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ABSTRACT VOLUME

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Preface

After five successful years, IGCP 596 is on-extended-term now and the time has come to conclude the project. Within the frame of the Closing Meeting of IGCP 596 on *Climate change and biodiversity patterns in the Mid-Palaeozoic*, we intend to bring together scientists that were heavily involved and attended annual project meetings or contributed publications in all the years since 2011. Beside written output several new collaborations and joint projects were established within the Devonian-Carboniferous community, but also interdisciplinary with friends from IGCP 580 and 591, which document the original intension of the *International Geoscience Programme*. It makes us happy to see some members of all these working groups again for discussion of results and consideration of future perspectives that will allow continuing research together!

The Organizing Committee

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The redefinition of the Devonian-Carboniferous Boundary: recent developments

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Since in the GSSP section at La Serre, southern France, the marker fossil for the base of the Carboniferous, the conodont *Siphonodella sulcata*, was found below the boundary just above a facies change, the definition of the base of the Carboniferous has been back on the agendas of the Devonian and Carboniferous subcommissions. A joint SDS/ISCS Task group was established in 2009 to redefine the base of the Carboniferous and thus to regain stratigraphical stability in this critical interval of Earth history. Task group members have been active in various aspects related to the boundary definition and a wealth of new data has become available. Characteristic for many studies are multi-disciplinary approaches, which combine palaeontological, sedimentological, geochemical and petrophysical methods and data.

Our aim is not to report all task group activities of the last years herein, but to summarize some, and especially to present a brief summary on the discussions and results. Special sessions on the DCB, or formal discussions were held at the 2nd International Congress on Stratigraphy (Strati 2015) in July 2015 in Graz, at the Congress on Carboniferous and Permian (Kazan, August 2015) and at the IGCP 596 final meeting in Brussels (September 2015). A dedicated workshop with two days of discussions and a field trip to the classical sections in Montagne Noire was organized in Montpellier in September 2016.

The task group is still gathering data and no decision has so far been made on a suitable level, an index taxon or a section. There are still many options to check. The task group is committed to stratigraphical stability, but also to a user-friendly definition of the base of the Carboniferous. In this respect the extinction events in the global Hangenberg Crises, which in the current definition predates the boundary, have been among many others one focus of our work.

It should be noted that a few papers (Becker et al., 2016; Corradini et al., 2016) discussed possible levels where to place the boundary, highlighting pros and cons for each, and several others discussed various aspects of the boundary interval (i.e.: Kaiser et al., 2015; Bábek et al., 2016).

In any case, the recent works demonstrated that the GSSP section and the auxiliary stratotype sections in China and Germany are not suitable for the definition of a new boundary. Hence the discussions are open in all directions and they require the input from all interested researchers.

Original Project title

The redefinition of the Devonian-Carboniferous Boundary.

Project leaders, funding agency, duration

Aretz, M. (chair), Corradini, C. (vice-chair), Devonian-Carboniferous Boundary task group, International Commission on Stratigraphy (ICS), contribution by ICS and ISCS for organizing the Montpellier workshop in 2016.

Scientific background

Because the first appearance datum (FAD) of the index conodont which indicated the base of the Carboniferous at GSSP was found below that level in connection with a facies break, beside taxonomic problems, the definition of the base of the Carboniferous system has to be re-evaluated, wherefore a special task group with members of both stratigraphic commissions (Devonian and Carboniferous) was established.

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Biodiversity of rugose corals from the Famennian to Viséan succession of Belgium: Dynamics and controlling factors

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The Famennian to Viséan shallow water successions around the Brabant Massif contain abundant rugose corals, which have been intensively studied in the last decades. A database has been compiled for the temporal and spatial distribution of 170 species regrouped in 64 genera. The dataset is considered to be taxonomically unbiased, because intra- and interspecific variabilities have been judged the same way for all specimens and all determinations validated by the last authors. The sample positions of all specimens are precisely known, and thus detailed data on facies, biostratigraphy and lithostratigraphy are available. Diversity varies considerably with time, from the lowest value of 3 to the highest value of 57, when calibrating to biozones. The highest diversity is found in the Warnantian (late Viséan), which correspond to global data and can be mainly explained by important speciation events among several colonial families as the Lithostrotionidae. Significant diversity lows are in the Ivorian (early Tournaisian) and latest Moliniacian Livian (early Viséan). Important extinction events and distinct faunal turnovers are found at the Devonian-Carboniferous Boundary, in the upper Tournaisian, and at the base of the Viséan, and to a lesser degree at the base of the Livian. These turnovers can be considered to separate individual faunal and possibly evolutionary assemblages in the Devonian (Strunian), in the early to late and late Tournaisian and in the Viséan, with the latter probably divided into two sub-assemblages (early and mid to late). It is interesting to note that the highest diversities are always reached at the end of the stages and that diversification takes rather long before the diversity peaks are reached. The important sea-level fluctuations documented in the platform carbonates have a large influence on coral abundance and distribution. Up to the latest Tournaisian, the strata considered to belong to transgressive system tracts (TST) show a higher diversity than the strata of the highstand system tract (HST) of the corresponding 3rd order sequence, whereas in Viséan times the opposite is observed. This change cannot be explained so far. The spatial distribution shows the highest abundances of rugose corals in the Visé and Condroz sedimentation areas. These maxima are largely bound to the well-exposed Warnantian strata in these regions, which enable the documentation of the global late Viséan peak. Facies influence the abundances, but a clear correlation between a distinct facies and its coral abundance can so far not be proposed, and factors like the evolutionary dynamics seem to be superimposed.

Original Project title

Diversity fluctuations on different regional and global scales of macro- and microfauna in neritic environments of the Mississippian.

Project leaders, funding agency, duration

Aretz, M., Université de Toulouse 3, January 2013-ongoing.

Scientific background

Profound changes in the biosphere and geosphere occurred during the lower Carboniferous (Mississippian). The major aim of this long-time research project is the identification of the extrinsic and intrinsic factors, which drive diversity fluctuations in selected groups of micro- and macrofauna in the neritic environments during the Mississippian, and the quantification of those fluctuations. Beginning on regional scales the ultimate aim is a global perspective. To achieve this aims datasets are and will be compiled for foraminifers and corals, and to a lesser extend for brachiopods, for various regions. The compilation of literature data is accompanied by detailed stratigraphical and sedimentological field studies. In the current state of the project, several key regions have been identified for very detailed studies and work is ongoing in Western Europe, North Africa and China.
First pilot studies on the global spatial distribution of corals in relation to extrinsic factors as ocean currents and temperatures (Aretz et al., 2013) and on foraminifers from south China have been demonstrated the successful application of the chosen (Aretz et al., 2014).

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Output:

Published papers

ARETZ, M., DENAYER, J., NARDIN, E. & POTY, E. (submitted): Biodiversity of rugose corals from the Famennian to Viséan succession of Belgium: Dynamics and controlling factors. - Palaeogeography, Palaeoclimatology, Palaeoecology.

Abstracts

ARETZ, M., DENAYER, J., NARDIN, E. & POTY, E. (2014): Biodiversity of rugose corals from the Famennian to Viséan succession of Belgium: Dynamics and controlling factors. - 4th International Palaeontological Congress, Mendoza, Abstract Volume: 858.

Devonian Anoxia, Geochemistry, Geochronology, and Extinction Research (DAGGER) - new directions from an interdisciplinary research team developed out of IGCP 596 projects

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Purpose and Scope

The DAGGER (Devonian Anoxia, Geochemistry, Geochronology, and Extinction Research) group is an interdisciplinary, international research team that consists of geochemists, sedimentologists, paleontologists, and stratigraphers who focus on the systematics of mass extinctions and anoxia events in the Late Devonian (http://devonian.appstate.edu). Most of what is known about Late Devonian anoxia (>80% of existing studies) comes from epicontinental basins in Europe, North America, and south China. Many of the existing hypotheses about these mass extinctions and associated anoxia events have been challenged in the last decade by a number of researchers who are either using new methodologies (De Vleeschouwer et al., 2012; Dopieralska et al., 2016) and/or are exploring field sites far outside of the Appalachian/Variscan orogenic belt and/or outside of epicontinental basins (Carmichael et al., 2016a; Carmichael et al., 2014b; George et al., 2014; Haddad et al., 2016; Komatsu et al., 2014; Königshof et al., accepted pending revision; Königshof et al., 2012). Although many of the questions about the triggers and mechanics of Late Devonian anoxia events that have been raised by these new approaches remain unanswered (summarized in Carmichael and Waters, 2015), the purpose of the DAGGER group is to look at these events from a multitude of perspectives (mineralogical, geochemical, paleontological, sedimentological, etc.) and to test new or emerging hypotheses about the potential causes of these events. Testing these hypotheses involves participation in fieldwork around the world; at the time of this writing, DAGGER team members have ongoing research in field sites in Mongolia, China, Vietnam, Iran, Germany, Belgium, and the USA. Once returned to the lab, they use a variety of analytical techniques including whole rock geochemistry, mineralogical characterization (via X-ray diffraction, petrography, and electron and cathodoluminescence microscopy), organic geochemistry, stable isotope geochemistry, magnetic susceptibility (for time series analysis and cyclostratigraphy models), and geochronology.

Original Project title

Devonian Anoxia, Geochemistry, Geochronology, and Extinction Research (DAGGER).

Project leaders

Carmichael, S.K. and Waters, J.A.

Personnel

Many of the members of the DAGGER group have been working together since 2005 as members of IGCP-596 (Kido et al., 2013; Suttner et al., 2014), but the group was initiated and named in 2014 to formally acknowledge the new collaborations that were forged as part of the Joint Meeting of IGCP 596 and IGCP 580 in Ulan Bataar, Mongolia, and in order to incorporate researchers within the United States that were not affiliated with IGCP 596/580. The group is centered at Appalachian State University in the Department of Geology, and is led by Sarah Carmichael (geochemistry) and Johnny Waters (paleontology). The DAGGER science team currently consists of Drew Coleman (isotope geochemistry, University of North Carolina - Chapel Hill, USA), Peter Königshof (biostratigraphy and sedimentology, Senckenberg Research Institute and Natural History Museum, Germany), Thomas Suttner (stratigraphy, University of Graz, Austria), Erika Kido (paleontology, University of Graz, Austria), David De Vleeschouwer (paleoceanography and cyclostratigraphy, Universität Bremen, Germany), Sersmaa Gonchigdorj (field geology, Mongolian University of Science and Technology), and Yarinpil Ariunchimeg (paleontology and biostratigraphy, Palaeontological Centre, Mongolian Academy of Sciences). The DAGGER student team is composed of undergraduates from the Geology Department at Appalachian State University; since 2012, 12 students have participated in this research program (four current students, eight former students). More information about each participant is available at http://devonian.appstate.edu/personnel.

Contributions to the study of Late Devonian anoxia events

Thus far, work by the DAGGER group in sites in northwestern China (part of the Central Asian Orogenic Belt) has shown that ocean anoxia was global in scope for both the Kellwasser Event (Carmichael et al., 2014b) and Hangenberg Event (Carmichael et al., 2016a), even in open ocean, shallow water environments. Recognition of these events has led to the development of a new model for Late Devonian ocean anoxia, where anoxia is “top down” and due to eutrophication due to terrestrially derived nutrients (Figure 1). This model contradicts the established models for anoxia, such as transgression and stagnation (Bond et al., 2004; Bond & Wignall, 2008) or upwelling of anoxic bottom waters (Algeo et al., 2007; Caplan & Bustin, 1999; Caplan et al., 1996; Cramer et al., 2008; Johnson et al., 1985; McGhee, 1996), but is consistent with more recent observations by others (Averbuch et al., 2005; George et al., 2014; Riquier et al., 2006; Tuite & Macko, 2013; Whalen et al., 2015). Development of a “top-down” eutrophication model rather than a “bottom-up” upwelling model likewise requires a climate-based trigger mechanism; whether this is due to orbital forcing (De Vleeschouwer et al., 2014) or large igneous provinces (Bond & Wignall, 2014) is unknown at this time, but will form the basis of future work.

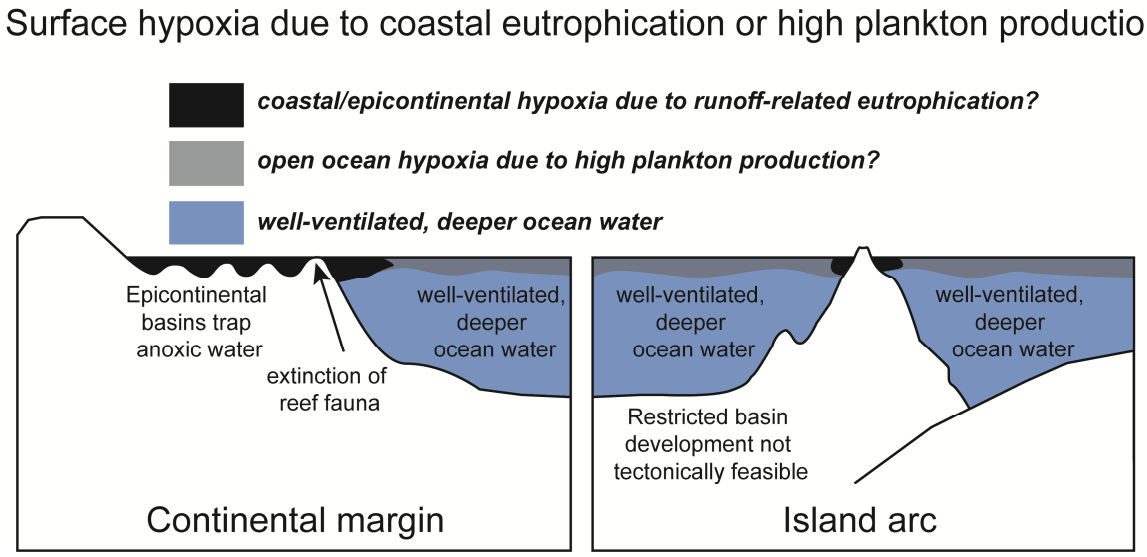

Figure 1. New model for Late Devonian ocean anoxia based on work from the Central Asian Orogenic Belt, invoking a "top down" eutrophication event rather than a "bottom up" event due to upwelling. From Carmichael et al. (2016a).

In addition to publications from work in northwestern China, the DAGGER group has published (or is in the process of publishing) papers on sites in Germany (Königshof et al., 2015), Iran (Königshof et al., accepted pending revision), and Vietnam (Königshof et al., in review). Undergraduate student researchers in the DAGGER group are active team members, and have presented their work at a number of conferences (Batchelor et al., 2015a; Batchelor et al., 2015b; Batchelor et al., 2014; Carmichael et al., 2014a; Carmichael et al., 2016b; DeReuil et al., 2013a; DeReuil et al., 2013b; Granholm et al., 2016; Waters et al., 2012; Waters et al., 2014). In total, the DAGGER group has presented more than 22 conference papers on interdisciplinary topics related to IGCP-596 field sites since 2012.

The contributions of the DAGGER team are not limited to academia; former student Cameron Batchelor presented her work in Mongolia at the Explorer's Club Annual Gala in March 2015 in New York City; she was the only student funded by the Explorer's Club who was invited to present. Sarah Carmichael was recently interviewed by Pixeldust Media for a documentary on mass extinctions, to be distributed by curiositystream.com (a streaming documentary service) as well as on television networks (both domestic and international). The early work of the group (Carmichael et al., 2014b) was distributed by Science Daily, a science news website (https://www.sciencedaily.com/releases/2013/12/131213092841.htm).

Funding

Much of the funding thus far for the investigations undertaken by the DAGGER group has been through Appalachian State University's University Research Council, Department of Geology and the College of Arts and Sciences. However, major funding from the National Science Foundation for a new scanning electron microscope with a state-of-the-art energy dispersive X-ray spectroscopy (EDS)

silicon drift detector and electron backscatter diffraction (EBSD) detector at Appalachian State University has recently been acquired by Carmichael and others (*NSF-MRI-EAR #1625137*, $561,842). Research by the DAGGER group was a major part of this successful proposal, and the new SEM-EDS technology will allow the student team to drastically increase their productivity in many of the mineralogical and geochemical analyses. Furthermore, SEM-EBSD can be used as a non-destructive way to detect *in situ* diagenetic alteration of carbonates (Cusack et al., 2008), in comparison with commonly used techniques such as powder X-ray diffraction and cathodoluminescence, which may not always show alteration (depending on the fluid source and/or diagenetic history). This new instrumentation is expected to be fully operational by mid-2017.

Data Availability

An overview of the DAGGER group's work can be seen at http://devonian.appstate.edu. Processed stratigraphic, geochemical, mineralogical, and isotopic data from sites associated with DAGGER group research is available to IGCP 596/580 collaborators through our DAGGER data portal (http://dagger.appstate.edu) upon receipt of a personalized login and password. This data is available in text (CSV) format for maximum compatibility with all software systems. The DAGGER image and raw data archive contains image files (field notes, field photos, and microscopy images are in TIFF or JPG format), XRD data (PDF and/or text format), and miscellaneous other data associated with each project location.

Future Directions, Ongoing Work

The DAGGER group is still working on a number of projects from previous IGCP 596 field excursions and workshops, with ongoing projects in China, Mongolia, Iran, Belgium, the USA, and Vietnam. These projects involve geochronology (particularly for the sequences in Mongolia), isotope geochemistry (China), detailed paleontology assessments (Mongolia, China), carbonate sedimentology (Belgium), organic geochemistry (Vietnam and the USA), and exploratory fieldwork (Iran). Although these methods may seem disparate, they all seek to address the mechanisms of Late Devonian ocean anoxia in as many different paleogeographic regions as possible. Our understanding of these events remains severely compromised by sample bias (both tectonic and sedimentological), and we plan to "look for anoxia in all the wrong places," i.e. in shallow water environments, in tectonically isolated regions, and in places outside the epicontinental basins that have shaped our understanding of these events thus far.

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The Pre-Variscan sequence of the Carnic Alps (Austria and Italy) - Results and highlights

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The Pre-Variscan sequence of the Carnic Alps includes rocks deposited between the Middle Ordovician and the early Late Carboniferous, and represents one of the most continuous sequence of the world in that time interval. In a relatively small area it is possible to distinguish rocks deposited at various latitudes and climate (from cold in the Ordovician to tropical in the Devonian), and in different sedimentary environments (from shallow water, including reef deposition, to basin). Despite the huge number of papers published on this sequence, a formal lithostratigraphic scheme does not exist and the units are indicated with informal names, often different in various papers. Because the region crosses the state border between Italy and Austria, different terminologies have been adopted on both sides of the mountain chain.

A joint research project was carried out from 2008 to 2015 with the goal to redefine the lithostratigraphy of the Pre-Variscan sequence of the Carnic Alps. More than thirty researchers from various European countries, mainly from Austria and Italy, were involved in four business meetings and three field workshops (Fig.1), and the (re)study of a huge amount of old and new data, in order to achieve a common but unified terminology.

PARTICIPANTS	I	II	III	IV	V	VI	VII
Carlo Corradini	■	■	■	■	■	■	■
Maria Corriga				■		■	
Anne Christine Da Silva					■		
Claudia Dojen				■	■	■	
Enzo Farabegoli		■	■	■			
Annalisa Ferretti			■			■	
Kathleen Histon	■		■				
Bernhard Hubmann	■						
Erika Kido			■	■	■	■	
Angelo Mossoni							■
Damien Pas				■	■	■	
M.Cristina Perri		■	■	■			
Werner Piller	■			■			
Susanne Pohler		■					
Monica Pondrelli	■	■	■	■	■	■	■
Philip Schnellbacher		■					
Hans Peter Schoenlaub	■	■	■	■	■	■	■
Paolo Serventi			■				
Luca Simonetto	■		■	■		■	
Claudia Spalletta		■	■	■	■	■	■
Thomas Suttner	■	■	■	■	■	■	
Gian Battista Vai			■				
Corrado Venturini			■				
Total	8	9	14	13	10	11	5

Figure 1. Participants of Carnic Alps Workshops I-VII. Colour code: orange = indoor; yellow = field workshop.

As result the Pre-Variscan sequence of the Carnic Alps is now subdivided in 36 formations, lithologically well characterized, with well-defined boundaries and designated stratotypes.

Beside several papers in international journals, a volume on the revised lithostratigraphy (edited by Corradini & Suttner, 2015) was published. It includes an introduction to the geology of the Pre-

Variscan sequence of the Carnic Alps and a short paper on each formation with general characterization and illustrations of the type section, formation boundaries and typical macrofacies.

Original Project title

Formal Lithostratigraphic Units in the Pre-Variscan Sequence of the Carnic Alps.

Project leaders, funding agency, duration

Corradini, C. and Suttner, T.J., research grants of the participants, 2008-2015.

Scientific background

The pre-Variscan sequence of the Carnic Alps is one of the most complete and better known in the world. Several workers investigated the area since the XIX century and produced a huge amount of papers dealing with different topics in geological sciences (geology, palaeontology, stratigraphy, structural geology, etc.).

However, the different parts of this sequence were mainly denominated with informal names, that derivate either from facies or historical terms. Furthermore, being the region across the state border between Italy and Austria, different terminologies have been adopted on both sides of the mountain chain, which result in different subdivisions of the sequence and a high number of names indicating similar -if not the same- lithological units. Also, in few cases, the same name was used to indicate different units. Moreover, almost none of these units was formalized according to the ICS (International Commission on Stratigraphy) rules.

The goal of the project was to achieve a common but unified terminology, subdividing the lithostratigraphic column of the Pre-Variscan sequence of the entire region into possible formal units, which are well defined according the ICS rules.

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Review on some European, North African and North American Devonian Ostracods

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Introduction on the scientific background of the project

Ostracodes are important elements of many marine faunas throughout the entire Phanerozoic. As many beds without conodonts turned out to be rich in ostracodes, the ostracodes are a vital source of auxiliary information on palaeoecology, biostratigraphy, and palaeogeography. Due to their strong facies dependence, ostracode assemblages and diversity change with the change of water depths and sediment input which can be interpreted in terms of climate change.

During the middle of the 20th century oil exploration motivated many research project on ostracodes, but since then, the interest shifted to other microfossils such as conodonts. Thus, nowadays only few researchers are specialised on Devonian ostracodes and several important Devonian sections are known to content ostracodes, but are only little studied so far. E.g., the Middle and Late Devonian ostracodes of the Ardennes (France) are well known due to the extended studies of J.-G. Casier, B. Milhau and S. Maillet. Also well-known are the Early and Middle Devonian ostracodes from Cantabria, which have been studied during years by late G. Becker. Other areas have not been that much in the focus of Devonian ostracode research such as the Pyrenees (e.g. Sanchez de Posada et al., 2008, Dojen et al., 2009a) or the Carnic Alps (only one succession described by Bandel & Becker, 1975). Therefore, the taxonomically, geographically and stratigraphically crossovers are still small.

The aim of this long-term project is to gather extensive data on early Devonian ostracode successions from both Laurussia and (Peri)-Gondwana as well as the in-between situated microcontinents. The comparison and correlation of these successions should provide us with a conodont-correlated ostracode zonation with interbasinal application potential, which is crucial for interpretation of a mid-palaeozoic climate change with ostracodes in a global sense.

Original project title

Change in biodiversity patterns of Devonian ostracodes from Europe, North America and North Africa as indicators for the mid-palaeozoic climate change.

Project leaders, funding, duration

Dojen, C., none, long-termed (various projects are included; some have been finished respectively are about to be finished).

Research results

For this purpose faunas have (and will be) studied especially form sections which have already been delivered ostracodes as a by-product of conodont work. Ostracodes have been provided from the Spanish Pyrenees by the J.I. Valenzuela Rios (University of Valencia), from Nevada by M. Murphy (University of California) and from Morocco by R.T. Becker (University of Münster) and by E. Schindler (Senckenberg Research Group). Further assemblages from SE Turkey have been provided by U. Mann (Research Center Jülich). Additional samples for ostracodes from the Carnic Alps have been taken, as the area has been between Gondwana and Laurussia in the Early Devonian.

Dra Valley (Anti-Atlas, S Morocco)

Within the last 5 years the research has been focussed on the Dra-Valley, where the Devonian is world-famous for its extensive outcrops incredible rich in well-preserved faunas. Early Devonian to early Middle Devonian ostracodes from various samples from sections Bou Tserfine, Rich Tamelougou and Hassi Mouf South have been studied by H. Groos-Uffenorde and C. Dojen. The results will be published soon as a joined paper with the research teams of the University of Münster and the Senckenberg Institute Frankfurt.

As one incredible rich sample has been found at an important position near the Emsian/Eifelian boundary, it is in the centre of our interest. In the literature the boundary is assumed to be within or at the top of the Rich 4 Sandstone Member, but due to the lack of macrofossils it cannot be pinpointed. A newly found occurrence of large beyrichiids (*Zygobeyrichia subcylindrica*) within the overlying crinoid marls and the studied ostracode faunas favour the Early/Middle Devonian boundary the overlying Yeraifia Formation and not in or on top of the Rich 4 sandstone. The late Emsian ostracode faunas belong to the shallow water Eifelian Mega-Assemblage, whereas the Early Eifelian ostracode faunas delivered more spinose species characterising a deepening.

As regards Devonian events and their effect on ostracodes both the Kellwasser-Event and the Hangenberg-Event are studied thoroughly. However, the smaller-scale events such as the Daleje, Choteč or Kačák Event have not been studied in detail so far. Without covering the event horizons in detail, our study gives nonetheless preliminary information on the possible influence of these events on benthic ostracodes faunas in the W Dra Valley, where the Kačák-Event seems to be the most effective one. However, further studies have to include more material covering the event horizons in detail.

Palaeobiogeographically, most taxa belong the Palaeotethysian Province, but North-American taxa are also present and corroborate migration paths between both areas via N-Africa.

Ardennes

A second point of interest was focussed on the historical type-area of the Givetian (Givet, Ardennes Department, France). In cooperation with S. Maillet and B. Milhau benthic ostracodes of Middle and Late Givetian age have been studied. The stratigraphical distribution of the highly diverse assemblages shows the installation of a Givetian fauna with many endemic taxa close to the base of the Fromelennes Fm. At the top of the formation, this fauna disappears and is subsequently replaced

with more cosmopolitan taxa with Frasnian affinities. This distribution is closely related to the major events of the Middle and Late Givetian in the Ardennes: the transgression pulse at the top of the Mont d'Haurs Fm., the global Taghanic Biocrisis and the global Givetian/Frasnian sea level rise. Climate change at the end of the Givetian possibly amplifies the effects of the sea level rise. This pattern of disappearance and replacement as early as the Late Givetian is at least a supraregional phenomenon (Maillet, Dojen & Milhau, 2013).

Spain

In **Celtiberia**, the palaeoecological conditions of most of the ostracode bearing horizons are well known by the wealth of faunas as well as sediment properties. Thus, the T-R-curves are well established and are by no surprise reflected by the ostracode diversity (Dojen, 2005: Text-fig. 9.5).

From the Spanish **Pyrenees** only a first study of Early Devonian hemipelagic ostracodes is published (Dojen et al., 2009a). The study reveals a locally remarkable biostratigraphical succession, although the taxa have been only tentatively identified. Many Lochkovian conodont zones are characterized through the entry of a new ostracode species. However, studies on ostracodes from other Pyrenean sections are needed to establish a stable regional subdivision. Studies on other coeval hemipelagic ostracode faunas will show whether this subdivision can be extended or compared with other basins. Due to a missing funding the project has not been finished up to now.

Central Nevada (Coal Canyon Sections, Northern Simpson Park Range)

Very little data on Silurian and Early Devonian ostracodes of central Nevada have been published in comparison with other groups of fossils. As faunal exchanges between Nevada and the Spanish Pyrenees in Early Devonian times are suggested (Dojen et al., 2009b), the study of the ostracodes discovered during the decades of conodont sampling by M. Murphy (University of California) is highly recommended for the future.

Turkey

Around 2007 ostracode faunas from carbonate sequences in the Hazro area of SE-Anatolia, were discovered and handed over for study. The samples of the Dadas Fm. yield abundant ostracodes, most of them beyrichioideans of the subfamily Amphitoxotidina, which was the first report of beyrichioideans from the Arabian platform (Dojen, 2009). The occurring taxa show strong affinities to *Hemsiella*, *Macrypsilon*, and *Juviella*, which are known from the late Silurian of the Baltic-British Province. Although the samples were considered to be of Early Devonian age, it turns out that according to palynomorphs, conodonts and ostracodes the samples are more likely of late Silurian age. The faunas are of special interest, as SE-Anatolia is situated at the northern margin of the Arabian platform, which belonged to Gondwana in Palaeozoic times and thus, should not yield beyrichioid ostracodes. A proceeding of the studies with F. Luppold is planned for the next year.

Several additional studies on ostracodes from the Istanbul area have been published in the meanwhile by A. Nazik and collegues.

Carnic Alps

Ostracodes of the Carnic Alps are of special interest, as the area was located in a key position between Laurussia and Gondwana in the Devonian. But obviously they are not silicified as within conodont samples provided by T. Suttner (Vienna Museum of Natural History) and C. Corradini (University of Cagliari) ostracodes are rare and poorly preserved. As it is highly unlikely that they should not occur in the limestone successions, samples have been taken for (hot) acetolysis and other related methods.

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Pridolian–Eifelian brachiopod faunas, palaeoenvironments and events of the Ardenno-Rhenish Massif

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Pridolian (uppermost Silurian) to lower Eifelian (lowermost Middle Devonian) rhynchonelliform (~"articulate") brachiopod faunas from the Ardenno-Rhenish Massif are taxonomically revised and subsequently used in biostratigraphic, palaeoecological and palaeobiogeographic studies. The stratigraphic successions under consideration document the time interval from the earliest Gedinnian transgression to the early Eifelian Kirberg Event (Struve, 1990; extinction of the "OCA Fauna" *sensu* Struve, 1982).

Rapidly evolving, short-lived spiriferide species warrant the biostratigraphic control, with 22 taxon range zones from the Pridolian to the lower Eifelian (see Fig. 1). A number of additional rhynchonelliform brachiopod taxa are associated with these and also used in biostratigraphic subdivision – a parallel subdivision into assemblage zones is in preparation. Close palaeobiogeographic relationships within the Maghrebo-European Subrealm enable supraregional biostratigraphic correlations. The Rhenish sections are correlated with successions in the Artois region and the Armorican Massif (France), Bohemia (Czech Republic), Podolia (Ukraine), the Iberian Chains (northeastern Spain) and the Dra Plains (southern Morocco), and this opens new possibilities of neritic-pelagic correlation and calibration to global pelagic biostratigraphies. The new data confirm that lowermost parts of the Gedinnian sequence in the classic sense have a Pridolian (latest Silurian) age, that the basal Emsian boundary in the present GSSP sense is much older than the traditional Siegenian-Emsian boundary in the Rhenish Massif, and that the latter boundary is distinctly older than the Belgian Siegenian–Emsian boundary as defined in the Ardennes.

Distribution and composition of the brachiopod faunas from the Ardenno-Rhenish Devonian are dependent on variations of the neritic-siliciclastic, rhenotypic ("Rhenish") facies, which is subdivided into three main subfacies: The eurhenotypic subfacies reflects shallow marine palaeoenvironments with turbid water and suitable living conditions mainly for diverse articulate brachiopods, for example coarsely ribbed spiriferides, associated with specific bivalves, trilobites, a few tabulate and rugose corals, and some ostracods, gastropods, bryozoans, crinoids and tentaculitides. Proximal, medial and distal variations of this subfacies show various distances from the coast and degrees of terrigenous influence. The pararhenotypic subfacies reflects restricted, marginal marine, deltaic or intertidal palaeoenvironments with changeable conditions, e.g. salinity fluctuations, suitable only for animals probably tolerant to these, in particular species of the terebratulide genera *Crassirensselaeria* or *Globithyris*, associated with lingulides, bivalves, agnathans, eurypterides, ostracods and tentaculitides.

The allorhenotypic subfacies reflects shallow marine palaeoenvironments with clear water, reduced or finer siliciclastic input and a higher content of calcium carbonate in the substrates. Its faunas partially contain species of genera regarded as rhenotypic, but less typical, more clear-water preferring species occur as well, for example taxa of the reticulariid spiriferides, atrypides and pentamerides. The brachiopods are accompanied by a specific trilobite fauna and a diversity of corals. The rhenotypic facies as a whole is typically developed from the Lochkovian to the Frasnian of Europe and North Africa.

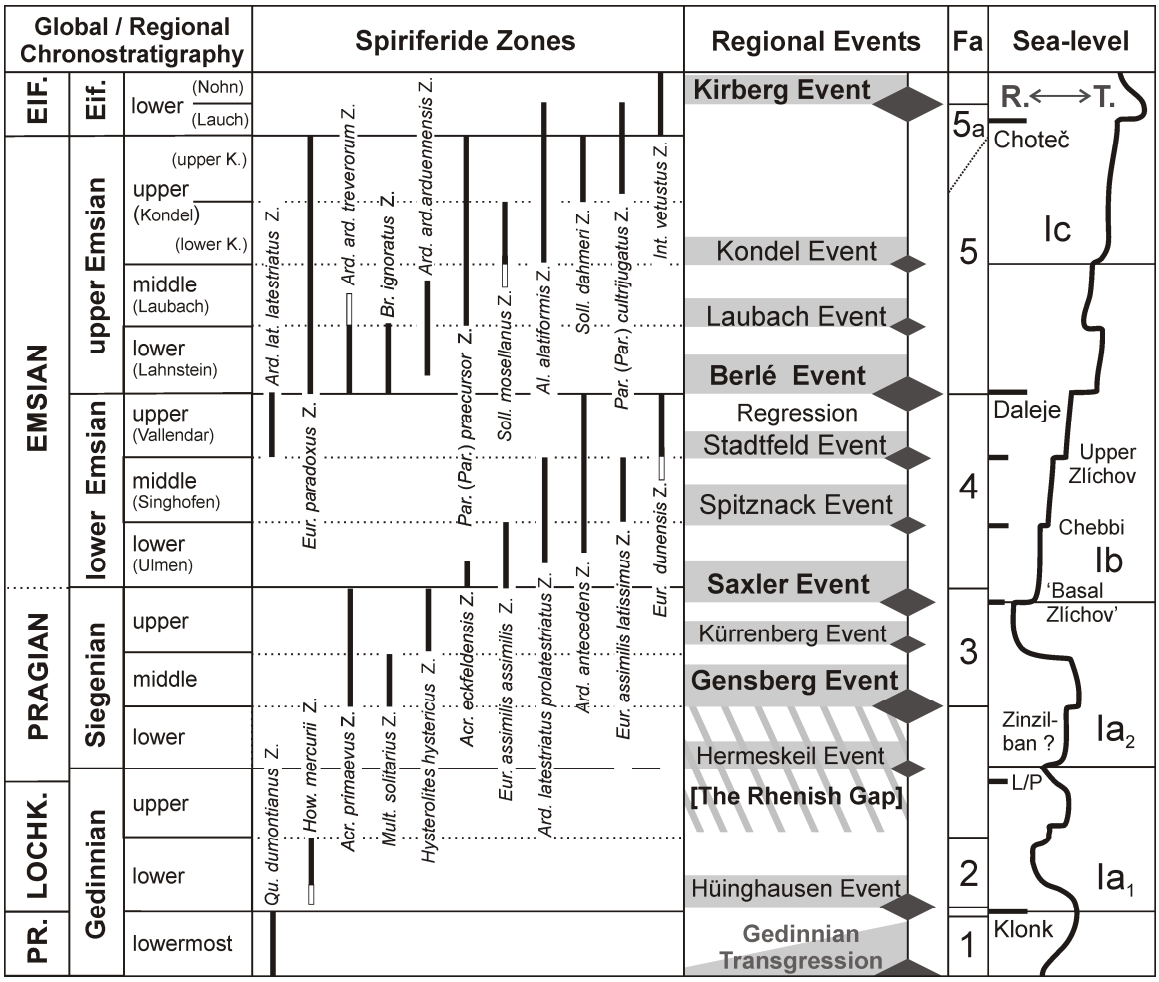

Figure 1. Pridolian to lower Eifelian of the Rhenish Massif: spiriferide zones, regional events, faunas (Fa), and assumed correlation with eustatic sea-level fluctuations and widely spread or global events (modified after Jansen, 2016). The Pragian-Emsian boundary is indicated provisionally (not the present GSSP level, but the envisaged possible level near the basal Emsian boundary in the Rhenish sense). "Basal Zlíchov Event" in the sense of García-Alcalde (1997). Diamonds symbolize the regional events, the size of the diamonds the suggested importance of the events. The extent of the "Rhenish Gap" *sensu stricto* is indicated. Abbreviations: (brachiopods) *Acr*. = *Acrospirifer*, *Al*. = *Alatiformia*, *Ard.* = *Arduspirifer*, *ard.* = *arduennensis*, *Br*. = *Brachyspirifer*, *Eur.* = *Euryspirifer*, *How.* = *Howellella*, *Int.* = *Intermedites*, *lat.* = *latestriatus*, *Mult.* = *Multispirifer*, *Par.* = *Paraspirifer*, *Qu*. = *Quadrifarius*, *Soll.* = *Sollispirifer*; (further abbreviations) K. = Kondel, L/P = Lochkovian-Pragian Boundary Event. R. = Regression, T. = Transgression, Z. = Zone. Faunas: 1 = *Quadrifarius dumontianus* Fauna, 2 = *Howellella mercurii* Fauna, 3 = *Acrospirifer primaevus* Fauna, 4 = *Arduspirifer antecedens* Fauna, 5 = *Euryspirifer paradoxus* Fauna, 5a = *Paraspirifer cultrijugatus* Fauna.

The studied Ardenno-Rhenish brachiopods are preserved as characteristic sets of assemblages, which stratigraphically follow one after the other as distinct “faunal intervals” or “faunas” named after characteristic spiriferide species: *Quadrifarius dumontianus*, *Howellella mercurii*, *Acrospirifer primaevus*, *Arduspirifer antecedens*, *Euryspirifer paradoxus* and *Paraspirifer cultrijugatus* faunas (Fig. 1). The changes between these faunas were possibly related to shelf-wide or more regional environmental perturbations or events of different magnitude and duration, leading to emigration or regional extinction of substantial parts of a brachiopod fauna. After these short-term events or more extended phases, a new fauna took over. If the faunal shifts always occurred with a severe or sudden crisis or with a more gradually changing palaeoenvironment stimulating a stepwise replacement of the fauna is still unclear. They possibly resulted from greater changes in the following factors: quantity of siliciclastic input, sedimentation rate, subsidence rate, eustatic and relative sea-level, and climate. In addition, smaller events are present between the major ones. The most distinct events (Fig. 1) are defined with locality names (Mittmeyer, 2008; Jansen, 2016) and may correlate mainly with transgressions (e.g. Berlé Event), but also with regressions (Kürrenberg Event). In the evaluation of the relative sea-level history of the Ardenno-Rhenish area, the published global sea-level curves (e.g. Johnson et al., 1985; Walliser, 1998) are taken into consideration as well.

Episodes of unsuitable or hostile conditions, on a shelf-wide or more regional scale, may have lasted for several thousands or hundred thousands of years, or even longer. Evolution continued, partly in small and isolated habitats probably within the main Ardenno-Rhenish Shelf or at its periphery – not necessarily documented in the fossil record – or in neighbouring shelf areas. Restricted panmixis may have led to accelerated evolution within smaller populations. With the widespread recurrence of more suitable conditions, brachiopods immigrated again from outside or spread over the shelf from isolated habitats, and benthic biocoenoses with brachiopods could re-establish on a wider scale – a case of habitat-tracking. This pattern is particularly obvious after the late Gedinnian to early Siegenian phase of the “Rhenish Gap” (*sensu stricto*). This is a previously often underestimated interval of 6–8 Ma representing a continuous, strong regressive phase in the Ardenno-Rhenish area which is not reflected by the global sea-level curve and presumably caused mainly by increasing siliciclastic input; terrestrial, limnic-fluvial, lacustrine, deltaic or intertidal conditions spread out in wide parts of the Ardenno-Rhenish region. Thick, mostly barren sequences largely lacking open marine faunas are typical. The “Rhenish Gap” may extend in the west to southwest England and in the east to southern Poland.

Only modest evolutionary change took place in the intervals of more stable marine palaeoenvironments and within the Ardenno-Rhenish Shelf, although certainly fostered by events of smaller magnitude.

In summary, the Pridolian to lower Eifelian sedimentary successions of the Ardenno-Rhenish area exemplify the dependence of the marine fossil record on the interplay of past geological processes such as eustatic sea-level changes, subsidence and sedimentation. In general, the global development of the sea-level was partly masked by regionally changing subsidence and sedimentation rates. The palaeoclimate played a role as well, as the suggested, partly tropical humid conditions resulted in strong physical erosion and fluvial transport of siliciclastic material and nutrients

from the Old Red Continent into the shelf sea. During transgressive intervals, the warm climate provided favourable living conditions for brachiopods in the coastal and shallow water palaeoenvironments of the Ardenno-Rhenish Sea. In general, rapidly changing environmental conditions and palaeogeographic constellations along vast shelf areas during a series of events enhanced the evolutionary development of brachiopods in the Early Devonian, finally leading to a diversity peak in the Emsian – this observation would fit well with the concept of a "Great Eodevonian Biodiversification Event" (Blieck, 2015).

Original project title

Revision of Rhenish Lower Devonian Brachiopoda.

Project leaders, funding agency, duration

Jansen, U., Senckenberg Research Institute, long-term project.

Scientific background

The main objectives are taxonomic revisions of many still poorly defined taxa, to establish a revised brachiopod biostratigraphy consisting of formally defined brachiopod zones, to analyse faunal changes and to reconstruct the brachiopods' palaeoecology, palaeobiology and palaeobiogeography. Thousands of specimens from numerous institutions, museums and private collections are studied for this purpose. Previously published biostratigraphic data are compiled and critically re-appraised. As the faunal developments across the lower and upper boundaries of the Lower Devonian shall be considered as well, brachiopods from the Pridolian and lower parts of the Eifelian are examined. Apart from the brachiopod biozonation, it is attempted to provide new data for the correlation of the Rhenish successions with sections in other parts of Europe and in North Africa where neritic–pelagic correlations are possible.

The general faunal development is examined and interpreted against the background of sedimentary sequences and the facies, discussing possible sea-level fluctuations, events and palaeoenvironmental changes. Aspects of palaeobiology and palaeoecology of the Rhenish brachiopods as shallow marine bottom-dwellers and suspension-feeders are focused. These had to stand the rough conditions of siliciclastic, often high-energy environments reflected by the rhenotypic facies. Relationships of form and function to these specific conditions are considered. Finally, it is intended to better constrict the palaeobiogeographic position of Rhenish brachiopod faunas. To achieve this aim, side-by-side comparisons with related species from other continents are made. In the future it is planned to apply for financial support to run subprojects dealing with selected topics, for example ecological and palaeobiogeographic analyses.

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FWF P 23775-B17 Late Eifelian climate perturbations: Effects on tropical coral communities

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Project FWF P 23775-B17 focused on late Eifelian climate perturbations and effects on climate sensitive organisms from low latitude shallow marine environments in central Europe. Results show that the so called Kačák crisis, which took place short before the Eifelian-Givetian boundary (numerical age: 387.7 million years ago), conforms to an interval of sea-level rise and fall contemporaneous with increasing and subsequently decreasing sea surface temperatures during the latest *kockelianus-ensensis* conodont biozones. This is confirmed by specific trends from the magnetic susceptibility of sedimentary rocks and by palaeotemperature calculations from the stable oxygen isotope composition of phosphatic microfossils (conodonts). An important issue of this project was the multidisciplinary study of sections from different bathymetric settings within a well-known platform to basin transect in low latitudes. Respectively, we worked out detailed profiles of five formations in the Carnic Alps, a mountain chain allocated at the Austrian/Italian border (Spinotti Formation, Kellergrat Formation, Freikofel Formation, Hoher Trieb Formation, Valentin Formation). We found out that sea surface temperature from shallow marine to pelagic deposits records increasing values across the event interval. Similar results are obtained for the neritic Middle Devonian sequence of the Prague Synform (Acanthopyge Limestone, Upper Dark Interval).

In order to establish a model on the cause of the Kačák crisis comprehensive geochemical analysis (stable carbon isotopy, XRF analysis and total organic carbon and sulfur contents) and gamma ray spectrometry together with information from microfacies were performed. Effects of the event on shallow marine communities are obvious. At least within carbonate platform deposits in the Carnic Alps, a change, for example in the composition of rugose coral taxa, from a low diversity fauna during and probably until short after the event interval to a rich and diverse fauna in the early Givetian is recognized. However, we could clarify that the rugose coral fauna preceding the Kačák Event is not late Eifelian in age, but older, which concludes that the disappearance of corals was not directly influenced by the Kačák Event, but probably a result of regionally changed palaeoenvironmental conditions. In order to display biodiversity patterns of climate sensitive organisms across the event interval we entered more than 1000 collections of published record on corals and conodonts into the Palaeobiology Database. This gives us the opportunity to model the response of rugose corals to late

Eifelian climate perturbations set in a global context. Because the Database is very complex it will take more time until we can conclude that issue.

For further comparison of results from the Carnic Alps and the Czech Republic, we started to investigate Middle Devonian deposits allocated in shallow marine settings of southern Laurussia (Eifel, Germany) and of an volcanic island arc complex in northern hemisphere low latitudes of the Palaeotethys (Baruunhuurai Terrane, Mongolia). Intense cooperation with two other international projects (IGCP 580 and 596) resulted in strong support of the community for dissemination of results.

Original project title

Late Eifelian climate perturbations: Effects on tropical coral communities.

Project leaders, funding agency, duration

Suttner, T.J., Austrian Science Fund (FWF), project budget: 271.050,86 EUR, 2011-2015.

Results

- The multidisciplinary investigation of Eifelian to Givetian sections especially in the Carnic Alps resulted in the most intensively studied area where the Kačák Event is evidenced. One of project related publications is cited under the Wikipedia entry for <Kačák Event>.
- Identification of conodont faunas from more than 300 rock samples led to a slightly changed age calibration of shallow marine and ramp deposits which previously was based on occurrence data of macrofossils or inferred by correlation of lithological features. Project results clarified age-related matters for sections in the Carnic Alps (Spinotti Formation, Kellergrat Formation, Freikofel Formation, Hoher Trieb Formation and Valentin Formation), the Graz Palaeozoic (Plabutsch Formation, Tyrnaueralm Formation), Prague Synform (upper limit of Acantophyge Limestone, Upper Dark Interval) and the Eifel (upper limit of the Junkerberg Formation).
- We addressed the question whether the Kačák Event represents a global extinction event or not. Whether sea-level change during the latest *kockelianus-ensensis* conodont biozones is related exclusively to climatically changed conditions or additionally forced by tectonic activity within the European Province accomplished by the closure of the Rheic Ocean will be tested by comparison of our results with studies from western Laurussia (Canada, Appalachian Basin), shelf deposits of eastern Laurussia (Holy Cross Mountains in Poland), Gondwana (e.g. the GSSP at Mech Irdane in Morocco) and from the Russian Craton (Altay and Ural mountains in Russia) with adjacent regions represented by volcanic island arcs (e.g. Baruunhuurai Terrane in western Mongolia).
- Effects of the Kačák Event on climate sensitive organisms such as rugose corals are obvious. In the Carnic Alps for example, we recognize a change in the coral community before and after the event interval. However, it turned out that coral-rich deposits of the Spinotti Formation, grown in nearshore environments of the carbonate platform before the Kačák Event, are older than proposed in literature (not latest Eifelian, but late Emsian to Eifelian) which documents that the decline/disappearance of coral taxa is not directly related to the Kačák Event in that specific case. However, in subsequently following deposits which are characterized by *Amphipora* limestone that persists until early Givetian

(and re-appears for several times until the Frasnian, for example in Moravia), significantly, only the rugose coral *Dendrostella* (at least two species) is present, e.g. at Mount Zermula (Cason di Lanza, Italy). Between the Marinelli hut and Plöcken Pass, *Amphipora* limestone interfingers with coral frame- and rudstone that had its onset in the earliest Givetian (*hemiansatus* conodont Biozone). With the onset of the coral reef species of *Dendrostella* disappeared. Based on palaeoenvironmental analysis, we conclude that the occurrence of *Dendrostella* in lagoonal deposits is linked with a change of specific environmental conditions on the carbonate platform during the Kačák transgression. In pelagic deposits of the same basin, corals from the platform are reworked and occur in distinct breccia levels below and above the Kačák Event interval. For biodiversity analysis about 200 oriented sections of rugose corals were produced. From the base of Spinotti Formation rugose coral genera such as *Acanthophyllum* sp. *Temnophyllum* sp., *Disphyllum* sp.?, *Phacellophyllum* sp., *Spinophyllum* sp., Ptenophyllidae were idenified. Within the Hoher Trieb Formation *Cyathophyllum* sp., *Grypophyllum* sp. and *Dendrostella* sp. are found among others.

- Stable oxygen isotope analysis of the PO_4-group of conodont apatite for calculation of palaeotemperatures (sea surface temperature = SST) in shallow marine, ramp and pelagic settings within the Palaeocarnic domain across the Late Eifelian Kačák Event gives implications not only on the palaeotemperature, but also addresses questions related to conodont ontogeny and salinity concentration of different bathymetric settings. Oxygen isotope values in shallow marine settings vary between 19.2-19.6 ‰ V-SMOW, while pelagic settings have values between 18.4-19.3 ‰ V-SMOW. Compared to that, conodont apatite from the highly condensed deeper marine Wolayer Glacier section shows values that range between 17.7-18.1 ‰ V-SMOW (measurements by Michael Joachimski and his team, Geozentrum Nordbayern, FAU). Interpretation of results from that study will help improving the quality of SST calculations based on conodont apatite.

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Palaeoenvironmental study of the Palaeotethys Ocean: The Givetian-Frasnian boundary of a shallow-marine environment using combined facies analysis and geochemistry (Zefreh Section/Central Iran)

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The studied section is located 6 km northeast from the Zefreh village, 60 km northeast of Isfahan, Central Iran. The shallow-marine environment was investigated using facies analysis and geochemical proxies. Middle- to Late Devonian deposites of the Bahram Formation are exposed in a several hundred meters thick section. The section shows an overall regressive trend from the base to the top and can be subdivided in several lithological units. The sedimentological record covers outer ramp- (deepest part) to inner ramp deposits as well as intertidal to supratidal deposits (shallowest part). The lower siliciclastic unit consists of an alternation of quartzites, tuffaceous sandstones, and quartzitic sandstones. Occasionally, thin bedded black shales occur. The fossil content is poor in that part of the sequence, although a good number of trace fossils occur. The next unit is composed of shales and sandstones with intercalations of thin-bedded limestones. In this interval many fossils occur, such as gastropods, trilobites, and bryozoans. Very common in those mid-ramp deposits are brachiopods which occur in distinct layers. The third unit is composed of thick- to thin-bedded grey limestones with dolomitic intercalations and thin shale layers. Very common are intraclastic grainstones-packstones. The upper part of the section is mainly composed of thick- to thin-bedded grey limestones with dolomitic horizons. The transition from distal to proximal environments is accompanied by a relative increase in the abundance of fossils, such as stromatoporoids, bryozoans, brachiopods, sponges, and gastropods. The upper part of the section shows many facies changes within the upper inner ramp to supratidal deposits. Oncoids, ooliths, intertidal mat deposits, desiccation cracks, and evaporitic pseudomorphes occur in this part of the Zefreh section. Occasionally, the occurrence of large moderately oriented ostracods in mudstones could represent a depositional setting ranging from ponds to an evaporation supratidal zone which suggests a shallow, semi-restricted lagoonal depositional environment. Redox conditions in the Zefreh section appear to be primarily oxic and support the facies and sedimentological results. The provenance of the Zefreh sediments using La, Sc, Zr, and Th indicates that they are most likely derived from continental arc volcanics which is consistent with the preliminary tectonic interpretations. Conodonts and brachiopods were used for

establishing the biostratigraphical framework. The lack of important zonal index taxa of the widely applied conodont standard zonation requires the application of an alternative shallow-marine conodont zonation. Based on conodont and brachiopod data the section Zefreh covers sediments ranging from the Upper Givetian to Lower Frasnian. The Bahram Formation is disconformably overlain by the white quartzitic sandstone of the Permian Jamal Formation. The presentation will provide a sedimentological, stratigraphical and geochemical overview of this newly sampled section in shallow-water facies.

Original Project title

Initiation of a resarch cooperation: Middle Palaeozoic of Central Iran.

Project leaders, funding agency, duration

Königshof, P., German Science Foundation (KO 1622/16-1), July 2014 – August 2015.

Scientific background

The major aim of this cooperation is to investigate Palaeozoic sediments of selected time slices in Central Iran. The Central Iran Microplate is a key region for Devonian and Carboniferous sediments because they display a great diversity of neritic depositional environments. Even if a large number of scientific publications of the last decade increased the knowledge of the entire area, there is still a lack of information which particularly concerns the knowledge of mid-Paleozoic climate changes and events in shallow water environments and correlation/comparison with other sections elsewhere. Thus, it is planned to study a number of new sections in detail. As a first step, the applied lithostratigraphic formations will be calibrated by microfossils in order to provide a good correlation with studied sections in Iran and elsewhere. We concentrated on sections containing the Bahram Formation (Givetian to Famennian), the Shishtu Formation (Devonian – Visèan), and the Sardar Group (Mid-Carboniferous). We tried to locate several events, such as Taghanic Event, F/F Event, and Mid-Carboniferous Event in hemipelagic and neritic environments order to test new theories on anoxia published recently (e.g., Carmichael et al., 2014). Some of the present-day observations explain coastal eutrophication via local nutrient availability, which causes enhanced primary productivity. Modern oxygen supply varies widely in time and space from deep water euxinia in restricted basins to ephemeral dysoxia in shallow coastal bays, lagoons and estuaries. In the frame of this project, geochemical methods will be also applied. The results may help to get a better understanding of anoxia events and climate change in deep time particularly in shallow water environments. After the first project phase (initiation of a cooperation) a project proposal is planned to be submitted in October 2016.

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Public outreach

Contribution in the following book:

SUTTNER, T.J., KIDO, E., KÖNIGSHOF, P. WATERS, J.A., DAVIS, L. & MESSNER, F. (eds) (2016): Planet Earth – In Deep Time, Palaeozoic Series: Devonian & Carboniferous, Schweizerbart Science Publishers: 1-261.

Events in the Mid-Palaeozoic: Examples from the Eastern Paleotethys (Ne Vietnam)

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During the mid-Paleozoic a number of global events occurred which were associated with faunal changes in marine and terrestrial environments. Subsequent work has shown that a number of biodiversity crises occurred in the Middle and Late Devonian including the Givetian/Frasnian (G/F) Event, the Frasnian/Famennian (F/F) Event and the Devonian/Carboniferous (D/C) Event. These biological and environmental fluctuations resulted in extinction events that left not only biological modifications in the geologic record, but also geochemical signals of change in Devonian sediments. Most studies of mass extinction events are located around the Rheic Ocean, while other areas such as the Paleotethys remain poorly documented.

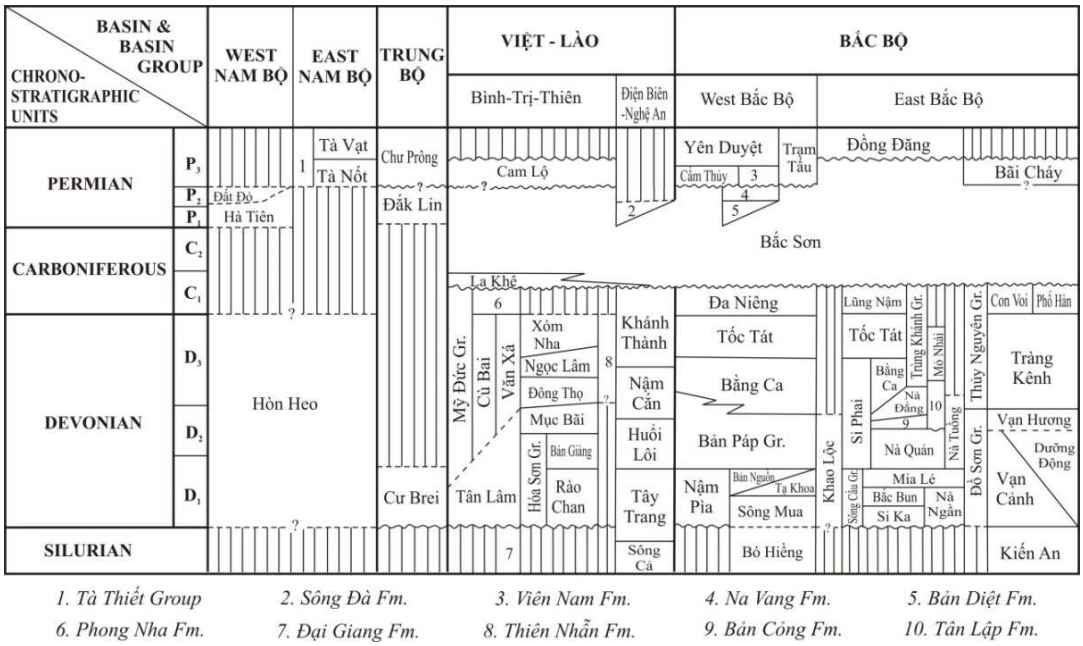

Figure 1. Stratigraphic correlation of the Devonian-Upper Permian (Wuchiapingian) Supersequence (after Tran Van Tri et al., 2011; Thanh et al., 2013).

In the framework of the ongoing project we investigate different Devonian and Carboniferous sections in northern and northeastern Vietnam, and Cat Ba Island (Fig. 1). Based on a detailed stratigraphy, sedimentology, microfacies and geochemical proxies we try to evaluate the presence of anoxic events associated with important extinctions in the mid-Paleozoic in basinal settings. The investigated formations are composed mainly of ramp platform carbonates and slope deposits yielding a number of fossils, such as conodonts, foraminifera, tentaculitids among others. Generally, the event layers are characterized by an alternation of thin, dark gray limestones and black shales containing abundant organic carbon.

In this presentation we will report on first results on the Devonian and Carboniferous conodont stratigraphy, depositional environments, and stable isotopes of Devonian and Carboniferous rocks in northeastern Vietnam. The study was supported by Deutsche Forschungsgemeinschaft (grant: KO 1622/15-1).

Original Project title

Carbon and oxygen isotope record and sedimentology/facies across selected time slices in the Mid Paleozoic in Vietnam.

Project leaders, funding agency, duration

Königshof, P., German Science Foundation (Ko 1622/15-1), October 2014 – Mai 2016.

Scientific background

The project focused on biodiversity crises which occurred in the Middle and Late Devonian including the events including the Devonian - Carboniferous boundary Hangenberg Event. Mid-Palaeozoic strata in Vietnam are mainly composed of limestones which have a thickness of several thousand meters (Middle Devonian to Late Carboniferous). Fluctuations in the records of several stable isotopes through the mid-Paleozoic suggest a reorganization of the global carbon reservoir, indicating that the mid-Paleozoic was a time of several unusual environmental changes. The extraordinary thick and mainly complete sequences in northern and southeastern Vietnam provide the possibility to identify and investigate Devonian and Carboniferous global events within this region, based on detailed carbon and oxygen isotope records. The analysis of geochemical proxies and sedimentological/facies analysis will provide data from an understudied area and would complement studies in Thailand (e.g., Savage et al., 2006; Dopieralska et al., 2012; Königshof et al., 2012), China (Chen et al., 2005), and Australia (Hillburn et al., 2012). A detailed stratigraphic scheme is a prerequisite for the planned investigations. Basic work has been done in one section (Komatsu et al., 2014) but more detailed work is in progress to get an overview on the global events in the eastern Paleotethys in comparison with sections around the Rheic Ocean. So far we have recognized several events in the Devonian, such as the Kačák Event, the (?) upper *pumilio* Event, the late Givetian Taghanic Event, and the Frasnian/Famennian Kellwasser Event.

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Abstracts

KÖNIGSHOF, P., PHUONG, T.H., CARMICHAEL, S., WATERS, J., BATCHELOR, C. & KOMATSU, T. (2015): Events in the Mid-Palaeozoic: Examples from the eastern Palaeotethys (NE Vietnam). - In: MOTTEQUIN, B., DENAYER, J., KÖNIGSHOF, P., PRESTIANNI, C. & OLIVE, S. (eds): IGCP 596-SDS Symposium, Programme and Abstracts, Brussels, 20-22 September, 2015. Strata, Sèrie 1, Communications, 16: 77-78.

Public outreach

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SUTTNER, T.J., KIDO, E., KÖNIGSHOF, P. WATERS, J.A., DAVIS, L. & MESSNER, F. (eds) (2016): Planet Earth – In Deep Time, Palaeozoic Series: Devonian & Carboniferous, Schweizerbart Science Publishers: 1-261.

Papers in progress (preliminary titles)

KÖNIGSHOF, P., NARKIEWICZ, K., PHUONG, T.H., CARMICHAEL, S., WATERS, J., BATCHELOR, C. & KOMATSU, T. Events in the Mid-Palaeozoic: Examples from the eastern Paleotethys (Si Phai section, NE Vietnam).

CARMICHAEL, S., KÖNIGSHOF, P., JOACHIMSKI, M., WATERS, J., PHUONG, T.H. & KOMATSU, T. Evidence for major environmental changes at the Devonian-Carboniferous boundary in the Paleotethys (Cat Ba Island, Vietnam)?

CARMICHAEL, S., KÖNIGSHOF, P., WATERS, J., BATCHELOR, C., JOACHIMSKI, M., NARKIEWICZ, K., PHUONG, T.H. Paleoenvironmental study of a deep marine environment using combined facies analysis and geochemistry (The Middle to Late Devonian Si Phai Pass section, NE Vietnam).

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Devonian-Carboniferous boundary in Europe - a multidisciplinary approach

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Elemental geochemistry of fourteen carbonate-dominated strata proved to be an excellent correlative tool in shallow- to deep-water marine settings close to the D/C boundary. Particularly useful correlative proxies included detrital elements as Al, Rb, K and Zr, their ratios as well as computed gamma-ray values (based on K and Th concentrations) from field gamma-ray spectrometry. Magnetic susceptibility doesn't show clear correlative patterns. The most distinct correlative horizon is the Hangenberg event *sensu lato* (HBE; including the Hangenberg black shales, gray shales and sandstones of the *costatus-kockeli* interregnum), which was associated with increased detrital influx into oceans inferred from the detrital element proxies. Sediment accumulation rates (normalized to terrigenous Al_2O_3) substantially increased even in the most distal pelagic depositional settings indicating a strong continental influence on marine realms during the entire HBE. The black shales including associated positive geochemical anomalies ($\delta^{13}C$, U_{GRS}) sometimes overlap with the entire HBE s.l. interval (Kronhofgraben section of Carnic Alps) but more often develop at its base (Rhenish Massif) or they are not present at all (Pyrenees - Saubette, Grüne Schneid of Carnic Alps, Montagne Noire, Moravia). We therefore assume that the deposition of the black shales represented only a local manifestation of the global detrital HBE event. Contrary to previous interpretations, the Hangenberg black shales did not develop due to sediment starvation during peak sea-level rise and they should not be regarded as a stratigraphic unit with isochronous top surface. The geochemical correlations between shallow-water sections with distinct facies stacking patterns and their deep-water counterparts indicate that the HBE was associated with a rapid sea-level drop (FSST to LST) followed by a sea-level still stand or minor rise and renewal of carbonate production in the *kockeli* to *sandbergi* zones (latest Famennian to early Tournaisian). No distinct sea-level rise probably occurred before the Lower Alum Shale Event in the middle Tournaisian times.

Several D/C boundary sections in the Moravian Karst shown the joint occurrence of foraminiferal and conodont fauna in earliest Tournaisian, which have important implications in tracing the extinction pattern of typical foraminiferal Famennian genus *Quasiendothyra*, crossing the D-C boundary and extending to *Siphonodella jii* conodont zone. The latest Famennian foraminiferal fauna from the Moravia compares well with the associations described in Belgium, the Timano-Pechora region and the Urals. In the early Tournaisian, the sections exhibit a unique fauna of quasiendothyrs and tournayellids (chernyshinellids, *Neoseptaglomospiranella*, *Uviella*), the representation of which

gradually increases over the course of the early Tournaisian. The Moravian conodont succession reveals a good correlation with other European areas. The *Siphonodella sulcata* morphotype (close to Group 1 sensu Kaiser and Corradini or to "nov. gen. nov. sp. 1" sensu Tragelehn) enters prior to the Hangenberg Events, which correlates well with Uppermost Famennian conodont successions from F ranconia, Bavaria and Morocco.

New position of the D/C boundary proposed by our working group is FAD of conodont *Protognathodus kockeli* (in lineage from *Pr. collinsoni*) in the first limestone bed just above the HE horizon, coinciding with a sudden drop in concentrations of K, Al, Th, Rb and other detrital proxies (CGR) and change in their ratios.

Original project title

Devonian-Carboniferous boundary in Europe - a multidisciplinary approach.

Project leaders, funding agency, duration

Kalvoda, J., Czech Science Fundation (project code P210/11/1891), 2011-2015.

Scientific background

The major aim of this project was the correlation of evolutionary changes in foraminifer and conodont faunas within the Devonian/Carboniferous (D/C) boundary interval in Europe, with a multiproxy stratigraphic analysis comprising carbon isotope geochemistry, element geochemistry and petrophysical logging (gamma-ray spectrometry and magnetic susceptibility). The studied sections included both basinal and more shallow-water depositional settings of Czech Republic (Moravian Karst), Austria (Carnic Alps), France (Pyrenees, Montagne Noire, Avesnois), Belgium (Ardennes) and Germany (Rheinische Schiefergebirge). The D/C boundary is perceived as an important step on the passage from the Devonian greenhouse to the Carboniferous icehouse global climatic regime. The high-resolution stratigraphic model will be used to better correlation between the basinal and shallow-water sequences at the D/C boundary. The project was a part of broader international effort within the IGCP 596, IGCP 580 and International Working Group on the Devonian Carboniferous Boundary (IUGS) aimed at redefinition of the boundary and reevaluation of the D/C boundary GSSP.

Output:

Published papers

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Abstracts (selected)

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KUMPAN, T., BÁBEK, O., KALVODA, J., MATYS GRYGAR, T. & FRÝDA, J. (2014): Correlations of the European Devonian-Carboniferous boundary successions: an integrated stratigraphic approach. – In: 4th International Palaeontological Congress, Mendoza, Argenita 2014. Abstract book.

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Givetian (Middle Devonian) Subdivision, Conodont biodiversity and Global Events in the Spanish Central Pyrenees. Preliminary results based on Conodont biostratigraphy

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The Pyrenean Givetian conodont investigation allows the establishment of a finest biostratigraphical subdivision that is coherent with the one observed in other places and supports the intention of the International Subcommission on Devonian Stratigraphy (SDS) of subdividing the Givetian into three substages, Lower, Middle and Upper Givetian, based on the occurrences of key conodont markers. The base of the Givetian is recognized by the entry of the index *Polygnathus hemiansatus* in sequence with its ancestor in the Pyrenean sections. Successive occurrences of the key markers *P. timorensis*, *P*. *rhenanus/ P.varcus* (the index of the base of the Middle Givetian), *P. ansatus*, "*Ozarkodina*" *semialternans/ P. latifossatus*, *Schmidtognathus hermanni* (the index of the base of the Upper Givetian), *P. cristatus, Klapperina disparilis, P. dengleri* and *Skelethognathus norrisi* permit recognition and evaluation of all standard conodont zones and represents one of the few places worldwide where the standard Givetian subdivisions can be thoroughly studied in a complete sequence, and therefore, the Pyrenees constitute a crucial area for testing the aforementioned threefold subdivision of the Givetian and for accurate intrazonal correlations and constitutes an area of global reference for Givetian studies. Records of early representatives of *Ancyrodella* above the uppermost Givetian *norrisi* Zone allows recognition of the base of the Upper Devonian Series and of it first Stage, the Frasnian.

A further outcome of the conodont research carried out these years is the preliminary studies on Givetian conodont biodiversity. This type of study is rare and the general previous idea was the existence of a low diversity episode (up to the *varcus* Zone) followed by a Late Givetian high-diversity episode after an innovation event. Our results permit testing this idea and improving the details of Givetian conodont biodiversity. The lowest Givetian Zone (*timorensis*) shows a minimum of diversity that is followed by a slight increment in the overlying *rhenanus*/*varcus* Zone at the base of the Middle Devonian, which is followed by a peak in conodont diversity in the *ansatus* Zone. After the *ansatus* Zone a descending trend follows in the lower *hermanni* Zone (Upper Givetian) that changes to an ascending one in the upper *hermanni* Zone. The following lower *disparilis* Zone represents a time of the lowest Givetian biodiversity. After this minimum, the tendency changes again and a higher diversity is observed in the upper *disparilis* and *norrisi* zones. These data show that the conodont Givetian high-diversity peak took place earlier than previously assumed and that the supposed high-

diversity Late Devonian Episode associated to a radiation phase, shows two moments of low diversity suggesting the presence of some pulses within the interval at least in the Pyrenees.

One of the Givetian Global Events, the Taghanic Event, has also been identified in the Pyrenees. The Taghanic Event is considered to be a multi-episodic event lasting about 800 ky and spanning from the *ansatus* zone through the *semialternans-latifossatus* Zone. A sedimentological change associated with a biotic turnover has not been yet clearly documented, and the relation of this Event with a large extinction has not been documented in detail yet. In one section from the Spanish Pyrenees a thin black layer of limestone and shale represents a pulse (sudden deepening, transgressive phase) within the upper Taghanic Event. Regarding conodonts, there isn't a clear correlation between the sedimentological expression of the Event and mass conodont extinction, neither at the level nor at adjacent (lower and higher) levels.

Original Project Title

Lower Devonian Global Events in Spain.

Project leader, funding agency, duration

Valenzuela-Ríos, J.I., Spanish Ministry for Science and Innovation, January 2012-December 2015.

Scientific background

The main goal of this project was commented in the paper by Valenzuela-Ríos and Liao (current volume) and was focussed in identifying and characterizing, with a multidisciplinary perspective, the Global Events recorded in the Spanish Lower Devonian palaeontological and stratigraphical sequences from the Pyrenees, Iberian Chains, Catalonian Coastal Ranges and Ossa Morena, and to relate the Spanish patterns to the observed in other regions aiming at a better understanding of the causation of such Global Events.

However, in the course of the investigation and adjacent to the Lower Devonian sequences, many Middle Devonian, mainly Givetian, strata were also investigated. This was especially relevant for supporting decisions of the International Subcommission on Devonian Stratigraphy and for contributing to the main goals of the IGCP-596 and to the specific yearly themes.

Output:

Published papers

GOUWY, S., LIAO, J.-C. & VALENZUELA-RÍOS, J.I. (2016): Graphic correlation of the upper Eifelian to lower Frasnian (Middle-Upper Devonian) conodont sequences in the Spanish Central Pyrenees and comparison with composite standards from other NW-Gondwana areas. - Paleontologica Electronica (in press).

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Public outreach

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VALENZUELA-RÍOS, J.I. & LIAO, J.-C. (2016): Programa Internacional de Geociencias (PICG), Proyecto PICG-596 (2011-2015) Cambio climático y patrones de biodiversidad en el Paleozoico Medio. - In: SUTTNER, T.J., KIDO, E., KÖNIGSHOF, P. WATERS, J.A., DAVIS, L. & MESSNER, F. (eds) (2016): Planet Earth – In Deep Time, Palaeozoic Series: Devonian & Carboniferous, Schweizerbart Science Publishers: 203.

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Late Devonian Trilobites from Western Mongolia

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A diverse fauna of phacopid trilobites is described from the Late Devonian of the Baitag Bogd range in Khovd Province, Western Mongolia. The collection material resulted from a biostratigraphic study performed on calcareous terrigenous sediments of the Samnuuruul Formation within the frame of the IGCP 596 & 580 Fieldworkshop in 2014.

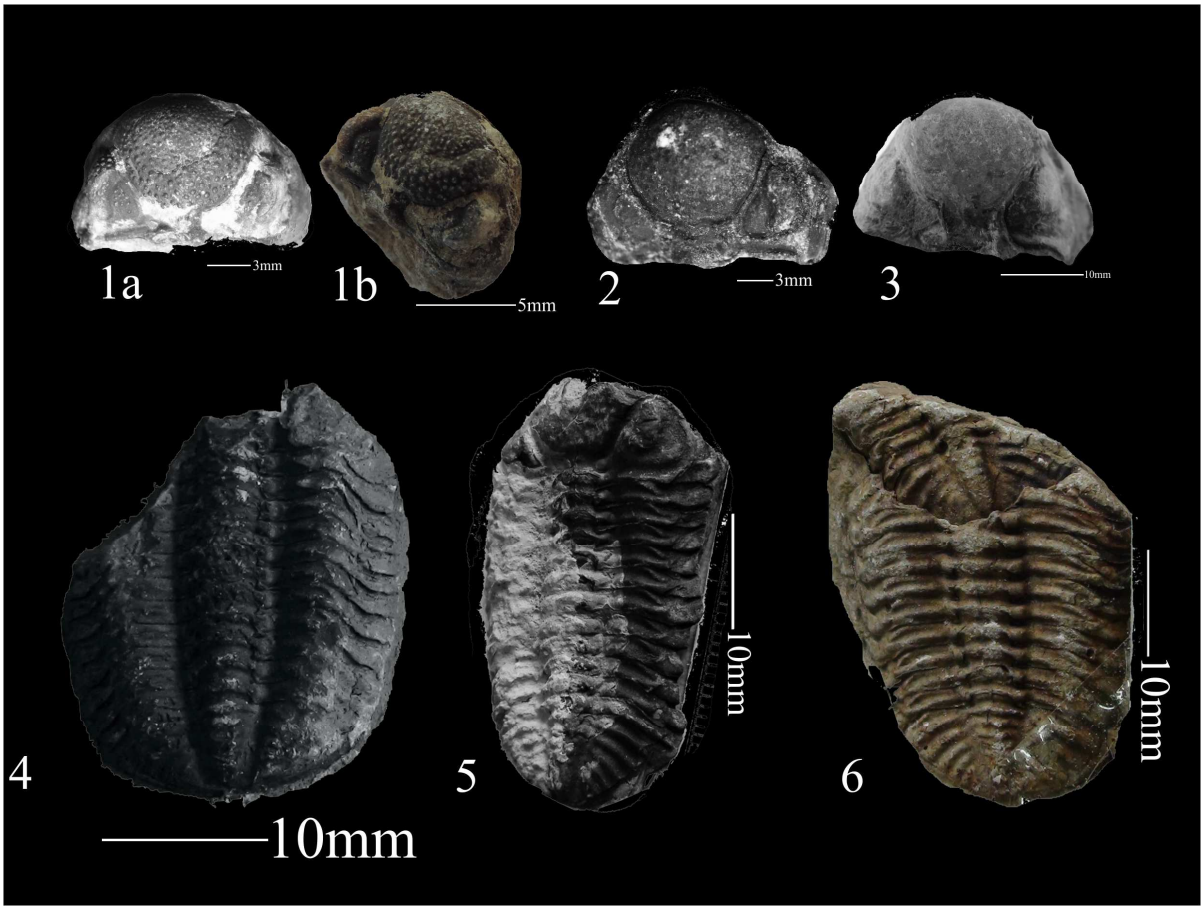

Figure 1. Phacopid trilobites from the Samnuuruul Formation, Late Devonian, Baitag Bogd range, Western Mongolia. (1-2) *Omegops*: cephalon in frontal and lateral views. (3-4) *Trimerocephalus*: cephalon in frontal view, thoracopygon in frontal view. (5-6) *Phacops* sensu lato: general view of thoracopygons.

These western Mongolian phacopid trilobites (Fig. 1) belong to the genera *Trimerocephalus*, *Phacops* sensu lato and *Omegops*. Phacopidae as well as specimens of *Omegops* include medium sized to large taxa which have large to very large eyes developed. This group occurs in the shelf facies of the uppermost Famennian and consists of several species in Europe (SW England, Belgium, N France, W Germany and Moravia), Asia (Kirghiz steppes, China) and North Africa (Morocco). Phacopid trilobites of the Samnuuruul Formation are Frasnian to Famennian in age.

Original project title

Late Devonian trilobites from Western Mongolia.

Project leaders, funding agency, duration

Munkhjargal, A., Mongolia University of Science and Technology, Bachelor thesis with no specific funding, 2014-2015.

Scientific background

Within the frame of an international workshop, trilobites were collected from the Samnuuruul Formation. The material was systematically described within the frame of my Bachelor thesis.

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Output:

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The geological map project of the Carnic Alps: selected areas with Devonian-Carboniferous sequences

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The rationale of the project of geological mapping of selected areas within the Pre-Variscan succession of the Carnic Alps is an outcome of the formal definition of the lithostratigraphic units (Corradini & Suttner, 2015). The goal is to correlate the sequences located in different parts of the basin in order to precisely define timelines and lateral transitions to constrain the basin evolution between Pragian and Visean.

The Carnic Alps, located across the boundary between northeastern Italy and south Austria, represent one of the classic areas of study of the Paleozoic in Europe and correspond to the non- to low-metamorphic portion of the Variscan substratum of the Southern Alps. The Upper Ordovician to Upper Carboniferous succession represents the best-preserved example of Variscan succession within the Alps. The Pragian to Frasnian stratigraphic interval is characterized by the differentiation of the basin in shallow water, including carbonate buildups, and pelagic parts, and the so-called 'transitional facies' represent a sort of 'connection' between these two parts. We focused mostly on these latter facies, because they 1) reflect well the depositional dynamics; 2) are datable using conodonts, unlike the shallow water units; 3) are less subject to tectonic elisions/repetitions than the basin units.

We performed geological mapping, measured stratigraphic sections of all the units and dated by conodonts all the lithostratigraphic transitions, in order to infer the lateral correlations throughout the

basin. Correlations are also supported by some marker beds/levels. The structural setting is characterized by thin-skinned tectonics reflecting extensional as well as compressional events of both Variscan and Alpine age (i.e., Venturini, 1990). Nevertheless, the stratigraphies are well preserved and generally well exposed.

We distinguished between proximal and distal 'transitional facies'. The succession of the proximal 'transitional facies' is shown in the excerpt of the geological map of Fig. 1.

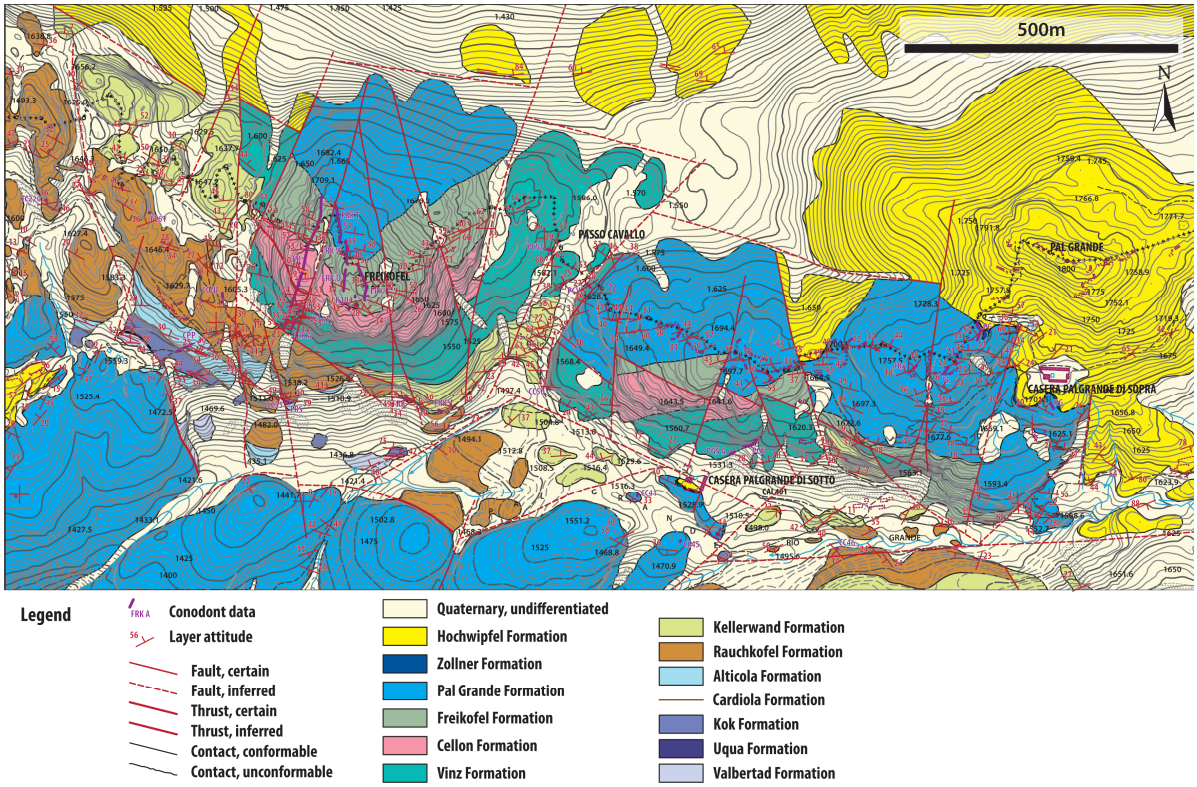

Figure 1. Geological map of the area around Mt Freikofel. Here the succession of the proximal 'transitional facies' is exposed.

The succession starts with the transgression of the Kellerwand Fm. on top of the Rauchkofel Fm. at the base of the Pragian. This transition most probably reflects the Lochkov–Prag Event (Suttner & Kido, 2015). The Kelletwand Fm. (Pragian-Emsian) consists mostly of wackestone to packstone interbedded with minor levels of fining upward packstone-grainstone and crinoidal-bearing grainstone. Only in the uppermost part of the unit beds of coral-bearing rudstone are present. This unit gradually passes upward to the Vinz Fm. (Emsian Givetian) which shows the same lithologies but the coral-bearing rudstone become increasingly dominant. This coarsening upward trend continues up to the Givetian with the deposition of the Cellon Fm. that consists only of very thick bedded rudstone. From the uppermost Givetian, with the deposition of the Freikofel Fm., breccia beds become different (different depositional processes, low occurrence of reef-builder debris and reworked fauna) probably reflecting dismantlement of the platform (Pas et al., 2014).

The succession of the distal 'transitional facies' is shown in the geological map of Fig. 2 (Pondrelli et al., 2015).

In these parts of the basin the first lithoclastic beds are the allodapic layers found within the mud- to wackestone beds of the Finding Fm. from the upper Emsian. The Finding Fm. passes upward to the Hoher Trieb Fm, that consists of corals-bearing rudstone and floatstone beds interlayered with pack-/grainstone, wackestone, cherts and black shales beds, whose deposition spans up close to the Givetian-Frasnian boundary.

These successions and their correlation suggest the presence of a transition between a ramp-type and a rimmed shelf-type profile during the Emsian. The evolution of the basin appears to reflect global trends at least up to the Givetian.

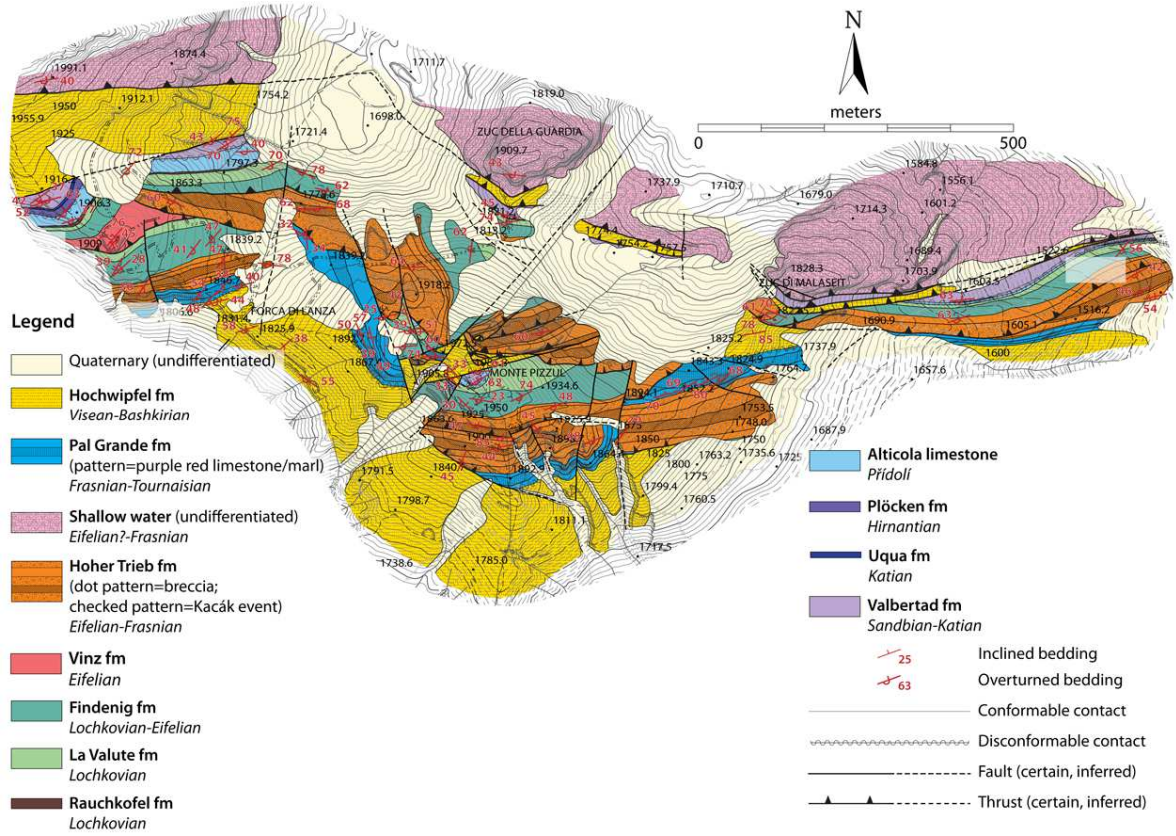

Figure 2. Geological map of the area of Mt Pizzul (Pondrelli et al., 2015). Here the succession of the distal 'transitional facies' is exposed.

Original Project title

The geological map project of the Carnic Alps.

Project leaders, funding agency, duration

Pondrelli, M., research grants of the participants, long-term project.

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Devonian and Carboniferous strata of the Baruunhuurai Terrane in Western Mongolia

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Devonian and Carboniferous deposits are well developed in the Baruuhuurai Terrane which covers a large area with complicated geological structure. The Devonian sequence is subdivided into the following formations: Nariinhar, Baitag, Hurendush, Baaran, Havtag, Baruunhuurai and Samnuuruul. Carboniferous strata are subdivided into following formations: Barlaggol, Borhavtsal, Inder, Olonbulag, Nuhniinuruu, Tsahirynnuruu, Tavanovoo and Uushgiinulaan (Ariunchimeg et al., 2014).

As part of IGCP 596, a field workshop was conducted in Western Mongolia in summer of 2012. The goal was to locate fossiliferous sections that expose the stage boundaries from the Eifelian / Givetian boundary (Middle Devonian) to the Devonian / Carboniferous boundary to expand our knowledge of the key Devonian biotic and geochemical events such as the Frasnian / Famennian extinction event and the Kačák, Kellwasser and Hangenberg oceanographic events (Kido et al., 2013). In summer 2014, a joint group of IGCP 596 & 580 projects organized an International Symposium and a field workshop in the Baruunhuurai terrane in Western Mongolia. During the field workshop, we studied sections in the Nariinhar Formation, Baruunhuurai Formation and Samnuuruul Formation from the Baruunhuurai Terrane.

The Devonian-Carboniferous deposits of the Baruunhuurai Terrane in Western Mongolia are characterized by volcaniclastic rocks with intercalated fossil-rich marl to limestone lenses. These units were deposited on an island arc complex of the same tectonic terrane of coeval Devonian-Carboniferous units in the western and eastern Junggar in northwestern China.

Research data indicate that the Eifelian to Frasnian Baruunhuurai Formation in the study area was deposited in a shallow marine near shore setting with regionally dispersed limestone lenses produced by locally restricted fossil communities and intermittent volcanically derived sediment. The lithological content of the sequence shows characteristics of both areas in NW China during the Eifelian, but seems to have a closer relation to the eastern Junggar region during the Givetian.

The Late Famennian Samnuuruul Formation is dominated by volcanically derived fine grained clastic deposition on a shallow shelf interspersed with sporadic deposition of limestone in the lower and middle part. The Samnuuruul Formation shares many biotic elements with the Hongguleleng Formation in western Junggar region of China, but seems to occupy a somewhat different sedimentary regime. We visited outcrops of the Samnuuruul Formation just in one subterrane (Ariunchimeg, 2015b; Gonchigdorj, & Kido, 2015; Hušková et al., 2015; Munkhjargal, 2015; Stephenson et al., 2015).

Several hundred kilometers farther southeast, an abundant marine Late Devonian Frasnian (Ariunchimeg, 2015a) and Carboniferous fauna is reported. In future we plan to analyse sections in the eastern part of the terrane and want to compare them with sections in adjacent areas.

A similar diverse fauna is observed in northwestern China and occurs in Middle-Late Devonian deposits of the Baruunhuurai Terrane. By the first radiometric ages for Late Devonian sediments in the CAOB (Batchelor et al., 2015) thought to contain both, the F–F boundary and the D–C boundary in an open oceanic setting.

Original Project title

Middle Paleozoic of Western Mongolia.

Project leaders, funding agency, duration

Sersmaa, G. and Ariunchimeg, Ya., research grants of the participants, 2012 – ongoing.

Scientific background

The Paleozoic fold belts of Central Asia, situated between the Siberian platform and Cathaysia are regarded as a part of the Central Asian Orogenic Belt. An attempt for subdivision of the Baruunhuurai into several zones was undertaken by Ruzhentsev et al. (1992) and Ruzhentsev (2001), who named this zone East Junggar and recognized five tectonic zones (from north to south): the Bij, North Baruunkhuurai, Olonbulag, Ulaanus and South Baruunkhuurai zones. In the Baruunhuurai region, Ruzhentsev et al. (1992), see the pinchout of a number of principal tectonic elements of eastern Kazakhstan and Xinjiang (Ob-Zaisan folded system, Chingiz-Tarbagatai system, Junggar-Balkhash system) and their replacement by structures of southern Mongolia. The south Baruunhuurai zone (Baitag and Ulaanus subterranes) is viewed as the eastern termination of the Junggar-Balkhash Variscan folded system; the Olonbulag and north Baruunhuurai (Baaran subterrane) zones are an analog of the Central Kazakhstan volcanic belt. The Bij zone is the connecting link between the Varizcan Ob-Zaisan and South Mongolian systems. The following paleotectonic model of the Mongolian part of East Junggar were suggested by Ruzhentsev (2001): the upper sheet of Baitag subterrane - a pre-arc paleo-oceanic trough; the lower sheet - the fore arc zone of the Baitag ensimatic island arc; southern part of the Ulaanus subterrane - the back arc zone, the Ulaanus subterrane - back arc basin, the Baaran volcanic belt (an Andean type continental margin) formed on the eastern continuation of the Caledonian Chingis Tarbagatai continent; the Bij paleooceanic basin, probably representing the eastern continuation of the ob Zaisan Variscian paleo-ocean.

All of the above mentioned structures probably were destroyed by the middle Carboniferous, due to a collision between the Caledonian continent and the Baitag island arc. The obduction of palaeo-oceanic elements on to the continent, with firstly the deposits of the back arc basin and then those of the island arc and the pre-arc trough being over trust on the continental margin, is well established. The neoautochthonous orogenic complex there is late Palaeozoic in age.

In recent years, according to Tomurtogoo (2014) the Baruunhuurai terrane is the south west end of the Gobi fold megazone.

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The Early Devonian sedimentary records, biostratigraphy and petrophysical logs from the key peri-Gondwanan sections and paleoenvironmental implications

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After successful application in the Prague Synform, the high-resolution petrophysical correlation methods were applied for the first time to the mid-Paleozoic rocks of the Pyrenees. These methods include magnetic susceptibility measurements (MS), gamma-ray spectrometry (GRS) and alignment of MS logs using the dynamic time warping (DTW) algorithm. The primary intention of the study was to attain the highest precision of stratigraphic correlation especially at the Lochkovian–Pragian boundary interval. Well elaborated conodont biostratigraphy provided the basic framework for the GRS and MS logging. In spite of differences in sediment patterns and accumulation/erosion rates, the logs from two selected sections in the Spanish Central Pyrenees show a striking symmetry that also correlates well with the previously published logs from the Prague Synform. The high similarity between the petrophysical records from paleogeographically related but distant areas has a potential to contribute to present discussions about the prominent eustatic and climatic changes at the transition from the Lochkovian to the Pragian.

The interpretation of petrophysical data from two key peri-Gondwanan regions lead us to the following conclusions (e.g., Slavík et al., 2016).

- The progressive condensation and shallowing-up tendency observed in the end-Lochkovian limestones, both in the Spanish Central Pyrenees and Barrandian area, indicate a major palaeoenvironmental phenomenon that may be connected with enormous sea level fall and rapid cooling of the sea water masses.
- The Pragian time is characterized by relatively well oxygenated sediments, where dysoxic conditions in the water column and stratification of oceanic waters were strongly suppressed. Possible frequent mixing of sea water in conditions of relatively depressed sea level resulted in formation of equivalents of oceanic red beds. An increased content of chemically weathered components in the Pragian carbonates indicate still hot but relatively humid climate conditions, governing the mid-latitude landmasses adjacent to peri-Gondwanan seas.

- With no evidence of polar ice sheets or alpine glaciers in Iapetus-collision mountain ridges, the Pragian must be characterized a very “hot” period, even though it was possibly cooler compared to the Lochkovian.
- The sedimentation of the middle to upper Pragian rocks is characterized by alternation of very contrastings rocks with an increased delivery of siliciclastics and extremely elevated and highly fluctuating GRS–MS patterns. This reflects a period of great climatic instability that could have been possible in conditions of sufficiently hot and humid climate.
- The subsequent stabilization of the climatic system and partial cooling can be seen in the upper Pragian to lower Emsian where amounts of non-carbonate impurities decrease considerably.

Original Project title

Hi-res correlation and dating of Mid-Paleozoic sedimentary sequences of Peri-Gondwana using integrated biostratigraphy and chemo-physical methods.

Project leaders, funding agency, duration

Slavík, L. (principal project leader) and Valenzuela-Ríos, J.I. (coordinator and leader of Spanish team), Grant-in-aid internal program of international cooperation projects of the Czech Academy of Sciences (Project Code: M100131201), July 2012 – December 2015.

Scientific background

The original aim of the finished Czech-Spanish project "Hi-Res correlation and dating of Mid-Palaeozoic sedimentary sequences of Peri-Gondwana using integrated biostratigraphy and chemo-physical methods" was to apply auxiliary correlation tools in intervals where the density of biostratigraphic time-marks is low. The correlation was then based on application of several methods in the sections: the detailed biostratigraphical framework was supplemented by multiple chemo-physical measurements (i.e. gamma-ray spectrometry and magnetic susceptibility) in order to avoid discrepancies in correlation of the peri-Gondwanan successions. In many regions, the complex petrophysical characteristics of the biostratigraphically well constrained Early Devonian strata are urgently needed in order to provide the most complete image of the impacts of possible global environmental changes. The principal environmental instabilities in the Early Devonian are well expressed, especially by the obvious differences between the classical megasequences that represent traditional hercynian (Bohemian) stages (Lochkovian, Pragian, Zlichovian, and Dalejan). These stages are characterized by typical marine successions/formations whose boundaries are independent of the official global Devonian subdivision. These may reflect the global or, at least, supra-regional trends in environmental dynamics and can very distinctively be recognized as turnovers in the marine faunal communities, described from many parts of the world.

The Prague Synform (Barrandian area, Czech Republic) and the Spanish Central Pyrenees are two key areas of European peri-Gondwana. Both areas show an excellent correlation by means of conodont biostratigraphy during Lochkovian and early Pragian times. Detailed correlation, based on conodont sequences, especially between middle and upper Lochkovian carbonate successions was

attained for the first time and resulted in considerable refinement of the biostratigraphic scale at this stratigraphic level (Valenzuela-Ríos et al., 2015). This correlation facilitates the definition of tie points for further multidisciplinary studies that seek to establish high-resolution temporal subdivision and global correlation. Some intervals have a precision of less than 0.5 Ma, which is significantly greater than in previous studies. The estimated elapsed time considered herein is about 3.2 Ma and is subdivided into five major zones of global scope: *transitanstrigonicus, trigonicus-kutscheri, kutscheri-pandora b, pandora b-gilberti* and *gilberti-steinachensis beta*. By providing tie points and globally applicable criteria, this research contributes to the international cooperative effort to subdivide the Devonian standard stages into globally recognized substages.

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The Famennian global conodont zonation

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Ziegler (1962, 1969)	Ziegler & Sandberg (1990)	NEW GLOBAL ZONATION
S. sulcata - Pr. kockeli	*sulcata*	*Protognathodus kockeli*
Low. *Protogn.* f.	Late *praesulcata*	
Upper *costatus*	Mid. *praesulcata*	*Bispathodus ultimus*
Middle *costatus*	Early *praesulcata*	
	Late *expansa*	
Lower *costatus*	Middle *expansa*	*Bispathodus costatus*
Upper *styriacus*		*Bispathodus ac. aculeatus*
	Early *expansa*	*Palmatolepis gr. expansa*
Middle *styriacus*	Late *postera*	*Palmatolepis gr. manca*
Lower *styriacus*	Early *postera*	*Polygnathus styriacus*
Upper *velifer*	Late *trachytera*	*Pseudopolygnathus granulosus*
Middle *velifer*	Early *trachytera*	*Palmatolepis r. trachytera*
Lower *velifer*	Latest *marginifera*	*Scaphignathus v. velifer*
Upper *quadrantinodosa*	Late *marginifera*	*Palmatolepis marg. utahensis*
Lower *quadrantinodosa*	Early *marginifera*	*Palmatolepis marg. marginifera*
rhomboidea	Late *rhomboidea*	*Palmatolepis gr. gracilis*
	Early *rhomboidea*	*Palmatolepis rhomboidea*
Upper *crepida*	Latest *crepida*	*Palmatolepis gl. pectinata*
	Late *crepida*	*Palmatolepis gl. prima*
Middle *crepida*	Middle *crepida*	*Palmatolepis termini*
Lower *crepida*	Early *crepida*	*Palmatolepis crepida*
Upper *triangularis*	Late *triangularis*	*Palmatolepis min. minuta*
Middle *triangularis*	Middle *triangularis*	*Palmatolepis del. platys*
Lower *triangularis*	Early *triangularis*	*Palmatolepis triangularis*
		Palmatolepis subperlobata

The new Famennian global conodont zonation is the result of a revision of the Famennian part of the Late Devonian Standard Conodont Zonation of Ziegler & Sandberg (1990). This revision was mainly based on two different kinds of consideration. The first one is philosophical, and is based on rejecting: i) the equivalence between biozones and time, and ii) the presumed phyletic concept on which the zonation of Ziegler & Sandberg (1990) was based. The second one is practical, and concerns with: i) solving difficulties that arose in the recognition of some biozones defined by Last Appearance Datum (LAD), ii) simplifying the zonation eliminating the zonal groups named after only one taxon.

The new zonation is largely based on the zonation of Ziegler (1962, 1969) and the Late Devonian Standard Conodont Zonation of Ziegler & Sandberg (1990) using mostly the same zonal markers, therefore it is perfectly correlatable with them (Fig.1). Modifications have been only made when strictly necessary, as the aim of the revision was to maintain what of good was previously done, improving and simplifying the Famennian part of the Standard Conodont Zonation, and keeping stability over more than 50 years of conodont studies.

Figure 1. Correlation of the zonation of Ziegler (1962, 1969), and the Famennian Standard Condonont Zonation of Ziegler & Sandberg (1990) with the new global zonation.

The 22 zones constituting the revised global zonation are defined by the First Appearance Datum (FAD) of species and subspecies that have a well-established stratigraphic range and wide geographic distribution, most of which have been already used as markers. Each zone is named after the taxon for which the FAD defines the lower boundary. The main changes regard the upper part of the Famennian, and take into account proposals already made by other authors, at least for regional zonation (Corradini, 2008; Kaiser et al., 2009; Hartenfels, 2011; Corradini et al., 2016).

The stratigraphic distribution of most Famennian conodont taxa has been updated on data available in literature, and unpublished information of the authors.

The lower boundary of the Famennian is identified as proposed by Klapper (2007). A revision of the current definition of the base of the Famennian is therefore suggested. The definition of the upper boundary (base of the Carboniferous System) being currently under discussion and study is left as an open problem.

Original Project title

The Famennian global conodont zonation.

Project leaders, funding agency, duration

Spalletta, C., University of Bologna, long-term project.

Scientific background

The Project is related to the activity of an informal group of SDS members with the aim of improving the Late Devonian stratigraphy and biozonation.

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Lower Devonian Events in the Spanish Central Pyrenees. Preliminary results based on Conodont biostratigraphy

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The identification and characterization of Global Events in distinct environments and their precise correlation are crucial to the understanding of the fundamental processes in biotic evolution, in the geologic development of the Earth's crust and in inferring their interrelations. During this project numerous Lower Devonian sections were studied in the Spanish Central Pyrenees. As a result several Bioevents based on conodont studies and four of the six global Geoevents were recognised in the Pyrenean strata. The Silurian/Devonian Global Event is identified in the Spanish Pyrenees with the occurrence of *Scyphocrinites* lobolithes below the local entry of *Icriodus woschmidti*. The *sulcatus* Event (= Lochkovian/Pragian Event) is suggested by a clear conodont turnover and by a drastic reduction on conodont taxa, which seems to be common in north Perigondwanan sections of Europe, supporting emerging opinions of a "Pragian conodont crisis". This faunal change is coupled with a smooth lithological change. Recent studies on Magnetic Susceptibility in two key Pyrenean sections (Segre 2 and CP-I) show a sharp increase in these values that is coherent with a positive excursion around the Lochkovian/Pragian in the type area of the Prague Synform. A sharp lithological change expressed by the onset of platy limestone overlying a thick siliciclastic succession (mostly white orthoquartzite) is observed in many sections of the Baliera Subfacies Area, especially in outcrops of the Isábena and Baliera rivers, in the Aragonian Pyrenees. A preliminary comparison with Global Events suggests that the Basal Zlichovian Event shall be positioned within the lower part of these dark-blue platy limestones. A remarkable change in the composition of the conodont record coupled with a marked lithological change represented by the onset of a dark micritic thin interval of limestone and shale is tentatively identified as the expression of the Upper Zlichovian Event in the Pyrenees.
Besides these Geoevents, a set of Global Bioevents are identified in the Pyrenees and recognized globally. The innovation, radiation and extinction of the genus *Lanea* took place in the Lochkovian; the entry of the genus was considered to be a good marker for defining the base of the middle Lochkovian. New data suggest, however, the convenience of using different defining taxa for the base of the middle Lochkovian. The innovation, radiation and extinction of the genus *Ancyrodelloides* seems to be restricted to the middle Lochkovian and the successive occurrence of key species allows the finest subdivision of the middle Lochkovian and, subsequently, the most detailed global correlation. The short and sudden innovation, radiation and extinction of the genus *Flajsella* within the middle Lochkovian provide more tie-points for supporting a very detailed correlation. The innovation,

radiation and extinction of the group of *Pedavis* belonging to the *robertoi-gilberti* branch increase correlation accuracy within the upper Lochkovian.

The innovation and radiation of the genus *Polygnathus* within the Pragian represents an important global Event that has to be considered for the redefinition of the Emsian and for upper Pragian and lower Emsian correlations worldwide.

Original Project Title

Lower Devonian Global Events in Spain.

Project leader, funding agency, duration

Valenzuela-Ríos, J.I., Spanish Ministry for Science and Innovation, January 2012-December 2015.

Scientific background

The main goal of this project was to identify and characterize, with a multidisciplinary perspective, the Global Events recorded in the Spanish Lower Devonian palaeontological and stratigraphical sequences from the Pyrenees, Iberian Chains, Catalonian Coastal Ranges and Ossa Morena, and to relate the Spanish patterns to the observed in other regions aiming at a better understanding of the causation of such Global Events.

The main studies will be bio- and chronostratigraphic, but they will be conbined with palaeocological, sedimentological, microfacies and geochemical studies. This combined analysis attains the recognition and characterization of Global Events, both in neritic and pelagic facies of Spanish selected sections.

Additionally, the Silurian/Devonian Boundary, the Lower Devonian Stage Boundaries and the Lower Devonian intra-stage boundaries will be examined in the selected sections. The results will be compared to data available from other regions with the intention to provide data for supporting decisions of the International Subcommission on Devonian Stratigraphy.

Output:

Published papers

MARTÍNEZ-PÉREZ, C. & VALENZUELA-RÍOS, J.I. (2014): New Lower Devonian Polygnathids (Conodonta) from the Spanish Central Pyrenees, with comments on the early radiation of the group. - Journal of Iberian Geology, 40, 1: 141-155.

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Public outreach

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Climates and Changes in Echinoderm Biodiversity in the Mid-Palaeozoic – IGCP 596 and Assembling the Echinoderm Tree of Life

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Introduction

The Mid-Palaeozoic was an extended time of climatic instability characterized by the largest drop in CO_2 in the past 500,000,000 years, multiple global oceanic anoxia events, highly fluctuating levels of O_2, and the fundamental shift from a Devonian Greenhouse world to a Carboniferous Icehouse world. Major changes in the biosphere in the Mid-Palaeozoic produced five of the top 11 most ecologically severe extinction events in the Phanerozoic. At various times marine plankton, tropical marine benthos, marine nekton, and terrestrial animals were devastated. Perhaps the most significant of these events was the loss of reef ecosystems at the Givetian/Frasnian and the Frasnian/Famennian boundaries. Copper (1994) and McGhee (2013) suggest that Devonian reefs occupied an area ten times the areal extent of modern reef ecosystems suggesting that reefs have never fully recovered from the Devonian extinctions.

Echinoderms

For the past five years, a U.S. National Science Foundation grant has funded “Assembling the Echinoderm Tree of Life”, which has been studying the phylogeny of echinoderms to better understand their evolutionary history. This ambitious multimillion-dollar project involved paleontologists, developmental biologists, and experts in genomics and bioinformatics using an interdisciplinary array of techniques from gene sequencing to morphological analyses of fossils to delineate the evolutionary history of this unique group of animals. Echinoderms share a recent common ancestor with chordates and other deuterostomes and occupy an important position on the tree of life. Echinoderms are unusual in that only five of the 21 classes are extant. The other classes are extinct living primarily in the Paleozoic. Although echinoderms were part of the Cambrian Explosion, the number of body plans expanded significantly in the Great Ordovician Biodiversification Event. These Palaeozoic echinoderm communities were dominated by crinoids and an array of blastozoan classes that were mostly pelmatozoans attached to the seafloor with a stem. The communities can be grouped into large macroevolutionary faunas. The Lower Palaeozoic Echinoderm Macroevolutionary Fauna was replaced by the Middle Palaeozoic EMF in the Silurian during the rise of coral-stromatoporoid reef communities. Although locally very abundant, echinoderms were relatively minor parts of this reef ecosystem and tended to be concentrated on the reef flanks in a halo around the reef crests.

Traditional thought suggested that the transition from the Middle Palaeozoic EMF to the Late Palaeozoic EMF occurred in the Carboniferous near the boundary between the Mississippian and Pennsylvanian and reflected changing sedimentological regimes associated with the onset of Gondwanan glaciation or changing patterns of predation among Carboniferous fishes. Waters and Webster (2009) proposed that the actual transition between these faunas occurred in the Famennian using data from Lane et al. (1997), Lane et al. (2001a, b) and Waters et al. (2003) and that the Central Asian Orogenic Belt acted as a refugia and a center of origin for the echinoderm rebound after the Frasnian/Famennian Extinction Event.

Echinoderms, IGCP 596 and DAGGER

Although they suffered significant extinction at the Givetian/Frasnian Event, echinoderms were major beneficiaries of ecological calamity at the Frasnian/Famennian Event and the D/C (Hangenberg) Event. Echinoderms dominated the carbonate factory in the Mississippian globally producing thousands of cubic km of carbonate. Data from the Hongguleleng Formation in the Central Asian Orogenic Belt indicates that the transition began in the Lower Famennian about 100,000 years after the Frasnian/Famennian Event.

For the past five years, I have been involved with the Morphology Working Group of the AETOL Project to better understand the evolutionary paleoecology of Paleozoic echinoderms. I have also been involved with the DAGGER group (see Carmichael and Waters, this volume), which seeks to better understand the triggers and mechanisms of Devonian anoxia events through a multidisciplinary approach. These two projects converge with the concept that echinoderms were ecological winners in the Late Devonian climatically driven perturbations that virtually destroyed tropical marine reef ecosystems. The two projects share similar goals in attempting to understand the details of the mechanisms involved both in terms of abiotic climate events and the ability of echinoderms to survive and thrive when other groups did not.

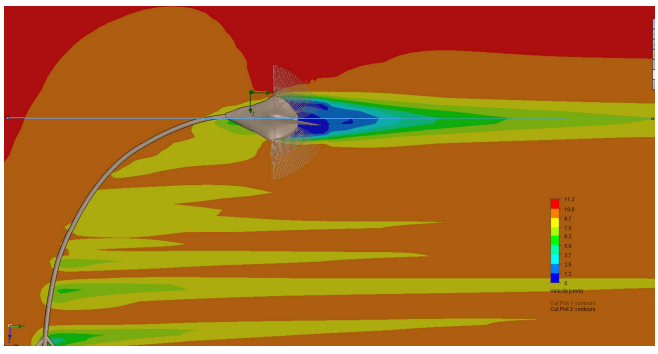

Figure 1. Computational Fluid Dynamics (CFD) simulation of a 3D reconstruction of *Hyperoblastus* sp. in feeding position in a current of 10 cm/sec. The current is flowing aboral to oral. The theca produces a zone of slow, turbulent water near the oral surface which presumably aided feeding efficiency.

Riding (2009) proposed an intriguing hypothesis that significant increases in suspension-feeding echinoderms in the Mississippian were the result of climate-driven changes in phytoplankton communities in the Late Devonian toward smaller sizes, such as picoplankton or the microplankton that feed on them. Testing this hypothesis requires a better understanding of feeding in blastoids (Waters et al., 2016). Although blastoids are rarely preserved as complete specimens, we can construct 3D models with theca, stem, and brachioles. These models can be used as input into

computational fluid dynamics simulations to analyze the dynamics of water flow over various thecal and brachiolar filtration fan morphologies. The results suggest that blastoids formed a parabolic filtration fan with the theca more of less horizontal and stem bent in an arc in currents flowing aborally to orally at velocities greater than 0.5 cm/s to 10 cm/s. At current velocities of 25 cm/s and 50 cm/s (the highest velocity modeled) hydrodynamic drag and adoral zones of turbulence were reduced suggesting that feeding efficiency of the filtration fan was compromised.

We also have been studying the internal anatomy of blastoids by digitizing the acetate peels of serially sectioned blastoids from the Naturalis Biodiversity Center (NCB), Netherlands and specimens imaged at the SLS synchrotron, Paul Scherrer Institute, Switzerland. The digitized acetate peels were registered and stacked in Photoshop to virtually recreate the blastoid that had been destroyed during serial sectioning. The digital images were lofted in Rhino to produce 3D models. We used Spiers to segment synchrotron images to produce 3D models of the internal anatomy. We have documented elements of the blastoid reproductive system including the gonopore, gonoduct and gonad in *Deltoblastus* and *Pentremites*. We have also imaged elements of the respiratory systems including hydrospires, which either are internal organs (in spiraculate grade blastoids) or externally exposed (in fissiculate grade blastoids). Elements of the water vascular system including ring canal and radial water vessels can be recognized both in peels and in synchrotron data. A single specimen imaged at the SLS has about 75% of the digestive system preserved including the gut and an enlarged mid-gut region (Rahman et al., 2015) and informs us as to the early evolution of the echinoderm gut. The data are critical in understanding the autecology of the blastoids and provide additional characters for phylogenetic reconstruction, which is the topic of ongoing research.

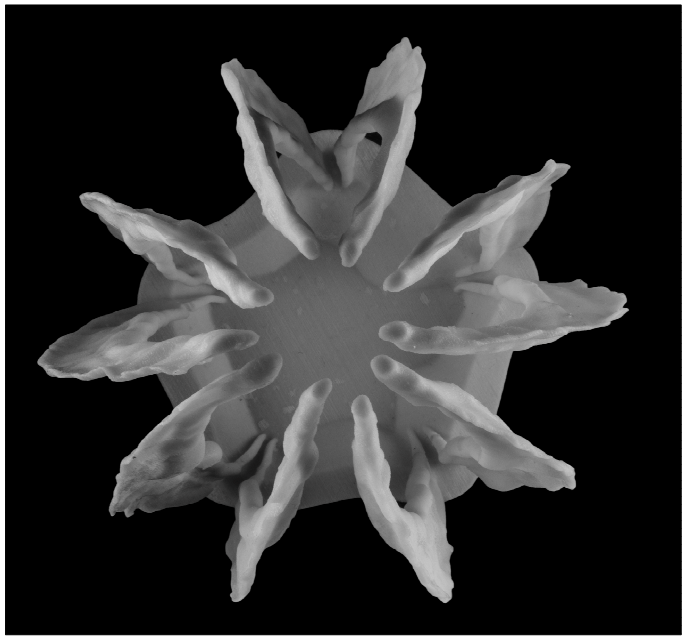

Figure 2. Reconstruction of the hydrospires of *Monoschizoblastus rofei* using digitized acetate peels in the collections of the Naturalis Museum. The peels were lofted into a 3D model using Rhino and then printed using a 3D printer at Appalachian State University.

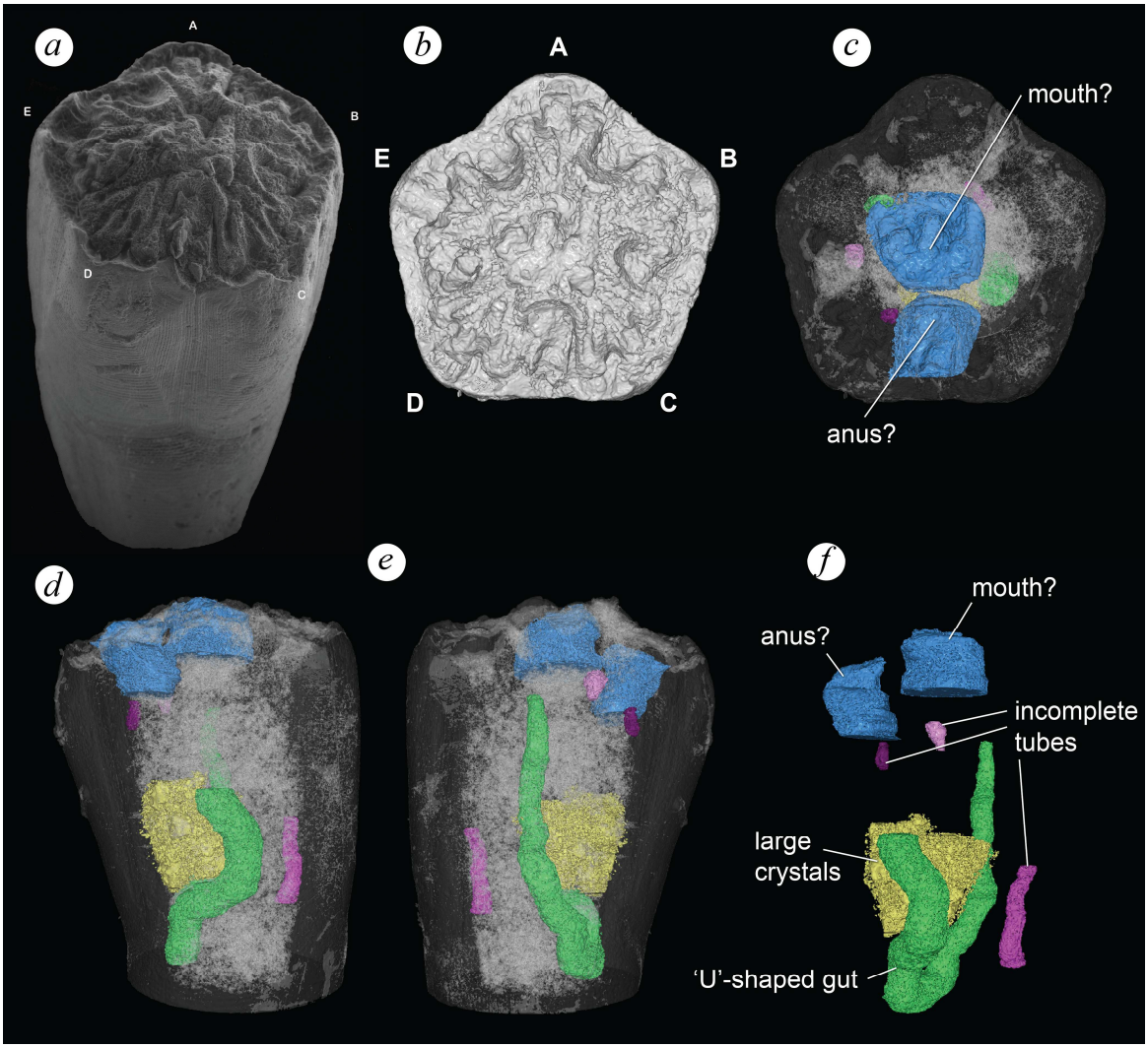

Figure 3. Reconstructions of early growth stage blastoid from the Carboniferous of China. **A.** SEM image of specimen (approximately 2mm in length). **B.** External reconstruction of oral surface using synchrotron imaging at the Swiss Light Source. **C, D, E.** Reconstructions of internal organ systems from SLS imaging. **F.** Interpretations of the reconstructed organs.

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2012-2013. EAGER - Exploratory Fieldwork in the Late Devonian of western Mongolia in the Summer of 2012. NSF. $11999.

2012-2013. Research Opportunity Award to NSF Grant DEB-1036260 "Collaborative Research: Assembling the Echinoderm Tree of Life." $25175.

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Output:

Published papers

The following papers on the echinoderm portion of this research are listed below. Papers emerging from the DAGGER group are detailed in Carmichael and Waters (this volume).

BAUER, J.E., SUMRALL, C.D. & WATERS, J.A. (in review): Hydrospire morphology and implications for blastoid phylogeny. - Journal of Paleontology.

BAUER, J.E., SUMRALL, C.D. & WATERS, J.A. (2015): Classifying Blastoids Through Hydrospire Morphology. - In: ZAMORA, S. & RÁBANO, I. (eds): Progress in Echinoderm Palaeobiology.Cuadernos del Museo Geominero, Instituto Geológico y Minero de España, Madrid, 19: 33-37.

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WATERS, J.A. (2015): The Evolutionary Paleoecology of the Blastoidea: What Have We Learned in the Past 29 Years. - In: ZAMORA, S. & RÁBANO, I. (eds): Progress in Echinoderm Palaeobiology.Cuadernos del Museo Geominero, Instituto Geológico y Minero de España, Madrid, 19: 189-192.

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ABSTRACTS AND CONFERENCE PRESENTATIONS

The following abstracts on the echinoderm portion of this research are listed below. Abstracts emerging from the DAGGER group are detailed in Carmichael and Waters (this volume).

ATWOOD, J.W., WATERS J.A. & SUMRALL, C.D. (2012): Blastoidea: Reconstructing the Echinoderm Tree of Life. - Presented at the annual meeting of the Geological Society of America, Charlotte, Nov. 3-7, 2012. Geological Society of America Abstracts with Programs, 44, 7: 137.

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BAUER, J.E., SUMRALL, C.D. WATERS, J.A. & RAHMAN, I.A. (2016): A Morphological and Synchrotron- based Tomographic Reevaluation of Macurdablastus as the Oldest Member of Blastoidea (Echinodermata). - Geological Society of America Abstracts with Programs, 48, 7: 282948.

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