Opening Meeting IGCP 652 --- Program
"Reading Time in Paleozoic sedimentary Rock"
Bremen, Germany

Pre-meeting workshop
"Time-series analysis of paleoclimate signals."

Wednesday 12th of September

09:00 - 10:30	Physics of the climate system. How does solar insolation reaches Earth's surface?
10:30 – 11:00	Coffee break
11:00 - 12:30	Milankovitch theory
12:30 - 14:00	Lunch
14:00 - 15:30	Theoretical introduction to paleoclimate signals and time-series analysis
16:00 - 17:30	Practical introduction to paleoclimate signals and their time-series analysis.

Thursday 13th of September

09:00 - 10:30	Sedimentary indications of Milankovitch forcing.
11:00 - 12:30	Paleoclimate signals and their time-series analysis: Exercise 1.
12:30 - 14:00	Lunch
14:00 - 15:30	Exercise 2
16:00 - 17:30	Exercise 3

Friday 14th of September

09:00 - 16:00	Exercise 4 or analysis of own data
15:00 – 16:00	Presentation and discussion of main results of the "Cyclostratigraphy Intercomparison Project".

Pre-meeting Fieldtrip:
Middle to Late Paleozoic sedimentary rock in the Rhenish Massif

Saturday 15th of September 2018

08:15	Meeting in front of the MARUM building.
08:30	Transport to Harz
11:00 – 19:00	Several stops in the Harz Mountains illustrating the late Permian "salt giants", the Zechstein transgression, Late Devonian anoxic events and Middle Devonian carbonate reef development.
	Lunch is provided and included in the registration fee.
19:00	LEINE Hotel Groner Landstrasse 55 37081 Göttingen
	Overnight stay is included in the registration fee. Dinner is not included in the registration fee.

Sunday 16th of September 2018

07:30	Breakfast (included in the registration fee)
08:15	Transport to northern Sauerland
10:30 – 19:00	Several stops in Sauerland to illustrate Givetian-Frasnian reef complexes, and the strongly cyclic deep-water successions of the Famennian.
	Lunch is provided and included in the registration fee.
19:00	Hotel Marburger Hof Elisabethstraße 12 35037 Marburg
	Overnight stay is included in the registration fee. Dinner is not included in the registration fee.

Monday 17th of September 2018

07:30	Breakfast (included in the registration fee)
08:15	Start of fieldtrip.
08:30 – 15:30	Lower Devonian to Lower Carboniferous basin development and volcanism in the southeastern Rhenish Massif.
	Lunch is provided and included in the registration fee.
19:00	Arrival in Bremen. Participants check into their hotels.
	Participants have to book their own accommodation in Bremen for this night.

Meeting IGCP 652 "Reading Time in Paleozoic sedimentary Rock"

Tuesday 18th of September 2018

09:00 – 09:30:	Registration Coffee and refreshments will be served.
09:30 – 09:40:	Welcome *David De Vleeschouwer.*
09:40 – 10:00:	Timing and pacing of the Late Devonian mass extinction event regulated by eccentricity and obliquity. *David De Vleeschouwer et al.*
10:00 - 10:20:	Astrochronology of the Frasnian–Famennian boundary section (Late Devonian) at Steinbruch Schmidt. *Anne-Christine Da Silva et al.*
10:20 – 10:40:	Divers depositional and geochemical signature of the Frasnian Famennian (F/F) global event in the western Thailand, as a record of Paleotethyan vs. western Australian geotectonic affinities. *Peter Königshof et al.*
10:40 – 11:20:	Coffee break
11:20 – 11:40	Tracing palaeoredox conditions across the Devonian-Carboniferous boundary event: a case study from carbonate-dominated settings of Belgium, Czech Republic, and northern France *Tomáš Kumpan et al.*
11:40 – 12:00	The upper Givetian – strange mid-Palaeozoic interval with maximum biostratigraphic time resolution and rapid eustatic fluctuations. *Ralph Thomas Becker and Zhor Sarah Aboussalam*
12:00 – 12:30	Preliminary reports from the pre-meeting workshop on time-series analysis. *Workshop participants*
12:30 – 14:00 Lunch	
14:00 – 14:30:	Tour of posters with all participants. Poster presenters introduce their poster with 5-minutes presentations
14:30 – 15:00:	Poster session
15:00 – 15:20 Coffee break	
15:20 – 15:40	High-resolution stratigraphy on the Ordovician strata from southwestern Ordos, China *Shuang Dai et al.*
15:40 – 16:10	**Keynote:** Upper Katian Cyclostratigraphy of the Vauréal Formation, Anticosti Island (Gulf of St. Lawrence, Canada) *Matthias Sinnesael et al.*
16:10 – 16:30 Concluding remarks.	

Wednesday 19th of September 2018

09:00 – 09:10:	Opening of the second day. *David De Vleeschouwer*
09:10 – 09:30:	The Lochkovian (Lower Devonian) in the Spanish Central Pyrenees: conodont high-resolution biostratigraphy as a basis for integrating Events, oceanic, climatic changes and Milankovitch cycles. *José Ignacio Valenzuela-Ríos and Jau-Chyn Liao*
09:30 - 09:50:	The Givetian (Middle Devonian) in the Spanish Central Pyrenees: conodont high-resolution biostratigraphy as a basis for testing the ties of biological and environmental evolution to astronomical forces. *Jau-Chyn Liao and José Ignacio Valenzuela-Ríos*
09:50 – 10:10:	Devonian (ca. 388-375 My) Horn River Group of Mackenzie Platform (northwestern Canada) is an open-shelf succession recording global anoxic events. *Pavel Kabanov*
10:10 – 10:50	Coffee break
10:50 - 11:10	Impact event stratigraphy: lessons from Paleozoic craters, Chicxulub and the K-Pg boundary deposits *Michael T. Whalen et al.*
11:10 – 11:30	Magnetic polarity time scale for the Devonian…? *Annique van der Boon et al.*
11:30 – 12:00	**Keynote:** Cross recurrence plot analyses of conodont community turnover – a model free, continuous, high-resolution correlation tool. *Andrej Spiridonov et al.*
12:00 – 12:20	To see or not to see Milankovitch cycles – Example of the Lower Devonian hemipelagic succession from Czech Republic *Anne-Christine Da Silva et al.*
12:20 – 14:00	Lunch
14:00 – 16:00	Where to go with IGCP 652? Division of tasks and future paper writing. Future meetings. Concluding Remarks

Posters

Title	Authors and *presenter*
A positive test for the Greater Tarim Block at the heart of Rodinia: Mega-dextral suturing of supercontinent assembly	*Bin Wen* & David A.D. Evans
Iterative speciation in Late Silurian Pristiograptine graptolites of the Baltic Basin and the value of stratigraphy in cladistics	Misha Whittingham, Sigitas Radzevičius, & *Andrej Spiridonov*
The Devono-Mississippian Besa River Group of Liard Basin, Canada: stratigraphy of a world-class shale gas resource	F. Ferri, B.C. Richards, M. McMechan, *Pavel Kabanov,* A. Mort, P. Thapa, J. Leslie-Panek & E. Little,
Reassessment of the Lower Devonian and lower Middle Devonian conodont biostratigraphy in the Northwest Territories, Canada: changes in the time-rock chart for the northern Mackenzie Mountains and adjacent plains	Sofie A. Gouwy & *Pavel Kabanov*
The remagnetization of marine carbonate rocks of late Ordovician in Pingliang section (China)	*Junhua Luo*, Shuang Dai, Mark J. Dekkers, Weiguo Wang, Xiaoke Qiang, Lei Qiang, Chao Tian, Haiyu Xi & Wout Krijgsman
Identifying cyclicities in different types of data series: a study of the Carboniferous rhythmites of the Itararé Group, Paraná Basin	Kochhann, M.V.L., *Cagliari, J.,* Kochhann, K.G.D., Tedesco, J., Aquino, C.D., Souza, M.K. & Souza, L.V.
Refining the end of the Late Paleozoic Ice Age – LPIA in the Paraná Basin, southern of Gondwana	*Cagliari, J.,* Netto, R.G. & Schmitz, D.M.
Trace Elements of the Middle-Late Ordovician in SW Ordos and Its paleoenvironmental implications	*Lei Qiang*, Shuang Dai, Anne-Christine da Silva, David De Vleeschouwer, Weiguo Wang, Guoshan Li, Junhua Luo, Haiyu Xi & Chao Tian
Magneto-cyclostratigraphy of Late Paleozoic rhythmites from Mafra Formation (Paraná Basin, Brazil)	*Franco, D.R.,* Brandt, D., Hinnov, L.A., Ernesto, M., Rodrigues, P.O.C., Weinschütz, L., Zhao, X.

The Effenberg Quarry – cyclic sedimentation patterns and simplified time relationships of conodont zones (Famennian, Remscheid-Altena Anticline, Rhenish Massif)	*Sven Hartenfels* and Thomas Becker
Cyclostratigraphy of the marl-limestone alternations (Berriasian) in the North-South Axis (central Tunisia): geochronology and chronostratigraphic implications	*Hamdi Omar*, Anne-Christine da Silva, Jihede Haj Massoud, Hela Fakhfakh and Chokri Yaich
The Eocene – Oligocene transition in the southern Tethys: astronomical calibration of calcareous nannofossil bioevents and geochemical changes in northeastern Tunisia	*Jihede Haj Massoud*, Chokri Yaich, Johannes Monkenbusch, Nicolas Thibault

Oral Presentations

The upper Givetian – strange mid-Palaeozoic interval with maximum biostratigraphic time resolution and rapid eustatic fluctuations

Ralph Thomas Becker & Zhor Sarah Aboussalam

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The International Subcommission on Devonian Stratigraphy (SDS) decided in 2006 to subdivide the Givetian formally into three substages. The upper Givetian has been proposed (Aboussalam & Becker 2002) to comprise roughly the time interval of the classical lower Frasnian (do Iα) of the ammonoid-based German subdivision. It is characterized by the rapid radiation of pharciceratid goniatites and, therefore, was named by House (1985) as *Pharciceras* Stufe. The substage base will be placed at the base of the *Schmidtognathus hermanni* Zone, leaving the oldest *Pharciceras* faunas of the Upper Taghanic Crisis Interval (Aboussalam 2003) in the topmost middle Givetian (Aboussalam & Becker 2001, 2011). Thus defined, the upper Givetian had a duration of only 1.4 (Menning et al. 2006), 1.9 (Kaufmann 2006), 2.3 (GTS 2012, Becker et al. 2012), or 1.5 ma (STS 2016, Menning et al. 2017). As emphasized by Brett et al. (2018), and since six conodont and ammonoid zones/subzones can be distinguished within, it was the most "volatile" interval of the Middle Palaeozoic. The average (sub)zonal duration was only 233 to 383 ka, less than a long eccentricity cycle, in comparison to the subsequent Frasnian (460-700 ka, 15 conodont zones/subzones, De Vleeschouwer & Parnell 2004 with 6.9 Ma duration versus GTS 2012 with 10.5 Ma) and Famennian (25 zones/subzones, 532 ka to 620 ka). It must be stressed that there is not a single zircon age for all of the Givetian, which could refine the current, rather variable time interpolations.

The short duration of the upper Givetian fits the extreme condensation of strata (mostly less than 2 m) in pelagic outer shelf carbonate settings. The best conodont and ammonoid successions were described from the Tafilalt Platform of southern Morocco (Aboussalam & Becker 2007, 2011), where all biozones are bound by re-transgression couplets. Comparisons with Europe (Aboussalam 2003) and North America (e.g. Day et al. 2013) suggest a eustatic trigger for most or all of them. The basal upper Givetian deepening is the Geneseo Transgression of the Appalachian Basin. Starting with the global Taghanic Cricis, the upper Givetian "volatile" phase coincided with the re-warming of global climate after a cool lower/middle Givetian interval (Joachimski et al. 2009). Oxygen isotope data are still too limited to recognize the individual warming and transgression times. Sandwiched between the multiphase Taghanic and Frasnes Events, which caused extinctions and facies shifts, reefs flourished globally, for example in the Rhenish Massif, Ardennes, Western Canada, South China, and Western Australia. In the offshore realm, it is highly intriguing that ammonoids suddenly increased exceedingly their septal complexity in

several parallel lineages of the Pharciceratacea (Becker 2009). Accelerated multilobation reflects the optimization of cameral liquid transport and of vertical mobility. This was perhaps a response to increasing and recurrent water agitation, e.g. by stronger storms, which required improved vertical escape mobility. The spread of the oldest forests with large trees, e.g. the Gilboa Forest of the Appalachians, may express a corresponding change of global climate in the terrestrial realm.

Apart from climate-eustatic pulses, the middle/upper Givetian transition was characterized by major synsedimentary tectonic movements and palaeogeographic re-organization, which may have been linked. This is exemplified by the first major phase of Eovariscan block faulting and tillting in the European-North African Variscan Sea, partly linked with a peak of basaltic volcanism (Rhenish Massif; also Timan and southern Siberia), basin starvation and sedimentary gaps (Bohemia, Carnic Alps), by the transformation of the Appalachian Basin into an anoxic sea with dominant black shales, or by the spread of radiolarites (e.g. Montagne Noire, South China). Because of the closely timed, recurrent fluctuations of facies and sea level, the upper Givetian remains a challenge for detailed cyclostratigraphic investigation. Pelagic sections are often too condensed and partly incomplete, thick reef complexes normally lack precise biostratigraphic dating, and seismically induced turbidites mask or erode cycles in adjacent Flinz basins. Orbital tuning of suitable sections would be much welcomed.

High-resolution stratigraphy on the Ordovician strata from southwestern Ordos, China

Shuang Dai[1], Rongxi Li[2], Jiwei Liang[2], Weiguo Wang[3], Anne-Christine Da Sliva[4], Mark Dekkers[5], Junhua Luo[1], Xiaoke Qiang[6], Lei Qiang[1], Chao Tian[1], Haiyu Xi[1], Guoshan Li[3]

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Ordos is located in the western North China block and includes Paleozoic strata which recorded abundant information concerning tectonic and paleoclimatic change. During the last five decades, most studies of the Ordovician in southwestern Ordos focused on the stratigraphy, paleontology, sedimentology, paleogeography and sea level reconstructions. Here we review consensus, progresses and remaining questions.

According to the published literature, Ordos is affiliated to North China and was located through the Early Paleozoic just south of the equator. The SW Ordos was a passive continental margin during the Cambrian and Early Ordovician, and then became a deep-water trench during the Middle - Late Ordovician. The Ordovician strata from SW Ordos can be divided into five Formations: carbonate rocks of the Yeli and Liangjiashan Formations (Lower Ordovician), the Majiagou Formation (Middle Ordovician), and fine clastic rock of the Pingliang Formation and coarse clastic rocks and carbonate rocks of Tangling Formation (Upper Ordovician). These Formations contain graptolite and conodont assemblages, correlatable to global biozones. Subsequently, the formations can be assigned ages between Tremadocian and Katian, this partially corroborated by Zircon U-Pb dating of a tuff in the Pingliang Formation. The paleoenvrionments and lithologies include a muddy-dolostone flat and dolomitic-limestone flat in the Early Ordovician, a carbonate platform in the early-middle Middle Ordovician and a transition to platform fore-slope and deep-water trough settings in the late Middle Ordovician and early Late Ordovician. Depositional setting variations indicate two stages of regression and one transgression, with seven sub-order transgression / regression phases. Carbon isotopic data point to a positive excursion near the boundary between the Pingliang

and Majiagou Formations, and Milankovitch cyclicities were found in Pingliang Formation.

However, a high-resolution paleomagnetic and astrochronology model would allow to propose high-resolution age model to help our understanding details of the paleogeography, paleoceanology and paleoclimate evolution. Our primary magnetostratigraphy and cyclostratigraphy study provide a new insight for these purposes.

Acknowledgement This study was funded by the fundamental research funds for the Central Universities (lzujbky-2017-k27) and contribute to IGCP652.

Astrochronology of the Frasnian–Famennian boundary section (Late Devonian) at Steinbruch Schmidt.

A.C. Da Silva[1], D. De Vleeschouwer[2], L. Percival[3], M. Sinnesael[4], N.J. De Winter[4], P. Claeys[4]

1. University of Liege, Belgium – 2. MARUM Bremen University, Germany – 3. Lausanne University, Switzerland – 4. Vrije Universiteit Brussel, Belgium.

The Late Devonian mass extinction was the second of five global mass extinctions that shaped life on Earth during the Phanerozoic Eon, and occurred at the Frasnian–Famennian boundary (FFB, 372 Ma). Here, we focus on this time interval at the famous Steinbruch Schmidt section in Germany. This section includes the well exposed Kellwasser black shale intervals, the FFB, and a U-Pb dated ash layer. In this study, we sampled an interval of 5.3 m around the FFB, with an average sampling interval of 3 cm, leading to a collection of about 200 samples. On every sample, we measured carbon and oxygen stable isotopes, magnetic susceptibility and micro XRF elemental geochemistry.

Magnetic susceptibility (MS) and detrital-input-related elements such as Ti and Al are higher during the Kellwasser, and there is a good correlation between Al, K, Ti, Fe and MS. $\delta^{13}C$ values are high at and around the Kellwasser levels. We selected the MS, Ti/Al and $\delta^{13}C$ signals for spectral analysis, as we expect these proxies to contain the best-preserved astronomical signal. We applied the technique developed by Meyers (2015) on the evaluation of eccentricity-related amplitude modulation independently to the 3 signals. Obtained results for the 3 signals are exactly in the same range, with a sedimentation rate of 0.47 cm/kyr and it allows the transformation of the signal from the distance domain (5.3 m) into the time domain (about a 1100 kyr). If we filter precession from signal and look at its envelope, we can see a clear modulation by 100 kyr cycle, including 5 to 6 precession cycles, as expected for the Devonian. These results are in agreement with the timing proposed by De Vleeschouwer et al. (2017). Furthermore, as in De Vleeschouwer et al. (2007), we have identified a strong obliquity Power at the FFB, which is associated at Steinbruch Schmidt with a low eccentricity power. This would correspond to a period with low seasonality and could have influenced the development of anoxia. This time frame combined with the dating of the ash layer below the FFB boundary (Percival et al., 2018) provides an anchor point for this cyclostratigraphic framework.

De Vleeschouwer, D., Da Silva, A.-C., Sinnesael, M., Chen, D., Day, J.E., Whalen, M.T., Guo, Z., Claeys, P., 2017. Timing and pacing of the Late Devonian mass extinction event regulated by eccentricity and obliquity. Nature Communications 8, 2268.

Meyers, S.R., 2015. The evaluation of eccentricity-related amplitude modulation and bundling in paleoclimate data: An inverse approach for astrochronologic testing and time scale optimization. Paleoceanography 30, 1625–1640.

Percival, L.M.E., Davies, J.H.F.L., Schaltegger, U., De Vleeschouwer, D., Da Silva, A.-C., Föllmi, K.B., 2018. Precisely dating the Frasnian-Famennian boundary: Implications for the cause of the Late Devonian mass extinction. Scientific Reports 8.

To see or not to see Milankovitch cycles – Example of the Lower Devonian hemipelagic succession from Czech Republic

Da Silva, A.C.[1]; Hladil, J.[2]; Chadimová, L.[2]; Slavík, L.[2]; Hilgen, F.J.[3]; Dekkers, M.J.[3]

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High-resolution time scales are crucial to understand Earth's History in detail. Indeed, precise and accurate temporal relations are essential to link events and their causality. In that context, the Paleozoic timescale still suffers from the largest time uncertainties of the whole Phanerozoic. A better-calibrated time scale would offer more insight into the mechanisms and causes of major biological evolutionary steps, adaptive radiations, mass extinctions and recoveries, as well as pattern of climate changes occurring throughout the Paleozoic. Finding good proxies for climatic cycles is essential, but diagenesis can have a strong impact on most of these proxies. In various cyclostratigraphic studies, the fit of spectral peak ratios with those of the orbital cycles, is classically used as an argument for a preserved climatic signal.

Magnetic Susceptibility (MS) is often-used in sedimentary rocks for correlations, paleo-sea level or paleo-climatic reconstructions and cyclostratigraphy, based on the link between MS and detrital input (influenced by sea level and climate). MS is a very attractive proxy parameter, because data acquisition is straightforward enabling the creation of high resolution records. However, the interpretation of MS records in terms of depositional environment can be less straightforward because MS is a convolved signal potentially mixing the desired climatic information with undesired contributions representing other geologic phenomena (during deposition or after).

The Pod Barrandovem section, from Czech Republic, recorded Pragian and Emsian (Lower Devonian) hemipelagic sediments. A complete high resolution MS record was generated and clear cyclicities are identified through spectral analysis of this MS record (Da Silva et al. 2016). The Praha Formation spans the first 172 m of the section and magnetic hysteresis results from this Praha Formation indicate a primary magnetic susceptibility signal, mostly carried by clay minerals. Following this and according to the fit between some of these cycle spectral ratios with orbital targets, these cycles were interpreted as Milankovitch cycles, leading to propose a precise duration for the Praha Formation. The portion of the section between 174 and 292 m corresponds to the Zlichov Formation and hysteresis results indicate a much more complicated magnetic susceptibility signal, carried by various ferromagnetic minerals. This probably means that the observed cycles are not related to Milankovitch cycles, despite the occurrence of similar spectral peak ratios than the orbital targets.

Da Silva, A.C., Hladil, J.; Chadimová, L.; Slavík, L.; Hilgen, F.J.; Bábek, O.; Dekkers, M.J. (2016) Refining the Early Devonian time scale using Milankovitch cyclicity in Lochkovian–Pragian sediments (Prague Synform, Czech Republic). Earth and Planetary Science letters. 455, 125-139

Timing and pacing of the Late Devonian mass extinction event regulated by eccentricity and obliquity

David De Vleeschouwer, Anne-Christine Da Silva, Matthias Sinnesael, Daizhao Chen, James E. Day, Michael T. Whalen, Zenghui Guo & Philippe Claeys

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The Late Devonian envelops one of Earth's big five mass extinction events at the Frasnian–Famennian boundary (374 Ma). Environmental change across the extinction severely affected Devonian reef-builders, besides many other forms of marine life. Yet, cause-and-effect chains leading to the extinction remain poorly constrained as Late Devonian stratigraphy is poorly resolved, compared to younger cataclysmic intervals. In this study we present a global orbitally calibrated chronology across this momentous interval, applying cyclostratigraphic techniques. Our timescale stipulates that 600 kyr separate the lower and upper Kellwasser positive $\delta^{13}C$ excursions. The latter excursion is paced by obliquity and is therein similar to Mesozoic intervals of environmental upheaval, like the Cretaceous Ocean-Anoxic-Event-2 (OAE-2). This obliquity signature implies coincidence with a minimum of the 2.4 Myr eccentricity cycle, during which obliquity prevails over precession, and highlights the decisive role of astronomically forced "Milankovitch" climate change in timing and pacing the Late Devonian mass extinction.

Devonian (ca. 388-375 My) Horn River Group of Mackenzie Platform (northwestern Canada) is an open-shelf succession recording global anoxic events

P. Kabanov[1]

1. Geological Survey of Canada – Calgary, Canada

At least four horizons of enhanced anoxia (AHs) are recognized in the latest Eifelian – Middle Frasnian mudrock-dominated strata of the Mackenzie Valley and Peel area of NW Canada (Fig. 1). Alumina-normalized Mo and U logs in two cored sections reveal the **AH-I** at the Eifelian/Givetian boundary, **AH-II** in basal Frasnian, and **AH-III** and **AH-IV** bundled in the Middle Frasnian interval (Fig. 1). These four horizons are characterized by attenuated siliciclastic components. Spectral gamma-ray K+Th, U[gAPI], and U_n (K-normalized U[gAPI]) are the best tools to trace these horizons in wells and outcrops. AHs are biostratigraphically correlated with "black-shale events" in several basins of the world. Depositional environment is depicted as a stratified basin where the water-column chemocline defined time-specific sedimentary pattern with anoxic mudrocks in topographic lows and oxic, argillaceous-carbonate facies and isolated carbonate banks on seafloor elevations. Based on 1687 ICP* elemental data, siliciclastics-lean basinal mudrock units that host AHs are strongly enriched in Mo (median EFMO*~97-172 EFMo/EFU*≈3-3.5 X SW*) compared to siliciclastic-rich units (median EFMO~17-37) and show strong EFU/EFMo covariation ($r \approx 0.8$ in Canol Formation and Bluefish Member). Supported by a lack of geological evidence for an oceanographic barrier, this enrichment indicates unrestricted water exchange with Panthalassa. At the same time, development of oligotrophy is indicated by a lack of P enrichment and weak to non-existent enrichment in Zn and Cu. These features are reconciled through the model of Kidder & Worsley (2010), which involves a global shift to a warm greenhouse mode with slowed oceanic convection, expanded OMZs, and a failure of nutrient resupply from upwellings. The onset of mass degassing in continental LIPs* represents a potential trigger for this mid-Devonian shift. Devonian black-shale events in this scenario represent genuine OAEs* marking hothouse episodes in their nascent form.

*Acronymy: ICP = induced coupled plasma; EFMo and EFU = Al-normalized Mo and U in enrichment factor notation; SW = average present-day seawater values; LIPs = large igneous provinces; OAEs = oceanic anoxic events

Kabanov, P. In press. Devonian (ca. 388-375 My) Horn River Group of Mackenzie Platform (northwestern Canada) is an open-shelf succession recording oceanic anoxic events. *Journal of the Geological Society of London*

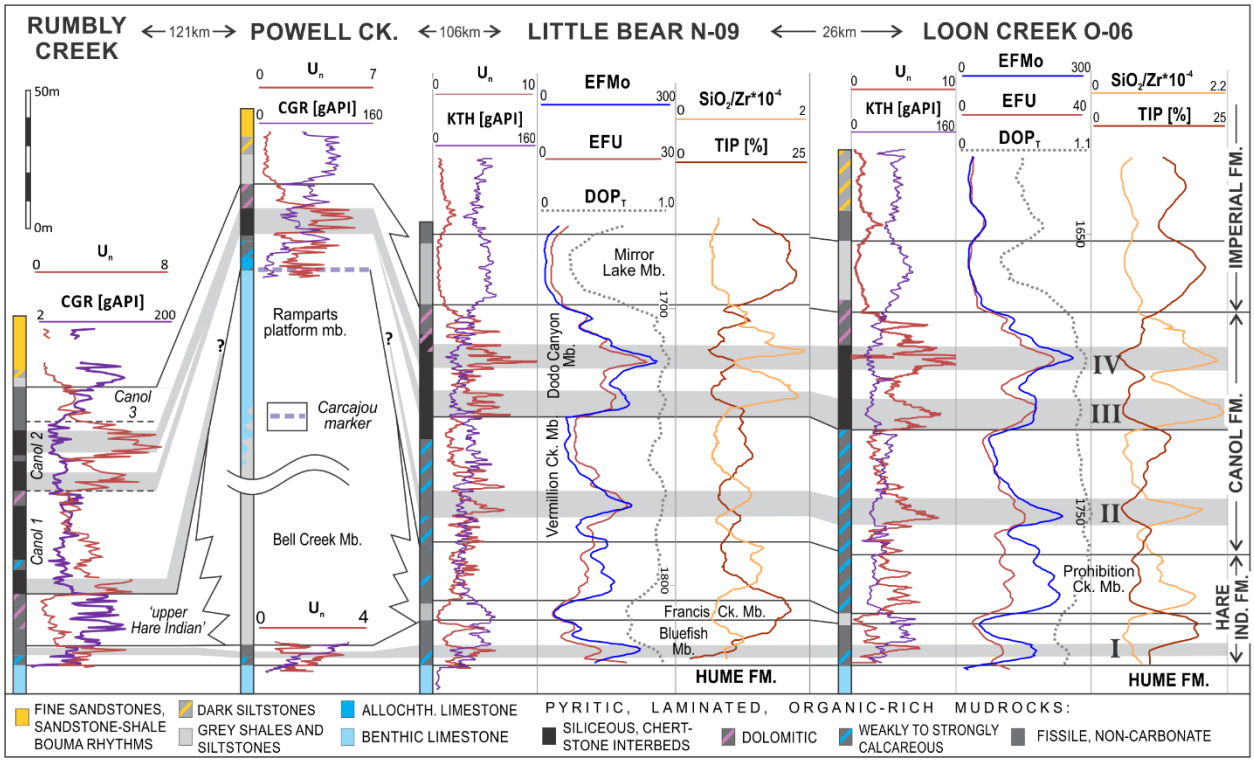

Figure 1. Anoxic horizons (I-IV) revealed by lithogeochemical proxies in Little Bear N-09 and Loon Creek O-06 wells and their SGR correlation in Powell Creek and Rumbly Creek outcrop sections. Lithogeochemical logs are smoothed by LOWESS regression with α-tension 4%;

Divers depositional and geochemical signature of the Frasnian/Famennian (F/F) global event in the western Thailand, as a record of Paleotethyan vs. Western Australian geotectonic affinities

P. Koenigshof[1], G. Racki[2], Z. Belka[3], J. Dopieralska[4], A. Pisarzowska[2]

1. Senckenberg Research Institute and Natural History Museum Frankfurt, Germany – 2. University of Silesia, Poland – 3. Adam Mickiewicz University, Poland – 4. Adam Mickiewicz University Foundation, Poland

The Frasnian-Famennian boundary beds are overall characterized by the co-occurrence of two particular dark, organic-rich shaly-limestone Kellwasser (KW) levels. The Upper KW determines a global biotic event, corresponding to a major ecosystem perturbation at the F-F boundary, as a dramatic final of the stepwise Kellwasser Crisis. Recently this biotic crisis and resulting disruption of epeiric carbonate factory (in particular a total collapse of metazoan reefs) is thought as a mass depletion of marine diversity resulted mainly from lowered origination rate (see Stanley 2016 and references therein).

In the western part of Thailand, Upper Devonian rocks are represented mainly by pelagic or hemipelagic limestones. Two sections, the Thong Pha Phum section (TPP) and the Mae Sariang section (MS) were reliably dated by conodont faunas, and combined with geochemical and microfacies/sedimentology data, including the key carbon isotopic signature (Savage et al., 2006; Dopieralska et al., 2012; Königshof et al., 2012; Savage, 2013). This high-resolution bio- and chemostratigraphical framework enables study of elemental inorganic geochemical signatures across the Frasnian-Famennian (F-F) boundary.

The studied Thai sections differ significantly in their geochemical signature, partly only explainable by more marly character of limestones from Thong Pha Phum. The more condensed MS record generally corresponds to the worldwide event-chemostratigraphic F-F pattern even if only brief-lasting anoxic conditions are recognizable in the key crisis timespan in the succession without dark, organic-rich intercalations. The TPP section shows specific characters: (a) the C-isotope positive excursion, determining the Upper Kellwasser level, is peculiarly two-staged, with a distinctly lower amplitude (below 1.5‰) and a highstand plateau prolonged to the Late *triangularis* Zone, and (b) elemental proxies point to only oxic and probably largely oligotrophic conditions during the both KW intervals. The distinctiveness of TPP section clearly indicates its affinity with the Western Australian shelf successions, characterized by well-known “atypical” record of the F-F global event (George et al., 2014; Hillbun et al., 2015). The Thai sections point primarily to tectonically driven episodes of distinctly increased and coarse-grained terrigenous

delivery in the KW Crisis time. Potential volcanic record is limited to hydrothermal signals in the Paleotethyan domain only, proved also by some Hg enrichments.

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Tracing palaeoredox conditions across the Devonian-Carboniferous boundary event: a case study from carbonate-dominated settings of Belgium, Czech Republic, and northern France

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The Devonian-Carboniferous boundary (DCB) was coeval with Hangenberg Crisis that is regarded as first order mass extinction event related with severe sea-level changes and widespread anoxia. This study aims with tracing of geochemical palaeoproductivity and palaeoredox proxies across the Devonian-Carboniferous carbonate-dominated successions of the Namur-Dinant Basin (Belgium, northern France) and the Moravo-Silesian Basin (Czech Republic), located in the Variscan Rhenohercynian Zone. Namur-Dinant Basin sections Gendron-Celles and Les Ardennes expose carbonate ramp limestones and marls and Moravian Karst section Lesní lom consists of carbonate slope limestones and marls around the DCB. Our research was focused on distribution of the main oxides (SiO_2, Al_2O_3, Fe_2O_3, CaO, Na_2O, K_2O, TiO_2, MnO) and trace elements (Th, U, V, Zr, Mo, Zn, Pb, Ni, Cu) measured by ICP-OES (inductively coupled plasma optical emission spectrometry) and ICP-MS (inductively coupled plasma mass spectrometry), respectively. In total 89 samples were grounded and analyzed. As main palaeoredox proxies were used enrichment factors of Mo and U and their ratios, whereas enrichment factors of Zn, Cu, Pb and Ni were employed for tracing of palaeoproductivity changes. Enrichment factors were calculated as Al normalized element concentrations relative to the post-Archaean Australian Shale (PAAS).

High values of Zr/Al_2O_3 (> 0.001), Ti/Al (> 0.06), Fe/Ti (> 20) and low values of Al/(Al+Fe+Mn) (< 0.35) coinciding with increase of palaeoredox proxies suggest possible volcanic and hydrothermal source of nutrients, related to Late Devonian and Early Carboniferous extensional magmatism in the Rhenohercynian domain. Relationship between higher palaeoproductivity and enhanced continental runoff of volcanic material cannot be excluded. Succession of the Gendron-Celles and Les Ardennes sections reveal three levels with similar vectors of Mo and U enrichments. The upper Fammenian pattern is typical for weakly restricted basins with Fe-Mn redox cycling accompanying vertical fluctuations of the oxic/anoxic chemocline close to the sediment/water interface and with the influence of particulate shuttle. The uppermost Famennian Mo_{EF} and U_{EF} patterns corresponding to the unrestricted or weakly restricted basin with alternating suboxic to anoxic conditions, possible related with the transgressive Hangenberg Black Shale Event. The lower Tournaisian Mo_{EF} and U_{EF} fall along a vector in the direction of the strongly restricted marine conditions with prevailing suboxic conditions.

In the Moravo-Silesian Basin (Lesni lom section), upper Famennian Mo_{EF} and U_{EF} vector indicates the unrestricted marine trend which converges with that of restricted systems. Redox conditions range from suboxic to euxinic. In the Tournaisian, Mo_{EF} and U_{EF} oscillate between oxic and anoxic conditions and fall along a vector of the strongly restricted marine conditions. Increased isolation of both

studied basins during the Early Tournaisian is regarded as reflection of significant eustatic fall during Hangenberg Crisis linked to a severe episode of Gondwana glaciation.

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The Givetian (Middle Devonian) in the Spanish Central Pyrenees: conodont high-resolution biostratigraphy as a basis for testing the ties of biological and environmental evolution to astronomical forces

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The Givetian is related to at least four major Events/Episodes whose ultimate causes are unknown. Also, numerous sea-level oscillations are recorded around the world and it seems that some of them, if not all, could be globally correlated. Their relation to Milankovitch-induced high order cycles still needs to be tested. Analysing the variety of environments recorded in Givetian strata would facilitate a better comprehension of the Earth System.

One of the main current challenges is the arrangement of all these happenings in different parts of the world, their scaling and subsequent due correlation. In this context, conodont high-resolution bio-chronostratigraphy plays a pivotal role and has become an essential tool. For instance, current studies in the Pyrenees have demonstrated a new transgressive phase within the late Taghanic Event. Also, conodonts provided recognition of two phases within the Kačák Episode. Such kind of improvements can only be achieved after a fine standard of reference is built and detailed studies in different regions can be related to this scale.

Ongoing research in the Pyrenees is based on conodonts high-resolution bio and chronostratigraphy. The Pyrenean conodont succession supports the threefold subdivision of the Givetian Stage into substages and identifies all the standard conodont zones, allowing integration of Pyrenean data into a global frame and adding an extra value for multidisciplinary studies. The conodont zonal subdivision combined with facies studies has already laid out a local T-R pattern for a Pyrenean section. This shows the potential of Givetian strata in the Pyrenees for further multidisciplinary studies, including those pertinent to IGCP-652 major goals and for contributing to a better understanding of the history of Earth.

Givetian strata measured between 30-40 ms and are studied in two different geological settings (basins?). Most sections are composed of reddish-pinkish and light grey nodular and platy limestone, with thin and thicker, sometimes massive, beds. A different section is composed of limestone with subordinated marl beds and few nodular beds.

Within the Givetian most faunal diversification, innovation and radiation events are clearly age-constrained. Now, we have the opportunity to link these biotic changes to major phenomena. The Pyrenean sequences facilitate the integration of already fine conodont biostratigraphic scale with other tools, as the envisaged in the IGCP-652, with the intention of improving the Givetian time scale. This in turn will help to document the biological and environmental evolution and changes and their possible links to astronomical forces.

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Upper Katian Cyclostratigraphy of the Vauréal Formation, Anticosti Island (Gulf of St. Lawrence, Canada)

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Anticosti Island (Gulf of the St. Lawrence, Canada) has some of the most complete, thickest and most richly fossiliferous carbonate successions in the world containing the Ordovician-Silurian boundary. This study focuses on the cyclostratigraphy of the upper Katian Vauréal Formation. Data from both continuously exposed coastal sections (West End) and complete stratigraphic drill cores (NACP and Laloutre cores) contains high-resolution (dm-scale) proxy profiles of natural gamma ray (NGR) profiles, handheld X-Ray Fluorescence (pXRF) measurements and bulk carbonate stable isotope values of oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$). Outcrop and core data are correlated using the high-resolution lithological logs and $\delta^{13}C$ profiles. Time-series analysis of the proxy series demonstrates meter-scale periodicities in lithological alternations (carbonate versus clay content), which are hypothesized to result from sea-level variations or variations in the supply of detrital material. Similar periodicity patterns can be seen in the $\delta^{18}O$ stable isotope data. The available age constraints (bio- and chemostratigraphy), indicate that the primary observed periodicities are in the order of the astronomical periods of precession and obliquity. The main periodicity (5-9 m) is on a larger scale than the typical tempestite alternations (dm-scale) and is thus probably not representing single events (e.g. storm deposits) or pure diagenetical features, but long term changes in carbonate versus clay in the local paleodepositional system. One working hypothesis is that astronomical changes in insolation were driving sea-level variations by the waxing and waning of the Late Ordovician ice sheets. An alternative hypothesis suggests changing detrital input into the basin (e.g. driven by a monsoonal system) altering the carbonate versus clay content. Ongoing signal processing investigations can shed light on long-term amplitude modulations of the proxy records – which can help determining the precession and/or obliquity driven nature of the records. Our results demonstrate the potential for constructing a high-resolution age model (down to the order of ten thousand years) for the Vauréal Formation and other similar formations on Anticosti Island. Such an astronomically based age model and corresponding climatic interpretations should shed more light on the dynamics of the Late Ordovician glaciations and the mass extinction event.

Cross recurrence plot analyses of conodont community turnover – a model free, continuous, high-resolution correlation tool

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Conodonts are a cornerstone of the biozonation based stratigraphy of the Paleozoic era and the Triassic period. Their high preservation potential, wide environmental distribution, and co-occurrence with other time-significant taxa, makes them ideal tool for integrating all sorts of stratigraphical information in to the coherent geochronological framework. Traditional stratigraphy, including quantitative stratigraphy, uses only first and last appearances of relatively short-lived species and sub-species of conodonts. On the other hand there is plenty of other time-specific information which can be obtained from conodont samples – i.e. their abundance, diversity, and compositional similarity. Usually these types of information are used in eco-stratigraphical applications, such as faunal gradient analysis, mostly in qualitative fashion in the stratigraphical correlation approach.

Here we present cross-recurrence plot and conodont community composition based stratigraphical correlation approach. Cross recurrence plots are binary filtered similarity matrices between two stratigraphical time series where black points represent similar states, and white dissimilar states. The diagonal trending black points are of preeminent importance, since they suggest similarities in compositional evolution of paleocommunities at two compared sites. The major task for the quantitative correlation is to find optimal monotonically increasing path (correlation line) through the cloud of recurring states. In this contribution we explored two approaches in the search of optimal correlation (synchronization) lines: namely classical dynamical time warping (DTW) approach, and a new approach which we termed moving window median (MWM) recurrence point search algorithm. Additionally we treated the primary conodont diversity data in two ways – as raw composition and as reduced multivariate non-metric multidimensional scaling (NMDS1) scores.

The presented approaches were tested on four core section from the Lithuanian part of the Silurian Baltic basin spanning from upper Homerian to the end of Ludlow. The quantitative correlation patterns were tested against traditional conodont zonation and $d^{13}C$ trends. It was found that in all four cross recurrence based correlation approaches which used conodont community compositional data (two synchronization line search methods * two data representations) shown expected correlation pattern just with the higher detail. The best results were obtained using NMDS1 scores as the compared variable and both DTW and MWM as synchronization line searching methods.

Therefore our results prove the potential for using conodont community compositional trends in high-resolution correlation in a cross recurrence plot synchronization line search framework. It has the advantage over some other approaches, such as cyclostratigraphy, in non-requiring specific statements about the mechanisms of the common forcing in several sections. This approach could serve well in the complicated situations (as exhibited by our studied sections) where abundant hiatuses, diastems, and significant sedimentation rate variations could be present.

The Lochkovian (Lower Devonian) in the Spanish Central Pyrenees: conodont high-resolution biostratigraphy as a basis for integrating Events, oceanic, climatic changes and Milankovitch cycles

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Lochkovian (Lower Devonian) strata from eight selected sections in the Spanish Central Pyrenees have proved to be instrumental for globally subdividing the Lochkovian into substages. Besides, the fine bio-chronostratigraphic subdivision provided by the record of several evolutionary conodont lineages supports the most detailed zonation and even further subdivision of zones. This in turn foster accurate global correlation, that for some intervals is estimated to be under 200 ky. Most sections are interpreted to be deposited in a hemipelagic carbonate ramp, where shallow water facies below storm wave base are common. The lower part of the Lochkovian in most sections shows dominant black shale and limestone, which were deposited in a calm shallow marine euxinic environment. Overlain sediments clearly mark an augment in oxygen content. Finally at the end of the Lochkovian a sea level fall is recorded. This change from euxinic to more oxygenated sediments happens after the entry of the first *Ancyrodelloides*, *Anc. carlsi*, however, the exact timing on this Geoevent seems to be diachronous in the Pyrenean sections. The subsequent rapid evolutionary steeps within *Ancyrodelloides* (up to seven species in less than 3 My), combined with the innovation and evolutionary steeps of the genera *Lanea*, *Flajsella* and *Masaraella* and complemented with records of *Icriodus* and *Kimognathus* supports the finest subdivision of middle Lochkovian strata and subsequent global correlations. Middle Lochkovian is characterised by well-bedded limestone (form 5-20 cm thick) with shale-marl inter-bedded (2-4 mm thick). The upper Lochkovian is not as detailed subdivided as the middle Lochkovian, but evolutionary steeps of *Masaraella* and *Pedavis* and an innovation within the genus *Icriodus*, provide enough detail for global correlations. The lithological pattern is comparable to the middle Lochkovian (limestone-marl/shale alternation) but increasing the limestone thickness. Initial studies on magnetic susceptibility in two sections help testing correlations independently.

This integration of high-resolution biostratigraphy, Geo and BioEvents, well-bedded limestone-marl (shale) alternation pattern, inferred sea level changes gives the Pyrenean sections one of the best conditions for initiating detailed cycle-stratigraphic techniques aiming at analysing the role of astronomical factors in the changes already observed in the Pyrenean sections. The development of the IGCP-652 project would be a good opportunity to start with the construction of an astronomically constrained relative time scale for the Lochkovian, and the Pyrenees offer good conditions for initiating such integrative studies.

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Magnetic polarity time scale for the Devonian…?

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The Earth's magnetic field is hypothesised to have a 'heartbeat', of varying intensity, with a period of 200 million years. A stronger magnetic field is generally associated with magnetic superchrons, periods of millions of years in which the magnetic field is extremely stable, and there are no reversals of the magnetic poles of the earth. On the other hand, a weak field is associated with many reversals. This hypothesis relies heavily on the behaviour of the magnetic field during the Devonian. The 'heartbeat' hypothesis predicts a weak field for this time, with a high reversal frequency. Currently, the Devonian is a relatively unconstrained period of the global polarity time scale, most likely due to the weak field and high reversal frequency. Constraining the global polarity time scale (GPTS) and reversal frequency for the Devonian is crucial for the understanding of magnetic field behaviour, and construction of the GPTS provides a valuable tool for age determinations of other studies.

We performed a pilot magnetostratigraphy study on samples of two quarries in the south of Poland, near the city of Krakow. The quarries contain a record of latest Devonian-earliest Carboniferous carbonates, which are correlated to the Dinantian of Belgium based on foraminifer and coral biostratigraphy. In total 98 specimens were subjected to thermal and alternating field demagnetisation at the paleomagnetic laboratory of Utrecht University.

Intensities of the magnetic signal were extremely low, in the order of tens of microamperes per meter. Demagnetisation behaviour is not straightforward, with many samples showing demagnetisation along great-circle paths. Most samples show a strong reversed Permo-Carboniferous reverse (Kiaman superchron) overprint, which in some cases cannot be removed. Around 40 percent of the samples shows directions that we interpret as most likely representative of the geomagnetic field at the time of deposition, both normal and reversed directions are present. This indicates that magnetic polarity stratigraphy might be possible in the Devonian, provided that sections have low enough thermal maturity. Our project is currently extending the Czatkowice quarry record to higher density sampling and younger (Tournaisian and Viséan) rocks.

We would like to make a callout to the Paleozoic community to notify us of additional low thermal maturity sections (ideally showing conodont alteration indices up to 2) in order to extend the magnetostratigraphic record further back into the Devonian.

Impact event stratigraphy: lessons from Paleozoic craters, Chicxulub and the K-Pg boundary deposits

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Extraterrestrial impacts are fundamental processes that shape the rocky planets. Well-studied marine impact craters, including Paleozoic examples, provide a wealth of information about impacts and resulting deposits. These catastrophes produce event deposits over timeframes that defy even the most precise age dating methods. Examination of the Ordovician Tvaren and Lockne craters provides insight into processes in newly excavated craters implying the following series of events: 1) Collapse of the transient crater/water cavity and initial resurge of water, 2) Radially resurging water produces a central water plume, 3) Collapse of the central water plume causes outward radiating anti-resurge, 4) Anti-resurge and reflected waves travel as tsunami and seiches in the open ocean. These processes result in a series of deposits that form within minutes followed by a series of waning current deposits over days to perhaps years post-impact.

Recent work on IODP-ICDP Expedition 364 core, Chicxulub crater, provides insight into these processes. Core was recovered from 505.7-1334.7 m below seafloor (mbsf), penetrating Paleogene sediments, impact breccias, melt-rock, and granitic basement. The impact breccia and overlying transitional unit record the catastrophic events resulting from the impact and subsequent processes. The lower breccia (>705 mbsf) is interpreted as debris flows similar to volcanic pyroclastic flows. The upper breccia, records a remarkable succession of 25 graded packages that fine upward from coarse pebble-to-sand size clasts and then sand to silt-clay-sized material. These are interpreted as the result of resurge, anti-resurge, and tsunami. The transition between breccia and Paleocene sedimentary rocks is an ~80 cm thick series of 39 mm-cm thick, dark/light, fining-upward, carbonate-rich couplets with scoured bases. Maximum grain-size decreases from ~6 mm (base) to 0.25 mm (top) indicating waning current deposition with velocities of 100-25 cm/s. At post-impact water depths (~650 m) the only types of currents capable of moving such grains would likely be tsunami, seiches or potentially storm currents. Attempts to gauge the duration of the transitional unit provide little constraint. It contains a mix of Cretaceous foraminifera and nannofossils (K-Pg boundary cocktail) and the first Danian fossils in overlying limestones indicate Paleocene zone Pa, estimated at ~30 kyrs post-impact. We utilized the abundance of ^{3}He, a common accumulation rate proxy, to improve constraints. ^{3}He implies a maximum duration of 8 kyr but assuming even a small amount of ^{3}He reworking indicates a duration below the proxy's resolution, <~1 kyr. Settling velocity calculations (minimum grain size ~2 mm) yield a duration of ~6 years. Given the sedimentary features it is unlikely it was deposited through settling alone. It appears to record the final waning of impact energy, tsunami and seiches. One additional clue is within fine-grained deposits near the top that indicate ejecta from the impact that atmospheric modeling implies would settle in 2-3 years, providing the shortest-term estimate for the transitional unit. Marine impact craters record a remarkable series of events related to the

dissipation of energy imparted by the impacts and the well preserved deposits at Chicxulub provide a unique insight into these dynamic and geologically short-lived processes.

Poster Presentations

Refining the end of the Late Paleozoic Ice Age – LPIA in the Paraná Basin, southern of Gondwana

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The Paraná Basin is a Paleozoic-Mezosoic intracratonic basin located in the southern Gondwana. It records the most spatially and temporal extensive icehouse, the Late Paleozoic Ice Age – LPIA. The Capané is one of the several paleovalleys on the Rio Grande do Sul shield, in the southern border of the basin, which have been interpreted as carved by LPIA glaciers. It preserves striated pavements indicating that the ice flowed northward, and a sedimentary infill composed of glacial-influenced and post-glacial deposits of the Itararé Group and Guatá Group, respectively. The Itararé Group lithologies are diamictites, conglomerates, sandstones, varve-like rhythmites, and mudstones, with dropstones in the fine-grained facies, and striated, faceted and bullet-shaped pebbles, cobbles and boulders in diamictite. A few radiometric datings and palynological studies suggest that the Itararé Group has been deposited between Kasimovian (Carboniferous) and Sakmarian (Permian), although several radiometric dating in the post-glacial deposits of the Rio Bonito Formation (Guatá Group) shows that the deposition of this unit is likely constrained to the Carboniferous. This study presents a high precision U-Pb radiometric dating for an ash fall sample collected in the uppermost Itararé Group, in the Capané Paleovalley, southern Paraná Basin (Rio Grande do Sul, Brazil). Ten of the youngest zircon grains analyzed by Cagliari et al. (2016) by LA-ICP-MS were selected. The analytical procedure includes thermal annealing, chemical abrasion and chemical dissolution of individual zircon crystals (Mattinson, 2005), followed by ion exchange chromatography, and U and Pb isotopic measurements made on a multi-collector thermal ionization mass spectrometer. The radiometric age obtained is younger than the one published before by Cagliari et al. (2016) but still constrain the end of the LPIA in the southern Paraná Basin to the Carboniferous. The result reaffirms that the whole of the Itararé Group in the southern basin was deposited during the Carboniferous. Comparing glacial and post-glacial deposits of the southern Paraná Basin with the Paganzo and Karoo basins indicates that the end of the Late Palaeozoic Ice Age is asynchronous thought the southern Gondwana.

The Devono-Mississippian Besa River Group of Liard Basin, Canada: stratigraphy of a world-class shale gas resource

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Canada requires new, globally competitive domestic energy sources while moving towards lower carbon and renewable energy sources. The stratigraphic knowledge is part of fundamental geoscience which is critical in accurate assessment of unconventional hydrocarbon resource (shale plays) and is transferable to other sources of energy such as geothermal and groundwater. As such, the applicability and importance of this research line up with similar projects around the world and remains key to energy sustainability.

The Middle Devonian to Middle Mississippian Besa River Group in the Liard Basin of northwestern Canada is a distal, shale-dominated succession that is time equivalent to thousands of metres of more proximal carbonates, shales, and sandstones spanning the Fort Simpson to Mattson formations. Petrophysical logs allow the recognition of specific formations within northeastern subsurface occurrences of the Besa River Group, but this is not possible in the western outcrop and subsurface belt where the unit remains at formation level.

The Besa River Group contains 6,196 x $10^9 m^3$ of marketable, dry gas within organic-rich shales of the Exshaw Formation and Patry interval. These units define an over 200 m thick, 20 to 30 km wide, north-northeast trending zone in the eastern Liard Basin. These siliceous shales occur at over 5 km depth, producing over-pressured reservoirs and resulting in prolific wells when stimulated through hydraulic fracturing.

The Famennian Patry shales are basinal equivalents of upper Kotcho ramp carbonates and calcareous shales, which in turn transition eastward into Wabamun Formation shelf carbonates. The upper Patry interval was deposited during a late Famennian to early Tournaisian second-order transgressive-regressive sequence. Transgression culminated with deposition of the lower Exshaw black shale and chert, whereas the subsequent regression is recorded by the overlying upper Exshaw and overlying Banff Formation Organic-carbon-rich Patry shales reflect establishment of anoxic bottom waters within deep, basinal environments. These anoxic conditions spread across much of the Western Canada Sedimentary Basin as transgression peaked during deposition of the lower Exshaw.

Convergent plate tectonism, and subsequent back-arc extension, occurred along the western edge of Ancestral North America during the latest Devonian and Mississippian. Compression and subsequent extension influenced deposition within Liard Basin and grabens within the Peace River Embayment. Felsic tuff layers within the Exshaw Formation and Patry interval are a reflection of the western convergent tectonism, plutonism, and volcanism. The dating of these tuff horizons is ongoing

and will help constrain the absolute timing of the second-order transgression represented by the Patry and Exshaw . This will further our understanding of this major marine late Famennian to early Tournaisian anoxic event that included the latest Famennian Hangenberg event.

Magneto-cyclostratigraphy of Late Paleozoic rhythmites from Mafra Formation (Paraná Basin, Brazil)

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The significant lack of paleontological, palynostratigraphic and radiometric data has led to a historically poor chronostratigraphic framework for the rhythmites of the Itararé Group (Paraná Basin, Brazil), which corresponds to one of the main Paleozoic glaciation sequences of the Gondwana supercontinent. This is particularly challenging given the scarcity of paleomagnetic data for the Carboniferous, the uncertainties regarding the APWP curves for the South American Plate during the late Paleozoic, and the predominance of the Kiaman Reversed Superchron throughout the most of Permian-Carboniferous times. In this context, the identification of Milankovitch forcing components along the stratigraphic profiles could provide important clues about the elapsed time for the accumulation of these rhythmic deposits, and if sufficient the means for eliminating the secular variation.

In this work, we conducted a magneto-cyclostratigraphic study based on magnetic susceptibility (MS) and anhysteretic remanent magnetization (ARM) datasets carried out on a ~ 360 cm thick rhythmite section of the Mafra Formation (Itararé Group). Spectral analysis was conducted with multitaper method (MTM) spectral estimator associated with a classical red-noise null model, and stability of the detected frequencies was evaluated with evolutionary fast Fourier transform (FFT) analysis. Potential astronomical forcing was tested identification of frequencies corresponding to the orbital eccentricity, obliquity and precession index predictions for the Upper Carboniferous-Lower Permian interval (~ 300 Ma) by Berger and Loutre (1994). The MTM power spectra for the MS and ARM datasets exhibit spectral peaks indicative of variable sedimentation rate, and supported by the evolutionary FFT analysis, nonetheless suggestive for a potential Milankovitch signal, especially for the ARM series. Our findings suggest that the Mafra section may comprise 6-7 short orbital eccentricity cycles and hence a duration of 600-720 k.y.

Reassessment of the Lower Devonian and lower Middle Devonian conodont biostratigraphy in the Northwest Territories, Canada: changes in the time-rock chart for the northern Mackenzie Mountains and adjacent plains

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The Lower Devonian and lower Middle Devonian in the northern Mackenzie Mountains is a succession of dolostone, limestone breccia and massive limestone with minor basal sandstone. The basal Delorme Group onlaps underlying Lower Silurian dolostones with a locally angular unconformity. The entire Lower Devonian represents a peritidal carbonate platform and evaporite – carbonate alternation occurs in the platform interior in the eastern part of the study area (Mackenzie Plain). The Lower Devonian peritidal carbonates grade upward into subtidal variously argillaceous and richly fossiliferous limestones of the Eifelian Hume Formation. Based on new field data and a restudy of GSC-Calgary conodont collections, the time-rock chart for this succession is updated to the current conodont biozonation.

The oldest Devonian deposits, the Delorme Group (Tsetso and Camsell formations) span the interval between the end of the Silurian and the end of the Lochkovian and overlie the sub-Devonian unconformity. The Tsetso Formation quarzarenite, a transgressive peritidal sandstone, represents the onset of the Devonian transgression in the study area and is locally followed by the brecciated dolomudstones and interbedded anhydrites of the Camsell Formation. Conodont material from the Delorme Group is very rare, only one sample from the Camsell Formation provides enough material and indicates a Lochkovian (*eurekaensis* to *delta* zones) age.

The Delorme Group is separated from the overlying Bear Rock Assemblage by an abrupt change from calcareous sandstone to clean limestone and dolostone. The Bear Rock Assemblage comprises the Bear Rock, Arnica and Landry formations. The crystalline, distinctly banded dolostone of the Arnica Formation and the overlying crystalline limestone of the Landry Formation pass laterally into the brecciated limestone and dolostone of the Bear Rock Formation. Conodont data from the Bear Rock Assemblage reconnaissance samples in the Colville Hills assign the strata to the *dehiscens* to *costatus* zones (lowermost Emsian to lower Eifelian). Arnica reconnaissance samples from the northern Mackenzie Mountains point to the lower Emsian (*nothoperbonus-inversus* zones). Samples from the Landry Formation contain a conodont fauna with a range from the lower Emsian to the lower Eifelian (*excavatus* to *costatus* zones).

A new transgressive pulse formed of the lower unit of the Hume Formation is marked by the deposition of argillaceous limestone and shale (Headless Member)

indicating a slight deepening of the environment. The upper unit of the Hume Formation is a fossiliferous thin- to thick- bedded platform limestone. Four sections were sampled through the Hume Formation in the mountain front of the northern Mackenzie Mountains, allowing a detailed conodont biostratigraphy that indicates a middle to upper Eifelian (*australis* to *ensensis* zones) position for the Formation (Uyeno *et al*. 2017). The drowning of the Hume platform is marked by the onset of the black shales of the Bluefish Member (Hare Indian Formation) in the *ensensis* Zone.

Uyeno, T. T., Pedder, A. E. H. & Uyeno, T.A., 2017. Conodont biostratigraphy and T-R cycles of the Middle Devonian Hume Formation at Hume River (type locality), northern Mackenzie Mountains, NWT, Canada.

Identifying cyclicities in different types of data series: a study of the Carboniferous rhythmites of the Itararé Group, Paraná Basin

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The Itararé Group records the end of the "Late Paleozoic Ice Age" (LPIA) in the Paraná Basin, southern Brazil. In the southernmost part of the Paraná Basin, glacial conditions are evidenced mainly by the presence of mudstones and varve-like rhythmites with dropstones, and diamictites with striated, faceted and bullet-shaped pebbles, cobbles and boulders, besides striated pavements. It is known that glacial and interglacial periods are controlled by insolation changes caused by orbital cycles related to variations of Earth's orbit through time. As a consequence, orbitally paced climate changes may influence the sedimentation patterns, which can record the cycles and enable their recognition in the geological record. Assuming the hypothesis that orbital cycles conditioned the deposition of the sedimentary succession of the Itararé Group, this research aims to (i) recognize the cyclicities preserved in rhythmites of Itararé Group in southernmost part of the Paraná Basin and (ii) compare cyclicities identified in two different data series and thus estimate sedimentation rates for the studied succession. The analyses were made in a core drilled by the Brazilian Geological Survey (CPRM), which is located in the Mariana Pimentel paleovalley, the southeastern border of the Paraná Basin. One dataset was obtained by measuring the lithological couplet thickness of rhythmites, and the other, by measuring the spectral reflectance of visible wavelength. Both datasets were processed with the software R, using the Astrochron package. We used Astrochron to perform time series analyses such as Robust Locally-Weighted Regression Spectral Background Estimation, Evolutive Harmonic Analysis, and Multitaper Method Spectral Analysis. Using these algorithms, the datasets were interpolated creating a more detailed scale and reducing noise in order to identify cyclicities and to estimate sedimentation rates. Preliminary results enabled the recognition of frequencies ranging between 1 and 10 cycles per meter in both couplet thickness and reflectance measurements. Overall, our analysis suggests an increasing-upward trend in sedimentation rates, based on the length of the cycles identified within the sedimentary succession. Furthermore, the results obtained so far are in agreement with previous studies carried out in other Carboniferous successions of the Paraná Basin (Santa Catarina and São Paulo states), which identified Milankovitch and millennial-scale cycles controlling sedimentation patterns. Future developments on the analysis presented herein will contribute to improving the chronology of deposition of the rhythmites within the Itararé Group.

The remagnetization of marine carbonate rocks of late Ordovician in Pingliang section (China)

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The natural remanent magnetization (NRM) of carbonate rocks in particular must be understood for the construction of a meaningful Paleozoic geomagnetic polarity time scale. This would enable evaluating geomagnetic features (e.g. reversal frequency) and provides a paleomagnetic dating tool. The Ordos block, central China, was reported at low latitudes on the Southern Hemisphere during Ordovician times. Ordovician strata, composed of carbonate and fine-grained clastic rocks, are well developed and exposed in the SW Ordos. Motivated by Project IGCP 652, we collected three parallel oriented paleomagnetic samples at 21 sites in the Pingliang section (SW Ordos) in 2017. With a total thickness of 95 meters, this section covers the boundary of the Majiagou Formation and Pingliang Formation, with an Early Sandbian age. The lithologies comprise mainly limestone, dolomite, siltstone, with several tuff layers intercalated. Most rocks are distinctly light brown, caused by weathering.

We cut the samples into 2 cm length cylindrical specimen in the laboratory. A set of specimens was stepwise thermally demagnetized up to 690°C or demagnetized with alternating field (AF) demagnetization up to 80mT, and measured with a 2G Enterprises Model-760R superconducting rock magnetometer in a magnetically shielded room. We identify two NRM components; the first is a low-temperature component (~250°C), interpreted as a secondary NRM. The second is a middle-high temperature component (between 250°C and 500°C, sometimes up to 580°C), which carried by magnetite (mostly fine particles) and would be the characteristic remanent magnetization (ChRM). Its direction is declination at NW and inclination pointing down, with mean direction of Ds=314.1°, Is=50.0°, alpha95=7.2°. Rock-magnetism measurements (including isothermal remanent magnetism (IRM), hysteresis loop and the first-order inversion curve (FORCs)) have been carried out for four representative specimens. The results show that the specimens are saturated in fields < 300 mT. This indicates that the magnetic minerals are soft coercivity minerals and low in content. In addition, the hysteresis loops are wasp-waisted, suggesting mixing of soft and hard magnetic minerals. Finally, FORC diagrams of three samples show a more or less closed concentric contour maximum at ~20 mT, which would indicate a fair proportion of SD particles. In a Day plot, all samples plot between

superparamagnetic envelope and the single domain - multidomain mixing line. Above all, we infer the NRM-carried minerals are mainly magnetite with a bit of pyrrhotite. The second component of NRM did not pass both the reversal and fold tests, indicating that the rocks are remagnetized. Using the ChRM to calculate the geomagnetic pole position yields Plong=23.3°, Plat=51.6°. If we consider North China as part of Eurasia, this pole position is not like any one since 200 Ma, thus the remagnetization might have occurred prior to Jurassic. This needs further study.

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The Eocene – Oligocene transition in the southern Tethys: astronomical calibration of calcareous nannofossil bioevents and geochemical changes in northeastern Tunisia

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The late Eocene - Early Oligocene transition is characterized by transient changes in environmental conditions from greenhouse to icehouse controlled by the onset of the major Antarctic glaciation phase (~34 Ma). The effects of this major climatic transition in Earth history have not been studied so far in the southern Tethys. Here, we present new data from the Ain Rahma section (Northeastern Tunisia, Cap Bon peninsula) across the late Eocene – early Oligocene. High-resolution magnetic susceptibility allows for an astronomical calibration of the section. Calcareous nannofossil biostratigraphy and carbon and oxygen-isotope stratigraphy permit an excellent tie to the global standard benthic oxygen and carbon isotope curves. Hand-held X-ray Fluorescence (HH-XRF) analysis is used to show changes in detrital elements (Fe, Si, Al, Zr,…). Two major changes are recorded in Tunisia corresponding to the Eocene/Oligocene transition 1 event (EOT1) and to the Oi-1 glaciation event and depicted by important shifts in detrital elements and calcareous nannofossil assemblages. The cyclostratigraphic analysis of the section demonstrates the major role of obliquity dominance and 1.2 Myr amplitude modulation of the obliquity over sedimentation in these southern Tethys deposits.

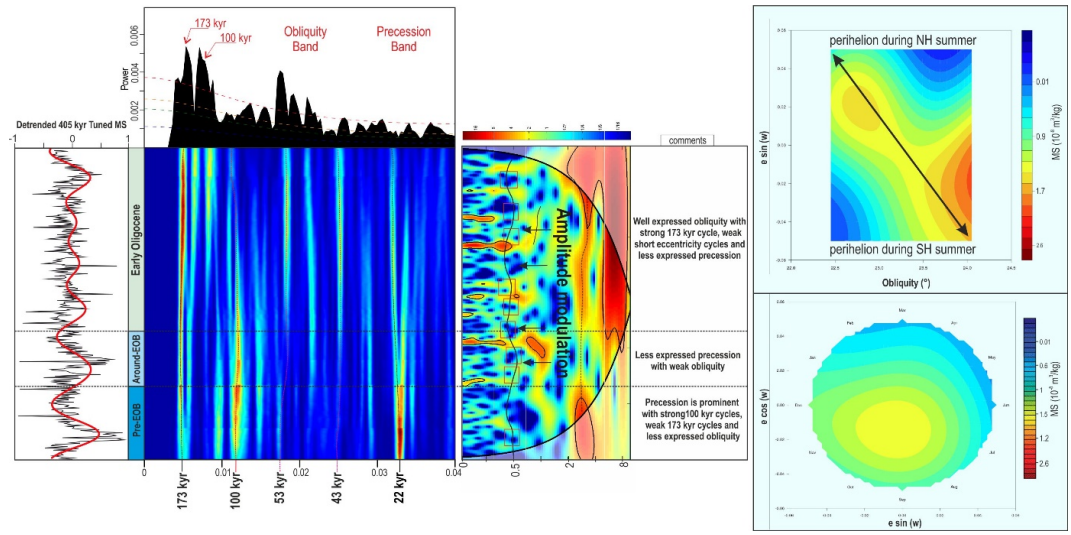

Figure 1. Gaussian process (left panel) applied to visualize the MS response to astronomical forcing between 31.5 and 35 Ma. Blue to red colors designate high to low MS. The e · sin obliquity plots represent a slice at e · cos = 0, while the e · sin – e · cos plots show the dependency of MS over the distribution of obliquity (e is eccentricity and ω is the longitude of perihelion measured from the spring equinox). NH—Northern Hemisphere; SH—Southern Hemisphere. CWT and the evolution of the 173 kyr and 43 kyr cycles are also presented.

Cyclostratigraphy of the marl-limestone alternations (Berriasian) in the North-South Axis (central Tunisia): geochronology and chronostratigraphic implications

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The lower Cretaceous marl-limestone alternation in central Tunisia (southern Tethyan margin) offer a scenic exposure of strata outcrop extremely suitable for cyclostratigraphic studies. However, some outcropping sedimentary series in central Tunisia suffers from a sharp lack of accuracy affecting their chronostratigraphic framework. Amongst, the Sidi Khalif Formation at Jebel Faidh locality (North-South Axis, central Tunisia) is the most affected one. Made up of marl-limestone alternation, this formation has never been targeted with neither biostratigraphic or magnetostratigraphic study. Hence, this study was carried out (for the first time along the southern Tethyan margin) aiming to build a reliable cyclostratigraphic framework using the Milankovitch forcing theory. These astronomical cycles are commonly used as a powerful geochronometer to refine some inaccurate geological times scales.

Very high-resolution magnetic susceptibility record (5 to 10 cm sampling interval) was employed to track astronomical cycles from our studied section. A total of 2187 samples were collected from the outcropping Sidi Khalif Formation and were measured for magnetic susceptibility as a paleoclimate proxy. We performed multiple spectral analysis and statistical techniques such as the Continuous Wavelet Transform, Evolutive Harmonic Analysis, Multi-taper method and Average Spectral Misfit, to obtain the best astronomical model. The section was divided into three parts assuming a stable sediment accumulation rate for each and the previous times series analysis techniques were applied for each sub-section and showed a pervasive dominance of E_{405}-kyr eccentricity cycles. The combination of these results allowed us to review and build a new chronostratigraphic framework of the Sidi Khalif Formation at Jebel Faidh as follow: 11 long eccentricity cycles E_{405} were extracted in addition which point to a duration estimate of 4.7 Myr with an average SAR of 2.317 cm/kyr. This value of SAR goes in line with deep marine environment succession which had been deposited under a passive margin associated with the opening of the paleotethyan ocean during the Jurassic-Cretaceous boundary.

Trace Elements of the Middle-Late Ordovician in SW Ordos and Its paleoenvironmental implications

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The Ordovician was characterized by a peak of greenhouse climate in Earth history, with extreme high sea level and atmospheric CO2 concentrations as well as a great development of marine life in the Early-Middle Ordovician, and it followed a glacial climate condition and mass extinction in the latest Late Ordovician. These events have attracted more attention which gave rise to a great deal of studies in the last decades. The North China is the most well-developed site of Ordovician, but study for those issues has been still lack. This contribution presents a set of trace elements data of carbonate rocks and fine grained-size clastic rocks in the southwestern Ordos (southwest North China), with aims to try uncovering their paleoenvironmental settings when deposited.

The Ordovician strata are composed of carbonate rocks (named as Yeli, Liangjiashan, Majiagou Formations upward) and fine grained-sized clastic rocks (Pingliang Formation) in SW Ordos. We collected 50 samples from Majiagou (Middle Ordovician) and Pingliang Formations (Late Ordovician) along the Qishan section. Previous studies indicate Majiagou Formation deposited in a carbonate platform and Pingliang Formation did in a platform foreslope and deep trough. Our data show that the contents of all measured trace elements, such as V, Cr, Th, Zr etc, are basically lower in Majiagou Formation (with averaged of V 1.38 ppm, Cr 0.93 ppm, Th 0.08ppm and Zr 1.16ppm, respectively) than in Pingliang Formation (with averaged of V 64.56 ppm, Cr 42.54 ppm, Th 12.11 ppm and Zr 163.3 ppm, respectively). In the second order, contents of carbonate rocks are lower than that of clastic rocks in Pingliang Formation, but also higher than in carbonate rocks of Majiagou Formation. Comparison to the PAAS or upper crust, the most samples are depleted in the redox sensitive elements of V, Mo, Ni, Cu. For U and Th, they are enriched in the clastic rocks of Pingliang Formation, and they depleted in the Majiagou Formation and also carbonate rocks of the Pingliang Formation. These variations would indicate carbonate rocks (Majiagou Formation and partial Pingliang Formation) formed in a shallow sea and suboxic environment, but clastic rocks (main Pingliang Formation) deposited in an anoxic environment and relative higher paleoproductivity. Subsequently, the interbedded carbonate rocks in Pingliang Formation reveal the alternative change of sedimentary settings and/or paleoclimate. In the other hand, the Sr/Ba ratio is much higher (47-363) in Majiagou Formation than in Pingliang Formation (0.11~14.5, averaged at 2.02), which suggest that the seawater are more salty when Majiagou Formation deposited.

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A positive test for the Greater Tarim Block at the heart of Rodinia: Mega-dextral suturing of supercontinent assembly

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The Tarim craton and neighboring terranes in Central Asia, i.e., the Greater Tarim Block (GTB), have been proposed to occupy a "missing-link" position at the heart of the Neoproterozoic Rodinia supercontinent between Australia and Laurentia. Such a reconstruction is tested with new paleomagnetic data from the GTB, and it is found that high-quality paleomagnetic poles conform to a stable missing-link configuration enduring from ca. 900 to 720 Ma. Integrating the new results with compilations of tectonomagmatic activity and geochronology throughout the GTB, we propose a novel paleogeographic model for Rodinia assembly. In our model, following initial phases of quasi-orthogonal subduction and collisions between southern GTB-Australia and northern GTB-Laurentia at ≥1070 Ma, the Rodinia supercontinent completed its assembly through a mega-dextral transpressional shearing along the Tarimian orogen. This scenario has noteworthy parallels to the history of collisions that created Pangea, and implies a more complicated geodynamic process for supercontinental assembly than previously proposed.

Iterative speciation in Late Silurian Pristiograptine graptolites of the Baltic Basin and the value of stratigraphy in cladistics

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Conducting cladistic analyses using exclusively fossil data presents a slew of unique challenges. The absence of genetic material and loss of morphological characters during preservation greatly reduces the amount of available usable characters, giving results more susceptible to convergence biases. Stratocladistic builds on traditional morphological parsimony by adding a unique characteristic of fossil data: stratigraphy. The addition of a stratigraphic component allows both for the inference of anagenic ancestor-descendent relationships and greater consistency of results with the available data. The case of the Late Silurian monograptids is ideally suited to the employment of stratocladistics, as many of the same morphologies appear in different species over large spans of time. In addition, the graptolites of the Baltic Basin are associated with especially high-resolution stratigraphy, making stratocladistic analysis less vulnerable to preservation bias. The inclusion of stratigraphy in the analysis of monograptid evolution allowed for us to parse apart morphologically similar but temporally disparate taxa. Using this analytical technique, we were able to indicate the presence of iterative speciation events from a central stem lineage in the Pristiograptinae of the Wenlock and Ludlow.