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A new project has been launched: FWF P23775-B17 "Late Eifelian climate perturbations: effects on tropical coral communities"

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3 Text-Figures

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FWF P23775 B-17
Climate change
Late Eifelian Kačák Event
Middle Devonian corals

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Zusammenfassung

Während des frühen bis mittleren Devon herrschten Treibhausverhältnisse auf der Erde. Die Klimaentwicklung zu jener Zeit führte schließlich zu einem Höhepunkt an Diversität, Größe und Verbreitung von Riffen im mittleren Devon (Eifelium und Givetium). Doch auch während des Klimax im Mittel-Devon kam es vermehrt zu Klimaschwankungen, die in mehr oder weniger schweren biotischen Krisen resultierten. Eine dieser Krisenzeiten entspricht dem Kačák-Event während des späten Eifelium, der als Schwarzschiefer- und Hornstein-Horizont in marinen Sedimenten global nachgewiesen ist. Das mehrphasige dysoxische/anoxische Ereignisintervall beschränkt sich auf die *kockelianus*- und *ensensis*-Biozone (Conodontenzonierung) und entspricht in etwa einer Dauer von 200±10 Tausend Jahren. Der Event ist geprägt von markanten Faunenwechseln, die mit signifikanten Exkursionen im geochemischen und geophysikalischen Signal gekoppelt sind. Bisher durchgeführte Untersuchungen haben gezeigt, dass vor allem benthische Organismen aus tiefer marinen Ablagerungen auf die veränderten Umweltbedingungen reagiert haben. Neuere Erkenntnisse über diesen Event basieren vor allem auf Conodonten-Stratigraphie sowie auf der Studie von stabilen Isotopen und Untersuchungen zur Magneto-Suszeptibilität von Sedimenten.
Im Rahmen des Projektes sollen Veränderungen in tropischen Korallen-Vergesellschaftungen (im Speziellen von rugosen Korallen) während der Kačák-Krise untersucht werden. Die Lokalitäten der ausgewählten Gebiete (Karnische Alpen, Grazer Paläozoikum, Barrandium und Mähren) befanden sich zur

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damaligen Zeit, als Teile des Kontinentalschelfs von Nord-Gondwana, an unterschiedlichen Positionen in den niederen Breiten. Vor allem aus dem Mittel-Devon der Karnischen Alpen und des Grazer Paläozoikums sind fossile Kollektionen bekannt, die eine reiche und vielfältige rugose Korallenfauna beinhalten. Neben einer Menge an nicht bearbeitetem Material, welches sich in den Sammlungen wiederfindet, gibt es unter den beschriebenen Korallen auch Arten, die Unstimmigkeiten hinsichtlich ihrer taxonomischen Stellung sowie der stratigraphischen Reichweite aufzeigen. Dazu kommt noch umfangreiches Material an rugosen Korallen aus Mähren, welches bis heute noch keiner detaillierten Bearbeitung unterzogen werden konnte.
Ziel dieses Projektes ist es, einen Überblick über die rugosen Korallen geben zu können, die vom Kačák-Event betroffen waren. Dadurch sollen Fragen zur Resonanz von klimaempfindlichen Organismen auf sich verändernde Umweltbedingungen geklärt werden. Zusätzlich soll die Berechnung von Meerwasser-Temperaturen aus unterschiedlich niederen Breiten und die Anwendung von geochemischen und geophysikalischen Methoden dazu beitragen, Ursachen, die für den Kačák-Event verantwortlich waren, herauszufinden. Ergebnisse aus dieser Studie sollen hilfreiche Informationen zum Verständnis und der Ernsthaftigkeit derzeitiger und künftiger Klimaschwankungen sowie deren Auswirkungen auf die Biosphäre liefern.

Abstract

The Early to Middle Devonian is known as an interval dominated by global greenhouse conditions with an acme in diversity, size and latitudinal distribution of reefs during the Middle Devonian (Eifelian–Givetian). Nonetheless, also the Middle Devonian climax witnessed several climate perturbations that resulted in more or less severe biotic events. One of these events is the Late Eifelian Kačák Event, which is represented by a black shale and chert interval globally documented in sedimentary sequences. The polyphase dysoxic/anoxic event interval is constrained to the *kockelianus-ensensis* conodont biozones covering about 200±10 kyr. It is characterized by distinctive faunal changes concurrent with significant variations in the geochemical and geophysical signals. As far as documented, biotic response related to the event is observed mainly from benthic organisms of pelagic deposits. Therefore recent comprehensive studies deal mainly with deeper marine deposits providing data related to conodont stratigraphy, stable isotope analysis and magnetic susceptibility.
The project focuses on changes among tropical coral communities (especially emphasizing rugose corals) from neritic deposits of the Proto-Alps (Carnic Alps and Graz Paleozoic), the Barrandian and Moravia, contemporaneous with this event. Chosen areas were located in different low latitudes on the continental shelf of northern Gondwana during that time interval. Fossil collections obtained from Eifelian to Givetian strata of the Carnic Alps and the Graz Paleozoic yield abundant and various rugose corals. Apart from a lot of un-described material present in these collections the coral assemblages described from proto-alpine localities include also species which show inconsistency regarding their taxonomy as well as according to their stratigraphic appearance. Additionally, comprehensive rugose coral material is known from Moravia which has not been studied in detail yet.
The aim of this project is to reveal an overview of rugose coral assemblages affected by the Kačák Event to clarify questions related to the reaction of climate sensitive organisms to changing environmental conditions. Additional calculation of seawater temperatures across the event interval from different low latitude settings and the application of geochemical and geophysical methods should contribute to uncover the nature of the Kačák Event. Results of this study will provide helpful information on the understanding and severity of recent and future climate perturbations affecting biota globally.

Introduction

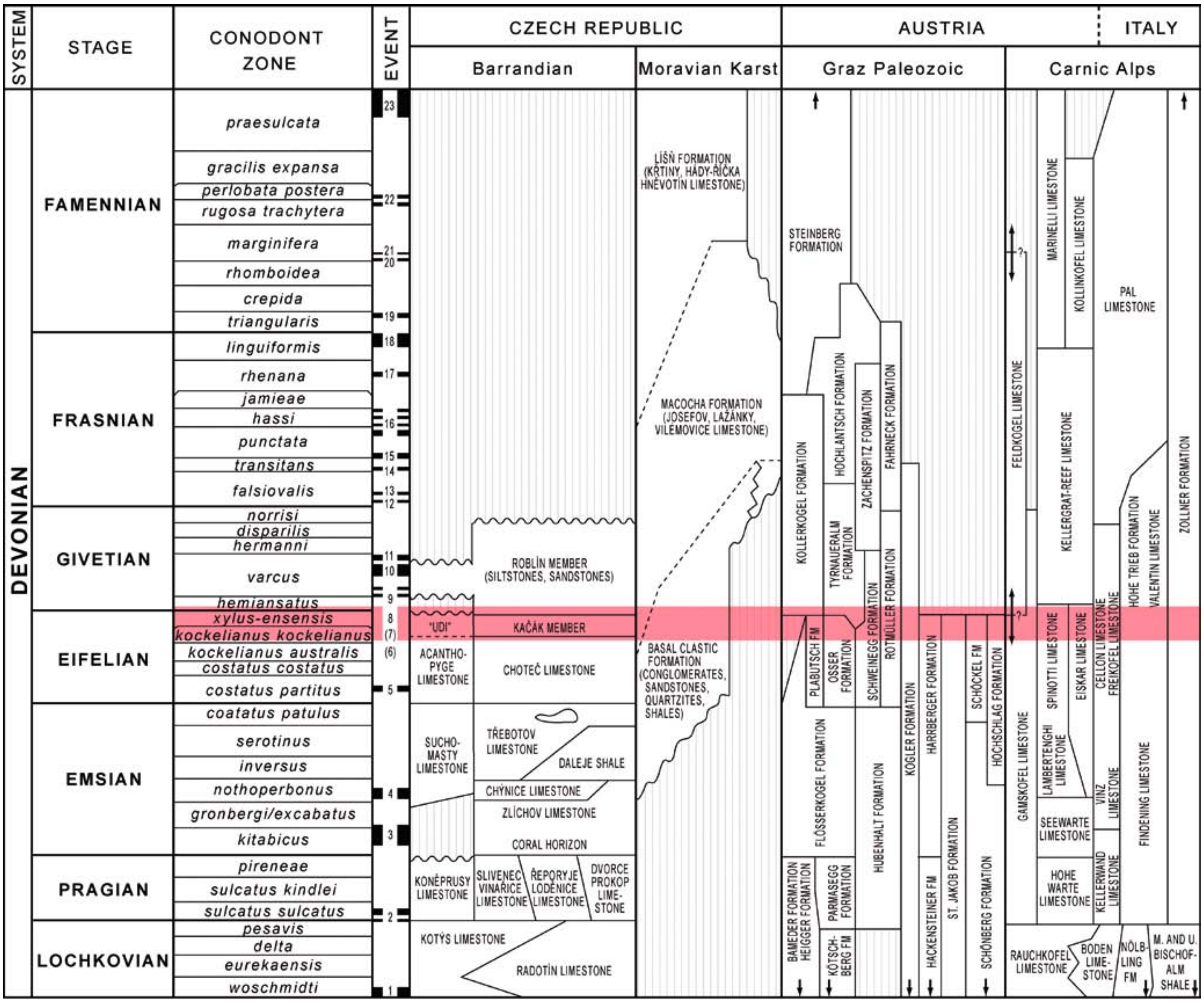
The Early to Middle Devonian (ca. 418–383 Ma) corresponds to an interval of global greenhouse conditions with high temperatures, which gradually changed to ice house conditions in the Late Devonian (e.g. KÖNIGSHOF, 2009). On the basis of developments in carbonate precipitating organisms that have produced an acme in diversity, size and latitudinal distribution of reefs during the Eifelian and Givetian (COPPER, 2002; VERON, 2008), it was suggested that the Middle Devonian time slice conforms to a *super-greenhouse* interval (COPPER & SCOTESE, 2003). This view has changed since JOACHIMSKI et al. (2009) published new insights on Devonian paleotemperature by providing their data on oxygen isotopes from conodont apatite, which show that during the middle Devonian sea surface temperatures around 23–25°C were prevailing, compared to the early and late Devonian, where higher temperatures around 30°C are presumed, that again decrease towards the late Famennian. Nonetheless, several minor climate perturbations documented during the Eifelian–Givetian (Text-Fig. 1) resulted in a certain loss of biomass or the formation of new, endemic or cosmopolitan taxa especially among tropical ecosystems such as coral reefs and other climate sensitive marine communities (compare TALENT et al., 1993; BOUCOT et al., 1995; HOUSE, 2002 and references therein; COPPER, 2002; BOSETTI et al., 2011). BENTON (1993) assumed that approx. 44 families were extinct during the Eifelian, but it is not clear yet, which of the intra-stage events had more severe effects on biomass, as the extinction rates usually are calculated for the entire duration of a stage interval. Following HOUSE (2002) it needs further detailed study of event intervals globally by application of methods facilitating stratigraphically high resolution to discriminate time and correlate single extinction phases and their intensity for proper estimates of extinction rates.

Late Eifelian climate deteriorations and biotic response

The Kačák Event

One of the most interesting Mid-Devonian events is the Kačák Event (HOUSE, 1985; CHLUPÁČ & KUKAL, 1986, 1988; BUDIL, 1995a; HOUSE, 1996; CHLUPÁČ, 1998), which is confined to near the Eifelian-Givetian boundary with an estimated duration of about 200±10 kyr (ELLWOOD et al., 2011). This event comprises several minor extinction pulses that started in the uppermost *kockelianus* Zone reaching a first extinction maximum at the base of the *ensensis* Zone, which equates with the base and top of the *eifelius* Zone of the alternative conodont zonation as compiled in KAUFMANN (2006) respectively. A second extinction pulse is documented just below the Eifelian-Givetian boundary (compare WALLISER, 2000; MARSHALL et al., 2007). According to the polyphase nature of the event interval it was quite difficult to discriminate and correlate the extinction pulses appearing in different sections from each other which has led to a confusion of single events (compare TRUYÓLS-MASSONI et al., 1990: Kačák-*otomari* Event). This has become more precise since the application of magnetic susceptibility (CRICK et al., 2000; ELLWOOD et al., 2011).

Due to increased concentrations of Ni, Cr, As, V, and Co and shocked quartz, documented from the GSSP at Mech Irdane (Anti-Atlas Mountains, Morocco), it was proposed that this bio-event might have been associated with bolide impact (ELLWOOD et al., 2003, 2004). Since an iridium anomaly is absent in the geochemical signal and only low concentrations of platinum group elements are measured



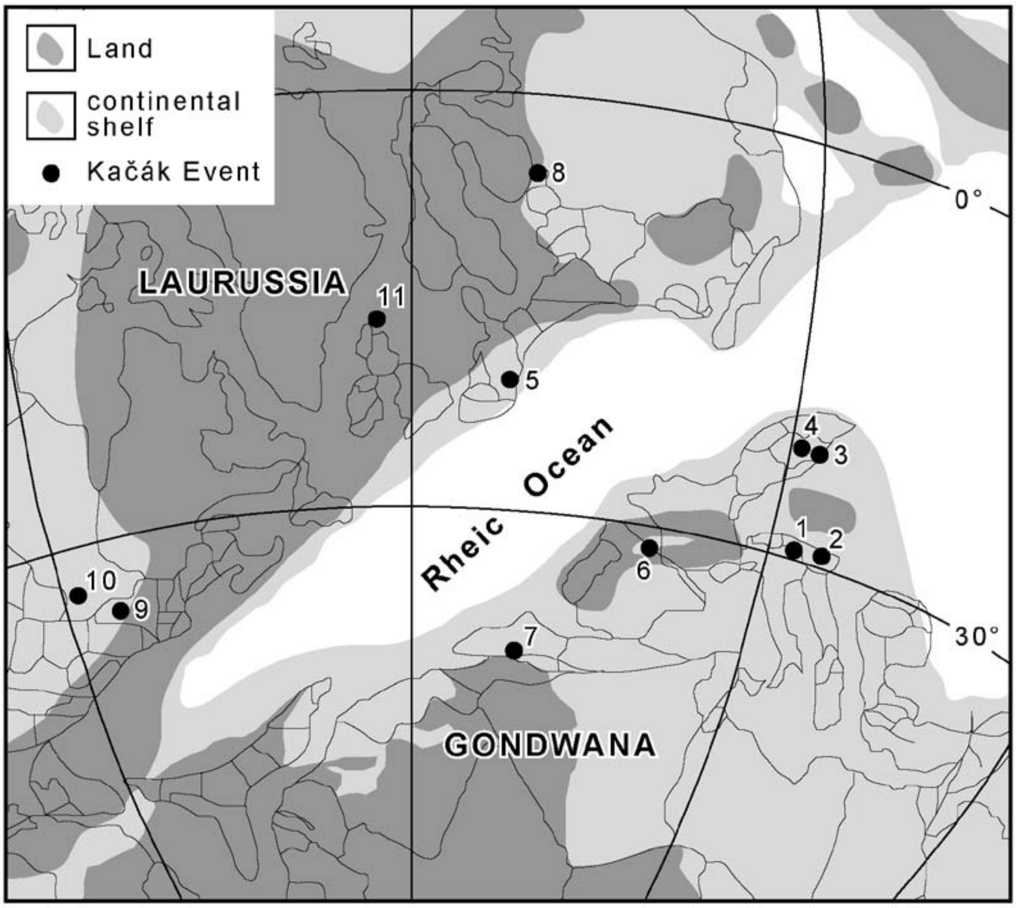
Text-Fig.1.
Globally recognized Devonian events and lithostratigraphic columns of Czech Republic, Austria and Italy: 1. Klonk, 2. Pragian/Lochkovian, 3. Lower Zlíchov, 4. Daleje, 5. Basal Choteč, (6). Bakoven, (7). Stony Hollow, 8. Kačák, 9. Pumilio, 10. Taghanic, 11. Geneseo, 12. Frasnes, 13. Genundeva, 14. Timan, 15. Middlesex, 16. Rhinestreet, 17. Lower Kellwasser, 18. Upper Kellwasser, 19. Nehden, 20. Condroz, 21. Enkeberg, 22. Annulata, 23. Hangenberg (as compiled in OGG et al., 2008; regarding events 6–7 see DESANTIS & BRETT, 2011). Color-bar spans the Kačák-Event interval.

(SCHMITZ et al., 2006), the bolide-impact hypothesis remains disputed (RACKI & KOEBERL, 2004). More likely is that variations in the geochemical record as well as anomalies in the magnetic susceptibility (MS) across the event interval are related to environmental perturbations (HLADÍKOVÁ et al., 1997; BUGGISCH & JOACHIMSKI, 2006; HLADIL et al., 2006; ELLWOOD et al., 2011).

However, a distinctive lithological change in pelagic sections is evident, which is represented by a horizon of black shale. This globally traced dysoxic/anoxic event was first documented by CHLUPÁČ (1960) in the Barrandian area of Czech Republic. He observed that the lithological change from Choteč limestone (Choteč Formation) to Kačák shale (Srbsko Formation) near the Eifelian/Givetian boundary was accompanied by significant extinctions among benthic invertebrate groups such as the disappearance of some trilobite taxa (CHLUPÁČ, 1994). Additionally, beneath effects on algae, ammonoids, brachiopods, crinoids, corals and conodonts (e.g. WALLISER et al., 1995; BUDIL, 1995a, b; EMPT, 2004), planktonic dacryoconarid index-taxa like *Nowakia chlupaciana* disappeared with the onset of the Kačák shale which, somewhat delayed, were substituted by species like *Nowakia otomari* (WALLISER, 1985; BUDIL, 1995a, b), whereas an abundance peak among radiolarians is observed already before the marking lithological change (BRAUN & BUDIL, 1999). The second "extinction" pulse did not exclusively result in extinction of marine faunas, but also documents the appearance of new conodont and ammonoid taxa (e.g. BUDIL, 1995b; WALLISER et al., 1995; BECKER et al., 2004). Furthermore the Eifelian–Givetian is also the time known for a revolution among land plants, when terrestrial floral communities developed arborescence, advanced root systems and seed habit (BUDIL, 1995a, b; KENRICK & CRANE, 1997; ALGEO & SCHECKLER, 1998; STEIN et al., 2007; MEYER-BERTHAUD et al., 2010).

Global record

Since its recognition, the Kačák Event is known from one lacustrine and at least ten marine areas within the Panthalassic, Rheic and Paleotethys oceans (MAWSON & TALENT, 1989; HOUSE, 1996; HUBMANN et al., 2003; MARSHALL et



Text-Fig. 2.
Reconstruction of the areas around the Rheic Ocean during the Eifelian (390 Ma), showing the locations where Kačák Event was recognized. Paleomap is based on SCOTESE (2002).
1. Carnic Alps (Austria-Italy),
2. Graz Paleozoic (Austria),
3. Moravia (Czech Republic),
4. Prague Basin (Czech Republic),
5. Eifel (Germany),
6. Cantabria (Spain),
7. Morocco,
8. Gorodenka (Russia),
9. New York State (U.S.A.),
10. Ontario (Canada),
11. Orcadian Basin (Scotland).

al., 2007 and references therein; VAN HENGSTUM & GRÖCKE, 2008; ELLWOOD et al., 2011), which reveals its global nature. On the paleogeographic reconstruction for the Eifelian (Text-Fig. 2) most important points around the Rheic Ocean are indicated.

Effects on marine ecosystems

As far as documented, biotic response to this event is observed mainly from benthic organisms of pelagic deposits (e.g. HOUSE, 1985; BUDIL, 1995b). However, from the type area, the Barrandian, it is reported that the coral community changed after the Kačák Event (GALLE & HLADIL, 1991). Within neritic deposits cropping out at Koneprusy area (Preissler and Jirasek quarries) the Eifelian/Givetian boundary interval is characterized by a "dark" horizon (Upper Dark Interval at Jirasek Quarry) near the top of Acanthopyge Limestone which may correspond to the Kačák Event (GALLE & HLADIL, 1991; GALLE, 1994; BUDIL, 1995a, b). Having a look at the distribution of Eifelian rugose corals of Acanthopyge Limestone, the basal part of the middle sequence includes a level termed Amplexus limestone yielding "*Amplexus" florescens* and *Bitraia bohemica* (GALLE & HLADIL, 1991). Following HILL (1981) the laccophyllid rugosan genus *Bitraia* is a small solitary, nondissepimented coral indicating environments of deeper and more unfavorable conditions. In the middle part of the middle sequence a second coral horizon (about or above *costatus* Zone: compare GALLE & HLADIL, 1981) is recognized which yields tabulate corals (favositids, alveolitids) and rugose corals (e.g. *Dohmophyllum* sp., *Lyrielasma*? sp., *Acanthophyllum* sp., *Disphyllum*? sp. and *Bitraia* ? sp.). In the upper sequence immediately below the Upper Dark Interval (UDI), species like *Grypophyllum deckmanni*, *Stringophyllum* sp., *Cystiphylloides* sp. cf. *C. schlueteri*, *Cystiphylloides* sp., *Dendrostella* sp. occur. GALLE & HLADIL (1991) documented that the event almost interrupted the coral communities and that a tabulate coral assemblage with common caliaporids (*Caliapora venusta*, *C. reducta*) and alveolitids (*Alveolites taenioformis*, *Spongioalveolites* sp. cf. *S. minor*) occurs, which, immediately overlying the UDI, already resembles a fauna of "Givetian type". A direct linkage between the Kačák Event and dominating coral assemblages seems to have been reported only from the Barrandian area.

However, a faunal change of corals through the Eifelian/Givetian boundary is also recognized in Germany, which at that time was located on the southern continental shelf of Laurussia in the Rheic Ocean. In the northern Eifel Hills of Germany, a coral crisis has been documented across the Eifelian/Givetian boundary, which actually is not based on the extinction of many species, but is reflected by a distinctive change of the coral assemblage. According to LÜTTE (1993), many of the well-known late Eifelian genera and species of the rugose corals from the Freilinger and Ahbach formations show a long stratigraphic range in Sotenicher Mulde (northern Eifel Hills). Some of them, such as *Cyathophyllum dianthus* and *Spongophyllum kunthi*, are still common in the Lower Givetian of the Loogher and Curten formations. Only some rugose coral taxa that occurred in the Upper Eifelian of the Ahbach Formation became extinct; most of them continued across the boundary with a reduced amount of individuals. Later, in the Lower Givetian the composition of the coral assemblage has completely changed due to the appearance and flourishing of new taxa rich in individuals. These are *Aristophyllum terechovi*, *Cystiphylloides* sp., *Glossophyllum dachsbergense*, *G. schouppei*, *G. soetenicum*, *Schlueteriphyllum looghiense*, *S. parvum* and *Soetenia struvei*. This coral assemblage is dominated by small cornuted corals like *Glossophyllum soetenicum*, *Schlueteriphyllum looghiense*, *S. parvum*, *Soetenia struvei* and *Aristophyllum terechovi*.

For a better understanding of the processes behind Late Eifelian climate deteriorations it is necessary to focus especially on changes in coral communities of neritic environments, which are observed before and after the Kačák Event as these are regarded as the first ones to suffer changing environmental conditions. Therefore we aim to reveal an overview of rugose coral assemblages affected by the event to clarify questions related to the reaction of climate sensitive organisms to changing environmental conditions. Additional calculation of seawater temperatures across the event interval from different low latitude settings and the application of geochemical and geophysical methods should contribute to uncover the nature of the Kačák Event.

Methods

The main method applied within the frame of this project is the taxonomic study of Middle Devonian rugose corals from the Carnic Alps, the Graz Paleozoic and Moravia. Together with this, for identification of the Kačák-Event interval and the reconstruction of the Middle Devonian paleoclimatic history, stable carbon and oxygen isotopes will be analyzed. Additionally, magnetic susceptibility and gamma-ray spectrometry will be measured for correlation and characterization of the sections in the Carnic Alps and Graz Paleozoic across the Kačák-Event interval. Finally, we try to achieve a specification of the coral assemblages related to a proper stratigraphic frame using conodont biostratigraphy in combination with stable isotope curves, MS-logs, and gamma-ray spectrometry. However, we are aware of the complexity of these methods and will test our results for possible secondary effects like diagenesis when using geochemical and geophysical data for paleoenvironmental interpretations and the reconstruction of Middle Devonian paleoclimate conditions. Below, each method is characterized.

Taxonomic study

Classification of fossil corals is based on the morphological features of their skeletal elements such as septa, tabulae, dissepiments and corallum-wall. For proper taxonomic identification, a series of transverse and longitudinal thin sections of each coral specimen, cut with a precision-sectioning saw, is necessary. For manipulation of thin sections via professional graphics software, high-resolution scans have to be produced. The material used will be collected during the study of several localities in the field. Additional coral specimens available from collections of the University of Graz and the Natural History Museum Vienna, as well as from geological repositories of the Czech Geological Survey (Klarov, Czech Republic), the Natural History Museum Prague and Museo Friulano di Storia Naturale (Udine, Italy) guarantee a sufficient quantity of material necessary for taxonomic study and revision.

Biostratigraphy

Conodont biostratigraphy was applied at sections that were either not sampled, or did not produce microfossils yet. Conodonts are extracted by dissolution of carbonate rocks (2–5 kg) in formic acid. Residues of each sample are sieved in sets of 4 different mesh-widths (63 µm, 125µm, 250 µm and 500 µm). In case fractions between 63 and 250 µm would fill more than 5 standard picking trays and therefore are too time consuming for being picked at that stage of separation, residues are further processed by heavy liquid separation using sodium polytungstate. The heavy fraction will be picked for conodont elements under a binocular microscope and scanned under a SEM (DSM 982 Gemini electron microscope) for taxonomic identification.

Geochemistry

Carbon and oxygen isotope analysis (bulk samples)

It is documented that high-resolution isotopic analysis of bulk sedimentary carbonate and organic matter for the Middle Devonian succession records a significant negative $\delta^{13}C$ excursion globally. This negative $\delta^{13}C$ excursion is considered as a result of marine anoxia associated with the Kačák Event (van Hengstum & Gröcke, 2008). We will collect rock samples across the Eifelian/Givetian boundary to see whether this negative excursion is also evident in neritic carbonate deposits, where no black shale is observed. Therefore bulk samples will be taken in short distances of 10 to 15 cm across the event interval. In further processes, each sample will be crushed to fine homogenous powder and analyzed in a Finnigan MAT Delta Plus stable isotope ratio mass spectrometer.

Oxygen isotope analysis for calculation of sea surface temperature (SST)

Oxygen isotope values are obtained from the PO_4^{3-} group of conodont elements via silver phosphate precipitation. The advantage of using phosphatic microfossils (0.5–2 mm in size) is the resistant nature of their carbonate fluorapatite composition compared to results from bulk-rock samples. $\delta^{18}O$ ratios will be used to calculate trends of sea surface temperatures using the new phosphate-water fractionation equation of Pucéat et al. (2010). Sections in Austria, Italy and the Czech Republic will be compared to already existing data from Germany and France (Joachimski et al., 2009).

Geophysics

Magnetic susceptibility (MS)

Magnetic-susceptibility measurements are considered to serve as proxy for impurities in sedimentary rocks. The detection of high magnetic-response in sediments corresponds with increased erosion-rates of iron-rich weathering products dispersed from subaerially exposed continental landmass during sea-level lowstands, enhanced rainfall or other factors forcing a raised detrital input.

In the late Eifelian a distinctive magnetosusceptibility event is recognized as broad depression in the MS-curve which is related to the Kačák Event (Hladil et al., 2002). In order to assess a high quality database, no field device (e.g. KT-6) will be used for application of this method. We will collect bulk-rock samples in intervals of approx. 10 cm across the event interval (depending on the proximity of the depositional area: thick shallow marine carbonates vs. condensed deeper marine sediments). Measurements will be performed under a KLY-3 kappabridge device. The MS values (δMS) measured will be plotted for high resolution correlation of single sections from the Carnic Alps (deeper marine sequence) and the Graz Paleozoic and compared to existing logs of Moravia and Morocco. Additionally, datasets will be used for paleoenvironmental interpretation of the investigated areas.

Gamma-ray spectrometry (GRS)

This method will be applied directly on rocks in the field (Graz Paleozoic, Italian part of the Carnic Alps, UDI of the Barrandian area). Measurements will be made in closely spaced intervals across the event interval by using a GS-512 (console) and GSP-3 (detector). In order to achieve optimum measurement conditions the field device requires full perpendicular contact of the probe front to clean and flat vertical rock face, with sufficient time for stabilization of counts (around 3 minutes per measurement). The results are directly recalculated to contents of potassium (K), uranium (U) and thorium (Th) and can be transferred from the field-device to a computer, where logs are plotted in adequate programs. This method provides information on natural gamma radiation of rocks which is used as correlation tool for high resolution stratigraphy.

Discussion of the study area

The coral assemblages that will be studied during the project are collected from localities of the Proto-Alps (Carnic Alps and Graz Paleozoic), Barrandian and Moravia. During the Devonian these areas were located in different low latitudes on the continental shelf of northern Gondwana. Fossil collections obtained from Eifelian to Givetian strata of the Carnic Alps and the Graz Paleozoic yield abundant and various rugose corals. Apart from a lot of un-described material present in these collections the coral assemblages described from proto-alpine localities include also species which show inconsistency regarding their taxonomy as well as according to their stratigraphic appearance. Additionally, comprehensive rugose coral material is known from Moravia which has not been studied in detail yet.

Devonian sediments of the Proto-Alps, together with those of the Barrandian and Moravia (Text-Fig. 1), were deposited on the northern margin of the continental shelf of Gondwana in the Rheic Ocean (Text-Fig. 2). It is proposed that two terranes or microcontinents may have existed in the Alps suggesting latitudinal differences between the Southern Alps and the Graz Paleozoic (KREUTZER et al., 1997). SCHÖNLAUB (1993) and other authors like SCHÄTZ et al. (2002) inferred that the Proto-Alps were located in low latitudes around 30°S or less during the Devonian. This conforms to latitudinal settings of approx. 10 to 15 degrees higher than the Barrandian terrane (KRS et al., 2001) and Moravia (HLADIL et al., 1999). An interpretation on the relations between different European areas by using faunal affinities shows that some areas of Austria (e.g. Graz Paleozoic) were closely related to Moravia during the Eifelian whereas other areas like the Carnic Alps show more affinity to N-Spain and parts of Germany during the Givetian (HLADIL et al., 1999). However, both the Carnic Alps as well as the Graz Paleozoic yield abundant Middle Devonian corals (FLÜGEL & HUBMANN, 1994; HUBMANN, 1995; HUBMANN et al., 2006; HUBMANN & SUTTNER, 2007; see Text-Fig. 3 for a compilation of coral taxa). In the Graz Paleozoic for example (compare HUBMANN & MESSNER, 2007, for lithostratigraphic background), 51 species belonging to 27 genera have been described from the Eifelian of the Plabutsch Formation and eight species in five genera are reported from the Eifelian to Givetian of the Tyrnaueralm and Hochschlag Formations. From Givetian deposits of the same area 12 species in 9 genera are known of the Flösserkogel Formation (Pleschkogel Member), Zachenspitz Formation and Kollerkogel Formation (Kanzel Member). In the Carnic Alps, only one rugose coral species is described from Eifelian to Givetian strata, whereas a diverse fauna with 57 Givetian rugose coral species in 29 genera is reported from the Kellergrat Reef Limestone (central Carnic Alps), reefal limestone of Mt. Zermula (Italy), limestone breccia-levels (yielding silicified corals) of the Hoher Trieb Formation at Findenigkofel, Oberbuchach, Casera Monumenz, Passo del Cason di Lanza, and from other limestone units in Austria and Italy (Text-Fig. 3). Although abundant rugose corals are known from "unit A" of the Spinotti Limestone (age constraint follows KREUTZER, 1990, 1992a, b; HUBMANN et al., 2003), coral occurrences in Eifelian strata of the Carnic Alps are absent in Text-Fig. 3, as they have not been studied in detail yet. Further comparison of the rugose coral taxa listed from the Carnic Alps and the Graz Paleozoic shows that both areas share some species obtained from deposits of different ages (compare color code of species in Text-Fig. 3).

A somewhat similar discrepancy is observed by GALLE (1994) and GALLE et al. (1995) from Eifelian rugose corals of the Barrandian (Acanthopyge Limestone), which essentially differ from Moravian corals (Čelechovice and Horni Benesov regions), but show conspicuous similarities to Givetian rugose faunas of Germany (mostly from the Rhenish Slate Mountains, northern Eifel Hills) and other regions. This can be due to several explanations such as a long range of some species or low stratigraphic resolution of coral-yielding sections during research in the past, but it could also be related to the migration of some taxa. To confirm any of these hypotheses and to conclude further climate-related interpretations uncovering the nature of the Kačák Event, as aimed by this project, Eifelian–Givetian rugose coral assemblages of the proto-alpine realm need to be studied in proper high-resolution stratigraphic context (including modern geochemical and geophysical methods) and compared with faunas of related areas such as the Barrandian, Moravia, Germany, Spain and Morocco. This would help to clarify migration processes as well as the development of endemic and cosmopolitan taxa across the event interval.

Project aims

Paleontology: Taxonomic revision – updating the database

Rugose corals from the Middle Devonian of the Carnic Alps and the Graz Paleozoic include species, which show inconsistency, not only regarding their taxonomy but also according to their stratigraphic appearance. For example,

	Carnic Alps (Austria - Italy)	Graz Paleozoic (Austria)
Givetian	○Tryplasmatidae *Tryplasma devonica* ○Cystiphyllidae *Zonophyllum* sp. *Cystiphyllum? cristatum* *C.? geyeri* ○Streptelasmatidae *Grewinglia? carnica* ○Stauriidae *Dendrostella trigemme* *D.* cf. *Favistella praerhenana* ○Mucophyllidae *Pseudamplexus frechi* ○Amplexidae *Amplexus mutabilis* *A. frechi major* *A. gortanii* *A. hercynicus* ○Laccophyllidae *Barrandeophyllum carnicum* ○Entelophyllidae *Entelophyllum articulatum* *E.? alpinum* ○Lykophyllidae *Pycnactis mitratum* ○Endophyllidae *Tabulophyllum heckeri giveticum* *T. delicatum* *Endophyllum priscum* *E. acanthicum* ○Spongophyllidae *Battersbyia* sp. *B. devonica* *B. petshorense* ○Ptenophyllidae *Acanthophyllum concavum* *A. vermiculare* *A. heterophyllum heterophyllum* *Acanthophyllum* sp. *Dohmophyllum helianthoides* *D. philocrinum* *D.* cf. *D. involtum* *Grypophyllum* sp. ○Stringophyllidae *Sociophyllum torosum* *Stringophyllum praecursor* *S. primordiale* *S. schwelmense* *Stringophyllum* sp. ○Cyathophyllidae *Cyathophyllum dianthus* *C. spongiosum* *C.? bathycalyx* *C.? angustum* *C.? lindströmi* *C.? volaicum* *C.? taramelli* *C.? conglomeratum pauciseptatum* *Peripaedium planum* ○Accervulariidae *Columnaria* sp. ○Disphyllidae *Temnophyllum* cf. *T. latum* *Ceratophyllum ceratites* *Disphyllum goldfussi* *D. caespitosum caespitosum* *D.? recressum* ○Phillipsastreidae *Phillipsastrea hennahi* *Phacellophyllum conglomeratum* *Pterorrhiza dubia* *Pexiphyllum heterophylloides* *Thamnophyllum caespitosum* *T. hoernesi*	○Tryplasmatidae *Tryplasma* cf. *T. fasciculare* ○Amplexidae *Amplexus mutabilis* ○Laccophyllidae *Neaxon symmetricus* ○Ptenophyllidae *Acanthophyllum concavum* *A. delicatum* *A. heterophyllum torquatum* *Acanthophyllum* sp. ○Stringophyllidae *Stringophyllum praecursor* ○Cyathophyllidae *Peripaedium planum* *Pseudohexagonaria amanshauseri* ○Disphyllidae *Disphyllum hsianghsienense kostetskae* *D. caespitosum pashiense* *Hexagonaria darwini* *H. hexagona* *H.* cf. *H. sanctacrucensis* ○Columnariidae *Columnaria* sp. A ○Phillipsastreidae *Thamnophyllum cylindricum* *Peneckiella achanayensis*
Eifelian-Givetian	○Stauriidae *Dendrostella vulgaris*	○Tryplasmatidae *Tryplasma?* sp. ○Phillipsastreidae *Thamnophyllum germanicum germanicum*
Eifelian		○Tryplasmatidae *Tryplasma devonica* *T. hercynica* ○Cystiphyllidae *Cystiphyllum?* sp. *Mesophyllum cristatum* *M. vesiculosum vesiculosum* *Mesophyllum?* sp. *Cystiphylloides macrocystis* *C. caespitosum* *C. pseudoseptatum* ○Calceoridae *Calceola sandalina* ○Kodonophyllidae *Zelophyllia? cornuvaccinum* ○Stauriidae *Dendrostella* sp. ○Pycnostylidae *Synaptophyllum? heritschi* ○Amplexidae *Amplexus ungeri* *A.* aff. *A. helminthoides* ○Metriophyllidae *Metriophyllum gracile* ○Ketophyllidae *Dokophyllum* cf. *D. murchisoni* *D.* cf. *D. subturbinatum* ○Endophyllidae *Tabulophyllum chernychevi* ○Halliidae *Hallia? sophiae* ○Ptenophyllidae *Acanthophyllum smyckai* *A. heterophyllum heterophyllum* *A.* cf. *A. moravicum* *Dohmophyllum helianthoides* *Dohmophyllum* sp. *Grypophyllum denckmanni* *G. frechi* *Grypophyllum* sp. ○Stringophyllidae *Stringophyllum buechelense* *S. isactis* *S.? schlüteri* *Sociophyllum elongatum* *S. longiseptatum* ○Cyathophyllidae *Cyathophyllum dianthus* *C.? hallioides* *C.? graecense* *C.? hoernesi* *Moravophyllum tenuiseptatum* *Peripaedium turbinatum* ○Disphyllidae *Disphyllum goldfussi* *D. caespitosum caespitosum* *D. aequiseptatum* *Ceratophyllum ceratites* ○Columnariidae *Columnaria* cf. *C. inaequalis* ○Phillipsastreidae *Phacellophyllum conglomeratum* *Thamnophyllum hoernesi* *T. murchisoni* *T. peneckei* *T. stachei* *T. caespitosum* *T. germanicum germanicum*

Text-Fig. 3.
Middle Devonian rugose corals of the Carnic Alps and the Graz Paleozoic. The corals with green color code are species which, following the literature, occur in both, the Eifelian and Givetian Stage of the Proto-Alps. Three species with blue color code occur in the Givetian of the Carnic Alps and the Graz Paleozoic. Rugose corals listed here refer to the compendium of Flügel & Hubmann, 1994 (see coral systematics for further references therein). The names of family and genera used here basically follow the classification proposed by Hill (1981).

Ceratophyllum ceratites which occurs in the ?Eifelian of the Tyrnaueralm Formation of the Graz Paleozoic and possibly in the ?Givetian of the Carnic Alps (FLÜGEL & HUBMANN, 1994; see Text-Fig. 3) should be revised from *Ceratophyllum* to *Glossophyllum*, hence LÜTTE (1987) included *Ceratophyllum ceratites* within the genus *Glossophyllum* from the Givetian of the northern Eifel Hills, Germany. Following LÜTTE (1993) this genus first appeared in Givetian strata and includes seven species (LÜTTE, 1987, 1990, 1993).

Another example is the so called *Cyathophyllum dianthus* Zone that consists of an assemblage of distinctive rugose corals (*Cyathophyllum*, *Acanthophyllum*, *Moravophyllum*, *Spinophyllum* and *Calceola*). This zone, formerly considered as latest Eifelian or early Givetian (compare GALLE, 1985), could be confined to the earliest Givetian (*hemiansatus* and early *varcus* zones) by HLADIL et al. (2002) through the application of magnetic susceptibility on the Čelechovice section (Moravia) in comparison to the MS log of the GSSP at Mech Irdane in Morocco (early Givetian rugose corals from Ma'der Basin in Morocco are described by PEDDER, 1999). In the Graz Paleozoic the rugose coral assemblage including *Cyathophyllum* (*C. dianthus*), *Acanthophyllum*, *Moravophyllum* and *Calceola* (obtained from the Tyrnaueralm Formation), which represent the *C. dianthus* Zone in Moravia, is proposed to be Eifelian in age (compare Text-Fig. 3). The last taxonomic study of rugose corals from the Southern Alps was in 1992 by OEKENTORP-KÜSTER & OEKENTORP, 19 years ago. During this time, the implication of the Kačák Event has been discussed much in detail and taxonomic study of Devonian rugose corals progressed.

A revision of problematic taxa described from the Graz Paleozoic and the Carnic Alps, when set in its proper stratigraphical context, would help to clarify the number of genus/species and identify synonyms per time slice. Such a contribution would improve the global databases on the fossil record of corals, which actually are used as the base for all further calculations e.g. on extinctions and diversification events among biomass during the Phanerozoic or the identification of paleobiogeographic provinces and related models.

Paleoclimatology: Hypothesis on the nature of the Kačák Event

Recently, several scientists involved in geology and geochemistry focus on the identification of Middle Devonian events globally. However, most of them deal exclusively with conodont stratigraphy, carbon isotopes and magnetic susceptibility of deeper marine sections for identification and to conclude mechanisms behind these events. We think that a multidisciplinary study is necessary and that knowledge especially on faunal changes and developments of marine climate sensitive organisms across the event intervals is important. The innovative aspect of our study on the Kačák Event is that we apply modern geochemical and geophysical stratigraphic methods together with common, but indispensable faunal analyses in shallow as well as in deeper marine sections of the Eifelian/Givetian tropical belt. Only a combination of several methods will help to uncover the nature of the Kačák Event. One of the main points we focus on is a high resolution paleotemperature log (based on oxygen isotope analyses from conodont apatite) across the event interval from different latitudes across the tropical belt of the southern hemisphere. These logs will be compared to contemporaneous developments in rugose corals to document whether changes in coral faunas can be related to temperature variations, or if they are distinctive for other causes.

Future perspectives

Actually, it is well documented by CO_2 proxy record (ROYER, 2006) that the rise given to land plants during the Middle Devonian was coupled with strongly decreasing atmospheric CO_2 values from 4000 ppm to nearly present day values during the Early Carboniferous of about 300 ppm. The development on land and its effect on marine biota (especially on skeletal frame-builders like corals) as documented by the fossil record will provide important information uncovering controlling mechanisms responsible for climate change. This might help to produce strategies to counteract rapid rising CO_2 levels during the recent climate change.

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