06. Stratigraphy and Sedimentology: processes and deposits through time

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Swiss Committee for Stratigraphy (SKS/CSS)
Swiss Palaeontological Society (SPG/SPS)
Swiss Geological Survey – swisstopo

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6.1
The Role Of Deccan Traps On The Environment And Faunas: Evidences From Central Anatolia, Turkey

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Arguably no mass extinction boundary has ever hosted such a highly debate and dispute like the end-Cretaceous event. It has been 40 years since the postulation of extraterrestial source as the prime suspect of this mass killing at the K-Pg boundary (Alvarez et al. 1980). It is unique among the other big five phenomena as no other event accommodates an impact (the Chicxulub impact) and LIP activity (the Deccan Traps). Specifically, the role of the Deccan volcanism on the environment and the ecosystem is crucial to gain better insight into the latest Maastrichtian world. To do so, we performed high resolution biostratigraphy, stable isotope and geochemical analysis on two basins (Haymana and Mudurnu-Goynuk) in Central Anatolia, Turkey.

In both basins the K-Pg boundary is sharp and characterized by 2-3 mm thick reddish oxidized layer. Moreover, measurements in the Haymana Basin shows an Ir anomaly (3,5 ppb in contrast to average 0,5 ppb background level). This layer also corresponds to sudden annihilation of large, ornamented ecological specialists (e.g., *Globotruncana, Rugoglobigerina, Racemiguembelina*) with minor survivors from ecological generalists (e.g., *Heterohelix, Globigerinelloides, Guembelitria*). We also detected surges of opportunistic planktonic foraminifera *Guembelitria cretacea* and calcareous dinoflagellate *Thoracosphaera* indicating the ecosystem collapse right after the impact. Molybdenum (Mo) measurements also peaks at the K-Pg boundary representing bottom water deoxygenation in the earliest Danian. However, detailed quantitative planktonic foraminifera analysis in Haymana Basin shows that there has been ongoing reduction in species in the Late Maastrichtian *Plummerita hantkeninoides* Zone. In fact, this total richness drops by 46% within the final 3.75 m before the K-Pg boundary. Proliferations of the *Guembelitria cretacea* through the Late Maastrichtian represents high terrigenous influx and hence enhanced food resources. High sedimentation rates observed in all sections might be linked to increased greenhouse conditions due to Deccan volcanism leading to enhanced weathering.

Overall, our multiproxy approach including quantitative biostratigraphy and geochemical analyses highlights the influence of the Deccan volcanism by releasing high amounts of atmospheric CO_2 and SO_2, leading to the climatic changes and associated biotic stress, which predisposed faunas to eventual extinction at the K-Pg boundary.

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6.2
Geomorphology of the coastal alluvial deposits of Asia (peruvian Atacama Desert)

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Due to their sensitivity to both tectonic activity and climatic variations, alluvial deposits along the coastal part of the Atacama Desert (western Peru) are important archives for understanding Quaternary environmental change.

Our study focuses on alluvial deposits of an exceptionnal fan complex located at nest to the city of Asia (Peru, 12°4) along the coastal zone of the Atacama. Despite being one of the driest desert in the world, the western side of the Peruvian Andes has experienced multiple pluvial periods since the Pleistocene, inducing phases of erosion and the formation of large alluvial deposits at the outlet of the main valleys. Our goal is to understand if and to what extend the peruvian coastal Atacama was affected by humid episodes that were until now only evidenced for the Altiplano.

Because the valley of Asia is relativelly small and do not reach the Altiplano, the study of this deposits succession is bringing insight on the localisation of the precipitations.
For that, a detailed geomorphological analysis of the coastal alluvial fan complex has been made to understand the fan's morphogenesis. This analysis was based on a digital elevation model with a resolution of 1 m generated from Pleiades stereo satellite imagery. Despite the loss of the northern part of the deposits, the top flat surface of an ancient terrace remains visible allowing the reconstruction of the paleo slope of the river.
Additionally, during field work, the size of the pebbles of the alluvial deposits have been mesured in multiple locations of the fan complex to reconstruct the paleo hydrology and the transport dynamics.

Previous studies have shown that during the humid phases, precipitations and subsequent erosion have mainly been located in the uppermost reaches of the rivers. However, this study shows the alluvial sediments of coastal Asia have been deposited during one humid phase for which precipitations occurred not only on the Altiplano but also in the closer to the Pacific fringe providing new insight for paleo climate reconstructions.

6.3
Offshore tsunami deposits in Lake Lucerne: insights from combined analysis of numerical tsunami modelling and sediment cores

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The 1601 AD earthquake (Mw 6.2) with epicenter in Unterwalden triggered multiple subaqueous mass-movements in Lake Lucerne and a subaerial rockfall from the Bürgenstock Mountain (Schwarz-Zanetti et al., 2003; Schnellmann et al., 2006). The seismically induced secondary effects are reported in the historical chronicles written by Lucerne's city clerk Renward Cysat, which is based on eyewitness reports and observations made by the author (Cysat, 1969). Immediately after the earthquake was felt, the lake was agitated, became wild and foamy. Further, it is mentioned that the water raised in the middle of the lake and resembled a mountain, while the coastal plain in Ennetbürgen was inundated by several hundred meters and repeated draining of the River Reuss was observed at the lake outlet in Lucerne. Last but not least, it is reported that fisher boats, boulders and wooden debris were washed ashore up to 4 m above the lake level and several casualties occurred.

To better understand tsunami evolution, inundation and hazard associated with the 1601 earthquake event, we combine numerical tsunami modelling and sediment-core analysis. A thick package of fining upwards sand dated with the radiocarbon method to around 1400 cal. AD. was recovered in sediment cores from the Lucerne Bay area. Based on our sedimentological investigations and radiocarbon dating results, we have high confidence that the observed sandy sequence was deposited during the AD 1601 Lake Lucerne tsunami event.

With the numerical software BASEMENT we simulate the tsunami propagation caused by a subaqueous mass-movement close to the village of Weggis. Performed numerical tsunami modelling provide further estimates on the bed shear stress, wave velocity and amplitude in the Lucerne Bay, which are some of the governing parameters defining sediment erosion as well as transport and depositional processes.

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6.4
A numerical modelling approach to study sediment erosion, transport and deposition in a fluvial system

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Numerical modelling has become an important tool to study landscape evolution of a variety of processes such as fluvial and glacial erosion, hillslope, sediment transport and aeolian processes. The most common objective of these models is to simulate the generation of stratal geometries in response to secular variations of parameters. Modelling techniques in the field of sedimentology and/or geomorphology have gained relevance over the past years for their ability to possibly predict the impact of tectonic and climatic changes on sediment generation, transport and deposition. We present our model developed using the FastScape to examine how fluvial systems react to upstream (water discharge and sediment supply) and downstream (rise and fall of sea-level) changes. The FastScape consists of a set of subroutines that allow us to model landscape evolution by river incision, sediment transport and deposition in continental and marine environments. FastScape routines solve (a) the stream power law (SPL) that has been enriched by a sediment transport and depostion term, (b) hillslope diffusion and (c) marine transport and diffusion. Earth surface process models are often computationally demanding in order to achieve a higher spatial resolution over large domains such as at the scale of a sedimentary basin (i.e., 10-1000 km). In order to overcome this problem, the assumption that sediment transport is linearly proportional to slope, the resulting transport equation can be solved using a set of algorithms that solve these equations such that the computational time increases linearly with the number of nodes N used to discretize the problem (i.e., *O(N)* method) along with using implicit time integration to ensure numerical stability independent of time steps. Here we explore the response of our fluvial landscape to variations in factors such as uplift rate, subsidence rate, precipitation rate and coefficient of sediment erodibility.

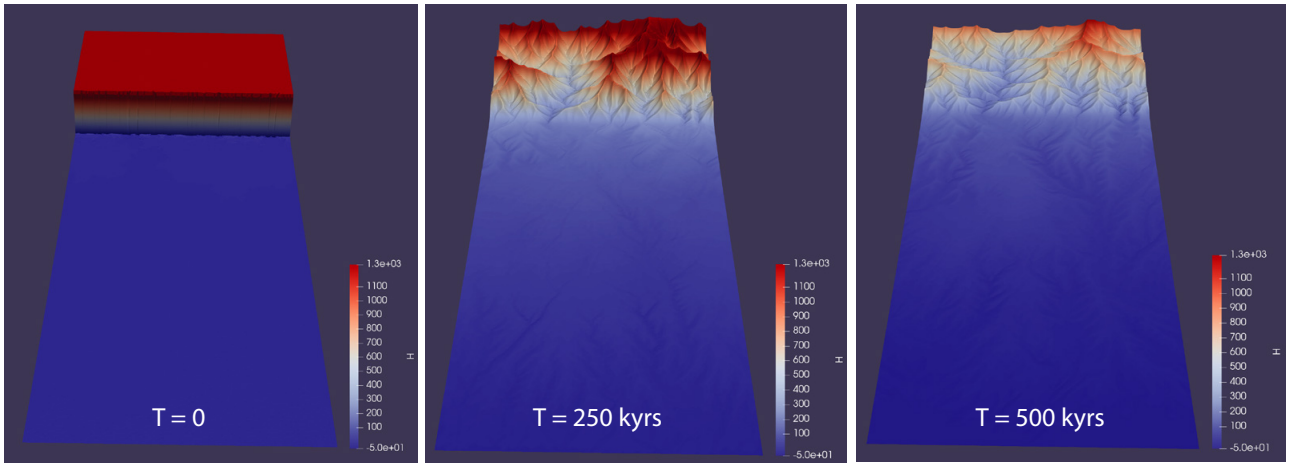

Figure 1. Landscape evolution in our model over time. Model consists of an initial plateau where sediment is generated and deposited downstream in the foreland basin. Each time step is 10^3 years. Color bar represents elevation in meters.

6.5
Mercury signals in Pyrenean Paleocene-Eocene foreland sections as evidence of enhanced volcanism across the Paleocene-Eocene Thermal Maximum

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The Paleocene-Eocene thermal maximum (PETM; ~56 Ma) was an abrupt and transient global warming coincident with a massive realease of carbon to the oceans and the atmosphere. This event is identified in the geological record by a prominent negative carbon isotope excursion (NCIE) in both carbonates and organic matter. The sequence of events triggering this disturbance, as well as the source of the ^{13}C-depleted carbon causing the NCIE remains controversial. External perturbation such as volcanism, associated with the setup of large igneous provinces (LIPs), is suspected to be one of the mechanisms responsible of this abrupt climate perturbation. Mercury (Hg) anomalies are now commonly used as a marker of volcanism and can therefore provide hints on the possible relationship between the LIPs development and the PETM or other major environmental disruptions.

In this study, we present Hg and stable isotope records from several peripheral basins of the Pyrenean orogen across the PETM. The high sedimentation rates which characterize these environments, in comparison to the oceanic realm, make them ideally suited to provide a high-resolution record of carbon and Hg cycle perturbations during the PETM.
Our data reveal the occurrence of two main NCIEs at each study sites. Based on biostratigraphy and similarity of shape and amplitude of the isotope excursions with global records, the largest NCIE is interpreted as major global NCIE characteristic of the PETM. This main excursion is immediately preceded by another, smaller one, that we interpret as the Pre-Onset Excursion (POE), also found in a few other sections worldwide. We find that these two major perturbations of the carbon cycle are systematically associated with important Hg anomalies without significant change in the total organic carbon content. These results show that important pulses of volcanism, probably associated to the emplacement of the North Atlantic Igneous Province, contributed to the onset and the long duration of the PETM. In addition, our study highlights the possibility to get reliable information about past extreme climate events from sedimentary successions even if deposited within active tectonic domains. Finally, our geochemical record allows to define robust isochronous lines and thus to propose a stratigraphic correlation between sections of the Pyrenean orogenic chain deposited in different palaeogeographical domains during the Paleogene.

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6.6
Orbital origin of the stratigraphic sequences in South-Pyrenean syn-kinematic sediments.

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Understanding the relative weight of allogenic drivers in the geological record still constitutes an unsolved problem in stratigraphy. Extracting the stratigraphic signature of orbital cycles may help to disentangle the complex causal relationship among the different drivers. Here, we study the role of orbital cycles in active tectonic emplacements in the South-Pyrenean Foreland Basin. In particular, we focus in the syn-kinematic delta to prodelta sediments of the Middle to Late Eocene Pico del Aguila anticline. Growth strata geometries evidence tectonic uplift and a shallowing upward stratigraphy. Superposed to that general trend, sedimentary sequences reveal shifts in the Accommodation/Sediment supply ratio forced by allogenic factors. A new *ca* 1000 m magnetostratigraphy combined with other regional magnetostratigraphic provides a high-resolution age model that permits to date the formations and also allows testing the role of orbital cyclicity. Based on facies description we built a clastic index depicting changes in either distality and depth of the facies. We conducted spectral analyses (Redfit, MTM) and Evolutive Harmonic Analyses to understand the correspondence of sequence duration with Milankovitch target frequencies.

Our results provide ages for the Guara, Arguis, Belsue formations and the base of Campodarbe formation for this sector of the basin. The contact between Guara and Arguis is very close of the top of Chron C19n. The Belsue and Arguis formations interfinger up to the chron C16n, leading to a major progradation marked by the obliteration of the Arguis marls by the Belsué formation, and subsequently the complete marine restriction occurs towards the top of C16n. This confirms the continentalization of the South Pyrenean Foreland basin-Ebro as an isochronous event.

Spectral analysis and evolutive spectra reveal significant frequencies throughout the stratigraphic column, in spite of the effects of the growing anticline. Constrained by our magnetostratigraphic model we show that these peaks fit well with Earth's eccentricity. In particular, the sequential stratigraphy division responds to the beat of 400-kyr eccentricity. In addition, it is also relevant the imprint of the minima of 2.4 Myr as well as the nodes of obliquity (1.2 Myr). Eccentricity minima is related to progradational trends, whilst eccentricity maxima are linked to transgressive, and-or high-stand conditions. We discuss the upstream or downstream forcing in the setting, and finally we suggest that accommodation driven cycles are the more likely scenario.

6.7
Formation calcified roots in terrestrial sediments and their implications for paleoenvironmental research - revisited

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Calcified roots, also known as rhizoliths, are widely distributed in Holocene soils and sediments of many different climates, which enables their use in environmental research. While one can frequently observe carbonate coatings on living and sub-recent root surfaces, it remains questionable, how rhizoliths of larger diameter (>10 mm) are formed and what their implications are for the paleoenvironmental information of the surrounding soil and sediment. Often one or a few dark colored channels can be observed within large rhizoliths, which suggested that organic matter from former tree or shrub roots was preserved in these areas. However, the internal structure of the rhizoliths commonly does not look similar like the internal structure of living roots, which led to the questions: 1) Which was the source vegetation of rhizoliths?; 2) How can large rhizoliths be formed?; 3) Where in the profile is the carbonate used for formation of rhizoliths originating from?; 4) What are paleoenvironmental implications of rhizoliths?

1) Stable carbon isotope and lipid molecular analyses analyses confirmed that frequently rhizoliths are formed by C3-vegetation.

2) A combination of micro-computed tomorgaphy (CT) and scanning electron microscopy (SEM) was applied to decipher the formation mechanisms of rhizoliths. The CT measurements of intact soil and sediment cores clearly confirmed that the calcification was related to former root growth. This was underpinned by side roots, some of which being calcified, whereas others remained visible in the CT scans as unfilled biopores. Surprisingly, SEM analyses showed that all investigated rhizoliths had a very similar internal structure, irrespective of their origin (Serbia, Hungary, or Germany). The large rhizoliths (>10 mm diameter) consist of an agglomeration of many microrhizoliths (<2 mm), which were formed by fine roots, showing the same internal structure like living roots. The SEM analyses suggest that calcification of roots starts at the surface, followed by coating of cortex cells of the roots and subsequent coating of internal cells. Finally, carbonate can be precipitated even within the root cells, the latter most likely after the death of the individual cell. However, the question remains, why one can find so many microrhizoliths in large rhizoliths? The answer is, that large biopores were formed by trees and shrubs. But during degradation of the large roots, smaller roots colonized the decaying root and used it as a source of nutrients. Such scenario is frequently observed for living fine roots. With ongoing degradation, more and more fine roots of different generations filled the pore space of the former root channel and started to calcify. Finally, the organic matter and nutrients entrapped in the primary large root are entirely consumed and one can find only the microrhizoliths that have the potential to persist for millennia.

3) Stable calcium and strontium isotope as well as radiogenic Sr isotope analyses suggest that Ca and Sr originate from a mixture of the leached fraction of the loess from the same stratigraphic level of the respective rhizoliths and from overlying soils or paleosols. However, we still lack of a detailed understanding of related leaching and transport processes in very deep subsoils, which requires further investigations.

4) The impact of rhizoliths on organic matter in soils and sediments depends on rhizolith frequency and organic matter concentration in the archive. On the other hand, rhizoliths themselves can provide valuable data on rooting plants and thus can contribute useful paleoenvironmental information.

In our presentation, we will explain the latest findings on the nature of rhizoliths and implications of these for their environmental interpretation.

P 6.1
Understanding the differences in aggradation styles in fluvial stratigraphy between upstream climate-driven processes (i.e., water discharge and sediment supply variations) and downstream sea-level changes: insights from physical modelling

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Fluvial deposits have the potential to record both changes in accommodation generated by upstream drivers (i.e., water and/or sediment discharge changes associated with tectonics and climate in the source area) and-or downstream drivers (i.e., sea-level change). Thus, the hypothesis is that upstream or downstream changes can potentially cause rivers to respond and adjust to a new equilibrium river profile by aggradation or degradation. Fluvial stratigraphy is a major record of past environmental changes, yet still we lack the capability to differentiate the expression of upstream and downstream driven changes when faced with fluvial stratigraphic successions. Here we explore this major challenge of sedimentary geology and geomorphology using physical modelling, which has the advantage of being able to independently control both upstream and downstream parameters.

In the Surface Dynamics Lab at the University of Geneva, we have designed and manufactured a long (2.25 m) and narrow (0.05 m) flume with an initial gradient of zero. The narrow width of the flume allows us to have a quasi 1-D system and additionally decreases experimental running time. We have developed an algorithm that captures the profile of the resultant sand wedge from side-profile photos and allows us to fit both linear regressions and polynomial ones to investigate slope changes through time. In addition, we are able to observe how volume changes and if sediment supply remains constant in the experiment. Finally, we have positioned a camera so that the wedge top is also captured and changes in channel width can be measured.

In our experiments we: (i) investigate the role of changes in upstream drivers, such as water discharge and sediment supply on equilibrium river profiles, and (ii) carry out a series of perturbation experiments varying downstream drivers (i.e., sea-level) which theoretically produce the same amount of aggradation as the upstream parameters we have used. This enables us to compare any similarities or differences in morphology that could then be used as diagnostic for upstream or downstream control. Our preliminary findings suggest that changes in sediment concentration are a major factor in controlling slope (when using a single grain-size distribution for all). Ultimately, we will migrate these experiments to a fully unconfined flume which will allow us to compare the changes we have seen in the '1-D' to the 3-D.

P 6.2
Possible relation between sediment flux and grain size extracted from coarse-grained Swiss Molasse deposits

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Pioneer studies in fluvial hydraulics revealed already in the 1950's a general relationship between sediment loads (sediment discharge and grain size) and stream power conditions (water discharge and river slope) (Lane, 1955). In this context, changes in hydrological conditions (sediment and water discharge) have been commonly related to shifts in tectonic, climatic or source-rock conditions (Heller and Paola, 1992), which changes affect the dynamics of alluvial systems, such as megafans. These dynamics are thus largely mirrored by shifts in temporal and spatial grain size trends where related changes are to some extent self-similar (Brooke et al., 2018). Trends in grain size thus bear crucial information on the hydrological conditions of these systems. In addtion, as proposed by Lane (1955), there might exist an explicit relationship between discharge rates (or sediment flux) and grain size. In this project, we test the hypothesis whether trends in grain size are directly related to shifts in sediment flux at the scale of an entire basin.

To this extent, we focus on the Oligo-Miocene strata of the Swiss Molasse basin consisting of km-thick conglomerate sequences. From these, we extract information on grain size using state-of-the-art techniques in grain size analysis and compare the data to published patterns on sediment flux to the Molasse basin (e.g. Kuhlemann et al., 2001). The study area includes three major depositional systems that were active between c. 31 and at least 13 Ma and that are situated in western, central and eastern Switzerland along the Alpine thrust front. Sediments of these megafans (i.e. the Thun-Napf, Rigi-Höhronen and Speer-Hörnli systems) resulted in the construction of three composite sections consisting of Lower- and Upper Freshwater Molasse deposits (Schlunegger et al., 1997, Kempf et al., 1999). The composite sections have been logged and dated with magnetostratigraphy at a temporal resolution of c. 0.5 Ma by the same authors. While this temporal resolution provides us ideal conditions to test our hypothesis, we need to consider three major sources of uncertainties before interpreting possilbe relationships to grain size trends:

I) We collect grain size data directly in the field by taking photographs of the target rock units from which we then measure the grain size on the digital photos. We measure the longest visible axes of individual clasts because the random orientation of various outcrops hinders us from a proper identification of a specific axis. However, relationships between the streams' hydrological conditions and grain size are commonly calibrated to the length of the intermediate (*b*-) axis of individual grains (e.g. Bunte and Abt, 2001). We thus propose to apply corrections to our grain size data through a probabilistic approach that considers (i) data on ratios between *a*- and *b*-axes, and (ii) a random orientation of clasts and how this is influences a grain size dataset measaured on photos.

II) The volumetric budget, from which the sediment flux to the Molasse basin has been calculated (Kuhlemann et al., 2001), involves the entire range of sediments including mud, sand and pebbles that was supplied to the Molasse basin. However, we are only capable of measuring grains c. > 3mm due to the resolution of our digital camera. This adds a possible bias to our dataset, as a large portion of the fine-grained material is excluded from our bulk grain size distribution. We propose to correct this bias by estimating the proportion of fine-grained material through sieving. We will conduct this task in gravel pits because a large proportion of this mateiral has been reworked from Molasse deposits, and since the unconsolidated material can easily be excavated for sieving. This yields in a proxy for the fine-grained fraction within the material in the Molasse conglomerates.

III) Sediments experience a decrease in grain size from proximal to distal positions on alluvial megafans upon transport (e.g. Brooke et al., 2018). Because within Molasse sections, the lowermost exposed sediments were deposited at farther positions in relation to the palaeo-apex than material exposed at the top of the same section, this distal-proximal relationships could add a bias. We propose to solve this spatial problem by defining a grain-fining factor by collecting data along sections with isochronous proximal-distal relationships. Such conditions are found at the Rigi, in the Hörnli area and in the conglomerates near Thun.

The resulting uncertainties will be used to correct the dataset extracted from the digital photos The resulting grain size trends will then be compared to data on sediment flux to the Swiss Molasse basin. We will then explore whether trends in grain size reflect either regional conditions as considered by Schlunegger and Castelltort (2016) or if shifts thereof reflect changes at the scale of the entire Swiss Molasse basin.

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P 6.3
Stratigraphic architecture and depositional processes across lower Paleozoic siliciclastic shallow-marine platfomes: insights from the Late Ordovician of the Anti-Atlas (Southern Morocco)

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During Cambrian-Ordovician times (542-444 Ma), the Anti-Atlas (Southern Morocco) was part of the Gondwana supercontinent and drifted from mid- to subpolar latitudes. The area was part of a shallow marine platform on the so-called northern passive margin of the continent. The stratigraphic succession records a long-term flooding of the platform from the Cambrian to the Silurian. Above Lower Cambrian fluvial to estuarine deposits, an essentially shallow-marine succession (from offshore shales to tidal sandstones) is punctuated by major flooding events in the Middle Cambrian, the lowermost Ordovician, the middle Ordovician and the lower Upper Ordovician. A superimposed eustatic sea-level drop due to the Late Ordovician glaciation marks the last transgressive-regressive cycle that includes the Ktaoua group (mid-Sandbian to Upper Katian) and the glaciation-related Second Bani Group (Hirnantian).

In spite of well-known stratigraphy, details of the depositional processes, the overall geometry of the clinoforms (shelf vs. ramp) and resulting stacking patterns of the high-frequency units remain poorly understood in the platform domain. Here, we present a stratigraphic correlation made through a field-based logging of seven sections along a 50 km long, well-exposed cliff located in the Central Anti-Atlas. The Ktaoua to Second Bani groups, part of the Jbel Bani Mountain, are investigated between the villages of Tissint and Foum Zguid. The Ktaoua succession is dominated by high-order regressive parasequences grading from shales into fine to coarse-grained bioturbated sandstones, presenting paraconformable contacts. Incursions of sandstones showing hummocky-cross-stratifications (HCS) are common and considered to represent offshore-transition storm deposits. In the Second Bani Group, which includes glacially-related depositional facies (diamictites), fine to coarse-grained sandstones are dominant as well, though HCS are virtually absent. In the study area, the upper Second Bani Group forms an unconformable unit, severly truncating the Ktaoua succession and emphasizing a regressive sequence initiated within the Ktaoua deposition.

These archives enable to constrain the basin geometry in the Upper Ordovician. Indeed, whereas offshore shales in the region of Zagora (Central Anti-Atlas) characterize the depocenter of the basin (eastward from the study area), the studied succession is surrounded by a belt of coarser-grained deposits to the north-east (Alnif, Eastern Anti-Atlas) and west (Tissint/Foum Zguid, Western Central Anti-Atlas). The stratigraphic correlation of the Ktaoua parasequences will be used to reconstruct the orientation, direction, and dip of platform clinoforms, which will allow to dissociate a scheme based on chronostratigraphic units from the usual lithostratigraphy. Besides, we aim to further characterize the geometry, shape, and stratigraphic position of HCS bodies in order to advance our understanding of the setting (e.g., paleobathymetry, position relative to regressive vs. transgressive trends) and hydrodynamic processes generating sandstones bodied with prevailing HCS beds.

P 6.4
Early Triassic Organic Carbon Cycle Perturbations in High Latitudes

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The Permian-Triassic mass extinction (PTME) is considered to be the severest extinction in Earth's history with an approximate loss of 90 % of all marine species (Raup, 1979). Global carbon cycle fluctuations, which are associated with radiation and extinction pulses characterize the Early Triassic following the PTME (Payne et al., 2004; Galfetti et al., 2007). Despite the well-documented global carbon isotope oscillations and changes in fossil assemblages (e.g. ammonoids and conodonts), little is known regarding relevant changes in marine primary productivity. The aim of the present work is to gain a better understanding of the fluctuations of marine primary productivity and to distinguish the influences of terrestrial controls on this cycle. This is essential for understanding long-term shifts in atmospheric CO_2 concentrations and to distinguish local from global effects on the carbon cycle. First results for the Smithian-Spathian boundary (SSB) from Svalbard show a positive carbon isotope excursion of about 5 ‰. This has also been observed at other localities in Svalbard (Hammer et al. 2019). Here, this excursion is contemporaneous with an an increase in total organic carbon, nitrogen and phosphorous concentrations. A gradual increase in redox sensitive elements is also noted for the Spathian. Such changes are best explained by an increased amount of weathering from the SSB onward, which may lead to a high nutrient flux to the oceans. This may subsequently cause an increase in marine primary productivity, leading also locally to exceptional preservation of organic matter under anoxic conditions. This newly aquired dataset and increased marine primary productivity interpretation is in contradiction to other highlatitude studies done in the Sverdrup Basin and Svalbard (e.g. Grasby et al 2020).

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P 6.5
Emergence and carbonate platform formation on the Caribbean Large Igneous Province – Exposures of the Bahoruco Peninsula (Dominican Republic)

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The Caribbean Large Igneous Province (CLIP) is characterized by a discontinuous >5km thick basaltic plateau, largely of Late Cretaceous age, resting on an (originally Pacific) Jurassic ocean crust. The CLIP is thought to have formed far below the photic zone in large areas of the Caribbean Plate, and has remained deep oceanic, except for convergent settings, where it eventually became tectonically uplifted and exposed. More recently, Late Cretaceous subaerial development of the CLIP was documented by Buchs et al. (2018) in accreted sequences of W-Colombia.
Emergence of the CLIP and onset of shallow carbonates during the latest Cretaceous – Paleogene is also documented along the northern edge of the Caribbean Plate in the Lower Nicaragua Rise, the Beata Ridge and its onshore exposures in Hispaniola. Volcanic edifices of a depleted "second stage" CLIP volcanism (Dürkefälden et al., 2019) and/or a post-CLIP intraplate volcanism, may constitute the shallow substrate for carbonate buildups.
The aim of our study in the Bahoruco Peninsula (S-Dominican Republic) is to precisely date and better understand the establishment of subaerial/paralic conditions and the onset of shallow carbonate systems along the N-edge of the CLIP. Our first field campaign (Nov. 2019) focused on the eastern Bahoruco mountains, where the volcanic basement (Dumisseau Formation, regarded as Upper Cretaceous CLIP and associated pelagic sediments) and the overlying carbonates are well exposed. In the studied outcrops, the first carbonates, mapped as Polo Formation (Joubert, 2010), are shallow, lagoonal to upper ramp rhodophycaean limestones that contain upper Paleocene (not middle Eocene as previously reported) larger benthic foraminifera.
This formation is overlain by the Upper Neiba Formation (s.l.), made of well-bedded, mostly micritic, sometimes cherty limestones containing planktonic microfossils. Dm-bedded turbidites occur occasionally and are made of reworked and displaced shallow benthic organisms. The peri-platform accumulations of the Neiba Formation cover the largest area of E-Bahoruco.

Hydrothermal activity and evidence of sub-aerial CLIP exposure have been largely debated in the Los Cheseses mining area (Espi & Pérez-Puig Obieta, 2017), where larimar, a hydrothermal blue pectiolite (gemstone) is mined. The mining area is one of our targets to understand the interaction of volcanic, hydrothermal and sedimentary processes. The hydrothermal activity has not been directly dated, but is considered to be of Late Cretaceous age. However, the overlying Paleocene-Eocene shallow carbonates show frequent silicification that we analyze to reveal their hydrothermal vs. biogenic origin. An 40Ar/39Ar plateau age of 52.8±1.7 Ma (Early Eocene) was obtained from a dolerite dyke (whole rock) by Escuder-Viruete et al. (2016), in the basaltic (CLIP) basement of a coastal outcrop in the study area. Hence, volcanic/hydrothermal activity may have co-existed with carbonate sedimentation and may have affected Paleogene sediments. The origin of this silicification could be of major importance for the paleoenvironmental and paleogeographic interpretation of the Bahoruco carbonates.
To achieve our objectives, we analyze the sedimentology in the outcrops and in thin sections, determine micro- and biofacies, and establish a detailed biostratigraphy. Diagenetic and/or hydrothermal events will be studied using Rahman microscopy, microprobe and La-ICPMS analyses, as well as stable isotope analyses and $^{4}0Ar/^{39}Ar$ radiochronology of selected minerals, such as larimar.

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P 6.6
$\delta^{18}O$, $\delta^{13}C$, trace elements and REE in situ measurements coupled with U–Pb ages to reconstruct the diagenesis of Upper Triassic atoll-type carbonates from the Panthalassa Ocean

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Owing to their isolated oceanic setting, atoll-type carbonates are well suited for documenting carbonate deposition and diagenesis in oceanic environments away from continental influence. The atoll-type Dalnegorsk limestone (Taukha Terrane, Russian Far East), deposited in the gigantic but poorly-documented Panthalassa Ocean, preserves a complete record of the diagenetic evolution of an Upper Triassic system, out of the Tethyan domain. To study the diagenesis of this carbonate system, we developed a novel analytical workflow, combining cathodoluminescence petrography with high-resolution analyses of environmental proxies in calcitic cements ($\delta^{18}O$, $\delta^{13}C$, REEY, trace and minor/major elements) and in situ U–Pb dating of calcite cements to precisely reconstruct the chronology of the diagenetic events. We combined these lines of evidence to establish a model of atoll evolution, from deposition to dismantling, based on 10 identified diagenetic episodes. The Dalnegorsk limestone records emergence at the Norian-Rhaetian transition, marked by meteoric and evaporitic cements, followed by dismantling of the atoll edges after drawning in the Early Jurassic. Neomorphism of calcitic shells occurred at the onset of calcitic sea conditions during the Toarcian-Bajocian. The limestone was thoroughly cemented during the Middle/Late Jurassic, and accreted within the Taukha Terrane during the Late Jurassic/ Early Cretaceous. Accretion resulted in fracturing, brecciation, and recrystallisation of the Dalnegorsk limestone. This model is potentially applicable to any similar atoll system, irrespective of age. The evidence presented here extends our knowledge of Late Triassic environments in the Panthalassa Ocean, and more generally, our understanding of mid-oceanic limestone formation and evolution.

P 6.7
Sedimentology and stratigraphy of the Upper Triassic carbonates from Hosselkus Limestone and Luning Formation (Western USA)

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Although the significant research carried out during the last years, knowledge about Panthalassan shallow-water carbonates remains distinctly minor than their Tethyan counterparts. Considering the broad diffusion of these limestones, the comprehension of their depositional environment, ecologic conditions and geographic extent, represents a unique way to better assess life evolution and recovery after the main Permo-Triassic biological crisis. Hosselkus Limestone and Luning Formation, respectively located in Northern California and Western Nevada, represent two completely different scenarios of limestone deposition during Upper Triassic. The first, deposited on a volcanic arc far from the coast of the American craton, shows a rapid change from shallow water facies to deep marine deposits, offering a wide spectrum of calcareous and siliceous organisms. The second, deposited in a large embayment attached to the continent, represents a much wider and homogeneous environment, where calcareous organisms thrive for a long period. Paleontological studies, started at the beginning of the last century and exclusively counting on large-dimension fauna, already proved strong similarities with both Panthalassan and Tethyan carbonates. Now, for the first time, the two formations are described in terms of microfacies and microorganisms, allowing a more exhaustive picture of the depositional environments and a sharper comparison of biological contents. Ages have been revised too, thanks to numerous Conodonts specimens, allowing a high temporal resolution and possibly providing new information about paleotemperature and water geochemistry.

P 6.8
Petrological and geochemical characteristics of the 3.47 Ga Middle Marker horizon in the Barberton Greenstone Belt, South Africa

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The Middle Marker (MM) horizon, the bottom horizon H1 of the Hooggenoeg Formation in the Onverwacht Group, is the oldest sedimentary unit in the Barberton Greenstone Belt (BGB), South Africa. A previous study suggested that the MM rocks accumulated originally as volcaniclastics (Lanier & Lowe, 1982). However, another study found microbial mat-like structures in the rocks and proposed a thriving microbial ecosystem on the original sediments (Hickman-Lewis et al., 2018). The petrological origin and depositional setting of the MM horizon is still controversial. To constrain them, we report petrology and geochemistry of the MM rocks. Rocks samples were collected from two outcrops on the western limb of the Onverwacht Anticline in the central BGB. In both sections, the ~10 m thick MM succession is composed of the black chert, characteristic lapilli beds, light gray chert, and uppermost black chert, in ascending order. The petrological and geochemical characteristics of the black and gray cherts are systematically different from each other. The black cherts are characterized by horizontal/cross lamination, high total organic carbon (TOC) contents, low sulfide contents, large mass-independent isotopic fractionation of sulfur (S-MIF), and flat chondrite-normalized REE patterns. In contrast, the gray cherts are characterized by their massive texture, low TOC contents, high sulfide contents, small S-MIF, and LREE-enriched patterns. The black cherts were likely deposited on shallow shelves with low accumulation rate, whereas the gray cherts accumulated rapidly as volcaniclastics during episodic volcanisms. Especially, the slow accumulation of the black cherts may have been favorable to proliferation of microbes and biofilm formation on the sediment-water interface.

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