednarczyk, 1979). The Hunneberg–Billingen sections of Estonia contain indigenous phosphatic lingulid brachiopods (Puura 1997), conodonts and other apatite occurrences pointing to the availability of phosphorus in the seawater. Indications of high primary productivity, such as black shales, are absent. In the Darriwilian, at the same time when the P content in north Estonia diminished, P content started to increase in the south. The values of P_2O_5 reached 0.5% in the south Estonian Mehikoorma, Laeva-13 and Ruhnu cores, and up to 1.1% in the Aizpute core in the Lasnamägi–Keila interval, upper Darriwilian–Sandbyan. In the Podlasie-Brest Depression the apatitic hardgrounds, grains and laminae are recorded in the Darriwilian sections (Podhalanska, 2002). In the Malopolska Block the phosphate-rich limestone unit (Trela, 2005) corresponds to the Lasnamägi–Oandu stages of the Baltic Basin. Together with condensation in Polish sections, an upwelling of the deep ocean waters is responsible for the high concentration of phosphorus, in Poland as well as in the East Baltic Basin. The uppermost Ordovician sections reveal low P contents, below 0.1%.

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THE DEVONIAN ECOLOGICAL REVOLUTION, AN UNDERRATED RADIATION

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Impressive discoveries of Neoproterozoic and Early Palaeozoic Fossillagerstaetten drew the attention on evolutionary and ecological processes of these timespans. It almost seemed that, except for some of the "Big Five", nothing essential happened after the Ordovician. Such a scenario is certainly not true. Partially, this may be an effect of the diversity analyses by Sepkoski (e.g., 1978, 1979), which revealed an explosive radiation at the genus level until the end-Ordovician, followed by a putative phase of erratic decline until the end-Palaeozoic.

Contrariwise, some major ecological fluctuations have been recorded from the Devonian, several of which have less prominent Silurian precursors. Famous examples are the radiation of land plants and jawed fish (both known already from the pre-Devonian). During the Devonian, several animal groups conquered the land (tetrapods and various arthropods). Marine invertebrates show significant ecological and morphological changes: Important cephalopod groups such as bactritoids as well as ammonoids evolved and reef growth increased until the Late Devonian crises. Both the global rise and fall of dacryoconarids occurred, graptolites became extinct, and various mollusc clades modified early ontogenetic strategies during the Devonian, documenting a planktonic turnover.

For the climatic background, various interpretations are available. The analyses show an overall rise in temperature until the Givetian or Frasnian, followed by severe sea-surface temperature drops in the end of these stages. These coincide with sea-level changes and marine mass extinctions, namely the Taghanic and Kellwasser Events.

Various interpretations are at hand to explain Devonian ecological changes and innovations : (1) Demersal (swimming close to the sea-floor) and nektonic modes of life were probably initially driven by competition in the diversity-saturated benthic habitats as well as (2) the availability of rich planktonic food resources (as reflected in evolutionary alterations in early ontogenetic stages of many mollusks). Escalatory feedbacks probably promoted the rapid evolution of nekton (jawed fish and some derived cephalopod groups in particular) in the Devonian, as suggested by the sequence and tempo of water-column occupation. Potentially, both these radiations and the Givetian to Famennian mass-extinctions were linked to a pronounced increase in nutrient input to sea surface waters during eutrophication episodes.

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PULSED CEPHALOPOD DIVERSIFICATION DURING THE ORDOVICIAN

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During the Ordovician Radiation cephalopods expanded their habitat from shallow marine environments of the low latitudes toward global occurrences in almost all marine environments. The expansion of habitat is accompanied by a drastic morphological and taxonomical diversification. The diversification was not a constant linear process, but involves intervals of diversity crises and fundamental faunal change at the global scale. A new database, comprising more than 5100 cephalopod occurrences worldwide with high stratigraphical resolution allowed for a subsampled and normalised calculation of mean standard diversities at the scale of the IGCP 503 time slices. For the first time the complete Chinese cephalopod literature is covered.

The resulting curves reveal a pulsed diversification pattern of Ordovician cephalopods with three main diversification phases, which were in each case preceded by a significant faunal change and a diversity crisis. The intervals of diversity crisis were highly selective. In contrast the diversification intervals affected all contemporaneous groups. Each diversification pulse lead to higher diversity levels reaching a Katian diversity climax. The diversification events are characterised by a poor correlation with major physical events, but are in good agreement with important events of the diversity evolution of trilobites, brachiopods and reefbuilders, The diversification is characterised by a statistically significant general trend of decreasing origination rates.

(1) The begin of the Ordovician radiation is marked by the middle Tremadocian appearance of endocerids and tarphycerids which considerably expanded the initial cephalopod disparity and depositional environment. In the earliest Tremadocian ellesmerocerids exclusively inhabited shallow tropical carbonate depositional environments. Endocerids and tarphycerids were widely distributed in Lower Ordovician epeiric seas.

(2) A major cephalopod faunal change at the Early/Middle Ordovician boundary can be directly compared with a contemporaneous faunal change in brachiopods and trilobites. The Early Ordovician ellesmerocerid-endocerid-tarphycerid fauna was continuously replaced by an actinocerid-oncocerid-orthocerid fauna during the Middle Ordovician. This turnover shows similarities with the turnover of the Ibex Fauna by the Whiterock fauna in trilobites. An important aspect of the Darriwilian diversification is the expansion of cephalopods with planktonic life habit, or planktonic early stages (e.g. orthocerids and lituitids). The diversity curves of presumably planktonic cephalopods are strikingly similar to that of the mikrozooplankton (e.g. chitinozoans).

(3) During the Late Ordovician discosorids and oncocerids diversified strongly. This diversification is largely parallel with that of reefbuilders such as bryozoans, corals and crinoids.

We interpret the canonical, pulsed diversification of Ordovician cephalopods as a result of ecosystem-inherent processes. Potentially an increasing ecosystem complexity, an increasing stability of the trophic structure and a decreasing influence of disturbing external physicochemical parameters led to the expansion of cephalopod habitats and the multiplication of niches.

NEW GEOCHEMICAL DATA (SR/CA, $\delta^{18}O$) FROM CONODONTS IN FAVOUR OF A GLACIATION DURING THE FRASNIAN-FAMENNIAN CRISIS

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The Frasnian-Famennian (F-F) crisis (376My) is one of the five major faunal extinctions (Sepkovski, 1985). Previous oxygen stable isotopes measurements on conodont apatite have suggested that the Upper Kellwasser (UKW) and the Lower Kellwasser (LKW) anoxic events which precede the F-F boundary, coincided with a temperature decrease (Joachimski and Buggisch, 2002). New geochemical data are presented in this study in order to better constrain the link between the faunal crisis and the environmental changes.

Sr/Ca and $\delta^{18}O$ analyses have been performed on conodont bioapatite extracted from the limestone levels across the F-F boundary at Coumiac (France) and M'rirt (Morocco). The Sr/Ca ratio is a good temperature proxy in apatite (Balter et Lécuyer, 2004), and contrary to $\delta^{18}O$, is independent of salinity variations (McCulloch et al., 1994; Rosales et al, 2004).

The Sr/Ca and $\delta^{18}O$ ratios are strongly correlated and discriminate 1°) the Late Frasnian and 2°) the UKW and Early Famennian periods both at Coumiac and M'rirt. The Frasnian and the Famennian periods are separated by a $\delta^{18}O$ shift of about 1‰ (V-SMOW). This result is discusted in perspective of a glaciation across the Frasnian-Famennian boundary (Isaacson et al., 1999).

IMPACT OF SEA WATER TEMPERATURE ON THE PALAEOBIOGEOGRAPHIC DISTRIBUTION OF ORDOVICIAN ECHINODERMS

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Echinoderms underwent a major diversification in Ordovician times. Three main types of echinoderm assemblages can be evidenced in the Middle to early Late Ordovician time interval. Their palaeobiogeographic distribution was apparently mostly controled by sea water temperature: *(1) a temperate assemblage* dominated by crinoids, sphaeronitid diploporites, eocrinoids, caryocystitid and hemicosmitid rhombiferans (Baltica, Iran, Sibumasu, South China); *(2) a tropical assemblag*e dominated by crinoids, edrioasteroids, eocrinoids, paracrinoids, cheirocrinid and pleurocystitid rhombiferans (Laurentia); and (*3) a cool, sub-polar assemblage* dominated by aristocystitid diploporites, eocrinoids, ophiuroids, solutes, and stylophorans (Mediterranean Province). These three assemblages are then used as a reference to describe two examples of major changes in Late Ordovician echinoderm communities: (1) during most of the Katian time interval, the tropical shelves of southeastern Laurentia were invaded and colonized by typical cool-adapted echinoderm faunas; this situation probably resulted from the drowning of the region, due to the coincidence of a global eustatic rise and local tectonic subsidence (Taconic orogeny); (2) in late Katian times, cool-adapted echinoderm assemblages living on sub-polar shelves of the Mediterranean Province were suddenly replaced by typical temperate communities; this major faunal turnover suggests the presence of warmer waters in this region (Boda event), immediately before the Hirnantian glaciation.

NEW ECHINODERM LAGERSTÄTTEN FROM THE UPPER ORDOVICIAN OF ERFOUD AREA (EASTERN ANTI-ATLAS, MOROCCO)

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In the past, sites in the Erfoud area (eastern Anti-Atlas, Morocco) have already yielded remarkable soft bodied fossils (e.g., eldonioids) preserved in coarse clastic sediments, showing Ediacara-type preservation. Here, we report on the recent discovery of four distinct Late Ordovician echinoderm Lagerstätten from the same region (W of Rissani, Tafilalt). They have yielded hundreds of exquisitely preserved specimens. Their taphonomy (fully articulated individuals, showing even the most delicate skeletal elements of their feeding appendages) and associated lithology are both suggestive of a rapid, in situ burrial of life assemblages by storm deposits, in relatively shallow palaeoenvironmental conditions (distal upper offshore). The oldest assemblage (Izegguirene Formation, lowermost Sandbian) is dominated by eocrinoids, ophiuroids, and stylophorans (cornutes and mitrates), associated with rare crinoids and cyclocystoids. It shows strong similarities with slightly older faunas described in the underlying Ouine-Inirne Formation (upper Darriwilian) in Central Anti-Atlas. The second assemblage (lower part of Lower Ktaoua Formation, Sandbian) is composed of abundant ophiuroids, small solutes, and mitrates, along with rare eocrinoids. The third assemblage was collected in the upper part of the Lower Ktaoua Formation (upper Katian). It is dominated by ophiuroids and large solutes, associated with common diploporites and rhombiferans, and rare crinoids and mitrates. Finally, the youngest assemblage (lower part of Upper Tiouririne Formation, upper Katian) has yielded abundant remains of edrioasteroids and rhombiferans.

GLOBAL CARBON CYCLE AND CLIMATE MODELLING IN LATE DEVONIAN TIMES: IMPACT OF EOVARISCAN MOUNTAIN BUILDING AND RELATED PROTOTETHYS ISOLATION

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The Late Devonian is a period of significant climatic and environmental changes exemplified by a severe biotic crisis of marine tropical faunas (the Frasnian-Famennian crisis) and by the onset of an episod of glaciation on Southern Gondwana at some time in the Famennian. The major pulse of the faunal extinction occurs from the Late Frasnian to the base of the Famennian over few million years. This time is marked by an extensive perturbation of marine environments expressed by two carbon-organic rich levels (the well known Kellwasser horizons) deposited under dysoxic to anoxic conditions. These two levels have been recognized in many places worldwide and are characterized by a positive carbon isotopic shift from 2‰ to 3‰ reflecting a period of enhanced organic carbon burial.
The causes of this two episodes remain strongly debated but, in recent years, our research group proposed these episodes to be linked to a large-scale fertilization and stratification of sea waters (especially that from the Prototethysian realm) as the result of the incipient uplift of a large sub-equatorial mountain belt, i.e. the Appalachian-Eovariscan-Ouralian cordillera. The latter would have enhanced, on one hand, the continental weathering and the related nutrient supply from continents and, on a second hand, the Prototethys sea-water stratification by the progressive closure of the equatorial seaway linking Prototethys to the Panthalassa. The climatic impact of this Frasnian-Famennian carbon cycle perturbation might have led to a global cooling at the beginning of the Famennian as documented in the geological record by a significant sea-level drop and an associated hiatus expressed in numerous localities as well as $d^{18}O$ and palynological data. To test this interpretation, we have used a global carbon cycle numerical model coupled with the Energy Balance Model (EBM) of François and Walker (1992). The model calculates phosphorus, carbon and oxygen concentrations and the alkalinity in each oceanic box as well as atmospheric pCO_2, $d^{13}C$ and $^{87}Sr/^{86}Sr$. The oceanic and continental configurations have been inferred from the Late Devonian palaeogeography (Polar ocean, Panthalassa and Prototethys). Oceanic circulations have been modelled using the present-day circulation for the Panthalassa Ocean and the pre-perturbation Prototethys realm, the latter evolving towards isolated conditions during the simulation. The mountain-building effects have been modelled by increasing the mechanical erosion (and de facto the chemical alteration) specifically on continental areas that were submitted to tectonic uplift. The respective effects of each process have been tested separately and then coupled to simulate the global impact of the incipient Laurussia-Gondwana continental collision on the Late Devonian climate.

IS A GLOBAL VOLCANIC EVENT RESPONSIBLE OF THE LATE ORDOVICIAN GLACIATION? A GLOBAL CARBON CYCLE MODELING APPROACH

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The cause or causes of the well-known Late Ordovician glaciation remain(s) unclear. This global cooling is generally attributed to a decrease of atmospheric pCO_2 during a time of greenhouse climate but its duration is not yet determined. This perturbation is synchronous with one of the biggest biotic crisis of Earth history, the Late Ordovician Extinction. It seems that a warming event called Boda Event (Fortey and Cocks, 2005) preceeded the glaciation that is clearly recorded in sediments at the beginning of the Hirnantian. Some authors have shown that, based on Ashgillian palaeogeographical reconstructions, a drop in pCO_2 up to a threshold of 8x to 10x PAL (Present Atmospheric Level) may have induced a decrease in temperature in high latitudes and supported the installation of an ice-sheet on Gondwana (Gibbs et al., 1997; Herrmann et al., 2004a; Herrmann et al., 2004b). Intensification of silicate weathering and enhanced organic carbon burial are the two major processes that lead to a decrease in atmospheric pCO_2.

The Late Ordovician is known to be a period of high mantellic activity marked by a lack of reversal magnetic field (Courtillot and Olson, 2007; Pavlov and Gallet, 2005) and high volcanic activity (Huff et al., 1992). Barnes (2004) and Courtillot and Olson (2007) link this process to a superplume event that may give rise to continental basalt flooding.

Here we have tested this hypothesis with a global carbon cycle numerical box-model coupled with an Energy Balance Model (François and Walker, 1992). The Model, that is an upgrade of that used by Grard et al. (2005), calculates the evolution of carbon, phosphorous and oxygen concentration and alkalinity. It also calculates atmospheric pCO_2, atmospheric and oceanic $d^{13}C$ and oceanic 87Sr/ 86Sr.

We have tested different scenarios of trap emplacements and organic carbon cycle interactions that could lead to the Hirnatian glaciation. The hypothesis of a high latitude basalt flooding matches with the Late Ordovician observation leading to a global warming, (that could be the Boda Event), followed by a drop in atmospheric pCO_2 allowing the installation of the Hirnantian glaciation. One question remains on the carbon isotopic 4-6‰ positive excursion that this modeling work can't reproduce.

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FIRST RECORD OF CRINOID (MAENNILICRINIDAE) FROM MIDDLE ORDOVICIAN STRATA (DARRIWILIAN) IN THE ARMORICAN MASSIF (WESTERN FRANCE): PALEOGEOGRAPHIC IMPLICATIONS

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A maennillicrinidae disparid crinoid (*Heviacrinus* cf. *melendezi*) is described for the first time in Middle Ordovician outcrops from Normandy (Armorican Massif, western France). Palynological analyses of the crinoid-bearing beds for acritarchs and chitinozoans revealed the presence of the L. pissotensis biochronozone (late Darriwilian). Even if Ordovician fauna from Armorican Massif has been the subject of considerable studies, no crinoid echinoderms have been previously mentioned from this area except from disarticulated remains; stylophorans, diploporans, edrioasteroids, eocrinoids constituted the known echinoderm community. The Armorican Massif represents an important segment of French Variscan belt and a significant basin of the peri-Gondwanan margin during early Palaeozoic times. These new data document the Cambro-Ordovician radiation of stemmed echinoderms (pelmatozoans) along the Gondwana margin and allow discussion of paleogeographic position of the different platforms and basin which constitute this margin during Ordovician times.

INTRA-BALTIC AND TRANS-IAPETUS CORRELATION OF UPPER ORDOVICIAN δ^{13}C DATA FROM THE BORENSHULT-1 CORE (ÖSTERGÖTLAND, SWEDEN)

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Lithostratigraphy and a detailed carbon isotope record indicate that the succession of the Borenshult-1 core includes late Darriwilian through early Llandovery strata (Uhaku through Juuru or Raikküla Stages in the Baltic Region). Some clearly identified carbon isotope events and the recognition of typical rock units allows comparison with other areas of the Baltic Basin and a correlation to equatorial Laurentia. The oldest strata in the core are equivalents to the Furudal Fm, which are overlain by the Dalby Limestone, the Kinnkulle K-bentonite, the Freberga Fm, the Slandrom Limestone, the Fjäcka Shale, the Jonstorp Fm, and the Nittsjö Bed, which is covered by a shaly unit (equivalent to the Glisstjärn Fm) and the Motala Fm. The isotope excursions are less pronounced than in coeval shallow-water environments of the East Baltic, reflecting a deeper-water setting, and the δ^{13}C data compare well with those of the Valga-10 and Mehikoorma-421 cores (Kaljo et al. 2007).

The early Katian GICE is observed in the lower to middle Freberga Fm. This event is known from the Chatfieldian of Laurentia (Bergström et al. 2007) and has been reported from different Baltic areas (e.g. Kaljo et al 2007). A new shift to higher values starts in the topmost Freberga Fm and continues across a discontinuity surface into the Slandrom Limestone. This excursion may correspond to the 1st late Caradoc excursion in the Rakvere Stage, which is coeval with the Kope excursion of Bergström et al. (2007). The 2nd late Caradoc peak is interpreted as missing due to a stratigraphic gap at the surface on top of the Slandrom Fm reflecting a dramatic sea-level drop that affected wide parts of the Baltic Basin and lead to paleokarst development. Calner et al. (this volume) suggest a glacio-eustatic origin and interpret the overlying Fjäcka Shale as the result of flooding during deglaciation. The deposition of the vitreous upper Eureka Quartzite in Laurentia (Keller & Lehnert, this volume) and the overlying lower Hanson Creek Fm or lower Ely Springs Dolomite may correspond to the Slandrom regression and Fjäcka flooding, respectively. The 1st Ashgill excursion in the lower Jonstorp Fm (early Pirgu, early Richmondian) is coeval to the Whitewater excursion (Bergström et al. 2007). The HICE starts in the uppermost Jonstorp Fm and reach peak values around 3.7‰ in the sandy, oolitic limestone of the Nittsjö Bed, which formed during the Hirnantian glacial (Porkuni). The overlaying thin shaly unit including the “falling limb” of the HICE represents the interval of post-glacial flooding.

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PALEOCLIMATE PERTURBATIONS BEFORE THE EARLY SHEINWOODIAN GLACIATION: A TRIGGER FOR EXTINCTIONS DURING THE IREVIKEN EVENT?

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Well-preserved conodonts from the Lower Silurian of Baltica were studied for oxygen isotopes. Samples from the upper Subzone of the *P. amorphognathoides amorphognathoides* Zone through the O. sagitta rhenana Superzone have been analysed A conodont color alteration index of 1 indicates only very minor thermal alteration of the late Telychian (Aeronian) to early Sheinwoodian Estonian conodont elements. The conodont phosphate oxygen isotope data cover pre- through post-Ireviken Event strata. The *O. s. rhenana* Zone represents the peak interval of the early Sheinwoodian oxygen isotope excursion on Gotland ($\delta^{18}O_{brach}$; Calner et al. 2004) presumably reflecting the coolest conditions in the subtropics during the early Sheinwoodian glaciation.

Samples derive from the Liiva Cliff section and the Viki core. Strata recovered from this core can be correlated by conondonts with high precision to the datum points of the Ireviken Event strata on Gotland (Jeppsson & Männik 1993). Across the Ireviken (biotic) Event we observe variations in oxygen isotope ratios of conodont apatite. Before datum point 1 of the Ireviken Event cool sea-water temperatures in the latest Telychian are indicated by relatively high δ18O values. The first step of extinction at datum point 1 affected mainly hemipelagic groups (e.g., conodonts, graptolites). Just before (topmost *P. a. amorphognathoides* Zone) and also after this datum point sea-water temperatures increase. Before the strongest extinction event with respect to conodonts and trilobites at datum point 2, and between this and datum point 3, cooler sea-water temperatures (a short glacial?) are indicated by higher $\delta^{18}O$ values again. At datum 4 (*Phaulactis* layer in the Visby Fm on Gotland), extinctions are observed in shallow-shelf groups (e.g., ostracods, corals, brachiopods).Warmer sea-water temperatures (interglacial?) above datum point 4 to a level above datum point 6 are reflected by a slight decrease in $\delta^{18}O$. Below datum point 7 (below the extinction level of *D. staurognathoides*), $\delta^{18}O$ values start to increase (by ~0.9‰) indicating that the cooling of the early Sheinwoodian isotope event (glacial) started in the upper part of the Ireviken biotic event (drop of about 4°C), thus post-dating most of the extinctions. Conodonts show only low extinction rates in this interval and benthic assemblages flourish. $\delta^{18}O$ values remain high after datum 8 (with only slight variations in the range of 0.5‰) indicating colder sea water temperatures for post-Ireviken strata than before the biotic events. It turns out that faunal extinctions are bound to intervals of climate perturbations and changing environmental conditions before the establishment of rather stable and cooler conditions during the main glacial.

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ACRITARCH BIOSTRATIGRAPHY OF THE LOWER-MIDDLE ORDOVICIAN BOUNDARY : THE GLOBAL STRATOTYPE SECTION AND POINT (GSSP) OF HUANGHUACHANG, SOUTH CHINA

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The Lower to Middle Ordovician Dawan Formation has been palynologically investigated at Huanghuachang (Global Stratotype Section and Point, GSSP, of the basis of the Dapingian, first Global Stage of the Middle Ordovician Series) with the aim to discuss the biostratigraphical potential of acritarch assemblages for the recognition of the Lower-Middle Ordovician boundary, that has recently been defined by the first appearance of the conodont *Baltoniodus* ? *triangularis*. For comparison the nearby Daping section has also been sampled.

The new results have been compared with those from previous investigations from the same sections, in particular the results by Tongiorgi et al. (2003).

Based on their First Appearance Data (FAD) some of the taxa recorded in the sections might potentially be used to determine the Lower-Middle Ordovician boundary. While the genera *Barakella* and *Liliosphaeridium* appear to be indicators of the base of the Dapingian, the genus *Stelomorpha* appears to be a diagnostic genus present in the boundary interval, because species of this genus are present both below and above the GSSP. Other diagnostic taxa useful for international correlation, including *Orthosphaeridium* and *Dicrodiacrodium*, first appear in the Dapingian, higher in the sequence.

Several of the stratigraphically significant taxa are typical of the peri-Gondwanan palaeobioprovince, while others also occur outside of the Gondwana palaeocontinent. *Barakella* allows a correlation of the Lower-Middle Ordovician boundary with sections from peri-Gondwanan Europe and North Africa, while *Liliosphaeridium* allows correlation with Baltica.

Acritarchs are therefore potentially useful for the identification of the Lower-Middle Ordovician boundary in sections where conodonts, graptolites or other fossils are absent.

LINKS BETWEEN SEA-LEVEL AND PALAEOCLIMATE IN THE PALAEOZOIC

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The sedimentary record of the Palaeozoic preserves evidence for globally correlatable, high amplitude sea-level change. During well-known ice-house intervals of the Palaeozoic, such as the Late Ordovician, an unequivocal link between global sea-level changes and ice-volume mediation can be demonstrated.

We have undertaken a sequence stratigraphic study of nearly all the world's sedimentary basins that reveals globally synchronous, high amplitude sea-level change occurred throughout the Palaeozoic, including in intervals not previously interpreted to have been associated with the presence of high latitude ice. Our interpretation of Palaeozoic sea-level change is based on a global sequence stratigraphic model that manifests itself as a globally correlatable record of major stratal surfaces, such as maximum flooding surfaces (MFS) and sequence boundaries (SB). Our model is built from a database of >11,000 outcrop sections and wells which, by careful biostratigraphic correlation, demonstrate the synchronicity of >200 MFS and SB distributed across the globe and in basins of highly variable tectonic evolution. The rapidity, magnitude and global distribution of the sea-level changes inferred from our model precludes local tectonics as a driver.

We have compiled records of key isotopic proxies through the Palaeozoic in an effort to explore the relationship between global sea-level and Palaeozoic climate. Our work has revealed a close link between a number of transient carbon-isotope changes and the timing of our stratal surfaces. This is particularly apparent in the Devonian where a recent high-resolution compilation of inorganic carbon-isotope values [1] can be unambiguously correlated to our sequence stratigraphic model using available biostratigraphic dating constraints. Of additional importance is that our results also reveal a close link between the timing of some of our large-scale MFS events with known episodes of palaeoclimatic warming, as well as a similar link between our SB and palaeoclimatic cooling. Based on these observations we suggest that glacioeustasy was a key driver of Palaeozoic sea-level and the existence of high-latitude ice at these times.

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RAMP TO PLATFORM EVOLUTION CONTROLLED BY SEA-LEVEL VARIATIONS: THE CASE OF THE LOWER GIVETIAN IN BELGIUM.

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The Eifelian-Givetian boundary at the southern flank of the Dinant Synclinorium corresponds to the transition from a mixed siliciclastic/calcareous ramp to a carbonate platform. This evolution is illustrated from many years by the succession of classical stratotype sections. The Hanonet Formation (which encompasses the Eifelian-Givetian boundary) is interpreted as characterized by a mixed siliciclastic/calcareous ramp-related sedimentation. The following Trois-Fontaines Formation is described as a platform initiation in three parts: a crinoidal sole, a biostromal unit and a lagoonal unit. Then, the entire Givetian (Terres d'Haurs, Mont d'Haurs and Fromelennes formations) is considered as related to carbonate platform sedimentation.

Our study is based on five stratigraphic sections covering the upper part of the Eifelian and the base of the Givetian (from *Polygnathus ensensis* to *P. timorensis* conodont zones): Les Monts de Baileux, La Couvinoise, Fromelennes, Marenne Centre and Marenne East sections. They represent a total thickness of 632 metres and 1398 thin-sections. It offers a detailed sedimentological investigation of the environmental succession within the Hanonet, Trois-Fontaines and Terres d'Haurs formations.

Excepted for La Couvinoise section (Hanonet Formation stratotype), each section studied here shows facies successions substantially differing from classical sections. It allows a better understanding of lateral variations but also imposes the drawing of a more complex and detailed paleoenvironmental model than previously expected.

The proposed model for the platform growth and demise is the result of microfacies interpretation in terms of palaeoenvironment, correlation between studied sections (biostratigraphy and magnetic susceptibility) and comparison with previously studied sections (in particular section considered as showing the "classical" succession). It clearly shows the influence of sea-level variations as a key parameter for the platform initiation and demise. Moreover, it offers the opportunity to integrate "non-classical" and recently studied sections in a coherent framework.

WHAT THE TERRESTRIAL UPPER FAMENNIAN TELLS US ABOUT PALAEOZOIC PALAEOCLIMATE CHANGE

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The Famennian Celsius Bjerg Group of East Greenland contains a record of terrestrial climatic variation from a palaeolatitude of 10°S. This includes a very significant interval of sustained aridity as recorded in the vertisols of the Britta Dal Formation. These vertisols are bundled into groups of 20 precessional cycles that define six 405 ky e2 eccentricity cycles. The transition to the overlying Stensiö Bjerg Formation is marked by a group of three bright red intensely arid cycles that are immediately succeeded by a grey shale that represents an interval of temporary flooding. The shale contains palynomorphs including *Retispora lepidophyta* and is the base of the LL spore zone. The Stensiö Bjerg Formation shows a distinctive change in the character of the cycles. Intervals of organic-rich mudstone represent times when stratified permanent lakes formed which contain abundant fossils of fish, plants and spores. The thickest of these mudstones is the immediately overlying Obrutschew Bjerg Formation where 4-6 m of organic-rich sediments with limestones were deposited in two precession cycles. It represents a single, deep, permanent lake of considerable size and stability. This lake is coincident with the Devonian-Carboniferous (D-C) boundary[1]. Nested with these lake cycles are thick intervals of nodular calcrete. Hence these cycles represent climatic extremes between aridity when the monsoon system was weakest contrasted with times of maximum lake development when it was strongest and bringing intense seasonal rainfall into the basin. There are some four such couplets in the Stensiö Bjerg Formation that define another four 405 ky eccentricity cycles. Above the D-C boundary the section changes to become much wetter with an established fluvial system.

We interpret the Britta Dal Formation as representing a long episode (2.5 My) of sustained aridity characterized by cycles that are remarkably even in amplitude. In contrast the Stensiö Bjerg and Obrutschew Bjerg Formation represents an interval where the climate cycles display increased climatic contrast including four high amplitude short duration (precession) couplets between more arid states and more warm states. The most significant amplitude pair being at the D-C boundary level.

In the southern hemisphere we have an incomplete and poorly dated record of glacial sediments. There is normally a single thick latest Famennian diamictite[2, 3] (e.g. the Itacua Formation of Bolivia) that represent the deposits of a glacial collapse[4]. It generally overlies a major stratigraphic gap or condensation level. This gap can now be correlated with the Britta Dal Formation that can be interpreted as a sustained episode of cooling and sea-level drawdown. The Stensiö Bjerg and Obrutschew Formations represents an interval of greater climatic contrast with the D-C boundary being coincident with the glacial collapse. As such it can be recognised that the late Famennian events are ultimately climatically driven and controlled by significant changes in the amplitude of the higher frequency orbital cycle couplets.

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TOWARDS THE ESTABLISHMENT OF A SILURIAN ASTROCHRONOLOGY

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When orbital rhythms are preserved in deep-time strata, they provide a chronometer that exceeds the resolution of any other relative or absolute dating method. Although astrochronology shows great promise as a dating tool, the lack of sufficient time control (such as radiometric data) to evaluate the orbital hypothesis in deep time strata has served as a major obstacle. Recent development of an inverse method for the quantitative identification and calibration of orbital signals in stratigraphic data (average spectral misfit; Meyers & Sageman 2007) now provides the opportunity to develop accurate high-resolution orbital timescales throughout the Paleozoic, and possibly beyond. Such timescales will be instrumental for quantification of rates of biogeochemical, paleontological and paleoclimate change throughout Earth history. In this study, we apply the average spectral misfit method to prospect for orbital rhythms in carbon isotopic data from the well-studied Lower and Upper Visby Formations (Gotland, Sweden; Telychian-Sheinwoodian). Our results indicate that the null hypothesis ("no orbital signal") can be rejected with a high-degree of confidence (<0.2% probability). The most pristine portion of the orbital record comes from the Upper Visby Formation, coinciding with the onset of the early Sheinwoodian (Ireviken) positive carbon isotope excursion (Munnecke et al. 2003). The method identifies an optimal sedimentation rate of 4.5 cm/kyr, which is consistent with previous estimates based on various semi-quantitative methods (3-5 cm/kyr, Jeppsson et al. 2006). This initial work demonstrates the high fidelity of the orbital signal in the Visby Formation, and begins the important work of establishing an astrochronologic timescale for the Silurian Period.

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THE SECULAR DECLINE OF EPICONTENTAL SEAS THROUGH THE PHANEROZOIC: IMPLICATIONS FOR MARINE DIVERSIFICATION AND EXTINCTION

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Throughout the Phanerozoic, there has been a large-scale transition in the locus of global marine biodiversity. Whereas preserved fossil biotas of the Paleozoic Era came primarily from epicontinental seas, there was a shift towards ocean-facing settings in the post-Paleozoic as epicontinental seas began to diminish in extent. The Paleozoic pattern is in part an artifact of the preserved geological record; sediments and fossils deposited in many shallow, ocean-facing settings on the margins of Paleozoic continents were subsequently lost when they were subducted. Therefore, if ocean-facing biotas of the Paleozoic were unique from their epicontinental-sea counterparts with respect to their compositional or macroevolutionary attributes, these differences have likely had only a minimal impact on synoptic, global-scale analyses of diversification and extinction for much of the Paleozoic because of the probable underrepresentation of ocean-facing fossil assemblages. On the other hand, the subsequent loss of epicontinental seas is clearly not an artifact; there was a secular, post-Paleozoic increase in the relative importance of ocean-facing biotas, culminating in their near-total dominance in the present day.

A growing body of literature suggests that paleoceanographic conditions in epicontinental seas were rather different than those in ocean-facing settings of comparable water depth, and it stands to reason that these differences should be reflected in the macroevolutionary dynamics of their constituent species. Furthermore, several recent, global-scale studies have pointed to significant dichotomies between the Paleozoic and post-Paleozoic in the nature of diversification and extinction. While these many well relate to the secular decline of epicontinental seas, rigorous paleobiological comparisons between epicontinental seas and open-ocean settings are still in their infancy.

In this presentation, I will review synoptic characteristics of Phanerozoic marine diversification and extinction, with an emphasis on recent studies suggesting a dichotomy between Paleozoic and post-Paleozoic patterns; comparative aspects of paleoceanography in epicontinental seas versus ocean-facing settings; preliminary paleogeographic dissections that point to important differences in the dynamics of the biotas in these two regimes; and an agenda for future research in this arena, including a possible role for molecular biology in determining what might have been present in the subducted ocean-facing record of the Paleozoic Era.

GROWTH PERIODICITY IN FAVOSITID TABULATE CORALS CLIMATICALLY CONTROLLED?

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As stated by numerous authors, growth periodicity, largely observed in present and fossil corals, seems to be caused, in a large account, by seasonal changes (i.e. temperature fluctuation). The amplitude of this variation can largely differs according to the latitudinal position. In actual oceans, amplitude of this temperature fluctuation is appreciatively 2°C or less in equatorial zone but four to five times more (up to 8°C to 10°C) in 30° to 40° latitudes, and, of course, not identical in North or South hemisphere.

It can result that corals developed in low latitude position (near equatorial) know few temperature fluctuation stress and consequently low or none growth periodicity. In another hand corals developed in higher latitudes (particularly when positioned near tropics) are confronted to larger variations and consequently could present a more developed growth periodicity.

Some *Pachyfavosites* sp. from Avesnois (North of France) previously analyzed (Zapalski et al, 2007) showing well expressed growth periodicity and situated at an approximatively 20° to 30° south palaeolatitude, according to different palaeogeographical reconstructions, are compared with specimens from other provenances in order to verify the possibility of a palaoelatitudinal gradient.

WAS ORDOVICIAN ACRITARCH (MICROPHYTOPLANKTON) BIODIVERSITY INFLUENCED BY CHANGES IN SEA LEVEL, OR NOT?

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The relationship between Ordovician acritarch biodiversity dynamics and second order sea-level change is ambiguous. Various studies have concluded that (i) high diversity coincided with highstands and low diversity with lowstands, (ii) high diversity coincided with lowstands and low diversity with highstands, and (iii) perhaps not surprisingly, that there was no consistent relationship between sea-level change and acritarch diversity. On the face of it, this last conclusion appears to sum up the influence that sea-level changes might have had on acritarch diversity – none, or at least very little.

Such a conclusion, however, might be misconceived. It is argued here that changes in sea level did have an influence on acritarch biodiversity, but that the observable relationship is scale-dependent. It is true that, at the largest scale, parallel trends in sea level and acritarch biodiversity have been reported in the literature, but these have been attributed to parallel responses to other factors rather than direct cause and effect. Those studies that have shown the closest relationship between acritarch biodiversity and sea-level, whether high diversity associated with highstand or high diversity associated with lowstand, have been at relatively small scales – a single basin or part of a basin such as the Yangtze Platform of south China or the Skiddaw inliers of northern England. It is at intermediate scales, the Gondwanan margin for example, that any observable relationship between sea-level and acritarch biodiversity begins to break down.

It is possible to reconcile documented instances of high-diversity-with-highstand and high-diversity-with-lowstand relationships by invoking the well-known onshore-offshore trend in acritarch distribution. If the morphologically complex forms that characterise increased diversity track their optimum positions in the onshore-offshore gradient during sea-level change, episodes of transgression might result in more diverse assemblages moving onto continental platforms, such as the Yangtze Platform, whereas regressions might have the opposite effect as the more diverse assemblages move towards basins, as in the Skiddaw inliers of northern England. As a result, larger scale studies that sampled platform areas and basinal settings, to obtain data on overall acritarch biodiversity through a specified interval of time, might not evince any relationship between biodiversity and sea-level change. This does not necessarily mean that the relationship does not exist, simply that it is hidden.

None of this excludes the possibility that other factors - palaeogeography, palaeoceanography, tectonism and climate - influenced acritarch diversity at broad spatial and temporal scales. So, if the primary effect of sea-level change was simply to shift the location of maximum diversity, can it be regarded as important? A shift in the locus of maximum diversity might be the most obvious consequence of sea-level change, but it also appears that changes in sea-level were in some way linked to changes in the composition of acritarch assemblages. Changes in sea level appear to have had some influence on the origination and extinction of acritarch taxa, at least locally, possibly as a result of ecological stresses associated with changes in the locus of acritarch populations. In this sense, sea-level changes can be regarded as having had a significant impact on acritarch diversity.

SEA LEVEL CHANGES AND BRACHIOPODS AND CORAL EXTINCTIONS DURING THE LATE FRASNIAN IN THE NAMUR-DINANT BASIN (BELGIUM)

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On the shallow part of the ramp situated in the north of the Namur-Dinant Basin, the upper Frasnian Aisemont Formation rests in disconformity upon the middle Frasnian Lustin Formation, and records a transgressive-regressive cycle corresponding to a third-order sequence. The maximum of relative sea-level (maximum flooding surface) is marked by the development in the middle of the formation of argillaceous deposits comprising an unit with dysaerobic-anaerobic facies, which is correlated with the Lower Kellwasser Event (LKW; lower part of the Upper *rhenana* Zone). The overlying Lambermont Shale Formation corresponds to the transgressive system tract of a following third-order sequence which crosses the Upper Kellwasser Event (UKW) and the Frasnian/Famennian boundary, and extends into the lower Famennian shales. Southwards, these formations passes laterally to more distal ones in which sequence system tracts and boundary can be followed.

Frasnian brachiopod decline occurred in three steps within the interval spanning the Lower *rhenana* Zone to the *linguiformis* Zone. Most brachiopod orders suffered severely and the major losses occurred at the top of the Upper *rhenana* Zone. These extinction episodes were linked principally to diachronous regional facies changes related to transgressions. For example, atrypids and pentamerids became extinct within the Upper *rhenana* Zone in the shallow parts of the basin, whereas they had already disappeared at the top of the Lower *rhenana* Zone in its distal part, just before the deposition of the dark shales of the Matagne Formation indicative of hypoxic bottom conditions. These orders vanished in the *linguiformis* Zone in other areas of the world.

The initial decline of the rugose corals within the Namur-Dinant Basin is recognized in the Lower rhenana Zone, and corresponds to the extinction of the colonial disphyllids and to their replacement mainly by members of the phillipsastreids. This coral turnover is correlated with the beginning of the rise in sea-level triggering the transgressive system tract of the “Aisemont sequence” and following the fall in sea-level which marks the top of the Philippeville and Lustin formations. But it was not due to the LKW *sensu stricto*, which happened later (in the middle part of the Aisemont Formation) and induced strictly no extinction in corals and brachiopods, those found in the lower part of the formation being still present in the upper part. Rugose corals disappeared progressively, along with the tabulates, in the Upper *rhenana* Zone, before the UKW.

Post-extinction brachiopod recovery was rapid in the basal Famennian but, despite their great abundance, their diversity was quite low. However, it is only close to the base of the Strunian Substage that the rugose coral recovery actually started. Tabulates never really recovered.

As considered by some authors, the ecological crisis probably resulted of a cooling. The fall and then a rapid rise of the sea-level at the middle–upper Frasnian transition could correspond to a ice cap freezing-melting cycle.

However the LKW (and the UKW?) was not triggered by a short-term cooling event, but corresponds to the maximum flooding surface of a upper Frasnian third-order sequence (“Aisemont sequence”), ie. a rise of the sea-level, and had no direct influence on the distribution of corals and brachiopods. The UKW had influence only on brachiopods.

PALEOGEOGRAPHIC CONTROL ON THE DIVERSITY FLUCTUATIONS OF BLASTOZOANS (ECHINODERMATA, EARLY PALEOZOIC)

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Paleogeographical aspects and biodiversity patterns (diversity, disparity) of the Cambro-Ordovician radiation of metazoans have been extensively investigated. However, most studies focused on the same three groups of marine invertebrates (articulate brachiopods, molluscs, and trilobites), whereas other significant components of Early Paleozoic biota, such as echinoderms, remained largely neglected. Few recent studies concern mostly either Ordovician echinofauna or Cambrian one during the Cambrian revolution. Those focused on the ecology of primitive echinoderms have suggested relatively different diversification patterns in Laurentia and on the northern Gondwanan margin, and a provincial distribution as for the majority of echinoderms.

The subphylum Blastozoa is a great component of the early echinoderm fauna, being composed of 10 classes. A comprehensive database including all records of blastozoans has been built to provide a global pattern of taxonomic diversity for this phylum during the Early Paleozoic. This global pattern has been subdivided in local trends to evidence a regional selection of blastozoan distribution. Blastozoans are mainly distributed on Gondwanan and Laurentian margins during Cambrian, on north-western peri-Gondwanan margins and Asiatic regions during Ordovician, and on Laurentian margins during Silurian.

Concerning the processes, during Cambrian, the great turnover seem to be related with a short longevity and an high endemicity of blastozoan genera. The extensive longevity of Ordovician blastozoan genera can be explained by their progressive colonization of most of the paleocontinental margin. During this period, blastozoans attained different provinces mainly characterized by quite homogeneous environmental conditions. The migration of blastozoans seem to be driven by the paleocontinental migration, and the appearance of new clades, by the freeing of ecological niches concordant with the environmental changes.

EVOLUTION OF ECOSPACE OCCUPATION OF EARLY PALEOZOIC ECHINODERMS

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Marine communities can be characterized by their occupation of the theoretical ecospace and its evolution through time. The ecospace gives an account of three fundamental parameters of autecology: the vertical tiering, the mobility level, and the feeding mechanisms. The combination of these features permits to draw reasonable conclusions about the modes of life of fossil organisms and probable correspondence between taxonomic and ecological radiations.

Several environmental changes occur during the Cambro-Ordovician period, i.e. Cambrian Substrate Revolution, development of hardgrounds, increase of atmospheric O_2... The evolution of the position in the ecospace of Cambro-Ordovician echinoderms is a good example to illustrate the impact of these dramatic paleoenvironmental shift on a major group of benthic metazoans.

Echinoderms represent a large component of the Early Paleozoic benthic fauna. They early/initially reached varied tiering and mobility levels, while they maintained only two feeding mechanisms (suspension and surface deposit). Echinoderms developed morphological innovations helping to extend their filtration stage from the low surficial (helicoplacoids) to the median to high (upper than 15cm) levels (eocrinoids) during Cambrian. They also acquired a facultative mobility during the early Middle Cambrian (e.g. cinctans, ctenocystoids) and a self-propulsion ability (slow and free mobility) during the upper Middle and the Late Cambrian (e.g. solutes, stylophorans). Then primitive echinoderms developed 18 over the 30 modes of life, commonly recognized for the Cambro-Ordovician fauna. The resulting variations of ecospace occupation of early echinoderms could be related with their diversity dynamics. Period of strong ecospace colonisation could correspond to periods of high evolutionary rates and phylogenetic diversification (Cambrian).

FACTORS SUSCEPTIBLE TO ALTER THE ORIGINAL $\delta^{13}C_{ORG}$ SIGNAL IN EARLY PALAEOZOIC MARINE SEDIMENTS

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Oxygen and carbon isotopes signals are now commonly used to document global climatic events in Early Palaeozoic sequences. However, when positive excursions of the $\delta^{18}O$ are generally regarded as a proxy for depicting a global cooling (i.e., ice cap development), the actual meaning of $\delta^{13}C$ shifting is more controversial. Many factors may influence the carbon isotopic composition of the oceanic reservoir (e.g. high organic productivity with a huge burial of organic matter, acceleration of the weathering and erosion processes on continents, mass release of carbon dioxide through volcanic activity or other catastrophic processes). All these factors are of global impact. Regional or even very local factors, however, are susceptible to strongly modify the original carbon isotopic values of marine sediments. When interpreting $\delta^{13}C$ excursions, these restrictions must be kept in mind. It is expected that technical bias are well controlled enough and thus do not intervene significantly on the obtained values. Other parameters may have much more impact, especially the biological and the mineralogical content of the sediment when bulk samples are used. Land derived plant remains (e.g. spores, tracheids, cuticles) modify the isotopic composition of the bulk organic content of marine sediments with a positive shift of the analysed $\delta^{13}C$ value of up to 5 per mil depending on the contribution of the terrestrial plant input to the Silurian or Devonian organic residues. The occurrence of large amount of detrital graphite in the processed samples is another factor that also deeply modifies the original $\delta^{13}C$ signal of marine deposits. The carbon of these graphite flakes has $\delta^{13}C$ values significantly less negative than the carbon of the associated marine organic remains. Consequently, the positive shift of the δ13C values in bulk rock samples may mostly reflect the dramatic increase of the inherited graphite in the sediment. Chemical etching of the organic matter during the processing has some limited effects. To prevent an alteration of the original marine $\delta^{13}C$ signal, we preclude the use of bulk rock samples for carbon isotope investigations. As an alternative, we recommend to analyse a carefully sorted organic fraction, ideally from a single marine organic microfossil group. Chitinozoans constitute an excellent carbon source for such analyses as they are usually abundant, continuously distributed all along the marine sequences, and large enough for a fairly easy sorting. In order to illustrate our statements, the $\delta^{13}C_{org}$ values of more than one hundred samples from various northern Gondwana localities ranging from the Early Ordovician to the Late Devonian, have been measured using the chitinozoans as the unique carbon source.

PALAEOCLIMATIC IMPACT ON LATE CARBONIFEROUS MARINE ECOSYSTEMS

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The Late Carboniferous (Pennsylvanian, c. 320-296 Ma) represents one of the most interesting periods within the Palaeozoic to assess the palaeoclimatic impact on marine ecosystems. Pennsylvanian strata record a dynamic scenario of alternating glacial-nonglacial episodes in Gondwana, with global effects and feedbacks on climate, sea-level and atmospheric CO_2, beginning with the onset of the glaciation in the mid-Carboniferous (~ 327 Ma) and the transition towards the Permian "greenhouse state" (~ 260 Ma). Responses of vegetation to this climatic variability are well-established but less information is available about consequences for marine biota. Global data compiled for single groups of organisms and ecosystems are analysed to determine possible major changes related to climate. A further comparison is also established with obtained data at outcrop level to differentiate regional from global phenomena. Overall observations suggest some analogies between the Late Carboniferous and Late Ordovician scenarios. Such a conclusion indicates the possibility of a combined analysis of Palaeozoic periods for a better understanding of the biotic response to climate.

ARE THERE PELAGIC OSTRACODS IN THE SILURIAN?

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The Silurian myodocopes (bolbozoids, cypridinids and entomozoids) are atypical and poorly documented ostracods, usually much larger (up to 2 cm long) than the average Lower Palaeozoic ostracods. They are present in many European localities during the Late Silurian and show a great numerical abundance and a relatively high diversity. We present here a revision of the different groups and the description of eight new species. The main diagnostic features of Silurian myodocopes are the outline of their carapace, the shape of their rostrum, the shape and the location of the muscle scar and the external ornament of the valves.

Some species such as *Parabolbozoe bohemica* or *Richteria migrans* (Perrier et al. 2007) have a wide palaeogeographic distribution (transoceanic distribution). This widespread distribution added to the facies where they were deposited (black shales), their recurrent pelagic faunal associates, and several morphological features of functional significance (rostrum and caudal process) led us to envisage a pelagic lifestyle for these faunas, an assumption formulated in the 1980's (e.g. Siveter, 1984; Siveter et al. 1991; Vannier and Abe, 1992) which we are testing here.

We describe nodules containing swarms of ostracodes with remains of cephalopods, eurypterids or phyllocarids. These peculiar associations, probably preserved in situ question the autecological niches occupied by myodocopes. The scavenging behaviour of myodocopes possibly feeding on carrions of larger animals deposited on the sea floor could explain this type of assemblages. If this assumption is correct then, it should be envisaged that these ostracods did not live permanently in the water column and were not pelagic organism sensu stricto as it is classically believed

The abundant 3D-preserved material shows that the anterodorsal bulb of bolbozoids was an unornamented and virtually hemispherical structure. The bulb seems to have housed the lateral eyes as well as a part of the swimming antenna (i.e. A2 protopod). An unornamented area is present in cypridinids and *R. migrans*, these groups probably also possessed a lateral eye. The rostral complex (e.g. rostrum, rostral incisure) of bolbozoids and cypridinids is identical to that of recent swimming myodocopes. The strengthening of the rostrum and the rounded shape of the notch led us to think that the Silurian myodocopes were swimmers using their second antennae (A2) in the same way as their Recent representatives. In conclusion, our data provide precise details on the possible lifestyle of Silurian myodocopes, interpreted here as swimmers (powerful antennae), living above the dysoxic bottom (hyperbenthic niches), having scavenging habits (assemblages in nodules) and possibly visually adapted to dim-light environments (eye hypertrophy, bioluminescence). Environmental changes (oxygenation) probably played a key role in the Myodocopes ecological shift of during the Silurian.

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SYRINGOPORID WALLS THICKNESS CLIMATICALLY CONTROLLED?

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Tabulate corals, particularly abundant in reefal environment during the 'green house' Devonian period (especially during Givetian and Frasnian) become less frequent during the Famennian and Lower Carboniferous (Tournaisian, Visean) 'ice house' period after the F/F event. This latter period (Famennian, Tournaisian and Visean) is essentially represented by Syringoporids and Michelinids, whereas during 'green house' period other groups such as Alveolitids, Thamnoporids… are particularly present.

The evolution of the wall thickness in Syringoporids during the Frasnian to Visean periods shows different patterns in Western Europe (France, Belgium) at that time located on the meridional border of the Laurussia, and South-Eastern Asia (South China) usually positioned, at the same time, on the northeastern prolongation of the Gondwana.

Traditional morphometric methods are performed in order to demonstrate a possible relation between the wall thickness and the palaeogeographical position or a palaoelatitudinal gradient? Moreover the ultrastructural feature of walls is also evocated.

HIRNANTIAN EVENT IN THE SEDIMENTARY SEQUENCE FROM THE NORTHERN POLAND: ISOTOPIC AND GEOCHEMICAL RECORDS

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The study presents an interpretation of the results of the isotope and elemental geochemistry research recorded the Hirnantian event in the latest Ordovician. The study area is situated in the north of the western slope of the East European craton, part of the Palaeozoic Baltic basin and its sedimentary infill. Towards the west, Upper Proterozoic and Lower Palaeozoic deposits of the Baltic basin are in contact with tectonically deformed Ordovician and Silurian rocks along the Teisseyre – Tornquist Zone. The deposits of the latest Ordovician and the earliest Silurian known from the deep boreholes were of small thicknesses and the facies showed a zonal pattern arranged from deep neritic facies, directly adjoining basinal facies in the west, to nearshore facies in the east. The Ordovician/ Silurian transition in the northern Poland is coincident with a conspicuous lithologic change that occurs at the passage from the Upper Ordovician marls and limestones with sandy intercalations to Lower Llandovery graptolitic black shales or nodular limestones. The lower Llandovery sedimentary succession records suboxic to anoxic conditions within the sediment-water interface and in the water column.

This study presents the isotopic and geochemical characteristics for the Hirnantian event by interpreting the course in the $\delta^{13}C$ and $\delta^{18}O$ values and elemental contents (Mn, TOC), and elemental ratios [Si/Al, Ti/Al, Na/K, K/(Mg + Fe), Th/U, V/Cr] variation curves for the rocks of the latest Ordovician and earliest Silurian age. A low content of total organic carbon (TOC) and rather high content of manganese, suggests oxic or suboxic seafloor, within examined Hirnantian sediments. An increase of Si/Al and Ti/Al ratios throughout the Hirnantian should be treated as increased siliciclastic weathering and eolian transport of periglacial dust. Th/U and V/Cr ratios indicate the palaeoredox conditions in the investigated sequence.

Positive carbon and oxygen isotope values coincided with global faunal extinction, eustatic sea-level fall and glaciation were for the first time identified in the Polish part of Baltica. Carbon isotope data increased from 0, 37 ‰ for pre-Hirnantian samples to 4,58 ‰ for the Hirnantian ones. The lower Hirnantian carbonates are characterized by generally high isotopic values. $\delta^{13}C$ curve in the Hirnantian Stage begins with a high positive tendency (max. values of the $\delta^{13}C$ is 4.7 ‰) and then it suddenly falls in the uppermost Ordovician to the lowest value of 0. 60 ‰. In the lowest Silurian the isotopic values are falling rapidly to the pre-Hirnantian levels. Oxygen isotope ratios which are more sensitive to diagenetic alteration show only a slight positive tendency. $\delta^{18}O$ values in whole rock samples in studied drill-cores are varied between – 8.2 ‰ for the earliest Silurian samples to – 3.4 ‰ in the Hirnantian ones. A slightly higher $\delta^{18}O$ values, comparing to the mean oxygen isotopic ratio for the Ordovician, coincide with the peak values of $\delta^{13}C$ for the lower Hirnantian.

Some correlation between the carbon isotope curve, biodiversity and facies changes is observed and biotic and isotopic events seem to be coeval. The drastic drop in the Ordovician biodiversity has began almost simultaneously with the Hirnantian major carbon isotope increase. The carbon and oxygen isotope fluctuation measured from the Polish part of East European Craton enables correlation of profiles not only within the Baltic shelf area but also with the other regions.

THE TRANSITION FROM UPPER ORDOVICIAN ICE HOUSE TO LOWER SILURIAN GREEN HOUSE IN THE TANDILIA SYSTEM, RIO DE LA PLATA CRATON, ARGENTINA

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The Tandilia System is an orographic belt located in the Buenos Aires Province, Argentina, with a maximum length of 350 km in the NW-SE direction. The hills are composed of an igneous metamorphic basement and a Precambrian and Lower Palaeozoic sedimentary cover, which displays horizontal to sub horizontal bedding. Two main stratigraphic units (the Sierra del Volcán Diamictite and the Balcarce Formation) are recognised in the sedimentary cover of the eastern sector of the Tandilia System. The Sierra del Volcán Diamictite is a 20 m thick unit that appears between the crystalline basement and the Balcarce Formation. The Lower Palaeozoic sedimentary succession of the Balcarce Formation is made up of thick quartz arenite beds together with kaolinitic claystones and thin fine-grained conglomerates. The Balcarce Formation is interpreted as the nearshore and inner shelf record of a tide-dominated open platform. The Balcarce Formation shows a large abundance and a great variety of trace fossils. Trace fossils have traditionally been used to assign the Balcarce Formation to the Lower Ordovician, due to the presence of *Cruziana furcifera*. Recently, Rapela et al. (2005) reported a complex zircon provenance age pattern for a quartz arenite of the Balcarce Formation. The youngest zircons are dated about 475–480 Ma (Early Ordovician), and provide a maximum estimate for the age of the Balcarce Formation. Based on its stratigraphic position, the Sierra del Volcán Diamictite was originally referred to the Ediacaran glacial event. However, van Staden et al. (in review) have found a Lower Ordovician age for detrital zircons of the Sierra del Volcán Diamictite. Therefore, this glacial unit should be referred to the Ashgill (Hirnantian), which has a very important record in southern South America and South Africa. The geochronological information provided by detrital zircons from the Sierra del Volcán Diamictite and the Balcarce Formation allows suggest that the kaolinite-rich Balcarce Formation could represent the beginning of the Silurian green house record. In this sense, during a keynote speech, Seilacher (1994) indicated a Lower Silurian age for the Balcarce Formation based on the occurrence of *Cruziana ancora*. The humid and warm climatic conditions of the Silurian green house period seem to be the main controls on the high compositional maturity (quartz arenites, kaolinite claystones) and trace fossil abundance and diversity of the Balcarce Formation. Although palaeogeographic reconstructions show that the Tandilia System occupied a tropical position during the Late Ordovician and Lower Silurian, with the South Pole in northern Africa, it is suggested that the Tandilia region records the transition from the Upper Ordovician ice house to the Lower Silurian green house global conditions.

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GLOBAL SEA LEVEL AND CLIMATIC CHANGES DURING THE LOWER CARBONIFEROUS

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From the uppermost Famennian (Strunian) to the lower Namurian, 11 third-order stratigraphic sequences were recognized by Hance et al. (2001) in Belgium and France, and were latter extended to England, Poland and South China. They correspond to major eustatic sea-level variations and have usually 3-4 MA durations. One of them (sequence 8 overlapping the Middle – Upper Viséan boundary) has probably less than 1 MA. An estimation of the amplitude of the eustatic changes was attempted, considering the subsidence and sedimentation rates and the relative sea levels recorded in the deposits. Results are of the order of 40-50 m, but among the sequences, some correspond to sea level changes larger than the others :

The uppermost Tournaisian sequence 4, is characterized by a very high highstand (HST) and a flooding of lowlands previously emerged (« Avins event » of Poty, 2007). This very high sea level was responsible for good connections between marine basins and the widespread nature of foraminifers, brachiopods and corals.

It is followed by a very strong fall in the sea level corresponding to the falling stage of the sequence 4. This low level persisted during the sequence 5 (lowermost Viséan), so much so that its transgressive system tract (TST) and its HST never reached the shallow marine platforms previously covered by the late Tournaisian sea (Hance et al., 2001). Areas which were previously well connected became more or less isolated, and their common stock of uppermost Tournaisian corals gave rise, by separate evolutions, to lowermost Viséan coral endemic assemblages. It is from the base of the sequence 5 that a marked four and/or five-order cyclicity developed, whereas it was not marked during the Tournaisian. That shift between the Tournaisian and the Viséan sea levels and patterns of deposition is considered as heralding change to the Carboniferous climate with glaciations and the development of an ice-cap. Shallow platforms were progressively flooded during the TST of the following sequence 6 (upper Lower Viséan).

The highest fall of the sea-level occurred at the end of the Viséan and caused, for the second time, the emergence of the carbonate platforms. In the palaeoequator zone, the latters were affected by an intense karstification due to the replacement of the relatively dry Viséan climate by the Namurian wet climate, as shown by the shift from the Viséan carbonate-dominant sedimentation to the Namurian siliciclastic-dominant one. That is considered as corresponding to an enhancement of the ice-caps and the starting of the upper Carboniferous glaciations.

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THE DISTRIBUTION OF RHYNCHONELLIFORMEAN BRACHIOPODS AND THE PALAEOGEOGRAPHY OF WESTERN GONDWANA DURING THE MID AND LATE DARRIWILLIAN (MIDDLE ORDOVICIAN)

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The generally low diversity of Early and Middle Ordovician brachiopods from the western Gondwanan margins has produced some uncertainty when analysing the changing relationships between the different regions that make it up. It is generally accepted that by that time, Bohemia, Armorica, Iberia, Sardinia and the Montagne Noire, were closely related to the North African region, while the Central Andean Basin and the Precordillera Argentina seem to have had a closer relationship with the proto-Avalonian terranes. Nevertheless, those comparisons are greatly influenced by the degree of knowledge of brachiopod faunas in the different regions. There are well known, relatively diverse Arenig assemblages from the Precordillera Argentina, Central Andean Basin, England, Wales and exceptionally the Montagne Noire. Nevertheless, particularly low diversity Arenigian assemblages are known from southwestern Europe and North Africa. Those latest assemblages were characterized by a suite of large lingulides, associated to inshore clastic deposits, the Armorican Quartzite facies, not recorded outside the region. The Llanvirn transgression made the Afro-South European margin of Gondwana more hospitable for rhynchonelliformean brachiopods, although diversities continued being very low. As a result, the main conclusions on the Early Ordovician palaeogeography of western Gondwana are based not on brachiopods but on trilobite distribution. A taxonomic study in progress on the rhynchonelliformean brachiopods from the Darriwilian dark shales of the Central-Iberian Zone (Central Spain) has increased considerably the number of orthides and strophomenides known from that age at the whole Afro-South European margin of Gondwana. This makes possible to attempt an improved assessment of the palaeobiogeographic relationships of this margin with the proto-Andean margin of Gondwana and the Avalonian margin. Our purpose is to analyze separately, whenever possible, Oretanian (approx. Abereiddian) and Dobrotivian (Llandeilian plus earliest Aurelucian) Gondwanan brachiopod assemblages, besides those from the other main palaeocontinents, in order to shed new light on the pace of palaeogeographic change of the region, in a time when Avalonia is considered to be already drifting off from Gondwana. With this aim clustering and ordering multivariate analysis have been performed on a database including 161 brachiopod genera and 15 sample points. Nevertheless, it has not been possible to maintain the same number of localities for the Oretanian and the Dobrotivian matrices, since brachiopod assemblages of this latter age are especially poorly known at South America. Clustering analysis has given very variable results, with important changes depending on the similarity index used. However, the different ordination multivariate analysis performed has given congruent results, even for the different similarity indices. The diagrams obtained for the Oretanian matrix with Detrended Correspondence Analysis, Principal Coordinates Analysis and Non Metric Multidimensional Scaling recurrently group separately the Afro-South European localities from a set of terranes considered to have lied at tropical or temperate latitudes, both clusters occurring at opposing places in the scatter plots. The British Avalonian localities occur at intermediate positions between both large clusters but very close to the Central Andean Basin sample, denoting that by the time it has not developed an independent faunal signal from Gondwana. The known Llandeilian brachiopods from the Central Andean Basin are too scarce to allow any multivariate comparative analysis, but it is clear that by the latest Darriwillian the British Avalonian localities increase their faunal isolation from the Afro-South European Gondwanan margin.

ENVIRONMENTAL CHANGES AND CLIMATIC PERTURBATIONS AT THE FRASNIAN-FAMENNIAN BOUNDARY

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The Frasnian-Famennian (F-F) mass extinction of marine shallow-water organisms, associated with two organic-rich limestone beds, the Kellwasser (KW) horizons represent the main environmental events recorded during the Late Devonian in many tropical and subtropical areas. Possible causes of both biological and sedimentological phenomena and impacts on the carbon cycle are still debated. Integrated studies, combining geochemistry and rock magnetism were carried out on several platform to deep basin key sections, belonging to Gondwana north margin (Morocco and France) and Laurussia south margin (Germany). The main goal of the study is to reconstruct the evolution of environmental conditions at the F-F boundary and to assess the possible causes, links and consequences of these perturbations.

Within the two KW horizons, noticeable enrichment in nutrient- and organic matter-related trace elements (e.g., Ba, Cu, Ni) and high values of redox indices (U/Th, V/Cr) indicate that the Late Frasnian is punctuated by periods of elevated primary productivity, mainly in platform setting within the Lower KW horizon, and oxygen-depleted conditions in bottom water, well recorded in deeper settings during the Upper KW horizon. These conditions are propitious to production and preservation of marine OM. At the top of the Upper KW horizon, the F-F boundary records an intensification of detrital input, highlighted by increased magnetic susceptibility values at the base of Famennian. This well-marked change results from a sharp decrease of sea-level, marked by sedimentary hiatus and discontinuities in several areas, and change of erosional regime.

Origins of the Late Devonian environmental change in marine domain are presumably linked to Earth-bound mechanisms. The organic-rich KW horizons could be mainly due to 1) enhanced continental weathering, stimulating primary productivity in proximal settings and 2) reduced oceanic circulation in epicontinental basins, due to continents collision, favouring water stratification in deeper environments. The main consequence of these environmental changes might have been a long-term perturbation of the carbon cycle, leading to noticeable drawdown of atmospheric pCO_2 and climatic cooling, linked to the major regression at the base of the Famennian.

NEW PALAEOGEOGRAPHY OF LATE PALAEOZOIC AND EARLY MESOZOIC – CLIMATE MODELLING AND GEOLOGICAL VALIDATION

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A new approach on the reconstruction of Late Palaeozoic and Early Mesozoic palaeogeography is based on ideas of Schneider et al. (2006) and Roscher & Schneider (2006) about the formation of the Pangaea supercontinent. The new plate tectonic concept is supported by palaeomagnetic data as it fits the 95% confidence interval of published palaeomagnetic data (Grunow, 1999).

Six Carboniferous and Permian reconstructions (340, 320, 300, 290, 270, 255 Ma) were chosen for a climate modelling approach as they represent the most important changes of the Late Palaeozoic climate development. Presently, three Triassic reconstructions (240, 220, 200 Ma) are also under investigation. The digital maps have a resolution of 2.8°x2.8°(T42), suitable for high-resolution climate modelling, using the PLASIM model (Fraedrich et al., 2005). CO_2 concentrations of the palaeo-atmosphere have been estimated from isotope records (Veizer et al., 1999) using the method of Freeman & Hayes (1992). Palaeo-insolation values were reconstructed according to the method given in Caldeira & Kastings (1992), and are approximately 3% lower than today's values.

For the purpose of validation, the quantitative model output had to be transformed into qualitative values in order to be able to compare digital data with qualitative geologic indicators. Therefore, the model output of surface temperatures and precipitation was converted into a simplified Köppen & Geiger climate classification. The reconstructed occurrences of geological climate indicators like aeolian sands, evaporites, coals, tillites, oil source rocks, phosphorites, cherts and reefs were compared to the computed palaeoclimate zones. Examples of the Permian Pangaea show a very good agreement between model results and geological indicators.

From the modelling approach we are able to identify climatic processes which lead to the deposition of hydrocarbon source and reservoir rocks. Additionally, soil temperatures from numeric climate modelling help to improve estimates on palaeo-heat flux in basin modelling, a tool commonly applied in hydrocarbon exploration.

Furthermore, the results of climate modelling can be used for the reconstruction of Late Palaeozoic environments and for analyses of possible floral and faunal migration corridors as well as for investigations on possible habitat conditions and their changes in space and time.

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EFFECT OF CLIMATIC AND GEOGRAPHICAL CHANGES ON THE DEVELOPMENT OF ECHINODERMS IN THE ORDOVICIAN BALTIC BASIN

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The development of echinoderms in the Ordovician Baltic Basin was primarily determined by morphogenetic and adaptive potentiality of immigrants in this area. This follows from comparison of morphological and taxonomic diversity of closely related taxa in the Baltic and Laurentia. Penetration into these basins depended on the ability of larval echinoderms to overcome oceanic and ecological barriers and on the geographical, climatic, and other external factors. Echinoderms migrated in the Ordovician Baltic Basin at the end of the Floian (Latorp), with the onset of transgression accompanied by an increase in sea depth and probably by the establishment of normal marine salinity in the basin near, for example, Karelian land, which originally had low salinity; this was important for a stenohaline group such as echinoderms. First echinoderms appeared in this part of the basin in the Floian (Latorp) and were represented by five monotypic genera of three classes (three genera of disparid crinoids, one genus of eocrinoid with a flat theca, and one rhombiferan). In the Dapingian (Volkhov) the number of classes increased to eight; however, each was represented by a few genera. The exception is crinoids (at least ten genera, some of which are only represented by columnals) and diploporans (five genera). These first echinoderms entered a cold basin, as follows from sedimentologyical data and paleolatitudinal position of the continent. The majority of echinoderms probably migrated from the west through the Ural paleobasin, from warm basins of "eastern" Gondwana. It is impossible to recognize the initial basins because of poor material. However, a comparison of the Baltic echinoderm fauna with Early Ordovician immigrants in the warm Laurentia basin suggests that the two epicontinental seas got echinoderms from the same center located in "eastern" Gondwana. The majority of these echinoderms were probably eurythermal, since they penetrated into cold seas from warmer environments. A small part of echinoderms apparently came from cool seas of "western" Gondwana. In the Dapingian (Volkhov) this was primarily *Spheronites* (*Diploporita*). At the Darriwilian (Aseri), it was followed by *Echinosphaerites*. Both genera migrated from cool seas of "western" Gondwana probably through a different route at the western margin of the Baltic Region. The Baltic and Laurentia regions did not show exchange of echinoderms until the Sandbian. This was connected not only with a great width of the Japetus Ocean between these basins but also with a considerable difference in temperature. Therefore, similarity in echinoderm faunas of Baltic and Laurentia was caused by the fact that echinoderms migrated to these continents from the same center of origin and some groups showed parallel development. The disappearance of Echinosphaerites and displacement of spheronitids to the cool deep-water regions of the Baltic Basin were connected a significant climatic warming. The warming of the Baltic and simultaneous narrowing of the Japetus Ocean in the Sandbian resulted in the appearance of some warm-water Laurentia taxa in the Baltic Region. However, these taxa were scarce and played a minor role in the development of Baltic communities. The majority of Late Ordovician echinoderm communities of the Baltic seas consisted of genera that appeared there during the cool period or of their descendants. These genera dominated in communities in abundance and biomass. In contrast to the cold-water ancestors, they increased in species diversity and maximum body size. The domination in biomass and calcitic production of non-crinoid groups combined with much higher morphological and taxonomic diversity of crinoids are characteristic features of echinoderm communities of the Ordovician Baltic Basin. As a result of the Late Ordovician fall in temperature, which was connected with the rearrangement of all marine communities, crinoids became dominants in the Silurian benthic communities, while the role of other pelmatozoan echinoderms sharply decreased.

ORDOVICIAN ACRITARCH BIODIVERSITY OF THE WESTERN GONDWANA ACTIVE MARGIN (ARGENTINA): AN OVERVIEW

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The major Ordovician basins in Argentina were developed in a "pericratonic area" of western Gondwana, which was an active margin since the Early Cambrian (Andean Belt). Continuous subduction occurred along the Proto-Andean margin, partially related to the development of wide retroforeland basins. The three main sedimentary basins are the Central Andean Basin, the Precordillera Basin, and the Famatina Basin. The continuous link of depositional settings and the gradual changes occurring across the Central Andean Basin evidence a foreland basin system, characterized by a double feed system with sediment input from the Puna arc, at the west, and an important imput at the east, related to major deltaic complexes coming from the craton (Astini & Marengo, 2006). The Precordillera basin is considered as a lithospheric block rifted from SE Laurentia in the early Cambrian, and amalgamated to the Famatina arc (W Gondwana margin), in mid-late Ordovician times (Thomas & Astini, 2003). The peri-Iapetus volcanic-arc depositional systems represented in the Famatina Basin were related to the eastward subduction under the proto-Andean margin and the approach and subsequent accretion of the Precordillera Terrane. In light of this complex geodynamic scenario, it is difficult to compare acritarch diversity, speciation and extinction trends in such different basins. Moreover, sea level curves of the Proto-Andean basins can only be drawn up reliably by basin, or even by different areas of the basins (i.e. Puna, Cordillera Oriental, Sierras Subandinas), because of the intense tectonic activity. Nevertheless, major and short-lived eustatic events, like glacially-induced Hirnantian one may stand out from local fluctuations. The majority of palynological studies have been focused on Tremadocian and Floian strata from the platform facies of the Cordillera Oriental, rich in macrofauna, where most of the acritarch assemblages have good independent age control. Palynological analysis on the Cambrian/Ordovician boundary have not been successful. Only sparse data from the late Cambrian and early Tremadocian, corresponding to poorly preserved acritarchs, come from the Cordillera Oriental. Acritarch diversity increases in middle to late Tremadocian, flourishing during the Floian, also in Sierras Subandinas and Famatina. Particularly in Famatina, an abundant and diverse acritarch assemblage occurs at the uppermost section of the Lower Ordovician (Time Slice 2c). Acritarchs from the Middle Ordovician of Famatina are less diverse and the lack of biostratigraphic markers prevent the restriction of the age. Middle Ordovician acritarchs also occur in marginal marine facies, where their abundance and diversity only reflect local palaeoenvironmental conditions. Low-diversity acritarch assemblages may correspond to the Dapingian. Diversity and abundance of acritarchs increase in the Darriwilian. In the Precordillera Basin low-diversity acritarch assemblages have been found in levels independently dated as Darriwilian to Sandbian. Late Ordovician glacial-related strata from Cordillera Oriental, Sierras Subandinas and Precordillera yield poorly preserved and low diversified acritarch assemblages characterize by abundance of reworked taxa from Early to Middle Ordovician sediments.

MARINE CARBON CYCLE EVOLUTION DURING THE PALEOZOIC

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A high-resolution Paleozoic (Middle Cambrian-Early Permian) carbon isotope curve from the Great Basin region shows multiple transient $\delta^{13}C_{carb}$ excursions, which are all known outside the region and represent paleoceanographic events. These excursions fall into three separate time intervals characterized by $\delta^{13}C$ volatility in the Late Cambrian (Steptoean), Late Ordovician-Silurian, and Late Devonian-Early Mississippian, all of which are separated by relatively stable periods with values between —2 and +2‰.
Large positive excursions were apparently common during cool periods but rare during established greenhouse climates. Cool episodes may have ventilated the oceans and switched the ultimate limiting nutrient for marine productivity to phosphorus from nitrogen. This allowed for carbon isotope excursions during organic carbon burial events that were sustained by positive feedbacks between productivity and anoxia. In contrast, periods of stability that lasted for tens of millions of years (e.g., Late Cambrian-Early Ordovician) are interpreted to reflect negative feedbacks on productivity in a nitrogen limited (low oceanic N/P) ocean in which anoxia led to increased denitrification. Suppression of N fixation, likely due to low levels of essential trace elements, is a requirement of N limitation.
All of the major mass extinctions of the Paleozoic are associated with periods of volatility in the carbon isotope curve, and may potentially be explained in the context of the oceanographic changes that accompanied ventilation of the deep ocean. Additional work has focused on coupling the inorganic carbon isotope records from the Great Basin with trends in organic carbon, strontium and sulfur isotopes, which provide important constraints on carbon cycle models and atmospheric oxygen.

INTERPRETING THE EFFECTS OF GLACIOEUSTATIC AND LOCALLY INFLUENCED SEA-LEVEL CHANGES DURING THE EARLY PALAEOZOIC: AN EXAMPLE FROM THE EARLY SILURIAN OF WALES

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Decoupling the effects of local versus global sea level change on the sedimentary record of a marine basin is fundamental to any investigation of the influence of deep time climate change. During the Ordovician and Silurian, British Early Palaeozoic sedimentary marine basins evolved on the active peri-Gondwanan/Avalonian and Laurentian margins during contraction of the intervening Iapetus Ocean and, in contrast to more stable contemporary cratonic basins, were strongly influenced by tectonically-driven changes in basin geometry. These gave rise to unique high frequency changes in sea-level. Understanding the interplay between local versus global influences on these sea level changes is one of the key themes investigated during regional geological surveying carried out by the British Geological Survey.

The Lower Palaeozoic Welsh Basin was an ensialic marginal marine basin that formed during the contraction of the adjacent Iapetus and Rheic oceans during the Early Palaeozoic Caledonian orogenic cycle. It was characterised by high subsidence rates that accommodated a thick sequence of basinal sediments, and this contrasts markedly with the contemporaneous, relatively stable, Midland Platform and the Brabant Massif successions to the east. The Nant-Brianne and Caban-Ystrad Meurig systems of the Welsh Basin represent narrow corridors of laterally supplied, easterly sourced, coarse-grained deposits that punctuated a Late Ordovician – Early Silurian (late Hirnantian to early Telychian, ca. 445 and 430 Ma) mudstone-dominated slope apron developed along the SE margin of the basin. Detailed geological mapping combined with the application of high precision graptolite biostratigraphy has shown that slope apron evolution, and that of coeval coarse-grained systems, was influenced by a number of factors including sea floor topography and synsedimentary faulting. However, the interaction of low frequency eustatic events, related to fluctuation of contemporary Gondwanan ice sheets, with high frequency, lower magnitude sea level changes, appears to have been a critical influence on sedimentary architecture. Thus, when these different events are superimposed the most dramatic sedimentary responses are observed, and conversely when the low and high frequency events are out of phase, the preserved sedimentary record commonly fails to reflect the eustatic signal..

ANOMALOUS PALEOZOOGEOGRAPHIC PATTERNS OF HIRNANTIAN AND EARLY SILURIAN BRACHIOPODS IN WESTERN LAURENTIA.

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Recovery of the megafauna in western Laurentia following the first pulse of the end Ordovician was far slower than in other areas of the world. From Nevada to Idaho exposures of Hirnantian Age carbonates have few megafossils and elements of the *Hirnantia* and related faunas have not been found. During the first two stratigraphic sequences of the Silurian, spanning the Rhuddanian and part of the Aeronian, low diversity *Virgiana* communities dominated shallow platform environments. From shallow to deep water, brachiopods in the Virgiana communites were increasingly scarce down the western facing carbonate ramp, but they were the only brachiopods present. Absence of more diverse brachiopod communities that lived near or below storm wave base in the early Silurian is in marked contrast to similar environments elsewhere, e.g. Anticosti Island, Estonia, United Kingdom.

The cause of this long delay in recovery from the Ordovician extinction cannot be explained at the moment. Physical barriers to migration into the area are unlikely because more diverse Hirnantian and early Silurian faunas are common in marginal settings on opposite sides of this region in Arctic Canada and Greenland and in the present southeastern Laurentia (e.g. Oklahoma and Missouri). It is more likely that anomalous physical properties in the off-platform environment or unfavorable oceanic current patterns inhibited migration into this region.

PALEOGEOGRAPHY AND PALEOECOLOGY OF CAMBRIAN FAUNA, ZANSKAR BASIN, NORTHWEST HIMALAYA, INDIA

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In Zanskar Basin (Tethyan Himalaya) the Cambrian rocks are well preserved and contains fossiliferous horizons intermittently with barren zones. The little biostratigraphic investigations in the Cambrian successions of this remote area of the Tethyan Himalayan belt resulted in lack of significant analysis of factors involve in the diversification, radiation, extinctions of fauna and causes of intermittently occurrences of unfossiliferous horizons. Recent paleontological and sedimentological studies reveled that the area is affected by the flooding and marine transgression events. In the basal Cambrian succession the *Skolithos*-Planolite ichnofacies occur in well preserved thin wavy laminated shale and silty shale facies. Shallow burrowing activity occurs at the sediment-surface interaction boundary. Up in succession the rigorous bioturbation activity, well-sorted silt and sands to interbedded muddy layers and associated faunal elements of the *Cruziana*-*Skolithos* ichnofacies represents the shifting to stable substrate condition of the depositional environment. Increase in ichnofaunal diversity in pre-trilobite strata reveals abundance of oxygen and organic matter, infrequent mixing of waves and progressively deepening of the basin. The trilobite fauna indicate the shelf-slope environment under the fluctuating conditions of sea-level. The identification of faunal elements of the *Lejopyge laevigata* biozone (in Teta Member, Karsha Formation) indicate that the sea inundated the northern margin or smaller fluctuations of relative sea level of Zanskar region occur during the latest Middle Cambrian time (Teta transgression) which is synchronous with globally recognized eustatic events during *Lejopyge laevigata* time. The identification of *Neoanomocarella asiatica*, *Parablackwelderia* sp. *Fuchiou* sp. *Fuchiouia bulba*, *Fuchouia* cf. *oratolimba*, *Damesella*, *Dorypyge* which also recorded from other perigondwanan regions is significant and constitutes the base for assessing the paleobiogeographic affinities of the northern region of Indian plate. In Zanskar Basin till so far no body fossils of Early Cambrian has been recorded. The recovery of late Middle Cambrian species i.e., *Fuchouia*, *Dorypyge* and early Late Cambrian species of *Eoshengia*, *Damesop*, *Parabalckwelderia*, *Damesella* from the Zanskar region and their correlation with that of Australia and south China suggest a contiguous margin in the Middle-early Late Cambrian. The Cambrian trilobite faunas also occur in western Yunnan, structurally part of the Kunlun-Tibet-western Yunnan geosyncline (Zhang 1988), and forms an extension of the Qiangtang terrane and possibly part of the continuous "Cimmerian" continent of Metcalfe (1996). The report of *Kunmingaspis* sp., and *Douposiella* sp., from the western Yunnan, probably conspecific with Tethyan forms also indicate a close relation during the Middle Cambrian. The *Laejopyge laeivigata* Zone-III and *Proagnostus bulbus* Zone (Zanskar region, Singh, 2008) shows close affinity with the Hunan province (South China) during the latest Middle Cambrian to early Late Cambrian and also with the Australia. Thus, new paleontological data of Cambrian age from the Tethyan Himalayan regions show close relation of Indian margin with the south China (outboard microcontinent), Antarctica and Australia during the Middle-Late Cambrian period, and hence supports the view of close proximity of Australia and China during the Cambrian period (Meert and Van der Voo, 1997).

GRAPTOLITES IN 4-DIMENSIONS

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Graptolites were a major macroplanktonic element of the Early Palaeozoic seas. Understanding the way in which they are preserved as fossils can provide a key to their mode of existence and permit the reconstruction of ancient water masses. This is a pre-requisite to modelling the ancient ocean systems, and therefore ancient climate.

Early Palaeozoic planktic environments are represented in the rock record by death assemblages preserved in laminated shales laid down on anoxic sea floors. The macrobiota, dominated by graptolites, has a long history of taxonomic and biostratigraphic study, which has been key to the geological mapping of regions such as Wales, the Lake District and southern Scotland (e.g. Zalasiewicz 2001).

However, analysis and reconstruction of the oceanic palaeoenvironments themselves have not advanced at anything like the same rate, and basic scientific questions remain unanswered. Thus, it is uncertain whether graptolites were the major or dominant element within the macrozooplankton, or simply a constituent that is widely recognised in the rock record because of the resistant nature of the graptolite skeleton. In the absence of such basic information, the use of the abundant stratigraphic data as, say, proxies in the reconstruction of early Palaeozoic climate is significantly hindered.

A major problem is that planktic fossils such as graptolites are typically only observed on two-dimensional surfaces of rock slabs, the bulk of the information lying within the slab itself and hence inaccessible to scientific study. This taphonomic blindness means that flux rates of graptolites to the seafloor have been virtually impossible to assess, the effects of small-scale temporal changes in ocean currents cannot be effectively analyzed, recognition of predation-induced distortion of graptolite skeletons is difficult, and taphonomic pathways in these non-uniformitarian deposits (cf. Jones *et al*. 2002) remain enigmatic.

In the Welsh Basin, there are frequent mudrock intervals in which many of the graptolites are wholly or partly pyritized. X-ray analysis of slabs bearing such pyritized graptolites has been used to create 3D stereo images to extract this hidden information. Attainable resolution allows good taxonomic discrimination, and makes possible estimates of the rate of flux of graptolites to the sea floor and of the degree of alignment of the fossils caused by ocean currents. It also allows recognition of predation-induced or tectonic distortion of graptolite skeletons and elucidation of taphonomic pathways in these non-uniformitarian deposits.

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CRINOIDS-LIKE PELMATOZOANS HOLDFAST-HOLDING HARDGROUND IN THE ORDOVICIAN BAOTA (PAGODA) FORMATION OF YANGTZE PLATFORM, SOUTH CHINA: CONSTRAINTS ON ITS DEPOSITIONAL ENVIRONMENT RECONSTRUCTION AND SEA-LEVEL CHANGE

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Recently, a new kind of hardground has been recognized for the first time from the Ordovician Baota (Pagoda) Formation (c.f., late Sandbian-early Katian, or the former middle Caradoc) in the Three Gorges area of the Yangtze Platform, South China. It shows a thin lithified relief, which has been cemented together with marl and packed-shelly fossil relics including that of cephalopods, trilobites, as well as gastropods, on the topmost of certain beds in the lower part of this formation. Most particularly, some in-situ stem- and root-system relics of some undetermined crinoids-like pelmatozoans have also been recognized on this lithified shelly relief. The well-preserved holdfasts strike their downward-thinning roots from the small upright centers on the relief into the surrounding rocks. This represents their typical original tree-like living style. Based mainly on the in-situ shallow water pelmatozoan-represented benthic fauna on the hardgrounds and the related sequence stratigraphic analyses in the Yangtze Platform of South China, it is suggested that the depositional environment of the Baota Formation should be probably within the upper part of the euphotic zone, which is located in the inner shelf near the slightly disturbed foreshore with the depth from 20 to 50m, less than 80m in the maximum. This differs from suggestions by many previous researchers, who held that it was deposited at a depth of 200-500 or more in outer shelf or even deeper with evidences including the SSI (Septal Strength Index) of the cephalopods and the general facies analyses. Consequently, it indicates that the maximum of the sea-level oscillation in the Yangtze Platform during the middle Caradoc was no more than 80m.

GEOCHEMICAL DATA AND FAUNAL DYNAMICS: ON THE EVIDENCE OF THE MID DEVONIAN CHOTEČ EVENT WITHIN THE NERITIC SEQUENCE OF THE GRAZ PALAEOZOIC (EASTERN ALPS, AUSTRIA)

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The sequence of the Graz Palaeozoic represents an Upper Silurian to Upper Carboniferous thrust complex which is isolated from other low metamorphic Alpine Palaeozoic occurrences. Especially the neritic Mid Devonian deposits are well-known for its abundant and well preserved flora and fauna. Therefore some representative sections across the Emsian/Eifelian interval were chosen to document the impact of the Choteč Event on the ecosystem.

The Choteč Event, first recognized in the Barrandian Area, is one of 3 globally documented Mid Devonian events (Choteč, Kačák and *pumilio* Event). Further, traced near the boundary of the *partitus*- to *costatus* conodont biozones, it is represented by a lithological change in the pelagic as well as in the neritic succession. The Choteč Event is indicated by a dramatic decline among the invertebrate and micro-vertebrate fauna, which is induced by changing sea-level. The Emsian to Eifelian sequence of the Graz Palaeozoic is represented by the Flösserkogel and Plabutsch formations.

The Flösserkogel Formation is characterized by grey dolostones and brownish sandstones. They pass into rocks of the Plabutsch Formation which at the base consist of yellow to brown argillaceous shales with orange to reddish marly limestone intercalation (approx. 3 m in thickness). The major portion of the Plabutsch Formation is built of coral-stromatoporoid bearing limestones with some few red marly layers in its upper part. The lithological change from dolostones to limestones (i.e. the lithostratigraphic boundary between Flösserkogel and Plabutsch fms.) roughly highlights the Emsian-Eifelian boundary. A small conodont fauna supports the assumption that the boundary of the Flösserkogel Formation to the Plabutsch Formation is allocated within the lower Eifelian. The fossil record within the shallow marine, subtidal settings of the primarily mentioned formation is dominated by *Amphipora* mounds (mainly *A. ramosa desquamata*) in some areas. Bedding planes of the shales of the basal part of the Plabutsch Formation sometimes expose area-wide covers of chonetid valves with subordinate trilobites (*Maladaia* sp.). Intercalated are thin limestone beds, which may be characterized as brachiopod/ostracod shell beds. Ostracods, mainly eridostracs (*Eridoconcha* sp.), are partly silicified. The Emsian pioneer fauna is replaced by diverse coelenterate carpets (biostromes) appearing in the well-bedded, dark blue limestones of the Plabutsch Formation. Coral-stromatoporoid biostromes with its characteristic *Thamnophyllum* fauna are overlain by well-bedded float- to rudstones which are dominated by thamnoporid corals and thick-valved brachiopods (*Zdimir* sp.).

Additionally to the palaeontological record and lithological observations, geochemical analyses were carried out. RFA- and stable isotope datasets were compiled intending to document whether the change in the marine community was triggered by factors related to sudden changes or trends within the geochemical record across the sampled interval.

THE UPPER DEVONIAN HANGENBERG EVENT IN CARBON ISOTOPE RECORD OF THE SOUTHERN HOLY CROSS MOUNTAINS (CENTRAL POLAND)

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Sedimentary succession across the Devonian-Carboniferous boundary in the southern Holy Cross Mountains (central Poland) was exposed in the trench dug nearby the northern margin of the Kowala quarry. The outcropped section, up to 42 m thick, includes: 1) nodular limestones (wackestones/mudstones) interbedded with marly shales that are within the expansa and lower *preasulcata* conodont zones, 2) grey shales with tephra layers and *Acutimitoceras* fauna, and 3) lime wackestones to mudstones spanning the middle to upper *preasulcata* conodont zone (Malec, 1995; Dzik, 1997). The overlying sedimentary record is represented by nodular limestones with shale interbeds, which are within the uppermost *preasulcata* to lower *sandbergi* conodont zones, thus, the Devonian-Carboniferous boundary lies in the lowermost part of this interval (Malec, 1995; Dzik, 1997). A prominent positive excursion in $\delta^{13}C$ with values ranging between 2.15 to 2.7‰ is observed in limestones of the middle to upper praesulcata zone. The $\delta^{13}C$ values below this excursion change from –0.96 to 1.77‰, whereas above the upper *preasulcata* they fluctuate between –1.15 and 1.54‰. It is noteworthy that the excursion was preceded by a mass extinction of the ostracode, conodont and ammonite fauna (disappearance of *Woclumeria* fauna) recorded in the topmost part of the *expansa*/ *paesulcata* nodular limestones and the overlying grey shales (Malec, 1995; Dzik, 1997; Olempska, 1997). This faunal turnover seems to be coeval with deposition of dark carbonaceous shales (equivalent of the Hangenberg Black Shale) in the nearby Kowala quarry, documenting water column euxinia and wildfires on land (Marynowski and Filipiak, 2007). The considered herein $\delta^{13}C$ excursion correlates with the sea-level fall spanning the middle to upper *praesulcata* zone – Hangenberg Event (Buggish and Joachimski, 2006).

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ORDOVICIAN/SILURIAN BOUNDARY IN THE NORTHERN HOLY CROSS MOUNTAINS (CENTRAL POLAND)

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The Ordovician/Silurian boundary in the northern Holy Cross Mountains (Łysogóry Unit in central Poland) is marked by a significant and conspicuous lithologic change. The uppermost Ordovician (Hirnantian) is represented by sandy mudstones and sandstones of the Zalesie Formation, up to 6 m thick. They are interpreted as lowstand deposits accumulated during regression initiated in the middle/late Katian (Trela, 2007). The overlying Rhuddanian succession consists of finely laminated and organic-rich black shales that form the Bardo Formation occurring in the Dębniak-1 well. They span the *acuminatus* to *cyphus* graptolite zones and are associated with the onset of transgression at the end of Hirnantian (*persculptus* graptolite zone), but most of them seem to correspond to the highstand interval. The Aeronian and Telychian sedimentary record consists of grey/ green carbonaceous claystones/mudstones with thin interbeds of black shales, reported from the Dębniak-1 and Wilków IG-1 wells. This mudstone succession is within the *triangulatus* to *crispus* graptolite zones and can be interpreted as deposits documenting sea-level fall. However, the occurrence of *Retiolites geinitzianus* (Barrande) indicates that this succession spans up to the upper Telychian. The grey/green claystones/mudstones are largely massive, however, in some cases, discrete biodeformational structures are emplaced upon the muddy background. The considered herein Lower Silurian mudstone facies appear to be closely linked with the fluctuation of chemocline, controlled by a sea-level state and primary productivity. The Rhuddanian black shales reflect increased organic carbon burial and anoxic bottom water due to high primary productivity in the upper water column. Their accumulation coincides with intense deep ocean upwelling in the southern Holy Cross Mountains supported by the occurrence of black radiolarian cherts and siliceous shales (Podhalańska and Trela, 2006). In turn, the overlying Aeronian and Telychian claystones/mudstones developed during period of decreasing primary productivity. However, the driving mechanism for deposition of this facies might have been a significant change of the paleoceanographic circulation in comparison to that one functioning during the deposition of black shales. The oxygenation level varied in intensity during deposition of the Aeronian/Telychian mudstone facies as evidenced by the occurrence of black shale interbeds.

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GROUND TRUTHING ORDOVICIAN CLIMATE MODELS USING SPATIAL ANALYSES OF CHITINOZOANS AND GRAPTOLITES

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Global cooling during the Late Ordovician culminated in one of the major icehouse intervals of the Phanerozoic. The causal mechanisms and duration of the latter remain contentious and to date workers have largely relied on region-specific studies. Few climate simulation models for this time interval have been produced and General Circulation Models (GCMs) have yet to be ground truthed with geological data. Here we examine the potential for using planktonic chitinozoans and graptolites as water mass indicators to ground truth Ordovician climate model predictions of ocean and climate state. We are following the techniques applied to Cenozoic and Mesozoic planktonic foraminifer and calcareous nannoplankton distributions, which are used to track ocean surface and deep watermasses in deep time. At the core of our research strategy is the compilation of a high stratigraphical resolution, biogeographical database of species occurrences, palaeoenvironmental and ocean-climate proxy data. This is used to compile surface water (and where possible depth assemblage) palaeobiogeographic maps of chitinozoan and graptolite distributions. Species assemblages are produced using multivariate analytical techniques such as correspondence analysis, R-mode, Q-mode and TWINSPAN clustering, allowing discrimination of the main factors controlling the plankton distribution. The maps produced can be retro-tested against GCM maps of surface currents and used to identify latitudinal temperature/climate belts and gradients. Preliminary results are presented for the key time slices that characterise the critical climate transitions namely the *N. gracilis* graptolite Biozone (greenhouse climate mode), and the Hirnantian (glacial maximum - icehouse climate).

DOCUMENTING CARBON ISOTOPE EXCURSIONS AND ASSOCIATED PALAEOENVIRONMENTAL CHANGES IN THE SILURIAN OF NORTH AFRICA (PERI-GONDWANA): A COUPLED GEOCHEMICAL-PALYNOLOGICAL APPROACH

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Records of Silurian isotopic excursions and associated faunal/palynological turnovers are so far mainly known from low to middle palaeolatitudinal settings (e.g., Laurentia, Baltica, Australia). Therefore, the oceanographic models that have been developed in order to explain the possible causes of these events are necessarily based on incomplete datasets. Observed similarities in facies changes, faunal extinctions and geochemical developments for different events in different palaeogeographical settings have been taken as evidence for underlying analogous controlling mechanisms throughout Proterozoic and Palaeozoic events.

We present herein a first carbon isotopic curve ($\delta^{13}C_{org}$) for the Silurian of high-palaeolatitude Gondwana (North Africa), coupled to detailed palynological analyses (acritarchs, chitinozoans, miospores, palynofacies) and organic geochemistry data. Some interesting correlations with existing isotope curves from other areas are evidenced, showing for the first time that the major early Sheinwoodian (earliest Wenlock) and Ludfordian (late Ludlow) carbon isotopic excursions are well detected also in high-latitude Gondwana. These excursions are associated, and probably causally linked to, changes in lithology, palynofacies, organic geochemistry parameters, as well as in changes in palynological composition, confirming that they reflect global changes occurring in the oceanic system. We show that the earliest Wenlock strong positive isotopic shift is associated to a protracted period (Rhuddanian to early Wenlock) of massive black shale deposition ("hot shales"), and thus of organic carbon burial, on continental platforms located in high-latitude settings. Unfortunately, acritarch assemblages are poorly diversified and badly preserved throughout the excursion interval. Significant black shale deposition does not occur in association with the Ludfordian excursion, and levels of primary productivity seem to have remained essentially unchanged before and during the event (oligotrophic conditions as suggested by palynofacies evidence). The present results show an evident similarity with the observations made by Stricanne et al. (2006) on compositional changes of acritarch assemblages across the Lau (Ludfordian) event at Gotland, Sweden in that a major acritarch turnover occur during the increase in isotopic values. However, the dominance of acritarchs with short, non–ramified processes in correspondence of the Ludfordian excursion which characterizes the Swedish acritarch assemblages at Gotland (Stricanne et al., 2006) was not observed in the present study. This might reflect different palaeobiogeographic settings (low versus high palaeolatitudes) of the two areas. Additionally, an input of organic matter of terrestrial derivation into the marine sedimentary record (miospores of early land plants) correlate exactly with the maximum values of organic carbon isotopic fractionation, similarly to what has been observed in the Baltic region.

Our study demonstrate that previous models developed in the low to intermediate palaeolatitude settings to explain the observed association among isotopic development, facies changes, and fluctuation in biodiversity, cannot be readily applied in the more general case, and particularly in the case of high-palaeolatitude localities. More detailed investigation from different Gondwanan localities are in progress to enlarge the dataset and improve knowledge of the Silurian global palaeoceanographic events.

SILURIAN-DEVONIAN PALYNOLOGY OF MG-1 BOREHOLE SECTION IN THE GHADAMIS BASIN, NORTH AFRICA: IMPLICATIONS FOR THE EARLY EVOLUTION OF VEGETATION COVER IN GONDWANA

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A study on well preserved and diversified miospore-cryptospore assemblages from the Silurian-Lower Devonian succession of borehole MG1 (Ghadamis Basin, Southern Tunisia) has been conducted with the aim of improving our knowledge on early phases of the terrestrialization process. The palynological analysis concerned, in ascending stratigraphic order, the Tanezzuft, Akakus, Tadrart and Ouan Kasa formations.

Four cryptospore-miospores Assemblage Zones have been established, respectively attributed to Gorstian, Gorstian-Ludfordian, Pridoli and Lockovian. Marine elements such as acritarchs and chitinozoans occur throughout the succession and are more abundantly from Gorstian to Pridoli. The lithostratigraphical boundary between the Acacus and the Tradart fms corresponds to the Silurian-Devonian boundary. In this time span, the Ghadamis Basin was the site of an extensive regression.

Changes in miospore specific diversity have been analysed by grouping the trilete spores and cryptospores on the basis of their morphological features: cryptospores respectively as monads, dyads and tetrads; and trilete spores respectively as sculptured and unsculptured. During the Gorstian to Pridoli stratigraphic interval, two main trends of miospore diversification are recorded:

- a gradual but steady increase of the miospores/cryptospores abundance ratio
- a rapid increase in the diversiy of sculptured trilete spores as opposed to slower diversification rates in the unsculptured trilete spores.

At the Silurian-Devonian boundary cryptospore abundance and diversity exhibits a drastic decline. Although the Acacus Formation was deposited during a regressive trend culminating with fully terrestrial conditions at the formation's top, the presence of abundant and well diversified marine palynomorphs indicate constant marine conditions from Gorstian times up to the Silurian/Devonian boundary.

The large dominance of trilete spores over cryptospores might be related to the so-called “Wellman Effect”, according to which the plants producing trilete spores and those producing cryptospores did not inhabit the same biotopes. Because cryptospores are generally uncommon in marine sediments, the “Wellman Effect” confines the habitat of cryptospores to swamps and/or lake margins. The present results appear to confirm this hypothesis, also supporting the recently postulated much closer palaeogeographical position of Gondwana and the Old Red Sandstone continent (Steemans et al., 2007). The increasing diversification of sculpture trilete spores from Gorstian to Lockovian strongly supports the hypothesis that the corresponding spore-producing land plants became much more diverse during these periods and were undergoing rapid evolution. Unfortunately, this is not so clearly reflected by the fossil megaplants recorded in continental successions from this time span. The sporomorph trends track evolutionary events in plants, but with a much higher (3 to 5 times) quantitative signal than that indicated by the megafossil record. This discrepancy has been interpreted in literature as the possibility that the sporomorphs were produced by a smaller number of morphological types of land plants as well as low preservation potential of the parent plants.

Steemans, P., Wellman, C.H., Filatoff, J., 2007. Palaeophytogeographical and palaeoecological implications of a miospore assemblage of earliest Devonian (Lochkovian) age from Saudi Arabia. Palaeogeography, Palaeoclimatology, Palaeoecology 250, 237-254.

SILURIAN SEA LEVEL FLUCTUATIONS ON NORTHERN GONDWANA

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Eustatic chart used for Silurian period are mainly constructed using Laurussia or Baltica data. The aim of the present work is 1) to document the sea level changes through the Silurian sequences of northern Gondwana regions, and 2) to collate the recorded regional signal with previous eustatic charts such as those of Johnson (1996) or Ross &. Ross (1996).

Two test areas are selected for the present study. The first one is located on the cratonic part the Saharan platform in Algeria. Extensive sedimentological and biostratigraphical data are available on this Silurian shelf succession. These data concern the proximal deposits of the Tassili outcrops (south-eastern Sahara), as well as the more distal sequences of the Illizi basins (eastern Sahara), and the deeper shelf sediments of the Oued Mya basin and of the Ougarta outcrops (respectively central and north-western Sahara). The second test area is located on the northernmost margin of Gondwana, in western France, where high resolution sedimentological and biostratigraphical studies have been carried out for years, through the whole Silurian succession.

In both regions, in addition to the sequence analyses, a special attention is paid to the biostratigraphic control. Because the Silurian sequences of northern Gondwana are mainly terrigenous, the main fossils used for biostratigraphic control are the chitinozoans which are usually abundant and well distributed, even in the core samples. Moreover, the Silurian chitinozoan biozones proposed by Verniers et al. (1995) correspond to time intervals of roughly 1 to 3 My, which are in the range of the third order bathymetric sequences (1-5 My).

The different bathymetric curves obtained respectively on the proximal sequences of south-eastern Algerian Sahara and on more distal deposits of north-western Algeria and of the Armorican Massif (western France), are compared in order to distinguish the global pattern from more local signals not exclusively driven by the eustatism. Amplitudes of these eustatic variations are quantified by measurement of the accommodation.

Johnson ME. (1996) Stable cratonic sequences and a standard for Silurian eustasy. BJ, Ludvigson GA, Day JE (eds), Geological Society of America Special Paper 306, 203-211.

Ross CA, Ross RP. (1996) Silurian sea-level fluctuations. In Paleozoic Sequence Stratigraphy: Views from the North American Craton, Witzke. BJ, Ludvigson GA, Day JE (eds). Geological Society of America Special Paper 306, 187–192.

Verniers, J., V. Nestor, F. Paris, P. Dufka, S. Sutherland, and G. Van Grootel (1995) A global Chitinozoa biozonation for the Silurian: Geolgical Magazine, v. 132, p. 651-666.

A REEVALUATION OF FAMENNIAN ECHINODERM DIVERSITY: IMPLICATIONS FOR PATTERNS OF EXTINCTION AND REBOUND IN THE LATE DEVONIAN

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Critical to understanding long term trends in diversity is a dataset that is both world-wide in scope and based on a sound taxonomic foundation. In this paper we re-evaluate the Famennian (Late Devonian) echinoderm dataset, which has changed radically in the past decade and reinterpret patterns of Late Devonian echinoderm extinction and rebound based on this new data. Historically Famennian (Late Devonian) and earliest Carboniferous echinoderms have been poorly known on a global basis leading to interpretations of prolonged rebound from the Devonian extinction events. Recent discoveries of abundant and diverse Famennian echinoderm faunas from northwestern China, Colorado, Australia, and Iran, together with re-examination of previously known echinoderm faunas from Germany and England, have altered drastically our understanding of the patterns of extinction and rebound of Famennian and earliest Carboniferous echinoderm communities. Overall, Famennian echinoderm diversity at the generic level is nearly five times greater than reported in the Sepkowski compilation, and familial level diversity is more than seven times greater than previously thought. Despite the increases in diversity, Famennian echinoderm faunas show a dearth of camerate crinoids that typify both older and younger faunas and portend the rise of cladid crinoid diversity later in the Carboniferous. Individual Famennian faunas are numerically dominated by blastoids, which also portends trends seen at various times later in the Paleozoic. In general, we are able to recognize the following trends. Rebound from the Late Devonian extinction events in echinoderms was more rapid than previously thought, but seems to be concentrated in Asia. Paleogeographically Famennian echinoderms can be grouped into two broad regions. One includes China, Australia, and Iran, all of which bordered the Paleotethys. The other includes regions from Laurussia (Europe and North America) and northern Africa (Morocco).

ORIGIN AND EARLY DIVERSIFICATION OF LAND PLANTS: EFFECTS ON THE ENVIRONMENT AND CLIMATE OF PLANET EARTH

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The current terrestrial vegetation constitutes some 90% of the living biomass of planet Earth and has a major impact on the environment (affecting climate, atmospheric composition and pattern of sedimentation through carbon sequestration, soil formation, weathering, soil/sediment binding and so on). Clearly the origin and adaptive radiation of terrestrial vegetation had a major influence changing and shaping the environment of planet Earth through its geological history. This talk will concentrate on the period Mid Ordovician-Early Devonian that witnessed the invasion of the land by plants. This invasion was a step-wise process. Prior to the origin of land plants the land surface is usually considered to have been barren. In reality it probably harbored a low biomass biota dominated by algae and ?fungi (referred to as an 'algal scum') that had little influence on the environment. The land plants (embryophytes) are believed to have originated in the Mid Ordovician (475 Ma). The earliest plants consisted of stem group embryophytes that dominated the planet for some 40 million years. The plants are considered to have been diminutive and possessed bryophyte-like anatomy and physiology. They were probably confined to permanently damp environments, although fossil evidence (chiefly dispersed spores) suggests that they were palaeogeographically widespread and tolerated a wide variation in climatic conditions. Vascular plants appeared sometime in the Late Ordovician and underwent a dramatic adaptive radiation from the Early Silurian and outcompeted the stem group embryophytes. They rapidly increased in abundance, diversity and disparity (including maximum size) in addition to expanding aerial coverage as they colonized new habitats (particularly as they evolved progressively sophisticated reproductive strategies). The different stages in the invasion of the land by plants witnessed increases in the stature and aerial coverage of vegetation leading to escalating terrestrial biomass (and carbon burial) and an intensification in soil development. This would have produced dramatic effects on the environment of plant Earth. In this talk these effects will be discussed and attempts made to quantify them.

REVISITING "THE ORDOVICIAN CLIMATE BASED ON THE STUDY OF CARBONATE ROCKS"

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Since Lindström's 1984 paper on this topic we have come a long way in our understanding of the controls on deposition of both warm- and cool-water carbonates, and in interpretation of palaeoceanographic and palaeoclimatic signals from limestones. Despite this, the abrupt appearance of limestones at high latitudes in the Ordovician Boda interval (late Katian) has mostly been taken at face value as indicative of "warmer-water sediments" and representative of global warming. However, evidence for the depositional conditions suggests that they formed as part of a glacially influenced cool-water carbonate factory. This example illustrates that the 'climatic' significance of partitioned Ordovician carbonate production into warm-water (tropical), cool-water and mud mound factories has, to date, not been fully appreciated. Throughout the Ordovician these three factories co-produced carbonate in juxtaposed depositional settings during warmer and cooler intervals, and switched type as 'climate' changed. Glacio-eustatic shallowing in the Late Ordovician had a profound effect on global sea-level, with estimates of sea-level fall ranging from 10s–100s of metres for the Hirnantian maximum. Shallowed shelf waters probably warmed more quickly and efficiently through the effects of solar insolation than those below the thermocline. The relative increase in shallow shelf seas was conducive to the local formation of warm-water carbonates in mid-high latitudes even though the oceans were cooling. A temperature stratified shelf model illustrates the scenario where the hydrodynamic regime is also a significant control on partitioning of carbonate production. Photozoan carbonates were deposited above the thermocline in sheltered warm-water enclaves, whilst contemporaneous cool-water carbonates and mud mounds accumulated below the thermocline under the influence of upwelling. It is important to disentangle such local effects from the global 'climatic' significance of limestones.

A review of available data from various palaeocontinents and terranes supports the model. In low-mid latitude Baltoscandia during the Sandbian/Katian (Kullsberg/GICE) cooling interval, stromatactis mud mounds (Sweden) were formed whose oxygen palaeothermometry suggests a seawater temperature decrease of up to 15°C, yet the nearby 'tropical' Steinvika and Mjøsa Limestone reefs (Norway) were forming in glacio-eustatically shallowed shelf settings. In the Upper Ordovician record of low latitude Laurentia, ocean cooling is recorded in warm-water limestones passing up into deposits of a mixed warm-cool water factory and then into cool-water limestones. From late Katian Avalonia at mid-high latitudes, the Robeston Wathen Limestone with corals and dasycladaleans represents a shallow warm-water carbonate factory upslope of cool-water phosphatic carbonates. Above the Boda Limestone mud mounds in the Hirnantian of Baltoscandia, which inter-finger laterally with cool-water limestones, the partly oolitic, cross bedded, coral-bearing calcarenites of the "bahaman" Limestone Member of the Loka Formation, in Västergötland, represents a local switch to warm-water carbonate production in shallow waters. This limestone contains Laurentian-type conodonts known from the tropical shallow-water carbonates of North America and not known elsewhere in the Ordovician of Baltoscandia. In low latitude South China, Hirnantian cool-water carbonate deposition (Kuanyinchiao Bed) passes up locally into very shallow warm-water facies (oolites and peloids) during maximum regression. Hirnantian cool-water carbonates at Meifod, Wales (Avalonia) accumulated in incised glacial channels, but limestones at Bala are partly ooidal.

$\delta^{18}O$ COMPOSITION FROM CONODONT APATITE INDICATES CLIMATIC COOLING DURING THE MIDDLE PRIDOLI SEA LEVEL FALL IN THE BALTIC BASIN

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Phosphatic microfossils, such as conodonts and early vertebrate microremains (fish teeth and scales), are studied for their oxygen isotope composition. Oxygen isotope ratios ($\delta^{18}O_{apatite}$) are used to calculate palaeotemperatures, if the phosphates are well-preserved and not altered by diagenetic processes. δ^{18}Oapatite analyses of early vertebrate microremains are performed for the first time, using the corresponding method for conodont elements (Joachimski et al., 2004).

The studied conodont and early vertebrate material originates from the Upper Silurian (Pridolian) sections in Lithuania. The conodont colour alteration index of 1 reflects very minor thermal alteration of the Upper Silurian strata in this part of the Baltic Basin. Conodont $\delta^{18}O_{apatite}$ values are used for palaeotemperature reconstructions with the values of the samples ranging from 17.5 to 19.5‰ V-SMOW. The analysis of early vertebrate remains from the same samples as the conodonts gave values lower by 2.5‰ in comparison to conodont apatite $\delta^{18}O$. These low values translate into about 10°C higher paleotemperatures in comparison to the estimates calculated from conodont apatite. Interestingly, the general trend of the early vertebrate $\delta^{18}O_{apatite}$ curve resembles that of conodont $\delta^{18}O_{apatite}$.

We present the first $\delta^{18}O_{apatite}$ curve from a Pridolian section in the eastern Baltic Basin (Geluva-99 borehole), which is located in the central facies belt of the Silurian of Lithuania. The position of a positive shift in the curve perfectly matches a facies change between the Lower Pridoli (Vievis Fm.), and the Upper Pridoli (Lapes Fm.). The positive excursion, indicating drop of palaeo-seawater temperature, also corresponds to an abrupt sea level drop in between Vievis and Lapes Formations in the middle Pridoli of the Baltic Basin (Lazauskiene et al., 2003). This formational boundary, biostratigraphically interpreted as a significant change in the faunal composition as well, is now supported by the $\delta^{18}O$ record indicating a cooling event in the middle Pridoli.

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