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MIDDLE DARRIWILIAN CARBON ISOTOPE EVENT IN BALTOSCANDIA

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At least five positive shifts in stable carbon isotope composition have been documented from the Upper Ordovician carbonate succession of Baltoscandian Paleobasin (Kaljo et al. 2004). Among them the glaciation-induced end-Ordovician isotope excursion is the most prominent. The reason for other second-order isotope changes (1-2‰) is not fully understood yet. In this presentation, a recently discovered distinct positive carbon isotope shift from the Middle Ordovician of the East Baltic and Sweden is described.

The Middle Darriwilian excursion is documented from the Segerstad Fm in southern Estonia and Latvia (Ruhnu and Jurmala core sections), in the outer ramp to basinal facies of the temperate-climate carbonate epeiric sea. The $\delta^{13}C$ values are 1.5‰ higher from the isotope curve plateau in the interval of about 10 m in both sections. Similar carbon isotope shift was found from upper part of the Holen Fm in Västergötland (Gullhögen quarry), central Sweden. The Segerstad Fm is traditionally correlated with the Aseri Stage, while the Holen Fm is attributed to the Kunda Stage in Baltoscandia.

The Middle Darriwilian excursion has not been found in the Kunda-Aseri stratigraphic interval in northern Estonia, in the sections representing the inner-middle ramp facies (Männamaa, Kadriorg). This may be explained by sedimentary gaps in the onshore succession. The beds with isotope excursion may be correlated with gap between the Kunda and Aseri stages in northern Estonia, the type area of these stratigraphic units. The above data suggest that the Middle Ordovician correlations in the Baltoscandia area may need to be reconsidered.

The Middle Darriwilian carbon isotope excursion is the oldest documented variation of its kind in the Ordovician of Baltoscandia. This excursion is similar to the Middle Caradoc and end-Ordovician excursions, as it can be correlated with sedimentary gap (and sequence boundary) in the upper shelf/ramp. The latter two are considered to be related to sea level falls, while some other Upper Ordovician excursions seem to be related with sea level highstands or transgressions and need different environmental interpretations.

Comparison with isotope data from Argentina Precordillera (Buggisch et al. 2003) demonstrates very similar carbon isotope shift in the Darriwilian Stage. This allows suggesting a global nature of the Middle Darriwilian excursion. If the second-order global carbon isotope fluctuations will be interpreted as evidence for onset of glaciation in high latitudes, we have to consider the cooling to start already in early Middle Ordovician. However, there is no geological data supporting this hypothesis.

REFERENCES

Buggisch, W., Keller, M. and Lehnert, O. (2003). Carbon isotope record of Late Cambrian to Early Ordovician carbonates of the Argentine Precordillera. Palaeogeogr. Palaeoclimatol. Palaeoecol. 195, 357-373.

Kaljo, D., Hints, L, Martma, T., Nõlvak, J. and Oraspõld, A. (2004). Late Ordovician carbon isotope trend in Estonia, its significance in stratigraphy and environmental analysis. Palaeogeog. Palaeoclimatol. Palaeoecol. 210, 165-185.

The Early Palaeozoic Strata Of Novaya Zemlya: Report From The SWEDARCTIC Expedition 2004

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Novaya Zemlya is a narrow, sinuous archipelago, that reaches from Pai-Khoi of northern Russia northeastwards to a c 77°N on the continental shelf. It is surrounded by the most important proven and potential hydrocarbon provinces in the Arctic (Barents Sea, Pechora Basin, West Siberian Basin and Kara Sea) thus being a unique area to study the deep subsurface geology of the nearby off-shore.

The Novaya Zemlya fold-and-thrust belt is regarded as the youngest (Cimmerian) segment of the Uralides (Korago et al. 2004). However, Palaeozoic ophiolite and associated island-arc rocks of the Polar Urals of the Uralide Orogen are not found in this domain.

The Early Palaeozoic strata of Novaya Zemlya were deposited along the northeastern (present coordinates) margin of Baltica. This area provides complete Vendian-Devonian sedimentary successions and palaeontology of the southernmost and northernmost Novaya Zemlya, that have both been correlated southwards into Pai-Khoi and the Polar Urals, and eastwards across the Kara Sea to northern Taimyr and Severnaya Zemlya. Cambro-Ordovician faunal affinities with Baltica and Laurentia have been claimed (Walcott 1924, Bursky 1970) and need further investigations. Interestingly, that Novaya Zemlya with its trend back northwards and eastwards is apparently connected with the Taimyr fold-and-thrust belt of northern Siberia. Stratigraphic and palaeontological evidence (Abushik et al. 1997, Korago et al. 2004) have been presented for the close affinity of the northern part of Novaya Zemlya's North Island succession with Severnaya Zemlya.

In 2004, the SWEDARCTIC international expedition visited Novaya Zemlya. It was the first western scientific expedition since the 1930s. The bedrock group had a wide range of expertise including structural geology and stratigraphy, sedimentology, palaeontology, igneous petrology and isotope geochronology, with interests ranging from the Neoproterozoic to the late Palaeozoic.

The lecture will concentrate on the first results of the expedition with more details on the Ordovician-Silurian stratigraphy, facies distribution, palaeontology and palaeogeography of this area.

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REFERENCES

Abushik A.F., Evdokimova, I.O. & Modzalevskaya, T.L. 1997. Severnaya Zemlya in the Silurian and the Early Devonian: ostracod and brachiopod biotas, correlation, paleobiogeography. *In Key problems of the geology of the Barents-Kara Shelf and adjacent land. Proceedings of workshop, EUROPROBE,* St Petersburg, 9-10.

Bursky A.Z. 1970. Early Ordovician trilobites of central Pai-Khoi. *In*: Bondarev (ed.) *Reference papers on the Ordovician in Pai-Khoi, Vaigach Island and Novaya Zemlya*. Leningrad, 96-138 (in Russian)

Korago, E.A., Kovaleva, G.N., Lopation, B.G. & Orgo,V.V. 2004. The Precambrian rocks of Novaya Zemlya. *In* Gee, D,G, & Pease, V.L. (eds.) *The Neoproterozoic Timanide Orogen of Eastern Baltica*. *Geol. Soc. London Memoirs*, 30, 135-143.

Walcott, C.D. 1924. Ozarkian brachiopods from Novaya Zemlya. *In*: Report of the scientific results of the Norwegian expedition to Novaya Zemlya 1921, 25. *Kristiania. A.W. Brøggers Boktrykkeri*. 3-10.

DO PALEOZOIC POSITIVE CARBON ISOTOPE EXCURSIONS REPRESENT A RETURN TO NEO PROTEROZOIC OCEANIC CONDITIONS?

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Comparison of $\delta^{13}C$ stratigraphy from the Neoproterozoic and Paleozoic demonstrates several important similarities and differences in the global carbon cycle of the two Eras. Although the duration of Neoproterozoic positive $\delta^{13}C$ excursions are an order of magnitude longer than Paleozoic examples, the maximum amplitude of isotopic

excursions is similar in both Eras (up to +12‰). The similar amplitude indicates the possibility of similar driving mechanisms for major positive $\delta^{13}C$ excursions during the Neoproterozoic and Paleozoic.

Recent oceanographic modeling has suggested that the Neoproterozoic ocean was highly susceptible to positive $\delta^{13}C$ excursions as the spatial decoupling of C_{org} and C_{carb} production and burial allowed increases in f_{org} to be sustained over long intervals. This condition however should not have been limited to the Neoproterozoic, but applies equally well to much of the Paleozoic. An oceanographic model first developed for the Silurian suggests that just such a decoupling of C_{org} and C_{carb} production and burial was responsible for major Paleozoic positive carbon isotope excursions (>+4‰), and by comparison represents oceanographic conditions quite similar to those proposed for the Neoproterozoic.

The conclusion that Paleozoic oceans resembled Neoproterozoic conditions during positive carbon isotope excursions is further supported by the observation that carbonate deposition during major Paleozoic $\delta^{13}C$ excursions often reverts to "anachronistic" facies frequently containing characteristically Neoproterozoic carbonates (microbialites, ooids/oncolites, stromatolite reefs, etc.) indicative of stressed environments in epeiric seas. Our study indicates that insight into Paleozoic oceans during major positive carbon isotope excursions (such as the upper Ordovician) may assist our understanding of the evolving global ocean-atmosphere system of the Neoproterozoic.

CHANGES IN FACIES AND SEDIMENTARY CYCLICITY BEFORE, DURING AND AFTER THE GAMACHIAN STAGE ON ANTICOSTI ISLAND, GULF OF ST LAWRENCE: SIGNIFICANCE FOR EUSTATIC AND CLIMATIC FLUCTUATIONS DURING THE LATE ORDOVICIAN GLACIATION

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The excellent Anticosti succession in the Gulf of St Lawrence provides an unique opportunity to examine the stratigraphic architecture of mixed carbonate-siliciclastic facies accumulating on a storm-influenced, slowly subsiding equatorial carbonate ramp contemporaneously with Late Ordovician glaciation on other continents. We present here preliminary results on facies and sedimentary cyclicity of the Anticosti succession that are grouped in three distinct packages including: 1) the upper Vauréal Formation of pre-Gamachian or Richmondian age; 2) the uppermost Vauréal and Ellis Bay formations of Gamachian age; and 3) the Becscie Formation of post-Gamachian or Rhuddanian age. The depositional facies represent sediments accumulating along a transect ranging from an inner ramp area (above fair-weather wave base), a mid-ramp area (between fair-weather and storm wave bases) and an outer ramp area (below storm wave base).

High frequency stratigraphic cyclicity expressed as repetitive successions at the metre scale are prevalent in both pre- and post Gamachian packages. In addition, multiple-cycle trends in tempestite facies and/or thicknesses define low frequency at the decameter scale in these packages. Repetitive successions are also present in the Gamachian package but only at the decametre scale and with a larger depth range of tempestite facies. The Gamachian package consists of four decametre trangressive-regressive cycles with the uppermost cycle corresponding with the typical "Hirantian" isotopic excursion identified on several continents and confining apparently the major glacio-eustatic changes associated with the growth and decay of a short-lived Gondwana ice cap at the end of the Ordovician. Unlike the more time-restricted scenario based on chemostratigraphy, our results suggest that the increase in the magnitude and the decrease in the frequency in sea level fluctuations during the Gamachian interval on Anticosti Island were likely driven by an equally abrupt increase in ice volume marking the onset of geographically extensive Late Ordovician glaciation on Gondwana. This scenario is similar to the mid-Pleistocene climate transition that was marked by an increase in global ice volume and a shift in the dominant periodicity of glacial-interglacial oscillations from obliquity- (41 k.y.) to eccentricity-driven (100 k.y.) variations in Earth's orbits.

In parallel to the changes in sedimentary cyclicity, deposition progressed from a carbonate mud-dominated ramp in the pre-Gamachian interval to an argillaceous mud-dominated ramp in the Gamachian interval and finally back to a carbonate mud-dominated ramp in the post Gamachian interval. This facies shift suggests that cooler, more humid climatic conditions on adjacent lands were coupled with significant sea level changes resulting into an increased terrigenous input and a reduced deposition of carbonate rich-sediments during the Gamachian interval.

CINCINNATIAN RUGOSE CORALS OF CRATONIC LAURENTIA: BIOGEOGRAPHIC, ECOLOGIC, AND MORPHOLOGIC PATTERNS

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In the Late Ordovician (Cincinnatian), there were three biogeographic divisions of rugose corals on the craton of Laurentia (North America): the Red River-Stony Mountain, Richmond, and Edgewood provinces. These provinces differed in overall ecologic structure, and in the morphologic complexity and intraspecific variability of typical members.

The Cincinnatian Red River-Stony Mountain Province coincided with a vast region of mainly carbonate deposition in the epicontinental sea and on the stable continental shelf. This province originated during a major transgression accompanied by widespread, normal-marine conditions. The ecologic structure was complex. There were specialized species, distinct species-associations, and fluctuations in species dominance related to environmental factors such as water depth, energy level, degree of circulation, and substrate type. The solitary rugosans tended to be morphologically complex. Many species had an axial structure, which was large and complex in some, and most species had a cardinal fossula. Among the colonial rugosans, there were species with low levels of colony integration (fasciculate coralla) and those with comparatively high levels of integration (cerioid coralla).

The Richmond Province, of Richmondian age, occupied a mixed carbonate-siliciclastic platform along a margin of the epicontinental sea. Runoff from terrestrial areas probably lowered water salinity and raised nutrient content in overall comparison with the Red River-Stony Mountain Province. Rugosans in the Richmond Province were, to varying degrees, specialized for particular environments. There were distinct species-associations and differences in species dominance in various environmental settings. Unlike the Red River-Stony Mountain Province, however, two widespread solitary rugosan species with highly variable morphologies spanned the spectrum of environments inhabited by corals. In both of these species, coralla ranged from those with an axial structure to simpler forms with an open axial region. One of these species had a cardinal fossula, but the other did not. Colonial rugosans having low levels of integration were rare; comparatively high-level forms were dominant.

The Edgewood Province, of Gamachian to earliest Silurian age, occupied an area of mainly carbonate deposition in a small epicontinental sea during a time when global sea-level was relatively low. It is probable that fluctuating, elevated levels of nutrients and runoff from adjacent terrestrial areas contributed to overall environmental instability in this province. The ecologic structure was simple. Although rugose corals inhabited a broad spectrum of environments and some species were environmentally specialized, there was just a single species-association, strongly dominated by a solitary rugosan displaying extraordinary morphologic variability. In general, solitary rugosans tended to be morphologically simple. Coralla of the dominant species usually had an open axial region; species with an axial structure were rare. A cardinal fossula was absent in most species and uncommon in the others. Colonial rugosans were rare and their levels of integration were low.

On the Laurentian craton, provinciality of rugose corals developed in regions that differed environmentally, while overall global environments changed during Cincinnatian time. As provinces originated under increasingly stressful conditions, they were characterized by simpler ecologic structure, simpler morphology of common faunal members, and greater maximum range of intraspecific morphologic variability.

RESTUDY OF THE HIRNANTIAN (LATEST ORDOVICIAN) GRAPTOLITES FROM DOB'S LINN, SOUTHERN SCOTLAND

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The present study is based on graptolite specimens of from Dob's Linn, Scotland, the stratotype section for the base of Silurian. Material from the Anceps Band E and the Extraordinarius Band collected by Williams (1983) and specimens from the lower 1.6 m of the Birkhill Shale Formation more recently collected by S. H. Williams. Two graptolitic zones, the *N. extraordinarius* and *N. persculptus* zones are recognized.

Normalograptus extraordinarius (Sobolevskaya) and *N. ojsuensis* (Koren and Mikhailova) occur in the Anceps Band E together with 14 species that are otherwise characteristic of the DDO fauna (Dicranograptidae – Diplograptidae – Orthograptidae fauna, Melchin and Mitchell 1991), which dominates the rest of the underlying *D. anceps* Zone. The presence of *N. extraordinarius* (Sobolevskaya) in this layer, however, suggests that it should be assigned to the *N. extraordinarius* Zone, as defined by the first appearance of this species.

The next overlying graptolite-bearing unit, the Extraordinarius Band, yields *N. extraordinarius* (Sobolevskaya), *N. ojsuensis* (Koren and Mikhailova), *N. persculptus* (Elles and Wood), as well as two long-ranging normalograptids, *N. angustus* (Perner) and *N. normalis* (Lapworth). This indicates the base of the *N. persculptus* Zone should be moved downward at this section to include this band. The boundary between these two biozones is marked by 0.96 m unfossiliferous strata between the Anceps Band E and the Extraordinarius Band. The lower 1.6 m of the Birkhill Shale Formation also belongs to the *N. persculptus* Zone and yields an abundant normalograptid fauna. It includes 17 cosmopolitan species belong to *Normalograptus* Legrand, 1987 or *Neodiplograptus* Legrand, 1987, such as *N. angustus* (Perner), *N. avitus* (Davies), *N. laciniosus* (Churkin and Carter), *N. medius* (Törnquist), *N. minor* (Huang), *N. mirnyensis* (Obut and Sobolevskaya), *N. normalis* (Lapworth), *N. parvulus* (Lapworth), *N. praetamariscus* (Li), *N. pseudovenustus* (Legrand), *N. rhizinus* (Li), *N. skeliphrus* (Koren and Melchin), *N. tilokensis* (Legrand), *N. ugurensis* (Koren' and Melchin), *N.* sp. aff. *N. indivisus* (Davies), *Neodiplograptus shanchongensis* (Li) and a new normalograptid (=*G.*? *avitus* Davies in Williams, 1983). The DDO fauna was completely replaced by an abundant normalograptid fauna in the 0.96 m unfossiliferus strata between the *N. extraordinarius* and *N. persculptus* zones. Only four normlograptids, *N. angustus* (Perner), *N. extraordinarius* (Sobolevskaya), *N. normalis* (Lapworth) and *N. ojsuensis* (Koren and Mikhailova) are known to extend into the lower part of the *N. persculptus* Zone. The diverse graptolitic faunas of the *N. extraordinarius* and *N. persculptus* zones, and the turnover between the two graptolitic biozones can be compared with those from other parts of the world, particularly as the Yangtze region (Chen *et al*., 2005).

REFERENCES

Chen Xu, Fan Junxuan, Melchin, M. J. and Mitchell, C. E. 2005. Hirnantian (Latest Ordovician) graptolites from the upper Yangtze region, China. *Palaeontology*, **48**, 1-47.

Williams, S. H. 1983. The Ordovician-Silurian boundary graptolite fauna of Dob's Linn, southern Scotland. *Palaeontology*, **26**, 605-630.

AN ENERGETIC ANALYSIS OF ORDOVICIAN PALEOACOMMUNITY CHANGESIN LAURENTIA

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Over the last two decades a series of taxonomically-based studies has linked the Ordovician diversity trends manifest in early, globally synoptic analyses to faunal turnover patterns at the regional scale. Recent studies incorporating abundance data have added a new dimension by allowing sample-standardization, by demonstrating a surprisingly strong linkage between global and bed-scale trends in diversity-abundance structure, and by providing insight into paleocommunity trophic and energetic structure. However, ecological interpretation of these data is complicated by the wide range in body sizes within typical assemblages of benthic macroinvertebrates. Due to the ~¾ power scaling of whole-organism metabolic rate with body size, the resource demands of co-occurring taxa often vary by several orders of magnitude. Counting all individuals and taxa equally obscures valuable information about resource allocation and energy flow within paleocommunities.

We have compiled a database consisting of more than 300 whole-macrofauna collections with abundance and body size data from the Ordovician of Laurentia. Ibexian and Whiterockian collections are primarily from our own fieldwork in Utah and Nevada, while most Mohawkian and Cincinnatian collections are from published studies of the Cincinnati Arch and Nashville Dome. The database currently contains more than 32,000 individuals and 1600 taxon occurrences. We measured body size dimensions for trilobite, brachiopod, gastropod, bivalve, and ostracod genera using both collections and published monographs, and estimated biovolume, as a proxy for biomass, using simple geometric approximations. Sponges, corals, bryozoans and echinoderms were not considered because of the difficulty of estimating biomass and because of taphonomic problems.

Because of the negative relationship between body size and population density, the distribution of biomass among constituent taxa is generally more equitable than the distribution of individuals. Large, rarely sampled taxa can account for a large portion of standing biomass. This has implications for the ecological interpretation of taxonomic diversity trends. For example, though there is a marked post-Ibexian decline in the diversity and relative abundance of trilobites in our dataset, this is partly countered by an increase in average trilobite body size such that Middle and Upper Ordovician samples are sometimes volumetrically dominated by single trilobite individuals.

In addition to trilobites, there are significant increases in average body size of rhynchonelliform brachiopods, bivalves, and possibly gastropods. While this suggests that overall rates of energy flow through benthic paleocommunities may have increased through the Ordovician, this cannot be definitively shown without absolute abundance data and better estimates of taxon-specific metabolic rates. Additionally, regional and environmental biases must be accounted for. Ibexian and Whiterockian collections come primarily from the passive margin and Mohawkian and Cincinattian collections are exclusively from the area impacted by the Taconic orogeny, raising the possibility that this trend is related to regional differences in nutrient flux and primary productivity. Future work will concentrate on gathering Late Ordovician data from passive margin settings in order to test for the environmental generality of body size and paleocommunity energetic trends.

SUBSTRATE AFFINITY AND DIVERSITY DYNAMICS IN PALEOZOIC MARINE ANIMALS.

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BIOTURBATION EVIDENCES ON THE MIDDLE ORDOVICIAN FOSSILS FROM MONTES DE TOLEDO (SW SPAIN)

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In the lower Dobrotivian (Middle Ordovician) of Montes de Toledo there are evidences of bioturbation in internal moulds of molluscs (bivalves, gastropods, rostroconchs and cephalopods), trilobites and echinoderms. In this way, we can identify the presence of the organisms that left those evidences in the fossil record, increasing therefore the knowledge about the marine communities of the Ordovician from the SW Spain. The analysis of the substrate where these structures are found (firm substrate), as well as the type of preservation of them (negative relief), allows us to discard the possibility of being evidences of bioerosion. The ichnotaxonomic study allows us to identify the specimens analysed as *Arachnostega gastrochaenae* Bertling.. The interest of these discoveries are related with the fact of being the first time that is discribed bioturbation in internal moulds of organisms from the Palaeozoic of Spain, with a complete description of this ichnospecies, recognized for the first time in siliciclastic facies. Also, there is an increase in the stratigraphical record distribution of the ichnogenus because the only similar cases known up to now refer to the Carboniferous?-Permian?, Jurassic, Cretaceous and recent. In the same way, the number of organism groups whose internal moulds present this type of structures is increased, since up to now the only references were in bivalves and brachiopods. The producers of these burrows could be errant polychaetes or small crustaceans.

UPPER ORDOVICIAN (UPPER ARDMILLAN) BRACHIOPOD ASSOCIATIONS IN THE UNSTABLE SHELF AND SLOPE ENVIRONMENTS OF THE LAURENTIAN MARGIN AT GIRVAN, SW SCOTLAND

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Completion of monographic work (Harper 1984-2005) on the abundant and diverse brachiopod faunas of the Upper Ardmillan Group of the Girvan district, SW Scotland has permitted a full inventory of late Ordovician species and their ranges through the upper Caradoc-Ashgill marginal clastic facies of this classic succession. Background, near autochthonous, assemblages are dominated by variants of the deep-water *Foliomena* fauna, in fine-grained sediments, supplemented by diverse shallow-water assemblages periodically transported downslope in a variety of channels and sediment flows. Diversity apparently peaked in the Rawtheyan, associated with deposition of the Lady Burn Starfish Beds (Harper 2001). Measures of taxonomic distinctiveness suggest, however, that although communities in the deep sea were diverse, fewer higher taxonomic groups than those on the shelf inhabited them. About 15 different assemblages, many sampled by downslope sediment transport, are now known from the Upper Ardmillan Group, providing a useful overview of the brachiopod-dominated palaeocommunities of this part of the Laurentian margin. These faunas are similar to those from coeval successions at Pomeroy, northern Ireland and some from the northern parts of the Appalachians; the Girvan faunas contrast markedly with those of the North American Mid-Continent, although a few of the latter taxa appear for the first time in the widespread *Hirnantia* fauna of the High Mains Formation at the summit of the Ordovician succession.

REFERENCES

Harper, D.A.T. 1984-2005. Brachiopods from the Upper Ardmillan Succession (Ordovician) the Girvan district, Scotland. *Palaeontographical Society Monograph* Parts 1-3 (in press).

Harper, D.A.T. 2001. Late Ordovician brachiopod biofacies of the Girvan district, SW Scotland. Transactions of the Royal Society of Edinburgh: Earth Sciences 91, 471-477.

THE UPPER ORDOVICIAN OF ESTONIA: FACIES, SEQUENCES, AND BASIN EVOLUTION

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Upper Ordovician strata of Estonia accumulated on the Estonian Shelf, and span the transition from the Baltic Shield and Livonian Basin. The section is predominately carbonate with variable siliciclastic content, and numerous boreholes provide good-to-excellent coverage of facies patterns. The correlation of the Baltic regional stages to international stages is relatively well established.

The upper Nabala-Porkuni Stages (equivalent to the uppermost Caradoc to Ashgill Series) consist of seven complete stratigraphic sequences, and the lowstand deposits of an eight sequence (Fig. 1 and 2). The sequences are represented in shelf sections by grain-supported (grainstone and packstone), mud-supported (wackestone, mudstone, and marls), and mixed facies. These occur in shallowing-upward, prograding carbonate shelf successions. Slope sections are predominately mudstones that are locally truncated by submarine erosion surfaces. Basinal deposits are mudstones and marls with greater siliciclastic content in more distal areas.

The lowest sequence (upper Nabala Stage) consists of low-energy mud-supported facies that extend across most of the study area except for some moderate-energy mixed facies associated with updip isopach thicks. In sequence 2 (Vormsi Stage), facies belts are more differentiated and siliciclastic muds are most abundant, probably reflecting tectonic influences. Sequences 3-6 (Pirgu Stage) record the step-wise progradation of shelf carbonates that produced a relatively wide Estonian Shelf. The Pirgu/Porkuni stage boundary is also a sequence boundary marked by localized updip erosion that marks the widely recognized, early Hirnantian sea-level drop. Within sequence 7 (lower Porkuni

Stage), shelf sections contain high energy (including cross-bedded grainstone) facies that indicate the relatively low sea level associated with the Hirnantian. The lowstand unit that caps the succession (uppermost Porkuni Stage) is restricted to slope and basin areas, and includes redeposited ooids (probably derived from lower Porkuni strata) and quartz (presumably from the Baltic Shield) sands. This lowstand unit corresponds to the widely documented, latest Hirnantian glacial sea-level drop. The remainder of the sequence occurs at the base of the Silurian section.

The Estonian sequences appear correlative to those defined in Laurentia, suggesting an eustatic sea-level control on sequence timing. However the facies change between sequence 1 and the overlying sequences probably reflect tectonic changes within the Baltic region, perhaps related to the initial convergence of Baltic and Avalonia. This suggests that the controls on facies patterns are a mixture of eustatic and tectonic influences.

SEQUENCE STRATIGRAPHY OF THE ORDOVICIAN OF THE GREAT BASIN: SELECTED EXAMPLES

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During the early Paleozoic, the Great Basin (Utah and Nevada, western USA) was a broad continental margin with a shelf that was divided into two intrashelf basins, the Northern Utah Basin and Ibex Basin, by the east-west tending Toole Arch. The shelf edge shifted eastward during the Cambrian to early Silurian, and was in central to eastern Nevada during the Ordovician. This area is a classic area for Ordovician stratigraphy of the western Laurentia (as documented in numerous papers by Ross and coworkers). The efforts of various research groups within the last decade allow the integration of the extensive lithostratigraphic, biostratigraphic and facies studies within a sequence stratigraphic framework.

Preliminary studies suggest that the Lower Ordovician (Ibexian) carbonates and shales consist of seven sequences (in the Ibex Basin, these are represented by one sequence in the upper Notch Peak, two in the House Limestones, and four in the Fillmore and Wah Wah Formations) (Datillo et al., 2001, 2003). The base of the Middle Ordovician (Whiterockian) nearly coincides with a sequence boundary marked by shallowing in shelf (Ibex Basin) and margin (east-central Nevada) areas (Finnegan and Droser, unpubl.). Six sequences constitute the Middle Ordovician section below the Eureka Quartzite: (a) sequences 1 and 2 are capped by shoals in outer shelf locations (lower Antelope Valley Limestone) but are defined by shale-limestone alternations in inner shelf sections (Juab Limestone and Kenosh Shale) (Boyer and Droser, 2003; Finnegan, unpubl.); (b) shallowing-upward successions capped by shoals, tidal flats and karst features characterize outer shelf sections (middle Antelope Valley Limestone) of sequences 3 and 4 whereas inner shelf sections consist of quartz sandstones overlain by thin carbonates (Lehman Limestone) (Boyer and Droser, 2003); (c) sequence 5 is marked by a thick basal quartz sandstone overlain by carbonates (Watson Ranch Quartzite and Crystal Peak Dolomite) but outer shelf sections are burrowed limestones (upper Antelope Valley Limestone); and (d) sequence 6 consists of a thin quartz sandstone overlain by shales (Copenhagen Formation). The overlying Eureka Quartzite represents a prolonged lowstand (Saltzman et al., this volume; Zimmerman and Cooper, 1999) and may locally include equivalents to some underlying sequences. The Upper Ordovician section (Fish Haven, Ely Springs and Hanson Creek formations) consists of five prograding carbonate ramps sequences that widened the shelf before a Silurian (middle-late Llandovery) caused local backstepping of the margin (Harris and Sheehan, 1997, 1998). The uppermost Hirnantian ramp sequence is absent in the shelf but well represented in middle ramp to basin settings (Finney et al., 1999).

The benefits of the developing sequence interpretation include an improved facies model and understanding of lithological units, the prediction of stratigraphic gaps and condensed intervals, the placement of community changes within a better environmental-temporal framework, and improved planning of geochemical studies.

REFERENCES

Boyer and Droser, 2003, Brigham Young Univ. Geology Studies, 47: 1-15.

Dattilo, Evans and Miller, 2001, GSA Abstracts 33 (6): 77.

Dattilo, Evans, Miller and Ripperdan, 2003, GSA Abstracts 35 (6): 544.

Finney, Berry, Cooper, Ripperdan, Sweet, Jacobson, Soufiane, Achab and Noble, 1999, Geology 27: 215-218.

Harris and Sheehan, 1997, Brigham Young Univ. Geology Studies, 42 (I): 105-128.

Harris and Sheehan, 1998, New York State Museum Bulletin 491: 51-61.

Zimmerman and Cooper, 1999, Acta Universitatis Carolinae – Geologica, 43 (1/2): 147 – 150.

GLOBAL COOLING AS A POTENTIAL CAUSE FOR STRATIGRAPHIC CHANGE IN THE EARLY LATE ORDOVICIAN OF LAURENTIA

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Earth scientists working in the Ordovician of eastern North American are faced with the problem that despite the fact that Laurentia was situated in tropical to subtropical latitudes during this time period, lithological evidence indicates that parts of the Late Ordovician was characterized by deposition under cool-water conditions. While the

Turinian deposition was dominated by warm-water carbonates, the Early Chatfieldian marks a shift to temperate-type carbonates, an increase in siliciclastic influx and phosphatic sediments. It has been proposed in several studies that these lithologic changes, which are also linked to biotic turnover events, have been caused by combined effects of the Taconic orogeny. In this scenario, the beginning of the Taconic orogeny brought led to a change in ocean circulation patterns, which led to the spreading of turbid, nutrient-rich, and possibly cooler waters across eastern North America. However, alternatively it has been suggested that the onset of the Late Ordovician glaciation caused a regional cooling of the epicontinental sea of Laurentia. Numerical models of the ocean-climate system indicate that during the Early Late Ordovician, water from the higher southern latitudes flowed north towards the equator. The cold-water masses upwelled on and penetrated into the epicontinental sea of Laurentia. The "cold-water conditions" existed under high levels of pCO_2 (~15x pre-industrial atmospheric levels), which do not necessarily indicate the onset of glaciation during the Caradocian. It rather indicates that this event could have been part of a series of climate fluctuations before the onset of a full glaciation at the end of the Ordovician. Furthermore, the observed distribution of cold-water masses across the southeastern margin of Laurentia is consistent with the interpretation that a cold water event caused a regional extinction event in the Turinian-Chatfieldian of eastern Laurentia.

MICROFOSSIL FREQUENCY PATTERNS IN THE LLANDOVERY–WENLOCK BOUNDARY INTERVAL OF WESTERN ESTONIA

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Numerical data on fossil distributions, although sometimes difficult and time-consuming to obtain, may contain useful information about communities and the environment, which could never be extracted from simple occurrence data. Our main objective was to acquire and compare frequency data on different microfossil groups, primarily chitinozoans, scolecodonts and conodonts, from the Llandovery–Wenlock boundary interval in some western Estonian core sections (Paatsalu, Viki and Viirelaid). This interval comprises the globally traced Ireviken Event, which possibly reflects transition between different states of oceanic circulation, and the "Velise transgression", which caused the most extensive flooding of the Baltic shelf during the entire Silurian. Altogether, about 50 species of chitinozoans, more than 60 apparatus-based species of jawed polychaetes and 40 species of conodonts were recovered. The absolute frequency data (specimens per kg) indicate that the maximum abundance of scolecodonts and conodonts is rather similar, up to a few thousands per kg. Chitinozoans display 10–100 times higher maximum frequency than scolecodonts.

The three groups display different frequency dynamics, as could be expected from their different modes of life. The limestones of the Rumba Formation (Fm), rich in shelly faunas, contain abundant and diverse scolecodonts. In contrast, chitinozoans show relatively low frequency and conodonts are very rare or absent. A rather good correlation between the smaller-scale fluctuations in absolute frequency of chitinozoans and scolecodonts, and the rock composition (content of skeletal debris and siliciclastics) probably reflects changes in sedimentation rate and/or compaction. Interestingly, however, the most significant change in the carbonate/siliciclastics ratio at the Rumba–Velise transition occurs without marked changes in absolute frequency of either chitinozoans or scolecodonts. Moreover, no abrupt changes take place in relative frequency of individual chitinozoan or polychaete taxa. Conodonts, on the other hand, display a distinct increase in abundance and diversity at the same level.

Marls of the Velise and Mustjala Fms, spanning across the Ireviken Event and the Llandovery–Wenlock boundary, show significant variations in absolute and relative frequencies of all groups. In the lower part of the Velise Fm the abundance of scolecodonts drops and some predominating taxa disappear temporarily. Chitinozoans display fluctuating frequency and a notable drop in diversity at about the same level.
The changes at the Llandovery–Wenlock boundary are very abrupt in the Paatsalu section, partly on account of a gap. Chitinozoans display an about 10-fold increase in absolute frequency; several species disappear and some new ones appear. For conodonts the Ireviken Event constituted a crisis, as revealed by the drop in abundance and disappearance of numerous species. The frequency curve of scolecodonts is less variable and shows gradual increase across the Llandovery–Wenlock boundary. Frequency changes and the disappearance or appearance of several species are recorded at this level, but the biotic effect of the Ireviken Event on polychaetes cannot be fully established without additional data from the overlying strata.

Our further efforts are directed at extending the study spatially, covering more groups in one section and increasing the resolution at key intervals.

The Paleobiogeographic Significance Of An Upper Ordovician Organic-Walled, Microphytoplankton Assemblage From Dawangou, Xinjiang, Northwestern China

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A moderately well-preserved and diverse organic-walled microphytoplankton assemblage was recovered from four Upper Ordovician formations (Kanling, Qilang, Yingan, Kalpintag) of the Dawangou section, Xinjiang, northwestern China (Tarim Block). The assemblage consists of 24 species and 16 genera of acritarchs (one of which is a new species) and three species of the prasinophyte *Leiosphaeridia*. The acritarch assemblage is dominated by acanthomorphs, whose species comprise 71 percent of the assemblage.

Microphytoplankton provinciality during the Early and Middle Ordovician is well documented with a clear paleobiogeographic differentiation between the "Baltic" and "peri-Gondwana" assemblages. During the Caradoc, however, this provinciality began breaking down, resulting in cosmopolitanism of the microphytoplankton palynoflora during much of the Late Ordovician.

Most of the published Upper Ordovician microphytoplankton assemblages have been described from Laurentia, Baltica, Avalonia, the northern Gondwana margin, and Armorica. Nothing is known from North China, and there are only two published reports from South China. The Tarim Block, which was an independent continent located at approximately 30^{o}S during the Late Ordovician, is equally poorly known with only three published papers from the region.

The Dawangou microphytoplankton assemblage has the most species in common with Upper Ordovician assemblages reported from Laurentia, followed by Avalonia and Baltica, with only a few species in common with Gondwana and Armorica. Cosmopolitan taxa (recorded as either "cf." or attributed species) reported from at least two additional locations outside the Tarim Block include: *Baltisphaeridium bystrontos*, *B. dasos*, *B. dispar*, *B. omniense*, *Dactylofusa cabottii*, *Excultibrachium concinnum*, *Leprotolypa evexa*, *Lophosphaeridium edenense*, *Multiplicisphaeridium irregulare*, *Navifusa ancepsipuncta*, *Ordovicidium elegantulum*, and *Polygonium gracile*. The presence of these species from the Tarim Block not only expands their geographic extent, but also reinforces the fact that the Late Ordovician microphytoplankton palynoflora was, for the most part, cosmopolitan.

In addition to a wide geographic distribution, all but four of the Dawangou palynomorph taxa are restricted to the Upper Ordovician, making them globally useful biostratigraphic taxa. Furthermore, eight species (*Baltisphaeridium dispar*, *B. omniense*, *B. pauciechinatum*, *Gyalorhethium chondrodes*, *Leiosphaeridia caradocensis*, *Leprotolypa evexa*, *Navifusa indianensis*, and *Ordovicidium elegantulum*) have previously been reported only from the Caradoc.

The distribution and changing composition of the palynomorph assemblage corroborates previous paleontologic and sedimentologic conclusions regarding the paleoenvironment during deposition of the four Upper Ordovician formations comprising the Dawangou section. The Sargan and Kanling formations were deposited in a near-shore, shallow water marine environment, followed by a transgression resulting in deposition of the Qilang formation in an offshore, outer shelf marine environment. Regressive conditions prevailed during deposition of the Lower Member of the Kalpintag Formation, such that it was probably deposited in a littoral environment. This is reflected in the generally low diversity of the microphytoplankton assemblage, and the prevalence of leiosphaerids, netromorphs, and *Dactylofusa cabottii*.

THE MOTIF OF DEPOSITIONAL SEQUENCES ACROSS A CARBONATE-TO-CLASTIC, ACTIVE FORELAND: EXAMPLES FROM THE UPPER ORDOVICIAN APPALACHIAN BASIN

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Upper Ordovician sedimentary successions display carbonate-to-siliciclastic depositional sequences of multiple temporal scales (10^5 to 10^6 years) across the Appalachian foreland basin. Vertical facies offsets mark major sequence stratigraphic surfaces: sequence boundaries, maximum starvation surfaces, and forced regression surfaces. Systems tracts between these basin-wide discontinuities exhibit consistent motifs. Skeletal grainstone-rudstone facies typify transgressive systems tracts (TSTs) in shallow cratonic areas. TSTs become increasingly condensed down-ramp, typified by compound hardgrounds, concretion horizons, and bone/conodont beds, but thicken and become increasingly sand-rich, eastward toward siliciclastic sources. Highstand systems tracts (HSTs) are characterized by widespread (>1000 km cratonward) mud deposition. On the western side of the basin HSTs are dominated by argillaceous wacke- to packstones, typically containing abundant shaly partings, which impart thin-bedded, rubbly to wavy/nodular weathering. Closer to siliciclastic sources HSTs become increasingly shale-rich and are readily differentiated from surrounding cleaner limestones. These intervals may show very well developed, small-scale carbonate-shale cyclicity. Down-ramp this cyclicity fades, as component limestones condense or pinch-out into dark, shale-rich HSTs toward the basin center. Siliciclastic grain-size increases eastward, producing HSTs that are dominated by alternations of mud, silt, and sand. Falling stage systems tracts (FSSTs) occur as sharply based, down-stepping packages on both sides of the basin. On the carbonate-dominated flank these deposits are composed of highly abraded and fragmented skeletal material and typically display distinctive parallel, swaly, and/or flaser-like lamination, indicative of shoreface-shallow shelf deposition. On the clastic side of the basin the FSST is sand-dominated and forms a thick, silty to sandy clastic wedge that extends well out into the basin. In many cases these coarser clastics stand in sharp contrast to underlying shales (HST) and overlying shelly, mineralized sands (TST). The widely correlative sequences that dominate sedimentary successions in the Appalachian basin suggest a predominance of allocyclic processes modified locally by tectonic overprint.

The motif described above, derived primarily from detailed analysis of Chatfieldian age strata, is very similar to Silurian and Devonian depositional sequences in the Appalachian foreland basin. However, preliminary analysis suggests that certain sections of Maysvillian and Richmondian age strata deviate slightly from this motif; primarily in decreased expression of small-scale cyclicity. These variations may represent the signature of shifting dominance of different scales of orbital forcing tied to the initial stages of end Ordovician glaciation.

A Hierarchical Model Of Discontinuity Surfaces: Contributions From Analysis Of Upper Ordovician Strata Of Eastern North America

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Major discontinuity surfaces, including hardgrounds, are abundant within Upper Ordovician strata of eastern North America and their study has contributed significantly to our understanding of sedimentary dynamics of an ancient epeiric sea. Stratigraphic work on the distribution of hardgrounds suggests that they occur within distinctive portions of depositional sequences and indicate periods of very low net sedimentation. They are most highly concentrated within and capping transgressive systems tracts, although may also mark forced regression surfaces (i.e. precursor bed). Within mixed carbonate-siliciclastic successions they are most commonly found on the upper surfaces of limestone beds at contacts with the overlying shaly interval, which coincide with tapho- and biofacies change suggestive of a drop in environmental energy. The persistence of this motif suggests that these hardgrounds form in response to relative sea level rise and subsequent siliciclastic and carbonate sediment starvation.

Stratigraphic and taphonomic study reveals a range of complexity in hardgrounds that we interpret as a response to sediment starvation at a number of temporal scales. The simplest short-lived hardgrounds display only a few generations of encrusters, which are typically well preserved on stabilized shell pavements. These simple hardgrounds have limited spatial distribution and may occur as amalgamation surfaces within grainstone packages or interbedded with shales; their occurrence is typically rare. More complex hardgrounds show multiple generations of encrusters, which display a wide range of preservational-states. These complex hardgrounds are typically widespread (100s-1000s km), traceable between multiple closely spaced outcrops. They typically display only minor mineralization and most commonly cap limestone bed bundles. The next higher scale of complexity includes monomictic limestone conglomerates. These beds contain encrusted and bored limestone clasts of a single lithology in a skeletal sand matrix. Genesis of the clasts may follow one of three slightly different pathways, 1) in mud-rich successions concretions are exhumed and encrusted, 2) in more limestone-rich successions an early-cemented layer is exhumed, broken up, and later encrusted or 3) a cemented layer is exhumed, encrusted, and later broken up and reworked. Monomictic limestone conglomerates are typically widespread and mineralization is fairly common. We interpreted them to occur at a scale similar to complex hardgrounds. Polymictic limestone conglomerates and laterally equivalent bone-conodont beds are the most highly condensed beds. Polymictic limestone conglomerates contain multiple lithologies of reworked bored and encrusted clasts, representing formation and reworking of multiple lithified carbonate layers. Mineralization of these beds is typically heavy and they are widely traceable (10,000-100,000 km).

Comparison of early to middle Paleozoic successions throughout eastern North America suggests that hardgrounds are most abundant/recognizable in the Middle to Late Ordovician. This trend signifies the presence of "calcite seas", where very early dissolution of aragonite and precipitation of interstitial calcite cements was a common process. The abundance of echinoderm and bryozoan holdfasts during this period enables recognition of short-lived hardgrounds, which show little evidence for their time-rich nature otherwise. Contributions to the understanding of discontinuities of a shorter duration have been vital as it allows for a more complete comprehension of the formation of more complex, long-duration discontinuities.

PALEOBIOGEOGRAPHY OF SILURIAN BRACHIOPODS

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Extensive studies on Silurian paleobiogeography have been done using brachiopods. Boucot (1975; 1990; 2001) recognized two Silurian paleobiogeographic realms, while Hallam (1994) considered the southern Malvinokaffric realm to be the only clearly distinct biogeographic entity during Silurian. These different opinions are probably a consequence of differing criteria being used to distinguish paleobiogeographic units.

This study provides an updated global paleobiogeography of Silurian brachiopods, which takes advantage of a new dataset as well as a new approach to the recognition of paleobiogeographic units. The initial stage of this work was the construction of a database of worldwide Silurian brachiopod localities. Each locality was described by its longitude, latitude, current country or region name, and Silurian paleoplate name. Within each locality, the stratigraphic formations and their corresponding lithologies, relative ages, benthic assemblages (if available) and taxonomic compositions at the generic level were recorded. The database contains 374 brachiopod genera, distributed in almost 7000 generic occurrences from 335 localities worldwide. This brachiopods database is larger and more complete, with wider spatial coverage, than those used previously.

The database was used to produce, for each epoch in the Silurian, matrices of generic occurrences by locality. These matrices were then analyzed using both nonmetric multidimensional scaling (NMDS) ordination and cluster analysis (UPGMA). Paleogeographic entities were tentatively recognized only if both methods supported their existence. Database queries were then used to search for endemic and shared taxa between and among regions. Furthermore, a graphical *a posteriori* test of the statistic results was performed: localities with high faunal similarity, as obtained from statistical analysis, were plotted on a Silurian basemap to confirm that they clustered spatially. Spatial distributions of the localities and generic occurrences were further analyzed using GIS. Combining the results from the multivariate statistics, database queries, and GIS-based spatial analysis allowed the recognition of paleobiogeographic units (provinces) for each of the Silurian epochs.

Five provinces were identified in the Llandovery, four in the Wenlock, six in the Ludlow, and eight in the Pridoli. Some of these provinces have been identified by previous researchers, but most have not previously been recognized. Cosmopolitanism was apparently the greatest in the Llandovery. Provinces are more clearly delineated later in the Silurian. This pattern may reflect the recovery of the biota from the extinction associated with the Late Ordovician ice age. The history of Silurian provinces, their development and extinction, is probably associated with major trends of plate movement, climatic zonation, and eustatic sea level change.

OSTRACOD DIVERSITY PATTERN IN THE UPPER ORDOVICIAN OF ESTONIA

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In the general distribution pattern of the Upper Ordovician ostracods in Estonia and adjacent areas, the most prominent faunal change occurs at the base of the Oandu Stage. Higher up of this level, the Late Ordovician ostracod assemblages show a close affinity. The geographical distribution of the ostracod assemblages in Estonia reveals the pattern of sublatitudinal facies belts (Meidla, 1996). Remarkable changes in the composition of the assemblages can be recorded along the facies gradient, whereas the diversity of ostracods generally decreases offshore.

Comparing the ostracod appearance/disappearance data and diversity curve to the sequence stratigraphic subdivision of the Ashgill strata (Harris et al., 2004), the local ranges do not reflect the sequence boundaries particularly well, because of the predominantly low diversity of the short-ranged taxa. Among the post-Oandu faunal changes the most remarkable level is the base of the Nabala Stage, where the first appearances of the ostracod taxa are concentrated. However, this boundary seems to be situated within the depositional sequence. The boundaries of the depositional sequences 2-6 defined by Harris et al. (2004) are not distinct in the appearance/disappearance plot, but are better reflected in the diversity curve.

The sequences 3-6 constitute the Pirgu Stage and record the step-wise progradation of the shelf sedimentation (Harris et al., 2004). The ostracod diversity changes in the central Estonian sections (Kaugatuma, Pärnu, Laeva-18) reveal a cyclic pattern, whereas the sequence boundaries mostly fall into the low diversity intervals. In the Kaugatuma section this is true for the sequences 3, 4 and 6, while the boundary of the sequence 5 can be distinguished as a level of rapid diversity increase. In the Pärnu section the boundaries of all sequences can be characterised as the diversity minima, but a diversity low is recorded also within the sequence 3. In the Laeva-18 section (eastern central Estonia) the boundaries of the sequences 3 and 6 are well reflected as diversity minima and the boundary of the sequence 4 is distinguished as a rapid diversity increase. The boundary of the sequence 5 has no particular signature, falling into a plateau within the falling limb of the ostracod diversity curve.

Although the ostracod diversity changes show moderately good correlation to the evolution of sedimentation, the biostratigraphic signatures of the sequences 3-6 in the ostracod record are different. This is particularly well reflected in the Laeva-18 section. This may principally due to biofacies shift, but may also suggest a different interpretation of the sequence architecture of the Laeva-18 section.

REFERENCES

Harris, M. T., Sheehan, P. M., Ainsaar, L., Hints, L., Männik, P. Nõlvak, J., and Rubel, M. 2004. Upper Ordovician sequences of western Estonia. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 210 (2-4), 135-148.

Meidla, T. Late Ordovician ostracodes of Estonia. *Fossilia Baltica*, 2. Tartu, 1996, pp. 1-224, pls. 1-32.

STABLE CARBON ISOTOPE DEVELOPEMENT ACROSS THE LATE SILURIAN LAU EVENT IN NORTHERN PERI-GONDWANA (PRAGUE BASIN, CZECH REPUBLIC)

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During the late Silurian the Prague Basin was located in mid southern latitudes. In contrast to palaeocontinents positioned in tropical and subtropical latitudes like Baltica, no reefs are developed, which is in accordance with the predicted cooler water. The Prague Basin represents a relative restricted and shallow rift basin with a complex tectonic history. In close vicinity to the volcanic centres, which are located at the intersections of WSW-ENE and NNW-SSE striking fault zones, the several hundred metres of Silurian rocks are interrupted several times by volcanoclastic deposits. The deposits of the Ludlow Kopanina Formation investigated in the key section of the present study have been deposited on the slope-to-basin transition near the Kosov volcanic centre.

The sediments are developed as alternation of dark, partly laminated limestones and marls with an increase of the limestone-marl ratio in the upper part pf the succession. A pronounced positive carbon isotope excursion starts in the *Neocullograptus kozlowkii* graptolite and late *Polygnathoides siluricus* conodont zone. The maximum of the shift is observed in the lower part of an interval characterised by the *Ananaspis fecunda-Cyrthia* *postera* community. The maximum values scatter around 8‰, which represent the highest values reported from the Prague Basin so far. In low latitudes, often a decrease of $\delta^{13}C$ values towards deeper water settings is reported. In contrast, in the present study the $\delta^{13}C$ values of about 8‰ are much higher than those recorded from the contemporaneous shallow-water sections studied in the classical Mušlovka and Požáry (GSSP) Quarries. The most reasonable explanation is the presence of gaps in the shallow-water sections of the tectonically and volcanically highly active basin caused by a prominent sea-level drop leading on volcanic and tectonic elevations to a strongly reduced sedimentation of the cephalopod limestone biofacies as well as to erosion, solution or karstification in certain areas.

ASSESSING MECHANISMS OF ENVIRONMENTAL CHANGES: PALYNOMORPH DEVELOPMENT ACROSS THE LATE LUDLOW (SILURIAN) POSITIVE ISOTOPE EXCURSION ($\delta^{13}C$, $\delta^{18}O$) ON GOTLAND, SWEDEN

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The Silurian is characterised by strong environmental changes, as indicated by several pronounced positive $\delta^{13}C$ and $\delta^{18}O$ excursions. The mechanisms responsible for these isotopic shifts are a matter of much debate. The purpose of the present study is a quantitative high-resolution evaluation of the palynomorph distribution across the late Ludlow (Ludfordian) isotope excursion on Gotland. Marine and terrestrial palynomorphs have been chosen as palaeoenvironmental indicators because they are widely distributed and exceptionally well preserved. Moreover the combined analysis of marine and terrestrial palynomorphs allows the reconstruction of contemporaneous palaeoenvironmental change in the marine and terrestrial realms. In order to correlate our results with the carbon isotope stratigraphy, we have sampled only localities with published isotope data from diagenetically unaltered brachiopod shells. Our results show that fluctuations in the composition of the acritarch assemblages are closely correlated with

the stable isotope development. Low abundances of acritarchs occur in times of high stable isotope values and vice versa, indicating that an increase in marine productivity cannot have been the reason for the positive $\delta^{13}C$ excursion. The results are in good agreement with climatic models for the Silurian assuming alternating humid and arid climatic conditions in low latitudes. Times of high isotope values correspond to arid climatic conditions in low latitudes, with low input of terrestrial nutrients resulting in impoverished acritarch and conodont communities, whereas times of low isotope values correlate with humid climate, high nutrient input, and abundant and diverse acritarch communities. The major change in the acritarch communities took place during the increase of the isotope values after hemipelagic planktonic or nektonic organisms (graptolites, conodonts) have been affected. This indicates that environmental changes connected with the isotope excursion first affected deeper-water settings and later the photic zone. The absolute abundance of terrestrial spores closely mirrors the marine $\delta^{13}C$ and $\delta^{18}O$ development, showing that both the marine and the terrestrial realm were synchronously affected by the climatic changes. The high abundance of spores during the isotope excursion might be explained by increased aeolian input.

SOME IMPROVEMENTS TO THE ORDOVICIAN CHITINOZOAN BIOZONATION SCHEME OF BALTOSCANDIA

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The correlation of Ordovician beds within Baltoscandia (East Baltic, Scandinavia, northeast Poland, Western Belarus, northwest Ukraine) is complicated due to the differentiation of the sequence into at least five composite belts, which are characterised by several contemporaneous lithofacies. In general the faunas remain different, expressed by the dominance of graptolites in the Scanian Confacies belt with rare chitinozoans, in contrast to the four other belts where shelly fossils dominate and abundant chitinozoans are well preserved. Among other fossil groups chitinozoans, regarded as being least influenced by facies variation, have proved to be useful in solving some of the correlation problems, despite being partly controlled by the palaeolatitudes, temperature and palaeocurrents. Application of chitinozoans in long-distance correlations between the major palaeogeographic domains, i.e. Baltica, Laurentia and North Gondwana (see Webby et al. 2004) will base on well-documented regional zonations. Such zonation has been proposed also for Baltoscandia (Nõlvak & Grahn 1993) and further studies were focused on these stratigraphical levels that have a greater potential for a long distance correlations between different Ordovician basins.

On the other hand, a more detailed biozonations of different groups are needed for the correlations of varied confacies belts within the Baltic Basin. Some additional chitinozoan data will be given for certain stratigraphical levels based on the new material from mainly East Baltic sections. Global subdivisions are given in accordance with the scheme of Webby et al. 2004. There are some changes needed in the Baltoscandian chitinozoan zonal scheme (Nõlvak 1999). (1) The usage of "*Fungochitina fungiformis* Zone" in the Time Slice 5c (upper part) and 5d should be discontinued (in the general correlation chart in Webby et al. 2004, fig. 2.2 this zone is unnamed) and renamed to "*Fungochitina spinifera*" caused by revision of *Fungochitina* by Paris and Grahn (Paris et al. 1999). (2) The Baltoscandian *Belonechitina gamachiana* Zone is known only from the beds of the Pirgu Stage (TS. 6b). (3) The Subzone *Conochitina tuberculata* should be subdivided into two part according to the appearance level of *Armoricochitina stentor*. The study was supported by the ESF grant No. 5922, and is a contribution to IGCP project 503.

REFERENCES

Nõlvak, J. 1999. Ordovician chitinozoan biozonation of Baltoscandia. Acta Universitatis Carolinae. Geologica. Praha, 43, 1/2, 287-290.

Nõlvak, J. & Grahn, Y. 1993. Ordovician chitinozoan zones from Baltoscandia. Reviw of Palaeobotany and Palynology 79, 245-269.

Paris, F., Grahn, Y., Nestor, V. and Lakova, I. 1999. A revised chitinozoan classification. Journal of Paleontology 73, 549-570.

Webby, B.D., Cooper, R.A., Bergström, S.M. and Paris, F. 2004. Stratigraphic Framework and Time Slices. In: Webby, B.D., Paris, F., Droser, M.L. and Percival, I.G (eds). The Great Ordovician Biodiversification Event. Columbia University Press, New York, 41-47.

LATE ORDOVICIAN DEEPWATER (BA 4) BRACHIOPODS OF CIRCUM-PACIFIC TERRANES

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Amongst the mosaic of brachiopod-dominated Benthic Assemblages (BA) recognised worldwide in the Early Paleozoic, the *Dicoelosia* - *Skenidioides* Community Group is a distinctive association of diminutive genera inhabiting deepwater BA 4 and 5 environments. A subset of this community specific to early Ashgill time involves co-occurrence of orthides *Dicoelosia*, *Skenidioides*, *Phragmorthis* and *Epitomyonia*, and strophomenides *Bimuria*, *Christiania* and occasionally *Xenambonites*. Sphinctozoan sponges e.g. *Cliefdenella* and *Rigbyetia*, are also characteristic. This fauna is known from circum-Pacific terranes accreted to the western margin of Laurentia (eastern Alaska and Yukon Territory, Canada, and the Klamath Mountains of northern California), and is now documented from eastern Gondwana (Macquarie Arc of eastern Australia). These occurrences are further linked by the presence of allochthonous blocks and debris flows, indicative of original deposition on the unstable upper slope of high gradient seafloor profiles prior to downslope slumping. For ease of referral, this faunal grouping is termed the B-E-D-S association, the acronym derived from four of the diagnostic brachiopods. In eastern Gondwana, the B-E-D-S association is only known from one area of central New South Wales, on the northeastern flank of Malongulli Trig between Orange and Cowra. Here, laminated siltstones of the upper Malongulli Formation contain graptolites of early Bolindian age (early Ashgill equivalent), including the diagnostic Bo1 zonal species *Climacograptus uncinatus*. Immediately overlying these strata at the top of the Malongulli Formation is a spectacular limestone breccia about 4 m thick containing subangular clasts which yield a diverse orthide and strophomenide fauna typical of the B-E-D-S association. *Lingulides Paterula*, *Elliptoglossa*, *Atansoria* and *Schizotreta*, together with acrotretides including *Biernatia*, *Hisingerella* and *Undiferina*, and the siphonotretide *Multispinula*, also abound in this BA 4 fauna, but have not been described from other circum-Pacific terranes.

The B-E-D-S association was contemporaneous with the deepwater (BA 5-6) Foliomena fauna that had a global distribution in Late Ordovician (early Ashgill) time, particularly in platformal settings with relatively gentle seafloor slopes. Some elements of the B-E-D-S association, particularly *Epitomyonia* and *Skenidioides*, have been recognised in South China at BA 4 depths, apparently near the upper limit of Foliomena. However, it is significant that the other diagnostic brachiopod genera are either not known in South China, or are doubtfully present. In Kazakhstan, some genera characteristic of the B-E-D-S association have also been reported from Caradoc-age strata of the Chu-Ili and Chingiz terranes, although *Epitomyonia* and *Dicoelosia* are absent.

Global distribution of the B-E-D-S association cannot be explained by latitudinal control, nor do paleogeographic reconstructions indicate that the circum-Pacific terranes of western Laurentia and eastern Gondwana were proximal. Indeed this widespread distribution is but a relict of what would be expected had not the B-E-D-S association inhabited such a precarious situation on an unstable steep gradient slope where preservation potential was limited. Further examples of the B-E-D-S association can be predicted to occur around the margins of oceanic terranes and volcanic islands in the Late Ordovician world, and it would appear to be a useful indicator of BA 4 environments in such settings.

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30 MYR RECORD OF TRIMERELLIDE BRACHIOPODS (CRANIATA) IN EASTERN GONDWANA

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Trimerellide brachiopods (Craniata) first appear in the basal Caradoc (Upper Ordovician) of Kazakhstan. In the Lachlan Orogen of central and southern New South Wales they have a more extensive record that commences in slightly younger (mid Caradoc) strata and persists for about 30 million years, enabling study of ecological preferences and evolutionary lineages within the group. *Eodinobolus stevensi* first occurs in basal units of the Cliefden Caves Limestone Group and Bowan Park Group where it forms prolific shell beds in nearshore environments (Benthic Assemblage 1) at levels approximately contemporaneous with occurrence of this genus in Britain and North America. Rare forms with features transitional between *Eodinobolus* and *Monomerella* occur in slightly younger strata, prior to the first appearance of true *Monomerella* in carbonates of late Caradoc age towards the top of the Cliefden Caves limestone succession and at an equivalent level at Bowan Park. There it is associated with the relatively diminutive endemic trimerellides *Porcidium*, *Bowanpodium*, and *Corystops*, none of which have recognizable evolutionary precursors in NSW (or other) sequences. These form a very minor component of a diverse offshore level-bottom community (BA 3), quite distinct from the restricted quiet-water inshore setting so successfully colonized earlier by *Eodinobolus*.

Trimerella australis, recently described from shallow water limestone of mid Llandovery age in the Bowan Park district, is the oldest Silurian species known from eastern Gondwana. Additional occurrences of *Trimerella* or closely related forms are known from a limestone of mid to late Llandovery age in the Manildra district, in Wenlock or early Ludlow strata of the Canberra area, in the mid-Ludlow Molong Limestone, and in the late Ludlow (Ludfordian) Yarrangobilly Limestone of southern NSW. This latter species is amongst the youngest known representatives of the group.

The large and rotund *Belubula spectacula*, from the Cliefden Caves limestone succession, more closely resembles Silurian genera than contemporaneous Late Ordovician forms in displaying prominent umbonal cavities and rudimentary platform vaults. *Keteiodoros bellense*, from the Dripstone Formation (Wenlock age), southeast of Wellington, NSW, shares these characteristics and is interpreted as a likely descendant of *Belubula*. Like *Eodinobolus stevensi*, both species inhabited very quiet, shallow water environments (BA 1-2) where they dominate a restricted fauna.

Over 30 million years from mid Caradoc to late Ludlow time, trimerellide brachiopods in the Lachlan Orogen of eastern Gondwana flourished mostly in quiet water nearshore settings (BA 1-2 water depths) where they frequently aggregated into nearly monospecific shell beds. At only one level in the Late Ordovician did somewhat atypical

trimerellides venture briefly into deeper shelfal waters. By Ludlow time, having been dislodged from marginal marine niches by megalodontid bivalves, trimerellides in the Molong and Yarrangobilly limestones competed with large robust pentameride brachiopods in environments of probable BA 2-3 depths. This attempt at ecological diversification was apparently unsuccessful, with trimerellides disappearing from the record shortly thereafter. The lack of strongly interlocking articulation is therefore likely implicated in their demise.

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TRACKING BRACHIOPOD BIOEVENTS IN THE LOWER MIDDLE ORDOVICIAN (KUNDA) OF BALTICA

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Investigation of the distribution of approximately 70 species of rhynchonelliformean brachiopods through the Kunda Stage in NW Russia, Northern Estonia and Öland (southern Sweden) suggest a number of bioevents can be traced across significant parts of the East Baltic basin. Three diversity peaks can be recognised, with varying degrees of confidence, within the *Asaphus expansus* Biozone extending from Lynna River in the east to the Saka Section in NE Estonia. In addition a marked peak occurs within the upper part of the *Asaphus raniceps* Biozone; this peak is also concomitant with the acme of *Orthambonites* during this interval. Four overlapping brachiopod-dominated associations are recognized; the shallow-water *Lycophora* and *Gonambonites* associations are more prevalent in the west whereas the deeper-water *Orthambonites* and *Orthis callactis* associations dominate the eastern sections supporting models for the bathymetry of this part of the basin. Recognition of these events across a geographic transect of some 400 km, through four different depth and substrate-related associations illustrates the regional nature of such events at least on this part of Baltica.

C AND SR ISOTOPE STRATIGRAPHY OF THE LATE ORDOVICIAN (WHITEROCKIAN-MOHAWKIAN) IN CENTRAL NEVADA: TECTONIC AND CLIMATIC IMPLICATIONS

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An integrated $\delta^{13}C$, $^{87}Sr/^{86}Sr$ and sequence stratigraphic analysis in central Nevada (Antelope-Monitor Range composite) is used to investigate the timing and causes of the transition to a Late Ordovician-Silurian icehouse climate. A $^{87}Sr/^{86}Sr$ drop of ~ 0.0008 is recorded in the uppermost Antelope Valley Limestone and lowermost Copenhagen Formation. The drop, which occurred over a time interval of ~5-6 myr in the middle to late Whiterockian (end Darriwilian), is comparable in magnitude to the well-known Late Cenozoic rise that occurred over a much longer time period during the Neogene. Sr isotope values reach a steady baseline and change little for the remainder of the Late Ordovician. $\delta^{13}C$ values are steady through the Whiterockian-Mohawkian transition interval, but record a significant positive excursion in the upper part of the Copenhagen Formation in the Chatfieldian Stage (mid-Caradoc). This isotopic shift, which is well documented on a global scale, was closely followed by relative sea level drop during deposition of the prominent Eureka Quartzite. $\delta^{13}C$ values appear to remain steady during the Cincinnatian until the anomalous Hirnantian excursion, which was previously documented in the Hanson Creek Formation by Finney et al. and Kump et al. (1999). Sr isotopes do not change during the Hirnantian, but begin to shift towards more radiogenic values in the early Llandovery (Shields et al., 2003).

The abrupt Sr drop in the late Whiterockian-Mohawkian corresponds to the transition between pure shallow-water limestones (Antelope Valley Limestone) and the clastic-dominated Copenhagen-Eureka interval. This falls within the Sauk-Tippecanoe sequence boundary zone, and may also overlap in time the Taconic orogeny in eastern Laurentia based on the stratigraphic record of K-bentonites in the Appalachians and Precordillera of Argentina. It appears that any regional input of radiogenic Sr from old cratonal rocks during sea level drop was overwhelmed by input from young volcanic rocks. The rapid erosion of juvenile arc volcanics associated with the beginning stages of the Taconic orogeny thus provides a possible source for lowering oceanic $^{87}Sr/^{86}Sr$. The Chatfieldian $\delta^{13}C$ excursion that follows signals enhanced organic carbon burial, which may have lowered atmospheric pCO_2 to levels near the threshold for ice buildup in the Ordovician greenhouse. Sr isotopes appear steady through the remainder of the Ordovician, perhaps buffered by a combination of carbonate weathering and continued high input from young volcanics.

THE ORDOVICIAN PHYTOPLANCTON DATABASE IN THE PALAEOZOIC CONTEXT

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The Proterozoic and Palaeozoic phytoplankton fossil record is composed principally of the cysts of acritarchs, the phycomata of prasinophyte algae and the remains of other algal groups. From the perspective of the fossil record it appears as if these phytoplankton groups formed the base of the marine food web. A major objective of IGCP project 410 “The Great Ordovician Biodiversification Event” (1997-2002) was the assessment of patterns in biodiversity for all taxonomic groups. In this context, the “clade team acritarchs” compiled all of the data concerning Ordovician acritarchs: some 700 articles have been published, describing more than 250 genera (Servais, 1998) and more than 1000 species and infraspecific taxa from Ordovician localities (Servais et al., 2004). Most of the species were established from localities in Gondwana and peri-Gondwana (some 400 species) and Baltica (some 300 species). More than 250 new species were described from the former Soviet Union, and nearly 100 from China. Data from North America and Australia added information to the global picture, whereas many other areas remain partially studied or totally unstudied. Moreover, most Ordovician acritarch data comes from publications on the Lower to Middle Ordovician, whilst the Upper Ordovician is less well known. Many taxonomic problems exist and the systematic position, as well as the spatial and temporal distribution, of many phytoplankton species remains poorly understood. The elements required to understand the diversity of the Ordovician phytoplankton on a global scale are far from complete and more precise information is only available at a regional level, especially in South China (Li in Servais et al., 2004) and North Africa (Vecoli in Servais et al., 2004). Based on the work of IGCP project 410, the major objective of the “clade team acritarchs” in IGCP project 503 “Ordovician Palaeogeography and Palaeoclimate” (2004-2008) will be to complete the database and critically evaluate the data in order to understand if marine phytoplankton productivity during the Ordovician can be correlated with invertebrate diversity. We present here the current status of our database, which has been compiled within the context of the phytoPal project (http://www.le.ac.uk/geology/glm2/phytopal.html), the principle aim of which is to document the diversity of Palaeozoic phytoplankton through the construction of a Sepkoski-type curve. The distribution of the phytoplankton is discussed in relation to changing patterns of global climate and macrofaunal diversity and with diversification, radiation and extinction events.

REFERENCES

Servais, T.,1998. An annotated bibliographical review of Ordovician acritarchs. Annales de la Société Géologique de Belgique, 120 (1): 23-72. Liège.

Servais, T., Li, J., Stricanne, L., Vecoli, M. & Wicander, R., 2004. Acritarchs. pp. 348-360. In : Webby, B.R., Paris, F., Droser, M.L., & Percival, I.G. (Eds.), The Great Ordovician Biodiversification Event. Columbia University Press, New York, 484 pp.

ECOLOGICAL SIGNATURES OF MAJOR EXTINCTION EVENTS

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Ecologic changes produced by extinction provide signatures that distinguish extinction events that had different causes. The Late Ordovician Extinction (LOE) had two pulses that were associated with the onset and end of a major glaciation. The extinctions were caused by a combination of climatic change and loss of living space when extensive epicontinental seas were drained by glacioeustatic sea-level decline. Signatures of impact (Ir, Os, shocked quartz, etc.) have not been found. Of the five great extinction events, the LOE ranks second in the magnitude of taxonomic loss, but it resulted in relatively little ecologic change.

The asteroid impact at the Cretaceous-Tertiary Extinction (KTE) had taxonomic losses comparable to the LOE but produced much greater changes in the ecosystem. The primary killing agent in the KTE was darkness induced by impact ejecta—both particulate and gaseous. Organisms in food chains dependent on primary production were particularly sensitive to loss of sunlight. Organisms that could move into food chains based on detritus, or those able to withstand months without food, were buffered from loss of sunlight. Significant reorganization of ecologic structures resulted when survivors evolved and radiated in niches they had not occupied prior to the extinction.

Extinctions in the LOE, though severe taxonomically, were spread across many groups and were not clustered in particular food chains as in the KTE. The lack of selective extinctions resulted in few niches being completely vacated. During the recovery survivors radiated into niches for which they were already adapted, and the new ecologic structures resembled pre-extinction ecology. The KTE was more selective, singling out herbivores and those carnivores specialized for feeding on the lost herbivores. Many niches were vacated and surviving groups evolved new adaptations that allowed them to move into the vacated niches. Using the KTE as a model, extensive reorganization of synecologic structures, especially in food chains based on primary production, may be a signature of impact related events.

THE UPPER ORDOVICIAN HOLLANDALE EMBAYMENT; TEMPORAL CHANGES IN FACIES, BIOTA AND CIRCULATION ON AN EPEIRIC SEA

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The Hollandale Embayment (NE Iowa), part if the larger North America Ordovician Epeiric Sea, occupies a transition zone between clastic and carbonate dominated environments. The interpreted source of the clastics and associated freshwater is the Transcontinental Arch. The carbonates form two facies belts; near the clastic belt are fine-grained carbonates with abundant hardgrounds, and to the south are grainy (often bryozoan-rich) carbonates with abundant evidences of storm reworking and bioclast abrasion. Through the Upper Ordovician, the clastic belt shrinks, and hardground abundance and availability of micritic sediment diminishes upward coinciding with stratigraphic condensation. Trends in brachiopod fauna correlate well with facies changes corroborating a close link between environments and dominant fauna communities. Correlation of K-bentonites (Deicke, Millbrig, Elkport, Dickeyville and Calmar) via apatite chemistry has provided a high-resolution stratigraphic and faunal framework for comparison of depositional environments and circulation history. Further, new $^{40}Ar/^{39}Ar$ ages for the Millbrig (449.3±0.9* Ma), Dygerts (447.1±0.9* Ma) and Riffle Hill (444.0 ±2.8* Ma) K-bentonites allow for quantification of physical, biological, and chemical variations. The lateral and vertical distribution of facies, fauna, and omission surfaces suggest that terrestrial factors in the Hollandale Embayment had the greatest influence, forcing changes from anti-estuarine to estuarine circulation and weakening the carbonate factory, producing a system that episodically was sediment limited and prone to the generation of omission surfaces.
*±2 sigma analytical uncertainty; all ages relative to 28.02 Ma Fish Canyon Sanidine.

ORDOVICIAN SEQUENCE STRATIGRAPHY AND SEA-LEVEL CHANGES AT THE SOUTHEASTERN MARGIN OF THE UPPER YANGTZE PLATFORM: REGIONAL OR EUSTATIC?

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The Ordovician at the southeastern margin of the Yangtze Platform can be broadly divided into two different depositional periods: an earlier, normal carbonate platform period (~pre-Arenig), and a later drowning period (~post-Arenig). During the later period, however, some short-duration shallowing and deepening phases also occurred. Three types of sequences were identified: Type I and II sequences of Exxon Company, as well as the Drowning or Type III sequence of Schlager. Additionally, sixteen 3rd-order sequences, with an average duration of 2-5 Ma, and seventeen corresponding regression- transgression events have also been recognized. These subdivisions were based on the identification of the key surfaces within a sequence (sequence boundary/unconformity, transgressive surface, maximum flooding surface) and the analysis of the aggradation styles of representative facies-successions in different facies-belts, including the platform-interior, platform-margin, and slope-basin. Furthermore, with biostratigraphic and sequence stratigraphic data, the sixteen 3-order sequences and seventeen regression-transgression events at the southeastern margin of the Yangtze Platform can be correlated fairly well with the Sino-Korea Platform and the Tarim Block of China, as well as the sections in Australia, North America and other paleo-continents. These observations suggest that most of the Ordovician regression-transgression events at the southeastern margin of Yangtze are widespread, and most 3rd-order and higher order cycles are eustatic in nature, although sometimes the formation of the sequences is partly effected by the regional tectonic setting.

An Evaluation Of The Dynamics Of The Late Ordovician Ice Sheet, West Gondwana

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In the latest Ordovician, a dynamic ice sheet occupied the continental shelves of West Gondwana but little consensus occurs about the number and ordering of glacial cycles or how they compare (dynamically) to the evolution of late Quaternary ice sheets. Ice-sheet growth commenced in the early *extraordinarius* Zone (Hirnantian) and showed a transition from a terrestrial ice sheet feeding paraglacial depositional systems to an extensive, amalgamated, glacial-marine ice-sheet, which extended from South America to Arabia and from North to South Africa. This glacial-marine ice sheet underwent 2 regionally recognized cycles of growth (probably moderated by orbital eccentricity). Rapid deglaciation occurred in the *persculptus* Zone and was followed by a phase of isostatic readjustment.

Late Ordovician glacial-marine systems tracts compare favorably to those of the late Quaternary. Architectural components of both include widespread mud-prone aprons, deposited and deformed during glacial advance, that are overlain and truncated by submarine ice-contacts terminal moraine (parallel to the ice front) or subglacial cut tunnel valleys (oblique to the ice front). Evidence for ice streams, and their associated trough mouth fans, is limited in the late Ordovician but includes the extensive development of stream-lined bedforms and the preservation of anomalously thick glacial-marine successions, respectively. Like their Quaternary counterparts, late Ordovician ice sheets are polythermal in character and variably coupled to their deforming or rigid bed. Warm-wet based conditions are supported by the development of tunnel valleys, whilst a partially frozen sediment column is implied by the development of multiple, stacked striated surfaces. It is suggested here that the dynamics of late Ordovician and late Quaternary ice sheets compare qualitatively. Therefore, models for the evolution of late Quaternary ice sheets could be used as appropriate analogues for late Ordovician climate change and ice-sheet growth.

Middle Ordovician Microbial Phosphate Sediments In The Holy Cross Mts. (Poland)

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Thin filamentous mats (0.8 cm) preserved in the phosphate-rich carbonate succession of the Bukowiany Formation (BF) in the northern Holy Cross Mts. (HCM, central Poland) record link between the benthic microbial activity and phosphogenesis

during the late Llanvirn. These phosphate mats are conspicuous component of the multi-event condensed bed (10 cm) occurring close to the base of the BF in the Pobroszyn section (Trela, 2003). The sedimentary record indicates that cyanobacterial mats stabilized the substrate and subsequently subjected to reworking during the high-energy events. Moreover, these mats behaved as physical barriers reducing P escape to the overlaying water column and due to metabolism of mat-forming organisms contributed to P concentration in porewaters. The phosphate-rich succession of the BF corresponds to the upper Llanvirn – lower Caradoc (Wrona, 2004), and rests on the upper Arenig limestones (Volkhov) (Dzik, 1999; Trela, 2003). Thus, stratigraphic record suggests a hiatus coeval (at least) to the uppermost Arenig and lowermost Llanvirn, which corresponds to a similar time gap reported in the Mójcza section (southern HCM – Malopolska Block) (Dzik et al., 1994) and central Sweden (Holmer, 1983). The upper Llanvirn limestones in the Mójcza section display an intense phosphatization that includes: 1) phosphate coatings on skeletal and non-skeletal grains, 2) phosphatic internal sediment in intragranular pores, and 3) phosphatic matrix in vicinity of minor discontinuity surfaces. The occurrence of phosphatized discontinuity surfaces in Estonia (Einasto and Hints, 2004) and the Polish part of Baltica (Podhalańska, 1992) in the rock record coeval to the upper Llanvirn suggests that phosphogenesis recorded in the HCM may not be a local feature, but expression of the P cycle accelerated in the Baltic area.

REFERENCES

Dzik, J., 1999. The Ordovician in the Holy Cross Mountains. In: J. Dzik, U Linnemann and T. Heuse (Eds) International Symposium on the Ordovician System, ISOS Prague 1999, Pre - Conference Field trip, Excursion guide Poland and Germany, 3-7.

Dzik, J., Olempska, E., Pisera, A., 1994. Ordovician carbonate platform ecosystem of the Holy Cross Mountains. Paleontologia Polonica, 53, 1 – 317.

Einasto, R., Hints, L., 2004. Stop 7. Kunda-Aru quarry. In: O., Hint and L., Ainsar (Eds), WOGOGOB-2004, 8th Working Group of the Ordovician Geology of Baltoscandia. Excursion Guidebook, 129-132.

Holmer, L., 1983. Lower Viruan disconformity surfaces in central Sweden. Geologiska Föreningens i Stockholm Förhandlingar, 105, 29-42.

Podhalańska, T., 1992. Phosphatization of the Lower-Middle Ordovician sediments from the Podlasie depression (eastern Poland). Archiwum Mineralogiczne, 48, 27-41.

Trela, W., 2003. Sedimentary environment of the Ordovician phosphate-bearing sequence in central Poland. INSUGEO Serie Correlatión Geológica, 17, 475 – 481.

Wrona, R., 2004. Gondwanan provenance of the Łysogóry block (Holy Cross Mountains, Poland) supported by Upper Ordovician chitinozoans from the Pobroszyn section. In: A. Munnecke, T. Servais, C. Schulbert (Eds), International Symposium on Early Palaeozoic Palaeogeography and Palaeoclimate, September 1-3, Erlangen, Germany, 77.

TRACE FOSSILS AND ICHNOFABRIC OF THE UPPER ORDOVICIAN MUDROCKS IN THE NORTHERN HOLY CROSS MTS. (POLAND)

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The bulk of the lower and middle Ashgill sedimentary record in the northern Holy Cross Mts., (central Poland) is made up of the grey/green bioturbated mudstones of the Wólka Formation (Trela, 2003). They are underlain by the dark claystones/mudstones of the Jeleniów Formation (uppermost Llanvirn and Caradoc), which, in turn, is divided by thin package (up to 2 m thick) of the grey/green bioturbated mudstones into two horizons (Trela, 2003). The Wólka Formation grades upward into unnamed siltstones and marls (upper Ashgill) (Trela, 2003). The bioturbated mudstones show both discrete and identifiable trace fossils with sharp outlines as well as unrecognizable structures with irregular outward morphologies and sometimes diffuse rather than sharp outlines. The burrows are easily recognizable due to their contrasting color (dark grey) in grey/green host sediment. Among identifiable trace fossils, *Chondrites* is the most pronounced burrow exhibiting two different sizes that include small (up to 2 mm) and large (3-4 mm) forms. The distinctive ichnofabric components are straight but unlined and unbranched burrows referable to *Taenidium* isp. due to meniscate backfill structures (see D'Alessandro and Bromley, 1987; Bromley et al., 2000). However, in the cross sections these traces exhibit preserved spreiten structure referable to *Teichichnus* isp. Some of the unlined burrows with structureless internal fill referring to *Planolites* isp. occur as well. The subordinate burrows interpreted as *Palaeophycus* isp. display large and oval form (in cross section) with distinguished thin to thick wall and internal structureless fill. The suite of trace fossils recorded in the Upper Ordovician mudstones represents an extensive colonization of the highly enriched substrate by pioneering opportunistic inhabitants. The occurrence of the bioturbated mudstones above the dark claystones/mudstones provides evidence that trace fossil suite records an increase of oxygen level in the bottom water (Trela, 2003). The stratigraphic data indicate that thin package of the bioturbated mudstones within the Jeleniów Formation corresponds to a short-term drop of relative sea-level close to the early and middle Caradoc boundary. In contrary, the Wólka Formation seems to reflect a progressive and persistent benthic oxygenation triggered by a major change in oceanic circulation prior to the late Ashgill.

REFERENCES

Bromley, R.G., Edkale, A.A., Richter, B., 2000. New *Taenidium* (trace fossil) in the Upper Cretaceous chalk of northwestern Europe. *Bulletin of the Geological Society of Denmark*, 46, 47-51.

D'Alessandro, A., Bromley, R.G., 1987. Meniscate trace fossils and the *Muensteria-Taenidium* problem. *Paleontology*, 30, 743-763.

Trela, W., 2003. Sedimentological record of Oxygen-depleted conditions in Upper Ordovician of central Poland (Holy Cross Mts.). *INSUGEO Serie Correlatión Geológica*, 17, 449-455.

THE SIGNIFICANCE OF THE NEW CHITINOZOANS DATA OF MOESIA, ROMANIA

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Moesia or the Moesian Terrane lies in the Carpathians and Balkan foreland. It occurs mostly as a subsurface platform and is hence also called the Moesia Platform. It occupies most of the southeastern part of Romania and the northern part of Bulgaria. Two parts, possibly two palaeoterranes, are recognized: East and West Moesia. The Bulgarian part corresponds roughly to West Moesia. During the last three years, palynological research on the Moesian Platform has started again after a long period of interruption. The results partially confirm the previously defined ages, but also lead to the revision of some stratigraphical boundaries and allowed the discovery of new chitinozoan genera and species. In the cores of Mangalia borehole, East Moesia, the chitinozoans *Eisenackitina bohemica* (Eisenack, 1934), *Margachitina catenaria* Obut 1973, *Fungochitina lata* (Taugourdeau & de Jekhowky, 1960) characterize global biozones as defined by Paris (2000), while other species have been recognized as *Cingulochitina plusquelleci* Paris, 1981, *Cingulochitina ervensis* (Paris, 1979), *Pterochitina spp., Calpichitina spp., Ancyrochitina spp., Anthochitina spp., Armoricochitina spp., Fungochitina spp.* and *Angochitina spp.* The Mangalia borehole is considered to be a lithostratotype of East Moesia. The chitinozoan association documents an late Lochkovian age. In another important borehole, Gârla Mare, situated in West Moesia, the chitinozoan assemblage was poorer than the previous. It consists mainly of *Bulbochitina bulbosa* Paris 1981a, and *Bursachitina riclonensis* Paris 1981a. These chitinozoans indicate an Emsian age for the respective succession, considered previously Pragian-Emsian in age. The results from other boreholes from East Moesia, showed the following chitinozoans like: *Eisenackitina bohemica* (Eisenack, 1934), *Urochitina simplex* Taugourdeau & de Jekhovky, 1960, *Cingulochitina plusquelleci* Paris, 1981, *Cingulochitina ervensis* (Paris, 1979), *Cingulochitina serrata* (Taugourdeau & de Jekhowky, 1960), *Angochitina filosa* Eisenack, 1955a, *Angochitina chlupaci* Paris & Laufeld, 1981 (indicating the Lochkovian), *Urnochitina urna* (Eisenack, 1934), *Urnochitina kameli* Boumendjel, 1987, *Linochitina klonkensis* Paris & Laufeld, 1981, *Bursachitina krizi* (Paris & Laufeld, 1981), etc. (indicating the Pridoli), *Conochitina pachycephala* Eisenack, 1964, *Conochitina tuba* Eisenack, 1964, *Conochitina subcyatha* Nestor, 1982 (indicating the Wenlock or Ludlow). Most of the chitinozoans have an important significance indicating a certain palaeoprovincialism. Thus, the present chitinozoan data corroborates previous studies and confirms the previous hypothesis that at least East Moesia shows a Northern Gondwanan affinity.

NEW EVIDENCE FOR THE HIRNANTIAN (UPPER ORDOVICIAN) IN BELGIUM? INTEGRATING MICROFACIES, CARBON ISOTOPE AND CHITINOZOAN DATA

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The Hirnantian is an important time in Earth history as it saw one of the major episodes of continental glaciation and marine mass extinction (e.g. Brenchley et al., 2003). Positive C-isotope excursions and eustatic sea level fall extend from a level near the base of the *N. extraordinarius-N. ojsuensis* zone (lower Hirnantian) to a level within the upper Hirnantian *N. persculptus* zone. C-isotope values decline to pre-glacial levels through the uppermost Hirnantian strata. At least two distinct positive shifts of $\delta^{13}C_{org}$ can be resolved globally, which may coincide with two pulses of peak glaciation (Melchin et al., 2003).

The sedimentology, carbon isotopes of dispersed organic carbon ($\delta^{13}C_{org}$) and chitinozoan biostratigraphy of the Génicot Formation (Condroz Inlier, Belgium, Avalonia) are documented. Overlying the Fosses Formation, the Génicot Formation comprises a mainly silty sequence, interrupted by few calcareous sandstone beds and two conglomerates.

The microfacies of the Fosses Formation is typical for an outer ramp setting (40-60 m depth), near the normal storm wave base level. Calcareous sandstone beds from the lower Génicot Formation are deposited between the fair-weather and the storm-wave base, hence indicate lowering of the sea level, which is corroborated by the presence of reworked chitinozoans. The lower conglomerate reflects a diminution of the sea level associated with an erosional episode. The upper conglomerate contains clasts of both karstic and euphotic environments, indicating sea level fall of at least 20-25m. This sea-level fall could be more severe, as some cobbles are derived from the outer ramp. Above the conglomerates, deposition between fair-weather and storm wave base was restored.

The obtained $\delta^{13}C_{org}$ values range from –29.28 ‰ to –26.91 ‰. Apparently, elevated $\delta^{13}C_{org}$ values occur in parts of the Génicot Formation. These might correspond with the positive $\delta^{13}C$ shift, recorded worldwide and corresponding to the Hirnantian glaciation events. Two peaks seem to be present in our data, one below the calcareous

sandstone levels and the lower conglomerate and one above the upper conglomerate. However, these peaks are defined on a too small number of samples at the moment and care must be taken interpreting these results. New analyses are in progress.

The Génicot Formation is geometrically situated in between the Fosses Formation and the early Silurian Criptia Group. The youngest known sediments of the Fosses Formation are dated with chitinozoans as late Rawtheyan. Some chitinozoans from the upper part of the Génicot Formation are close to *A. ellisbayensis* from the upper Hirnantian of Canada. The oldest chitinozoan dated sediments of the Silurian Criptia Group are mid Rhuddanian in age. Worldwide, the early Silurian is transgressive and responsible for deposition of black shales. The Génicot Formation lithologically clearly differs from this by its generally coarser sedimentation. We hence think it is plausible that it has a Hirnantian – lowermost Silurian age and the sediments reflect the sea-level drops associated with the glaciational peaks.

REFERENCES

Brenchley, P.J., Carden, G.A., Hints, L. Kaljo, D., Marshall, J.D., Martma, T., Meidla, T., And Nõlvak, J. (2003).- High–resolution stable isotope stratigraphy of Upper Ordovician sequences: constraints on timing of bioevents and environmental changes associated with mass extinction and glaciation.- *Geological Society of America Bulletin*, v. 115, p. 89–104.

Melchin, M.J., Holmden, C. & Williams, S.H., (2003).- Correlation of graptolite biozones, chitinozoan biozones and carbon isotope curves through the Hirnantian. *In:* Albanesi, G.L., Beresi, M.S. and Peralta S.H. (eds.): Ordovician from the Andes; Proceedings of the 9th International Symposium on the Ordovician System. *INSUGEO*, *Serie Correlación Geológica* 17.

IS THE ORDOVICIAN BIODIVERSIFICATION BASED ON AN INCREASED PRIMARY PRODUCTION?

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The Ordovician fossil record shows evidence of the most rapid, long sustained burst of biotic diversification in the history of marine life on Earth (The Great Ordovician Biodiversification Event). Radiation events during Early and Middle Ordovician caused the tripling of marine biodiversity and the establishment of Palaeozoic and Mesozoic evolutionary faunas which have the greater relevance to present-day biotic communities.

The great ecological changes were associated, throughout the Ordovician, to intense tectonic and volcanic activity and major re-organization of the plate-tectonic global assembly.

Different authors have suggested a direct correlation between the tectonic evolution, volcanism and the Ordovician radiation events. However, as Sepkoski & Sheehan (1983) already pointed out, there seems to be "no immediately obvious physical trigger for such a great burst of evolutionary activity" that could have caused the Ordovician biodiversification.

Here, we analyze the relationships between biodiversification patterns observed in marine invertebrates and oceanic microphytoplankton during Ordovician times, with the aim of a better understanding of the role of primary production in the Great Ordovician Biodiversification Event.

The fossil record of oceanic primary producers in the Palaeozoic is largely dominated by acritarchs. In spite of uncertainties regarding their precise biological affinities, acritarchs are currently considered to represent the resting cysts of algal protists; their morphological and biogeochemical characteristics, and mode of occurrence in the marine sedimentary record are very close to those of the dinoflagellate cysts and to phycomata stages of various chlorophycean algae. However, it is not clear how palaeoecological information derivable from the fossil record of acritarchs can be related to oceanic productivity. The easiest parameter to be quantified, the diversity of the microphytoplankton cysts (acritarchs), cannot be taken directly as a proxy for palaeoproductivity. Abundance of microfossils in the sediments is a complex function of the variables: cyst production, hydrodynamic sorting, and preservation of the organic matter, and gives no direct information on microphytoplankton density in the water column.

However, evidence from the fossil record of consumers seems to indicate that primary production increased strikingly during the Ordovician. Increasing complexity in food webs during Ordovician times is suggested by the following facts: 1) the first appearance and radiation of graptolites, phyllocarids, several groups of echinoderms, of the chitinozoans, as well as the diversification of radiolarians; 2) innovation of planktotrophy in molluscs larvae; 3) the bursts in diversity observed in the great majority of the macroinvertebrate groups; 4) the innovations and increasing complexity within benthic and reef communities on the shelf including filtrating organisms such as sponges, corals, and stromatoporoids.

The observation of major diversification events in all fossil groups implies drastic changes in the basal food chain and a tremendous increase in primary production (“plankton explosions”). This major change was possibly the main trigger for the “Great Ordovician Biodiversification Event”.

Richmondian-Hirnantian (Upper Ordovician) Carbon Isotope ($\delta^{13}C$) Stratigraphy From Anticosti Island, Quebec: Implications For Oceanography, Glaciation, And Organic Carbon Burial

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Changing climate and oceanography, during the Late Ordovician (Hirnantian), led to multiple episodes of Gondwanan glaciation and resulted in two phases of mass extinction. A large positive carbon isotope excursion (up to +7‰) has been documented from many Hirnantian sections worldwide and shown to be a global perturbation of the carbon cycle. The Hirnantian carbon isotope ($\delta^{13}C$) excursion has now been documented in new high-resolution carbonate and organic-matter carbon isotope ($\delta^{13}C$) data from Anticosti Island, Quebec, with values as high as +4.7‰ in carbonates and –25.3‰ in organic-matter. Carbon isotope values remain steady (~0‰) through the Vaureal Formation (Richmondian), the excursion is recorded in the uppermost Lousy Cove and the Laframboise Members of the Ellis Bay Formation. Previous conodont, chitinozoan, and brachiopod biostratigraphic work has demonstrated that the Ellis Bay Formation is Hirnantian. The relatively unaltered Upper Ordovician through Lower Silurian carbonate sequence on Anticosti Island records the Hirnantian excursion in both carbonate and organic matter isotopes, and allows for a unique opportunity to examine an interval of major climatic, oceanographic, and biological change in Earth's history.

Our data reveal that peak $\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$ values are not coincident, and that the heaviest $\delta^{13}C_{org}$ values occur prior to the heaviest $\delta^{13}C_{carb}$ values. These paired carbonate and organic-matter carbon isotope data suggest that atmospheric pCO_2 was declining and reached its lowest levels prior to the $\delta^{13}C_{carb}$ peak. High pCO_2 was coincident with high $\delta^{13}C_{carb}$ values, and falls again after the $\delta^{13}C_{carb}$ excursion. The excursion has been previously attributed to increased burial of organic carbon (i.e. black shales) due to increased marine productivity. While this is a likely mechanism, the excursion appears to have occurred during an interval of clean carbonate deposition in epeiric seas, not black shale deposition. Continental margin/shelf black shale deposition (e.g. Vinini Creek, Polk Creek Shale) took place in the upper Richmondian (Rawtheyan) (*D. ornatus/P. pacificus* Graptolite Zones) prior to the $\delta^{13}C_{carb}$ excursion. Sedimentological and biological evidence are consistent with the heaviest values of the excursion having been recorded during a sea-level highstand (interglacial), rather than glaciation. In this scenario, strong thermo-haline circulation occurred prior to and after the peak of the excursion and led to development of black shales in shelf settings. The excursion is attributed to either enhanced preservation in the deep oceans during formation of warm, saline bottom waters in an interglacial, or to higher productivity in more open ocean settings beyond the craton.
