Abstract Volume
11th Swiss Geoscience Meeting

Lausanne, 15th – 16th November 2013

4. Cycles and Events in Earth History

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Swiss Academy of Sciences
Akademie der Naturwissenschaften
Accademia di scienze naturali
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4. Cycles and Events in Earth History

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4.1

Deccan Volcanism: a main trigger of environmental changes leading to the KTB mass extinction?

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Model results predict that Deccan Traps emplacement was responsible for a strong increase in atmospheric pCO_2 accompanied by rapid warming of 4°C (Dessert et al., 2001) that was followed by global cooling. During the warming phase, increased continental weathering of silicates associated with consumption of atmospheric CO_2 likely resulted in the drawdown of greenhouse gases that reversed the warming trend leading to global cooling at the end of the Maastrichtian.

Massive CO_2 input together with massive release of SO2 may thus have triggered the mass extinctions in the marine realm as a result of ocean acidification leading to a carbon crisis and in the terrestrial realms due to acid rains (Fig. 1). Global stress conditions related to these climatic changes are well known and documented in planktic foraminifera by a diversity decrease, species dwarfing, dominance of opportunistic species and near disappearance of specialized species. Recent studies indicate that the bulk (80%) of Deccan trap eruptions (phase-2) occurred over a relatively short time interval in magnetic polarity C29r (Chenet et al., 2007). Multiproxy studies from central and southeastern India place the Cretaceous-Tertiary (KT) mass extinction near the end of this main phase of Deccan volcanism suggesting a cause-and-effect relationship (Keller et al., 2012).

In India a strong floral response is observed as a direct response to Deccan volcanic phase-2. In Lameta (infra-trappean) sediments preceding the volcanic eruptions, palynoflora are dominated by gymnosperms and angiosperms with a rich canopy of gymnosperms (Conifers and Podocarpaceae) and an understory of palms and herbs (Samant and Mohabey, 2009). Immediately after the onset of Deccan phase-2, this floral association was decimated leading to dominance by angiosperms and pteridophytes at the expense of gymnosperms. In subsequent intertrappean sediments a sharp decrease in pollen and spores coupled with the appearance of fungi mark increasing stress conditions apparently as a direct result of volcanic activity. The inter-trappean sediments corresponding to Phase-2 (80% of Deccan basalt emissions, latest Maastrichtian) are characterized by the highest Chemical Index of Alteration (CIA) values. This can be explained by increased acid rains due to SO_2 emissions rather than a global climatic shift, because clay minerals from the corresponding sediments do not reflect a significant climate change. The increased weathering is coeval with the sharp decline in pollen and an increase in fungal spores observed by Samant and Mohabey (2009) and corresponds to the main phase-2 of Deccan activity.

Beyond India, multiproxy studies also place the main Deccan phase in the uppermost Maastrichtian C29r below the KTB (planktic foraminiferal zones CF2-CF1 spanning 120ky and 160ky respectively), as indicated by a rapid shift in $^{187}Os/^{188}Os$ ratios in deep-sea sections from the Atlantic, Pacific and Indian Oceans (Robinson et al, 2009), coincident with rapid climate warming, coeval increase in weathering, a significant decrease in bulk carbonate indicative of acidification due to volcanic SO_2, and major biotic stress conditions expressed in species dwarfing and decreased abundance in calcareous microfossils (planktic foraminifera and nannofossils). These observations indicate that Deccan volcanism played a key role in increasing atmospheric CO_2 and SO_2 levels that resulted in global warming and acidified oceans, which led to increased biotic stress that predisposed faunas to eventual extinction at the KTB.

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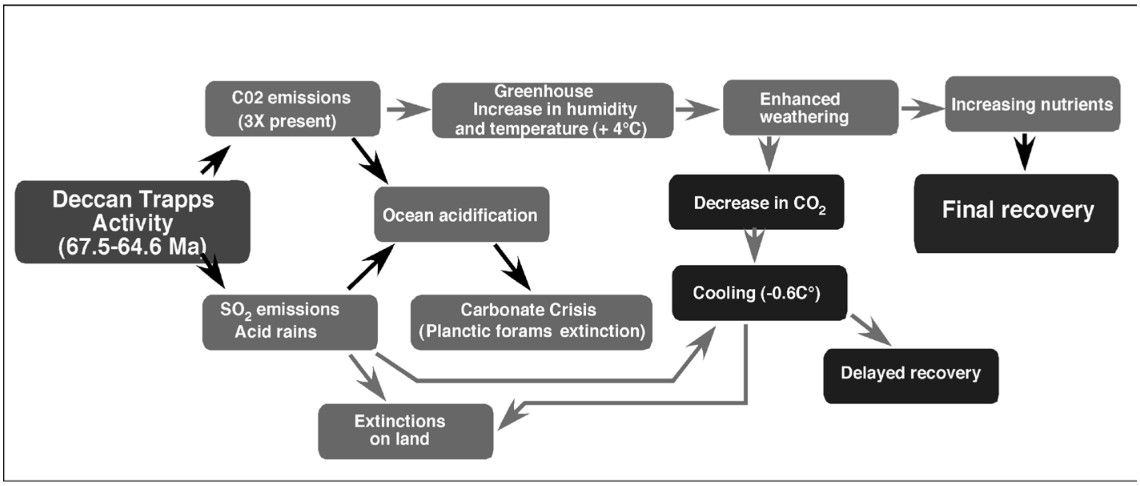

Figure 1: Flow chart for the model of massive Deccan volcanism as a main trigger of environmental changes leading to the KTB mass extinction.

4.2

High precision time calibration of the Permo-Triassic boundary mass extinction event by U-Pb geochronology

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Thermal Ionization Mass Spectrometry (TIMS) has and continues to be the principal analytical method for geochronologists, allowing high sensitivity and high time resolution analyses of single grain samples. For zircon geochronology, the advent of multicollector instruments, the development of double spike methodologies coinciding with the reassessment of the uranium decay constants and further improvements in ion counting technology led to nowadays precision better than 0.1% for single grain and 0.05% for population ages, respectively. These analytical innovations now allow to calibrate the record of biological evolution at a resolution relevant to magmatic and biological timescales.

To construct a revised and high resolution calibrated time scale for the Permian-Triassic boundary (PTB) we use U-Pb zircon geochronology from ash layers in the marine Nanpajiang Basin (South China) in combination with quantitative biostratigraphic methods and carbon isotope variations across the PTB. Establishing stratigraphic tie points between the Late Permian to the Early Jurassic allows globally valid intercalibration of biochronological, chemostratigraphic, and astrochronological time-series with radio-isotopic ages for quantifying extinction and recovery rates.

4.3

Depositional geometries in the Tierwis and Schrattenkalk Formations: a geochemical and sequence stratigraphic correlation

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Urgonian platform carbonates are a common feature of subtropical and tropical shallow-water environments of late Early Cretaceous age. They include the remains of rudists, corals, chaetetids and stromatoporoids, which are interpreted as indicators of a predominantly photozoan, oligotrophic carbonate-producing ecosystem. The late Early Cretaceous is also marked by the occurrence of several oceanic anoxic episodes, such as the latest Hauterivian Faraoni and the early Aptian Selli Events, which are both interpreted as the consequence of generalized eutrophic conditions. These observations imply that the late Early Cretaceous underwent larger fluctuations in nutrient supply, which may have interfered with the evolution of the widespread Urgonian platforms.

Our goal is to study the interactions between paleoceanographic and paleoclimatic change, and Urgonian carbonate buildup in the northern, Helvetic Alps. This unit remains understudied relative to its counterparts in eastern and central France. We specifically intend to compare the Urgonian units of late Barremian age and early Aptian age, which are separated by the so-called "Lower Orbitolina Beds". The late Barremian was less affected by anoxia, whereas the early Aptian witnessed progressive change in paleoceanographic conditions, which led up to the Selli Event.

The preliminary results of a selection of representative sections from the Helvetic Alps will be shown. They were analyzed both for their phosphorus and stable-isotope (C, O) contents, as well as for their microfacies in order to develop a sequence stratigraphic framework. One of the key features is the total disappearance of a late Barremian depositional sequence in proximal areas, and the progressive morphological change of the platform, from a ramp-like (early Barremian) to a distally-steepened platform (late Barremian and early Aptian).

4.4

Latemar - What dictates the rhythm?

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Around two decades ago the ca. 600 sedimentary cycles identified in the Middle Triassic platform interior at Latemar in the Dolomites (northeastern Italy) became a reference example for Mesozoic shallow water carbonates that were considered to record Milankovitch-type sedimentary rhythms. By 1987 L.A. Hardie, R.K. Goldhammer and co-workers had established a solid cyclostratigraphy based mainly on visual analysis and „Fischer plots" of bedding patterns. Support for the then "in vogue" interpretation came from sophisticated mathematical analysis (Goldhammer & Hinnov 1991; Preto et al., 2001) and available age constraints were largely neglected or discredited. However, the Milankovitch interpretation of the Latemar cycles was soon challenged by new paleontological evidence and later by U-Pb-zircon age constraints for the cyclic interval. The contradicting results triggered a heated debate known in the literature as the „Latemar controversy". Another, probably related consequence was that the then state-of-the-art radio-isotope data were not considered in the International Geological Time Scale until 2011, i.e. almost 15 years after they had been published!

Meanwhile a precise calibration of the Latemar stratigraphy has been established on the basis of elements observed in both, platform carbonates and corresponding basinal successions: i) macrofossils (mainly ammonoids), ii) physical stratigraphy (tracing of sedimentary layers and intervals between platforms and basinal successions), iii) different generations of U-Pb zircon age data of tephra layers, iv) patterns of magnetic reversals and data series on magnetic susceptibilites. The result is one of the arguably best calibrated Mesozoic platform-basin settings with a short duration in the order of 1 myr.

The ca. 450 m thick “cyclic” succession at Latemar corresponds to only a small interval of basinal sediments at short distance (< 4 km) from the toes of actively growing platforms (Fig. 1). The short-term carbonate production in the Middle Triassic was evidently high and probably compares to recent figures. Unlike many modern settings only little sediment was available for far travelled off-platform transport.

The age calibration of the “cyclic” portion at Latemar results in an average duration in the order of 1-2 kyr for the 600+ shortest “beats” (Kent et al., 2004; Spahn et al., 2013). These are considered to reflect small amplitude fluctuations of sea level. Frequencies of the Milankovitch band seem to be superimposed on this basic signal (e.g., Meyers 2008). The driver of such a short rhythm remains unknown but Pleistocene examples suggest that short low amplitude (< 10 m) sea level fluctuations may also be preserved in modern environments.

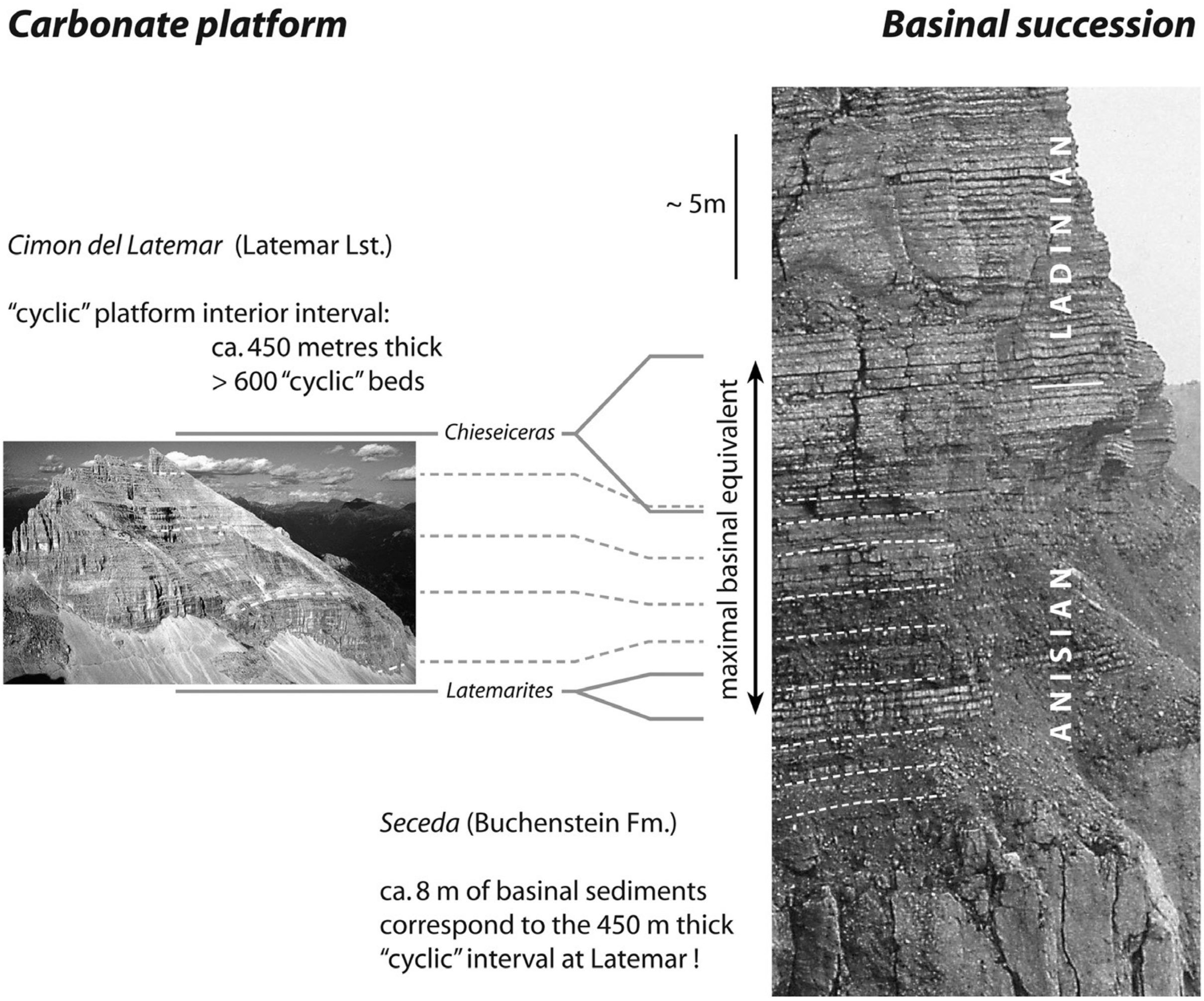

Figure 1. Comparison of the Latemar stratigraphy and the basinal succession at Seceda. The thickness of the basinal carbonates corresponding to the “cyclic” interval at Latemar is almost two orders of magnitude smaller!
Full lines indicate the distributions of the oldest and youngest ammonoid genera used for correlation. Dotted lines mark possibly corresponding tephra layers. The time span represented by the Latemar as shown is < 2 myr and possibly as small as 1 myr or even less.

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4.5

Detrital and nutrients influxes in the Northwestern Tethyan margin during the Valanginian: new insights from weathering changes during the Weissert episode

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The Valanginian stage is characterized by a positive carbon isotope excursion (CIE, 1.5‰), the so-called « Weissert Event » (Erba et al., 2004). This event coincides with a widespread crisis of carbonate producing biota associated with important platform drowning events (Föllmi et al., 1994). The formation of the Parana-Etendeka large igneous province (LIP) (ca. 134 Ma) (Janasi et al., 2011) has been widely assumed to be responsible for an increase of CO_2, triggering long-term greenhouse conditions, increased weathering and elevated nutrient transfer rates from continents to oceans. However, many aspects of this model have recently been questioned. Climate is the fundamental parameter of the model proposed in the previous studies as it is linked to both geodynamic and stratigraphic events. However, despite the ongoing importance of the debate on Valanginian climate variations, there are relatively few studies that detail high-resolution climatic changes during the positive C-isotope shift.

The aim of the study is to assess the changes in terrigeneous and nutrients influxes in the Vocontian Basin associated to fluctuations in weathering processes. The used herein multiproxies approach is focused on high-resolution mineralogical (clay assemblages) and geochemical (major elements, $CaCO_3$ and phosphorus contents) analyses performed on the marl-limestones alternations of the Upper Berriasian–Valanginian Orpierre section (SE France). This section consists of a continuous sedimentation, well-time calibrated by biostratigraphy and cyclostratigraphy (Charbonnier et al., 2013).

At Orpierre, it appears that mineralogical and geochemical trends reflect a primary signal driven by palaeoenvironmental changes. Based upon the previous cyclostratigraphic study, performed at Orpierre, terrigeneous, nutrients and clay influxes are calculated for the first time during the Valanginian.

The fluctuations of the terrigeneous, phosphorus and clay influxes reflect changes in terrigeneous inputs and nutrients levels linked to changed in the weathering regime in the source areas. At Orpierre it appears that during the Valanginian time interval, the weathering pattern results mainly from climate variations. Three major climate episodes have been highlighted: (i) at the Late Berriasian–Valanginian boundary : the Berriasian–Valanginian Episode (BVE) with a duration of ~576 kyr ; (ii) at the Early–Late Valanginian transition that includes the positive carbon isotope excursion : the Weissert episode (WE) with a duration of ~653 kyr ; and (iii) in the Late Valanginian : the Late Valanginian–Hauterivian Episode (VHE) with a duration of ~516 kyr. These episodes are marked by higher terrigeneous and nutrient influxes related to enhanced humid conditions. They coincide with major platform demises in the northwestern tethyan margin. Over the full record, they closely follow the variations in the insolation induces by Earth orbital parameters. Particularly, maxima eccentricity are recorded when the wetter conditions and the higher terrigeneous inputs are recorded in the Vocontian basin. The orbital forcing is probably the major driving force behind the palaeoenvironmental changes that prevailed in the northwestern margin during the Berriasian–Valanginian interval.

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4.6

Orbital chronology of the Lower-Middle Aptian: Palaeoenvironmental implications (Serre Chaitieu section, Vocontian Basin, France)

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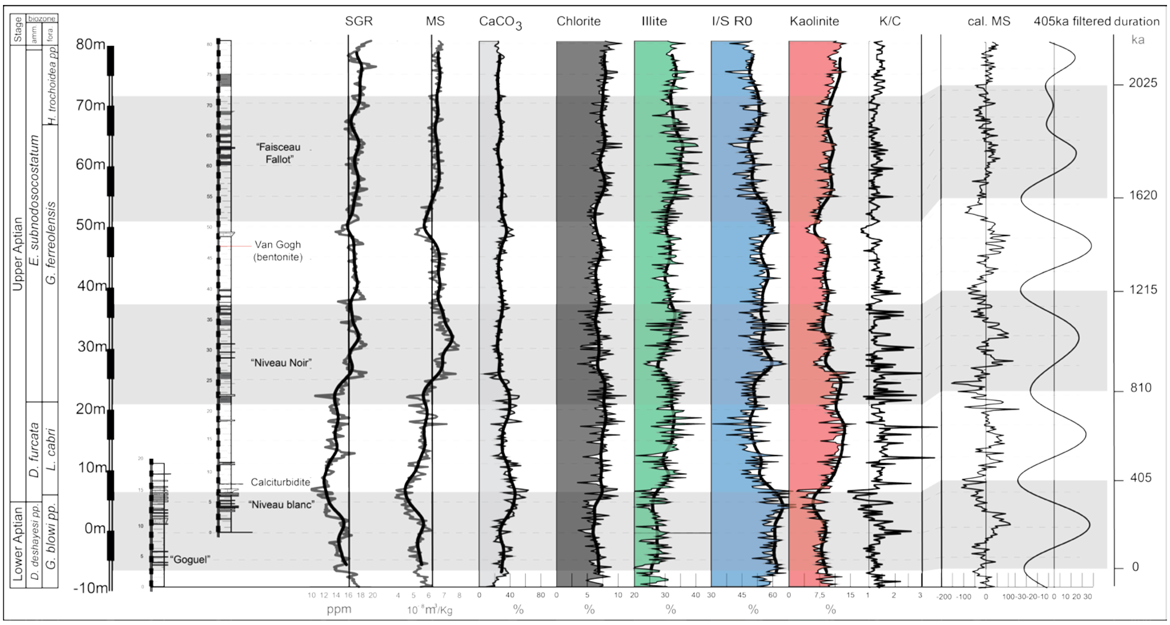
In the early Aptian, the OAE 1a is well defined by a negative $\delta^{13}C$ excursion followed by a positive $\delta^{13}C$ excursion, covering the *Deshayesites deshayesi* and *Dufrenoya furcata ammonite* zones (Menegatti *et al*., 1998). To estimate the time required for the carbon cycle recovery following the major disruption due to anoxia after OAE1a and to provide durations of ammonites biozones, a cyclostratigraphic approach was performed in the Aptian of the Vocontian Basin (VB). The sedimentary succession mainly consists of hemipelagic blue-grey marl with frequent slumping and turbidites controlled by syn-sedimentary faulting, but in the Serre Chaitieu (SC) section located close to Lesches-en-Diois, resedimented material represents less than 10% of the succession (Friès & Parize, 2003) making this section a reference for cyclostratigraphy.

At the base of the SC section, above the OAE1a called "Niveau Goguel", marls become clearer and the carbonate content increases up to the "Niveau blanc", a limestone bed considered as a reliable marker throughout the VB (Fig). Above this bed, the continuous hemipelagic sedimentation is interrupted by a centimetric calciturbidite, which may have induced the erosion of some meters of marls (Bréhéret, 1997). The section studied encompasses the *Deshayesites deshayesi* Zone to the end of the *Epicheloniceras martini* Zone (Dutour 2005). Using a field Spectral Gamma Ray (SGR), 450 measurements were performed with a sample step of 20 cm. Each measured point was sampled for calcimetry, clay mineralogy and magnetic susceptibility (MS). Spectral analyses were then performed on all proxies. The lower part of the section (0 to 25 m) shows relatively low SGR and MS values while from 25 m to the top of the section, these values increase. These two parameters show a good correlation (r = 0.79), while carbonate content and MS show an inverse correlation, which confirms that the MS reflects mainly the clay content. Clay mineral assemblages consist of illite, illite/smectite mixed-layers (I/S), kaolinite and chlorite. The proportions of illite and kaolinite covary and fluctuate in opposition with I/S. Cyclic fluctuations of relative proportions of clay minerals are particularly well expressed by the kaolinite/chlorite ratio. Spectral analyses, using the multi-taper and the amplitude spectrogram methods, were performed on SGR, MS, $CaCO_3$ and K/C signals to detect sedimentary cycles related to an orbital forcing throughout the series. The geochronometer 405-kyr eccentricity cycle well expressed and significant (up to 99% confidence level) is used to provide a robust temporal framework. More than five 405-kyr eccentricity cycles are recognized (Fig.), allowing a total duration of at least 2.33 myr for the whole sedimentary succession to be proposed. The minimum duration of the *D. furcata* Zone is assessed at 0.46 myr, the duration of the *E. martini* Zone at 1.45 myr. Amplitude spectrograms show a strengthening signal of obliquity during the *D. furcata* Zone, which would confirm the global cooling characterising this interval, probably leading to the development of low-extension polar ice and the lowering of the sea level. Finally, the return to equilibrium in the carbon cycle in the aftermath of OAE1a covering the *G. ferreolensis* foraminifer Zone occurred in more than 1 myr.



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4.7

Cyclic Sedimentation in the Drusberg Beds, Wägital region, Helvetic Alps, Switzerland

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The Lower Cretaceous limestones of the Drusberg Beds in the Wägital region of the central Helvetic Alps (Switzerland) exhibit three orders of rhythmic (cyclic sedimentation) in several well-exposed outcrops, (Fig. 1):

1. small scale laminations (.1mm to 1mm thick),
2. alternating limestone and marl beds (10 to 20 m thick), and
3. rhythmic units (2 to 6 m thick).

The clear interrelationships of the rhythms, excellent correlativity along strike, and the record of unbroken sedimentation lend good bases for discussing variations in bedding and facies, climate control of the depositional record, and of periodicities relating to rhythmic sedimentation. The marine basinal environment of deposition did not itself change, but the Drusberg sediments were affected by terrigenous detritus in suspension, variations in current regimes, and changes in nutrient supply, ocean anoxic events, temperature, and salinity of the surrounding water. Clearly, most of these may be interrelated in complex ways.

The first order (mm) cycles appear to be modes of deposition influenced primarily by variations in autochthonous sedimentation and local current regimes, perhaps even storm tempestites. These rhythms are clearly sedimentary-spatial and time-irregular. The wavy appearance of the bedding surfaces is most probably due to diagenetic transfer of calcium carbonate. The second cyclic order (cm) may have been influenced by local basin paleotopography as the controlling factor of facies variations. Shoals could have provided local detritus and shielded seaward basins from terrigenous influxes. Anoxic conditions may have alternated with more oxidizing environments (Föllmi, 2012).

The third order of cyclic sedimentation, (m-scale), may mirror real periodic cyclic fluctuations on a planetary-global scale. Global climate during the Quaternary exhibits periodicities and variations in the calcium carbonate content similar to those of the rhythmic units. The only true regular time cycles are related to planetary motions, the orbital eccentricity, obliquity, and precession of Earth's movements. Combining these periodicities give the well-known Milankovitch cycles of ca. 110,000 years. Using the biostratigraphy of Föllmi & Godet (2013, Fig. 6), the Drusberg Beds were deposited over a time period of ca. 1-2 Ma. Many of the third order (m-scale) cycles between the underlying Altmann Beds and the overlying Schrattenkalk formation can be correlated, but the total number varies along strike due to the diachronous inception of the younger Schrattenkalk. The number of m-scale cycles in the Wägital area range from 7-15. The number of Milankovitch cycles in the bracketed 1-2 Ma time period range from 9-18 and certainly occurred during the Lower Cretaceous. Thus it is possible that global climatic variations caused by planetary motions and may be reflected in the m-scale rhythmic sedimentation of the Drusberg Beds.

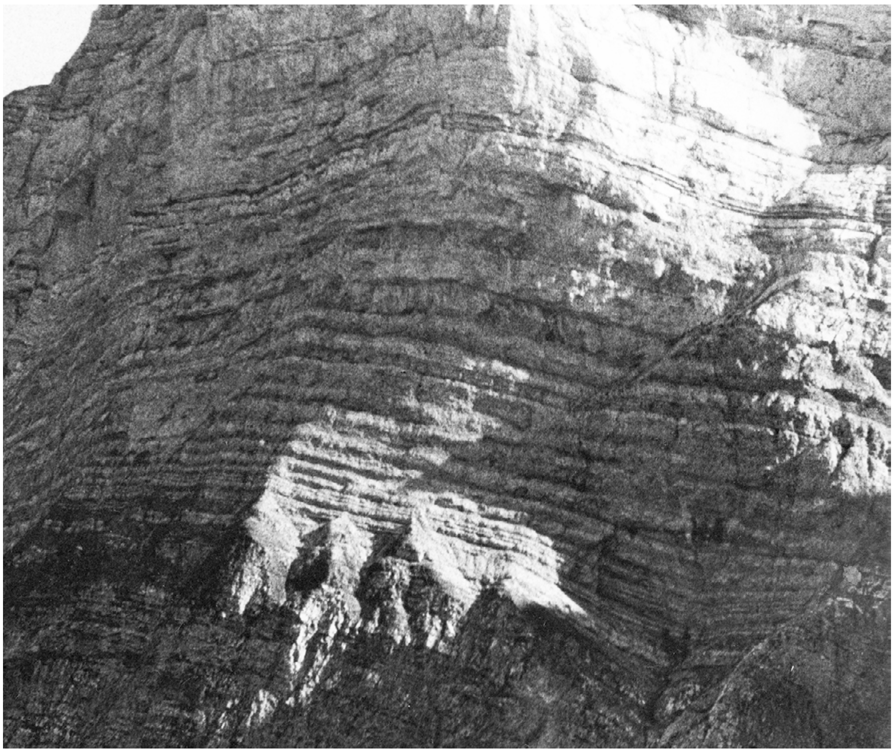

Figure 1. Brünnelistock, Wägital, Schwyz (view looking SW from Oberseetal). Middle: Drusberg Beds, below, dark marly Altmann Beds, top of image, thick banks of the light gray Schrattenkalk Formation (photo R. Freeman).

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4.8

Environmental and climatic changes on the Brazilian shelf during the Campanian-Maastrichtian

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The upper Campanian to upper Maastrichtian interval was examined in the Olinda sub-basin near Recife, Brazil, to determine the response of inner to outer shelf environments in the equatorial Atlantic realm to global environmental and climatic changes of the late Campanian – Maastrichtian time. A multi-proxy approach involving sedimentological observations, carbon and oxygen isotopes, organic matter quantification and evaluation, bulk-rock mineralogy and planktic foraminifera biostratigraphy was carried out on three cores (Olinda, Poty and Itamaraca) drilled in 2005.

Sediments consist of phosphatic marly limestone topped by bioturbated light to dark gray marly limestone/marls. Although planktic foraminifera preservation is relatively poor, integrated planktic foraminifera and isotopic stratigraphy reveals that Poty and Itamaraca cores span the entire Maastrichtian, whereas the Olinda core is truncated with a major hiatus between the late Campanian and the late Maastrichtian (planktic foraminifera biozones CF8 to CF3). Each core shows a disconformity at the Cretaceous-Tertiary (KT) boundary similar to the short hiatus (280 kyr) observed by Gertsch et al. (2013). Bulk-rock mineralogy suggests a secondary dolomitization of the phosphatic marly limestone interval with the absence of calcite and the prevalence of dolomite, ankerite and Ca-apatite. Calcite (50-90%) and phyllosilicates (20-30%) are dominant in the bioturbated marly limestone/marl interval. Organic carbon is abundant (up to 4%) and of mixed origin (terrestrial and marine) indicative of both marine productivity and input of terrestrial organic matter from continents on the Brazilian shelf.

Isotopic measurements on bulk sediment suggest that oxygen isotopes are strongly affected by dolomitization. Minor diagenetic effect leads to negative values (up to -4.6‰) in the marly limestone/marl interval, but climatic trends are well-preserved with characteristic negative excursions in the terminal Maastrichtian indicative of warming events associated with Deccan volcanic activity. Carbon isotopes are more reliable with overall positive values (0 - 2‰). A negative shift in the terminal Campanian correlates well with global carbon isotope records (Wendler, 2013). In the Maastrichtian, carbon isotope trends show a plateau in the early Maastrichtian (up to CF4) followed by a regular increase up to the KT disconformity. This contrasts with global carbon isotope curves that record a positive excursion in the late Maastrichtian and suggests a local influence.

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4.9

Experimental investigation of molybdenum solubility under low atmospheric O_2 concentrations: Implications for pre GOE conditions

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The history of the rise of atmospheric oxygen in the late Archean is a matter of considerable debate. Mass independent sulfur isotope fractionation in marine sediments before the great oxidation event (GOE; ~2.4 Ga ago), is generally considered to be the best indication of an anoxic early atmosphere (Farquhar et al. 2000). Model calculations performed by Pavlov et al. (2002) suggest that the O_2 level prior to the GOE was not higher than 10-5 in respect to the present atmospheric level (PAL). However, this model result is not yet confirmed by experimental findings. New trace elemental isotope proxies as e.g. molybdenum (Wille et al. 2007) or chromium (Frei et al. 2009) suggest a mild increase in O_2 before the GOE, starting at around 2.7 Ga. These elements are redox sensitive and exhibit isotope fractionation, when oxidized to in water-soluble oxyanions.

The relation of Mo isotope fractionation to atmospheric O_2 levels is not yet quantified. To improve on this parameter, we conducted laboratory experiments on molybdenite (MoS_2) using a glove box set up. The oxygen concentration in the N_2 atmosphere of the glove box has been controlled with platinum scrubbers and logged with an external computer. Pulverized molybdenite samples, pre-treated in a several weeklong process to reduce and wash out impurities and oxidized surfaces, have been put in water at different atmospheric oxygen concentrations ranging from 0 to 320 ppm. The O_2 concentration needed to oxidize and partially dissolve the molybdenite has been found to be around 3·10-4 PAL and therefore slightly higher than the proposed value of Pavlov et al. (2002). The laboratory conditions used in our setup probably results in a maximum value of the needed oxygen. In any case, these results indicate that prior to the GOE the atmosphere has already seen a whiff of oxygen with concentrations probably slightly higher than suggested until now.

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4.10

Valanginian Weissert event in a shallow-platform setting, Zagros fold-thrust belt, southern Tethys

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A well-defined, positive carbon isotope excursion (2.03‰ in $\delta^{13}C$) was recognized in a shallow platform carbonate succession, the Fahliyan Fm. Location is in the Zagros fold-thrust belt of SW Iran, corresponding to the northeastern part of the Arabian Platform. This significant perturbation and change in the carbon cycle, is reported for the first time from the Southern Tethyan realm. It is interpreted as corresponding to the "Weissert Event", dated late Early Valanginian-early Late Valanginian (135 Ma). The excursion may be related to (1) a rise of CO_2 in the atmosphere-ocean system, (2) an increase in the amount and preservation of buried organic carbon and/or (3) the growth of extended photozoan platforms which operated as a sink for dissolved inorganic carbon of continental origin.

In the Zagros fold-thrust belt, an important phase of carbonate-platform growth started in the Late Triassic, and continued until the Early Cretaceous along the northeastern passive margin of the Arabian Plate (Alavi 2007). Platform margins are rather stable, reflecting different settings in the Zagros region: neritic conditions prevailed in the Fars and Khuzestan areas, while pelagic facies were deposited in the Lurestan area during the Early Cretaceous.

The dataset used for this study includes two outcrops respectively located in the Fars and Izeh zone, that were studied in details for biostratigraphy and facies analysis, essentially based on benthic foraminifera and dasycladacean algae.The dating was calibrated using the Sr-isotope method following the LOWESS version 4:08/04 (Howarth and McArthur 1997, McArthur et al. 2001). The benthic foraminifera and calcareous green algae found in shallow-platform deposits were identified and, relying on sequence stratigraphy and platform-basin transects, indirectly dated by assemblages of planktonic foraminifera, dinoflagellates and calpionellids occurring in interbedded deeper marine intervals. A portable gamma-ray spectrometer (GRS) was used to measure the in-situ total gamma values, and to quantify three major naturally radioactive elements, potassium (K), uranium (U) and thorium (Th) in the studied outcrops. Results were used to correlate the amount of clay content and siliciclastic input, considered a proxy for organic matter.
Seventy measurements of stable carbon and oxygen isotopes of sedimentary carbonates were carried out on 200-300 µg of powdered bulk samples, derived from the sediment matrix alone. In order to avoid lithology and diagenetic-related side effects, rock samples were first slabbed to avoid calcite veins, then washed with normal and pure waters, dried at 110°C in an oven, and finally crushed and homogenized in an agate mortar.

Besides the positive carbon isotope excursion, in the studied sections the interval assigned to the Weissert Event is characterized by the highest amount of uranium (up to 9.0 ppm), tentatively explained by the precipitation of authigenic uranium under oxygen-depleted conditions. Preliminary interpretation consequently calls for the signature of a short-lived anoxic event which, new for the record, is identified in the shallow-platform setting of the study area. Based on oxygen-isotope analyses carried out so far, such an anoxia was likely accompanied by global warming and greenhouse conditions.

In the same intermission, a biotic crisis occurred in the marine realm, with the extinction of approximately 50% of the genera of benthic foraminifera and 75% of the genera of dasycladacean algae. Only opportunistic photozoan communities, presumably tolerant to oxygen-poor conditions, are found within the corresponding interval. Moreover, the average size of some dasycladacean algae was affected by anoxia. Specimens from the Berriasian and Early Valanginian are large, whereas those from the Late Valanginian and Early Hauterivian are dwarfed (Hosseini et al. 2013). The same is true for benthic foraminifera, only low spiral and basal-inflated trocholinids being present within this interval.

We are thankful to the Exploration Directorate of the National Iranian Oil Company (NIOC) and also to the Department of Geology and Paleontology, University of Geneva for permission, under a co-operation agreement, to publish this abstract as a part of an ongoing Ph.D. thesis of the first author. This research was partly supported by a grant from the Société de Physique et d'Histoire naturelle de Genève (SPHN, "Bourse Lombard").

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4.11

Response of terrestrial environment to the Paleocene Eocene Thermal Maximum (PETM).

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The late Paleocene Early Eocene transition (56Ma) is marked by the warmest climate period of the Cenozoic, known as the Paleocene Eocene Thermal Maximum (PETM). The importance of the PETM studies is linked to the fact that the PETM bears some striking resemblances to the human-caused climate change unfolding today (Zachos et al. 2001; 2005 and Norris et al 2013). Most notably, the culprit behind it was a massive injection of heat-trapping greenhouse gases into the atmosphere and oceans, comparable in volume to what our persistent burning of fossil fuels could deliver in coming centuries. Knowledge of exactly what went on during the PETM could help us foresee what our future will be like. The response of the oceanic and continental environments to the PETM is different. Many factors might control the response of the environments to the PETM such as paleogeography, paleotopography, paleoenvironment, and paleodepth. Herein, we present two different examples from terrestrial environment and their response to the PETM warming.

In northwestern India, the establishment of wetland conditions and related thick lignite accumulations reflects the response of the continental environments to the PETM. This continental climatic shift towards more humid conditions led to migration modern mammals northward following the migration of the climatic belts. What remains uncertain is the timing and tempo of this mammal migration event and whether it originated in Asia or more specifically out of India.

Biostratigraphy and carbon isotope analyses in three lignite mines located in NW India reveal the presence of both PETM and ETM2 organic carbon isotope negative excursions and demonstrate that modern mammals appeared in India after the PETM. Relative ages of this mammal event based bio-chemo- and paleomagnetic stratigraphy support a migration path originating from Asia into Europe and North America, followed by later migration from Asia into India. The delayed appearance of modern mammals in India suggests a barrier to migration that is likely linked to the timing of the India-Asia collision.

In contrast, at Esplugafereda, north-eastern Spain, the terrestrial environment reacted differently; increased weathering due to enhanced runoff led to the formation thick paleosoil accumulation enriched with carbonate nodules (Microcodium like) suggesting a coeval semi-arid climate (Retallack 2001, Calvet et al., 1999). $\delta^{18}O/\delta^{16}O$ analyses performed on these soil nodules formed during the PETM provide important clues to better constrain the temperatures, intensity of warming and PCO_2 fluctuations through the PETM. Preliminary data shows: 1) two significant $\delta^{13}C$ shifts with the lower one linked to the PETM and the upper corresponding to the Early Eocene Thermal Maximum (ETM2); 2) $\delta^{18}O/\delta^{16}O$ analyses of two different carbonate nodule types (microsparitic and micritic) reveal a temperature increase of around 10°C during the PETM; 3) This warming corresponds to a significant increase in PCO_2 values; 4) a prominent increase in kaolinite content within the PETM linked to increased runoff and/or weathering of adjacent and coeval soils. These preliminary results demonstrate that the PETM coincides globally with extreme climatic fluctuations and that terrestrial environments are very likely to record such climatic changes.

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4.12

Continental climate reconstruction during late Eocene–early Oligocene in Europe

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The most recent shift between greenhouse and icehouse climate modes is placed at the Eocene–Oligocene transition (EOT, ~34 million years ago–Ma), where the marine record reveals stepwise cooling and increased ice accumulation at high latitudes. The terrestrial responses to the EOT climate change, however, show strong spatial heterogeneity and the reported palaeo-climate records are often contradictory (Kohn et al., 2004; Grimes et al., 2005; Zanazzi et al., 2007; Hooker et al., 2009; Hren et al., 2013). Here, we present stable isotope data for tooth enamel of large, herbivorous terrestrial mammals from Europe's mid-latitudes (N 40-50) to better comprehend the continental environment during the late Eocene–early Oligocene between 40 and 27 million years ago.

Our isotope data show general decrease in average $\delta^{18}O_{PO4}$ and $\delta^{13}C$ values during the studied period, but strong spatial heterogeneity is apparent as well. Southern maritime localities have high and steady isotope values indicating warm and dry climate till 32 Ma. Northern sites, yielded lower isotopic values with an average offset of -2.4 ‰ in $\delta^{18}O_{PO4}$ from the southern localities. These data indicate different moisture sources (Atlantic vs. Tethys Ocean) in these regions and point to the existence of an already moderately high Alpine chain at this time. Further on, variation in the isotope values in the north reveals a minimum of 1.3 ± 0.7ºC drop in mean annual temperature at the EOT, confirming this cooling event in the terrestrial realm of Europe.

After 30 Ma, we find more fractionated meteoric water in Central Europe, which we explain by sudden relative altitude changes of at least 1100 meters based on modern relationship between altitude and isotopic composition of precipitation in the Alps. Considering that the proto-Alps acted already as a climatic barrier before 30 Ma, average palaeo-altitude could have been as high as 2000 meters in the Alps by the end of the Early Oligocene.

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4.13

Latest Permian to Early Triassic high-resolution stable carbon isotope record from North-east Greenland

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Large and rapid fluctuations of the global carbon cycle during the Late Permian and Early Triassic left a global imprint in the organic carbon isotope record observed in numerous Permian–Triassic sections (Payne et al., 2004; Galfetti et al., 2007). Expanded and well preserved successions, i.e. Norway and NE Greenland covering the lower part of the Lower Triassic (Griesbachian/Dienerian), are crucial for assessing the evolution of the carbon cycle in detail. Sections of this interval are rare, and often incomplete or condensed. Expanded sections also allow the construction of a reliable biostratigraphic zonation, and therefore a better assessment of the temporal patterns of recovery after the end Permian mass extinction events, in both marine and terrestrial ecosystems.

At the north-western margin of Pangea, the rifting system between Greenland and Norway led to the accommodation of thick sedimentary sequences of earliest Triassic age. In East Greenland this interval is represented by a succession of deltaic sediments reflecting a general regressive trend. They are an excellent archive to study the evolution of terrestrial and marine ecosystems during this time. At Hold with Hope (East Greenland, 74°N) a 700m a thick fossiliferous succession of the Wordie Creek Formation has been logged and sampled.

Here we present a high resolution lithostratigraphic and organic carbon isotope record of a composite section, covering the uppermost Permian and the lower part of the Lower Triassic (Dienerian). Palynofacies data are used to assess the composition of the organic matter.

Measurements of about 580 samples show several distinct trends and major shifts in the organic carbon isotope record. The following major excursions can be recognised (from 1 to 8): 1. a first negative shift of ca. -6‰ corresponds to the unconformity between the Late Permian Ravnefjeld Fm. and earliest Triassic Wordie Creek Fm., regionally known as the lithological Permian–Triassic boundary; 2. after a short interval with stable carbon isotope values around -28‰ a second negative shift of -4‰ (to values of ca. -32‰) follows. This correlates with the negative carbon isotope shift recorded in numerous globally distributed Permian–Triassic successions. 3. This shift is followed by a steady trend to more positive carbon isotope values. 4. This trend culminates in a distinct positive shift reaching values of ca. -22‰, comparable to the values of the Ravnefjeld Fm.; 5. Another negative shift of ca. 7‰ leads again to negative values of around -31‰; 6. This interval of low carbon isotope values is followed by a steady positive trend reaching values around -26‰. 7. At around 350m a step-like negative shift follows with a minimum at around -32‰, its most negative values are observed close to the *Bukkenites rosenkrantzi*-bearing layers, possibly corresponding to the Griesbachian–Dienerian boundary (Bjerager et al., 2006). 8. The last part of the curve shows fluctuating but progressively more positive values, reaching ca. -23‰ at the top of the section. Palynofacies data reflect alternating marine and terrestrial conditions in the lower part of the section changing to predominant terrestrial conditions near the top.

At basinal scale our isotope data are closely comparable with the coeval section from the Trøndelag platform in Mid-Norway (Hermann et al., 2010). At global scale similar trends can be observed in organic carbon isotope records from Pakistan (Hermann et al., 2012). In NE Greenland the distinct negative shift (7) tentatively interpreted to be close to the Griesbachian–Dienerian boundary can be compared and correlated to the shifts in the carbonate carbon isotope records from the Arabic Peninsula (Clarkson et al., 2013) and from China (Galfetti et al., 2007; Korte & Kozur, 2010). Thus our data from NE Greenland reflect multiple and major changes in the global carbon cycle, which occurred at the onset of the Triassic within less than one million years.

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4.14

Evaluating the causal link between the Karoo LIP and climatic-biologic events of the Toarcian Stage with high-precision geochronology

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The emplacement of the Karoo Large Igneous Province (LIP) has been previously invoked as a causal mechanism for Lower Toarcian ocean anoxia, climate change, and marine biotic turnover. This causal relationship has been questioned because of a general lack of precise geochronologic constraints. One narrow time interval in the Early Toarcian in particular, approximately at the level of the *H. falciferum* ammonite zone, has received much attention because it contains a prominent negative carbon isotope excursion (CIE) of global importance, as well as other geochemical and biological perturbations. Potential links to igneous activity have been proposed as causal mechanisms, one of them being the release of massive amounts of carbon to the atmosphere via rapid sill emplacement in the sedimentary Karoo basin. Here we test some of these hypotheses with new high-precision U-Pb zircon and baddeleyite dates from both the Toarcian sedimentary record in southern Peru, as well as of volcanic rocks and sills from the Karoo volcanic province.

The U-Pb zircon dates come from tephra interstratified with ammonites in marine sedimentary rocks in southern Peru (Palquilla section near Tacna). We also present new U-Pb zircon and baddelyite dates from three sills and one rhyolite of the Karoo LIP. The duration of *falciferum* Zone negative CIE is now constrained by U-Pb zircon ages to be between 1.4 and 0.75 myr and is likely of shorter duration on the basis of stratigraphic relationships. The age of the *falciferum* Zone is between 182.097 ± 0.085 Ma and 183.17 ± 0.24 Ma (2σ analytical uncertainty), thus the Pliensbachian-Toarcian boundary must be somewhat older than 183 Ma. The onset of the *falciferum* Zone CIE appears to correlate in time with the onset Karoo LIP dike emplacement. Sill emplacement, however is recorded by our data to take place over a time span of some 2 million years. It is therefore substantially longer than the duration of the *falciferum* zone CIE and cannot be considered as one catastrophic event that caused global ocean anoxia, instantaneous carbon gas release, global warming, and biotic perturbation. Volcanic activity in the Karoo persisted at least until 179 Ma.

Our new U-Pb results support the interpretation made on the basis of published ^{40}Ar-^{39}Ar data that Karoo LIP magmatism had a duration of more than 4 myr from approximately 183 to 179 Ma, and therefore do not support global extinction or anoxia hypotheses that require rapid magmatism of Karoo LIP.

4.15

Towards accurate numerical calibration of the Late Triassic: High-precision U-Pb constraints on the duration of the Rhaetian

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Numerical calibration of the Late Triassic stages is arguably the most controversial issue in Mesozoic stratigraphy despite their importance for assessing mechanisms of environmental perturbations and associated biologic consequences preceding the end-Triassic mass extinction. Here we report new CA-TIMS zircon U-Pb dates for volcanic ash beds within the Aramachay Formation of the Pucara Group in Northern Peru that place precise constraints on the maximum age of the Norian-Rhaetian boundary. Previous estimates for the age of this boundary and the duration of the Rhaetian stage were primarily derived from magnetostratigraphic correlations of biochronologically well constrained Tethyan sections and the astrochronologic record of the Newark basin. Different correlation schemes lead to the concept of a short (4 m.y.) versus long Rhaetian (up to 10 m.y.; for a synthesis see Ogg, 2012). Sampled ash beds are closely associated with a characteristic uppermost Norian bivalve assemblages comprising the last occurence of large flat clam *Monotis subcircularis* as well as thin shelled *Otapiria* aff. *O. norica* and *Oxytoma* cf. *O. inaequivalvis*. Zircon U-Pb dates of sampled ash beds constrain the deposition age of this interval to be between 205.70 Ma and 205.30 Ma. We further recalibrate previously published zircon U-Pb dates for ash beds bracketing the Triassic-Jurassic boundary in the same basin (Schoene et al., 2010; Guex et al., 2012) employing the most recent calibration of the EARTHTIME tracer solution. These dates constrain the duration of the Rhaetian to be <4.5 m.y., thus strongly supporting the concept of a short Rhaetian. This ends a prolonged controversy about the duration of this stage and has fundamental implications for the rates of paleoenvironmental deterioration inferred for the Late Triassic, culminating in the end-Triassic mass extinction and provides an absolute tie-point for magnetostratigraphic and cyclostratigraphic correlations of marine and continental Late Triassic sedimentary sections.

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P 4.1

Origin of Devonian conical mud mounds of Hamar Lakhdad Ridge, Anti-Atlas, Morocco: hydrothermal or hydrocarbon venting ?

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In the Eastern Anti Atlas desert of Morocco, 8 km S-E of Erfoud stands the Hamar Laghdad ridge. An E-W orientated monoclinal ridge of 8 km length for 1.5 km width, which exposes a Devonian sedimentary succession crossed by important senestral N-E to S-W transforming faults. The western part of the ridge overlies directly the Silurian shales succession, whereas the eastern part spreads over 100 m thick pillow basalts of early Devonian age. This particularity produced a significant difference in the sedimentation patterns. The western part of the ridge consists of marine outer shelf sediments dominated by shales and marls intercalated with scarce fossiliferous limestones enriched in cephalopods (orthoceratids) deposited during the Pragian and early Emsian. However, the eastern part experienced shallower deposition characterized by crinoidal limestones.

The most interesting features consist of a constellation of 48 calcareous cones emerging from the sediment surface, the Kess-kess; they are 30 to 60 m in diameter and 30 to 50 m high. They correspond to thick limestone layers organized around a central funnel. The mound walls, as the inter mounds layers, are enriched in fossil especially crinoids, but the mounds seem to have been colonized from time to time by communities of organisms such as bivalves et corals. Some of these mud mounds have been formed during the early Devonian (Kess-Kess) and others (Hollard mound) later in the middle Devonian. Some neptunian dykes and up to 0.5 m large cemented fractures postdate the Kess Kess, but predate the formation the Hollard mound.

Two different interpretations mainly based on stable isotopes analyses have been proposed for the origin of these peculiar carbonate mounds: (1) accretion of the material driven by hydrothermal venting linked to volcanism (Mounji et al, 1998), (2) hydrocarbon venting (Peckman et al., 1999). The sediment micrite of the Kess Kess is characterized by very negative $\delta^{18}O$ values, ranging from -10 to -6‰ VPDB and positive $\delta^{13}C$ values, between 0 and 2‰ (Fig.1), which suggest a precipitation from hydrothermal waters derived from underlying volcanic intrusives.

The mounds also contain cemented cavities (stromatactis). The latter are filled by three different generations of cement with $\delta^{18}O$ 6-8‰ higher than the host rock, in or near the field of early Devonian seawater. Some fully recrystallized corals (Auloporids) have also been observed in the limestone layers and in the mound flanks indicating that at least some of the stromatactis are in fact relicts of dissolved organisms fossils recrystallized later in isotopic equilibrium with sea-water.

A younger mud mound framework of middle Devonian age (Peckmann et al., 1999) is present in the western part of the ridge. They are characterized by very low $\delta^{13}C$ values (-22‰ to -10‰ VPDB) derived from degradative oxidation of methane or higher hydrocarbon. The neptunian dykes and associated fractures are more variable fluctuating between very low $\delta^{13}C$ and $\delta^{18}O$, and normal Devonian values (-22‰ to -10‰ and 0‰ to 4‰ VPDB, respectively), indicating a precipitation of the earliest cement influenced by both hydrothermal circulations and hydrocarbon venting (Fig.1, phase A) followed by normal marine carbonate cement precipitation (Fig.1, phase B)

In addition, the distribution of the saturated hydrocarbons (analyzed by GC-MS) in both Hollard mound, neptunian dyke and associated fractures samples indicates a similar origin for the petroleum staining these rocks (Silurian graptolith shales). The generation/expulsion of this petroleum was most probably accelerated by exceptionally high geothermal gradient linked to regional volcanism. For the first time, a model integrating both Kess-Kess and Hollard mound formation is proposed. To sum up, the younger mudmounds (Hollard mound) originated in an environment influenced by hydrocarbon venting, contrary to the older Kess-Kess, which are related to hydrothermal venting

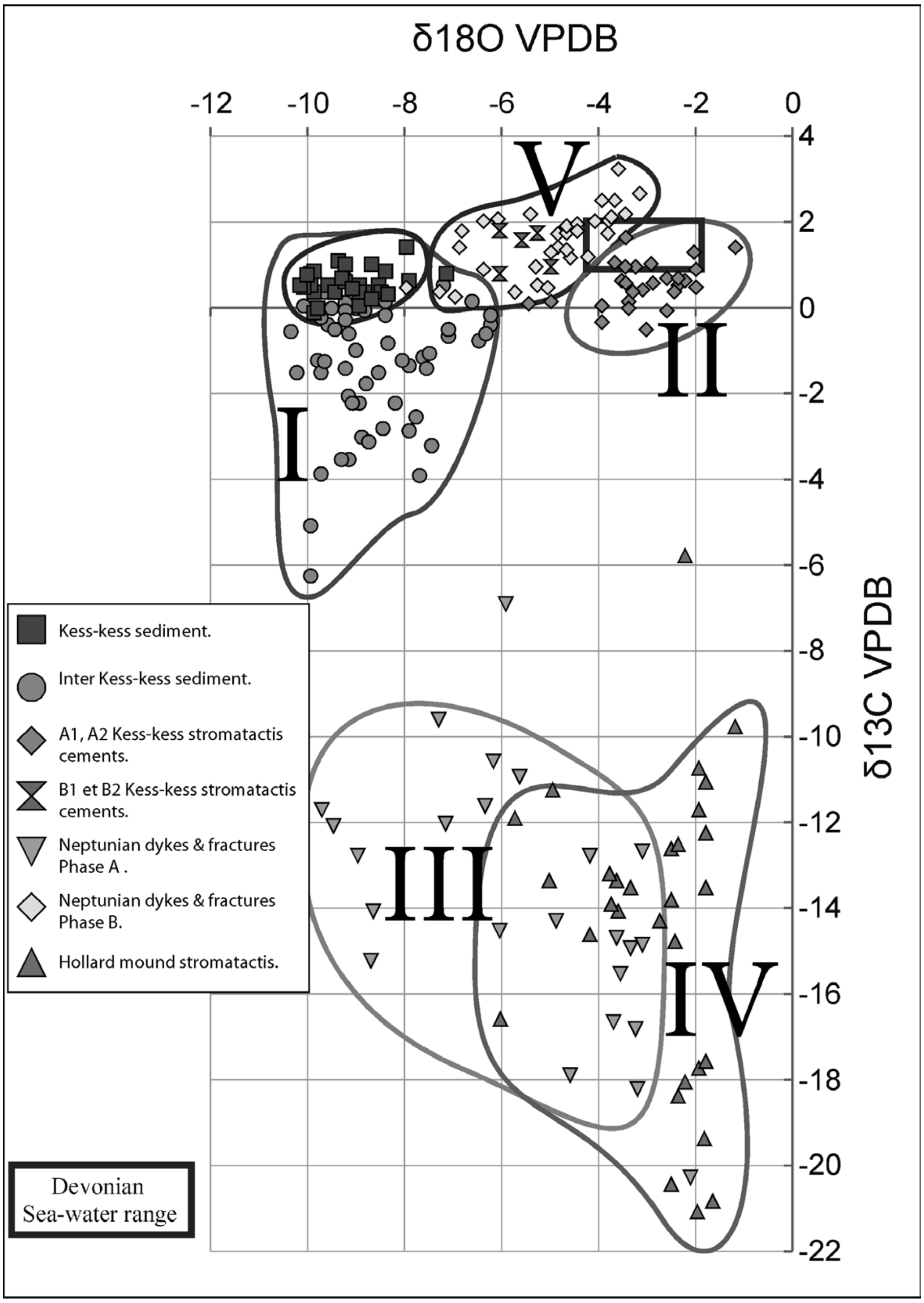

Figure 1. Cross plot of $\delta^{18}O$ versus $\delta^{13}C$ for the Kess-Kess sediment, Kess-Kess stromatactis, neptunian dykes and associated fractures, Hollard mound stromatactis

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P 4.2

Sedimentological, mineralogical and geochemical study of sediments associated with the Deccan Traps in the Nagpur area, India

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The sedimentary beds (infra- and inter-trappeans) associated with Deccan volcanism in India are located in the eastern part (Madhya Pradesh and Maharashtra States) of the Traps, in the Nagpur, Chandrapur and Chhindwara districts. These sediments were deposited in terrestrial environments during periods of quiescence of the volcanic activity, mainly in alluvial-limnic to lacustrine environments.

A sedimentological, mineralogical and geochemical approach has been achieved to evaluate the changes triggered by the Deccan volcanism in central part India. The results have been compared with the existing palynological data (Samant and Mohabey, 2009). Bulk rock, clay minerals, phosphorus, organic matter and major/trace elements analyses indicated that the inter-trappean sediments deposited during the Deccan volcanism do not reflect the same characteristics than the infra-trappeans sediments preceding the volcanic eruptions.

Sedimentological and mineralogical observations indicate alluvial-limnic environment under arid climate for the deposition of the infra-trappean sediments. Moreover, palynoflora are dominated by gymnosperms and angiosperms with a rich canopy of gymnosperms (Conifers and Podocarpaceae) and an understory of palms and herbs. The low content in organic matter could be related to excessive desiccation and/or oxidation under arid conditions (Samant and Mohabey, 2009).

The eruption of Deccan volcanic flows severely affected the environment. Inter-trappean sediments associated with volcanic phase-1 and phase-2 were deposited in terrestrial to lacustrine environments under arid seasonal climate alternating long dry and short humid cycles. Moreover, clay minerals indicate a predominance of smectites resulting from the basalts alteration. Dinoflagellates, diatoms and ostracods blooms in the sediments preceding phase-2 could be related increased micronutrients availability. Organic matter is well preserved in the sediments deposited before the onset of the main volcanism phase consists of a mixed source with low oxidized lacustrine organic matter and terrestrial inputs. Trace elements (Ba, Cu, Ni, Zn, U and V) revealed a high productivity under low oxygenated conditions.

A strong floral response is observed with the onset of the main volcanism phase leading to dominance by angiosperms and pteridophytes at the expense of gymnosperms. In subsequent inter-trappean sediments a sharp decrease in pollen and spores coupled with the appearance of fungi mark increasing stress conditions apparently as a direct result of intensified volcanic activity. The organic matter analyses indicate a strong degradation suggesting that the biomass was oxidized because of strong volcanic activity and resulting acidic conditions. The chemical index of alteration (CIA) shows a gradual increase culminating within the main phase of volcanism reflecting increased acid rains. Ti/Al and K/(Fe+Mg) ratios are high and close to Deccan average basalt values indicating a strong influence from the basalts.

Mineralogical and geochemical observations indicate more contrasted sources for the sediments deposited after the main phase of volcanism and paleontological observations indicate a floral and fauna recovery.

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P 4.3

The Jabal Rayah meteorite impact crater, Saudi Arabia

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Only two certain and two likely meteorite impact sites are so fare known on the Arabian Peninsula (Fig. 1): 1) The Wabar impact crater cluster in Saudi Arabia (e.g., Philby, 1933; Wynn and Shoemaker, 1998; Gnos et al., in review), 2) the Jebel Waqf as Suwwan impact structure in Jordania (e.g., Kenkmann et al., 2010), 3) the As Shutbah impact crater in Saudi Arabia (e.g., Gnos et al., 2011) and 4) the obscured Albian Murshid impact crater in Oman (Levell et al., 2002). Only in the Wabar case impact melts and fragments from the iron meteorite impactor were found. Shocked material and shatter cones have also been found at Jebel Waqf as Suwwan and at Ash Shutbah.

The ~5.5 km sized Jabal Rayah ring structure (Fig. 1) is the fifth impact crater on the Arabian Peninsula. It is a strongly eroded, complex impact crater located in Saudi Arabia, 68 km NE of Tabuk at 28°39'N and 37°12'E (Fig. 1). It is well visible on aerial and satellite photographs (e.g., Garvin and Blodget, 1986) and was mapped by Janjou et al. (1997). Erosional processes led to a relief inversion. A ring depression consisting of displaced blocks of Silurian to Early Devonian strata is now forming a topographically outstanding, up to 150 m high ring crest. The displaced blocks show internal folding and faulting and some of the sediment packages were thrust over others. The drainage towards the centre of the structure is controlled by a set of radial faults. The central uplift part of the structure consists of strongly folded, graptolite- and orthocone-bearing micaceous sandstones of the Qusaiba Formation of Early Silurian age. This part is eroded to the level of the surrounding plateau and partially covered with gravel.

Despite the fact that the sampled sediments are devoid of shock features, outward plunging fold axes of the central uplift and folded and displaced blocks forming the ring crest clearly indicate an impact origin of the ring structure. Based on the crater diameter it can be estimated that the rocks forming the central uplift come from a depth of ~400 m.

Figure 1. Overview map of the Arabian Peninsula showing known impact craters and the Jabal Rayah ring structure located NE of Tabuk.

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P 4.4

Early-Middle Triassic boundary – precision and accuracy achieved by combining U-Pb zircon geochronology and biochronology

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The importance of the Early-Middle Triassic boundary (EMTB) lays in the fact that this boundary marks the end of the time interval characterized by the biotic recovery after the end-Permian mass extinction. Therefore, to gain highest possible time accuracy and precision for quantification of biotic processes, we undertook a detailed calibration of the EMTB with high-precision CA-ID-TIMS U-Pb age determinations on zircons from volcanic ash beds interbedded with biostratigraphically well dated marine sedimentary sections. These dates have been used to quantify and calibrate different stratigraphic schemes across the EMTB in the Nanpanjiang basin in South China. Despite an optimal control on the continuity of the studied stratigraphic record and on the accuracy of analytical procedures, we recognized that some single ash-beds yielded ages that are too old and contradict the stratigraphic succession. We therefore try to tackle questions such as: How can we improve the confidence in the interpretation of zircon dates as proxies for the age of deposition of these ash beds? How can we define more precisely and accurately EMT boundary?

We sampled 14 volcanic ash beds within a 15m stratigraphic section bracketing the EMTB in the Monggan-WanTuo section (Luolou Fm., NW Guangxi) in the Nanpanjiang basin, South China. The section is biostratigraphically well calibrated with conodonts (Goudemand et al., 2012). Our ash bed data start with the so called "green-bean rock" (GBR), which is a composite volcaniclastic greywacke, customarily used as a mapping unit to separate Lower from Middle Triassic marine rocks in the Nanpanjiang Basin (Lehrmann et al., 2006).

In 9 out of 14 ash beds zircon dates are following the stratigraphic succession within analytical uncertainty (from the late Early Triassic Luolou Formation – 247.41 ± 0.12 Ma to the Middle Anisian "Transition Beds" – 246.44 ± 0.14 Ma). The studied sequence shows four samples with reworked zircons, indicating that the zircons in this magma batches were crystallizing over a long period of time or remobilized from deeper levels within the same magmatic system. Another four samples show clear residual lead loss (mainly the lower part of the section represented by GBR). If such Pb loss is combined with the presence of antecrystic material, no information can be reliably derived from such material.
This study exemplifies that in such complex cases the number of analysed samples to build up a robust dataset that agrees with the stratigraphic sequence can be substantial. Through analysis of an insufficient number of samples, not recognizing reworked greywacke type layers, missing lead loss effects and magmatic reworking effects, one could arrive at highly inaccurate numbers for rates of sedimentation and biotic change.

Spline interpolation age model for the eight selected radiometric ages yields an EMTB boundary age of 247.11±0.08 Ma. This result is well within the uncertainty interval of the previous 247.2 ± 0.4 Ma age of Lehrmann et al. (2006), which was obtained by linear interpolation between two U-Pb ages. The new EMTB age interval is significantly more accurate and precise and is based on the robust residual maximal associations of conodonts, avoiding biostratigraphical discrepancies.

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P 4.5

Sea level and current controlled sedimentary successions in the Hawasina Basin (Oman) during the Late Jurassic to Early Cretaceous time

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The Oman mountains preserve a Late Jurassic to Cretaceous continental margin transect with the Arabian carbonate shelf and the adjacent deep Hawasina Basin. The whole nappe pile containing the continental margin transect is today outcropping in the Central Oman Mountains. The sediment successions of the Hawasina Basin (Sumeini, Hamrat Duru and Kawr Group) provide the opportunity to investigate the response of an eastern Tethyan equatorial ocean system to multiple perturbations of the carbon cycle in the Cretaceous.

The Hawasina Basin and also the easternmost Arabian Platform was affected by the Late Jurassic sea level rise and by regional tectonic (Rousseau et al. 2005). The widespread change "to a "Maiolica Facies" of the Rayda, the Lower Sid'r and also the Nadan Fm documents this transition in oceanography.

Chemo- and biostratigraphy serve for correlation of the pelagic facies across the Hawasina Basin. Pelagic to hemipelagic conditions existed until the time of the Valanginian carbon isotope excursion. With the onset of this excursion chert and silicification features in the pelagic sediments disappeared for a while. On the seamounts (Kawr Group) the top of the Nadan Formation (Maiolica facies) is marked by a hardground spanning the Valanginian to the Early Cenomanian time. The hardground documents intensification of an erosive deep current. Chemostratigraphic work combined with radiolarian biostratigraphy from Blechschmidt et al. (2004) shows a reduced sedimentation rate with a strong silicification during the mid-cretaceous time in the Hamrat Duru Group. The hardground and the reduced sedimentation reflect the current pattern as simulated by Hotinski and Toggweiler (2003).

Because of the equatorial position of the Arabian Platform and the offshore Hawasina Basin, the wind driven equatorial current produced an upwelling current bringing nutrient rich water masses to the surface of the Hawasina Basin. This may explain the chert pulse during the onset of the OAE1a. Until now the data suggest that the Hawasina Basin was not affected by major anoxia during the OAE 1 and 2.

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