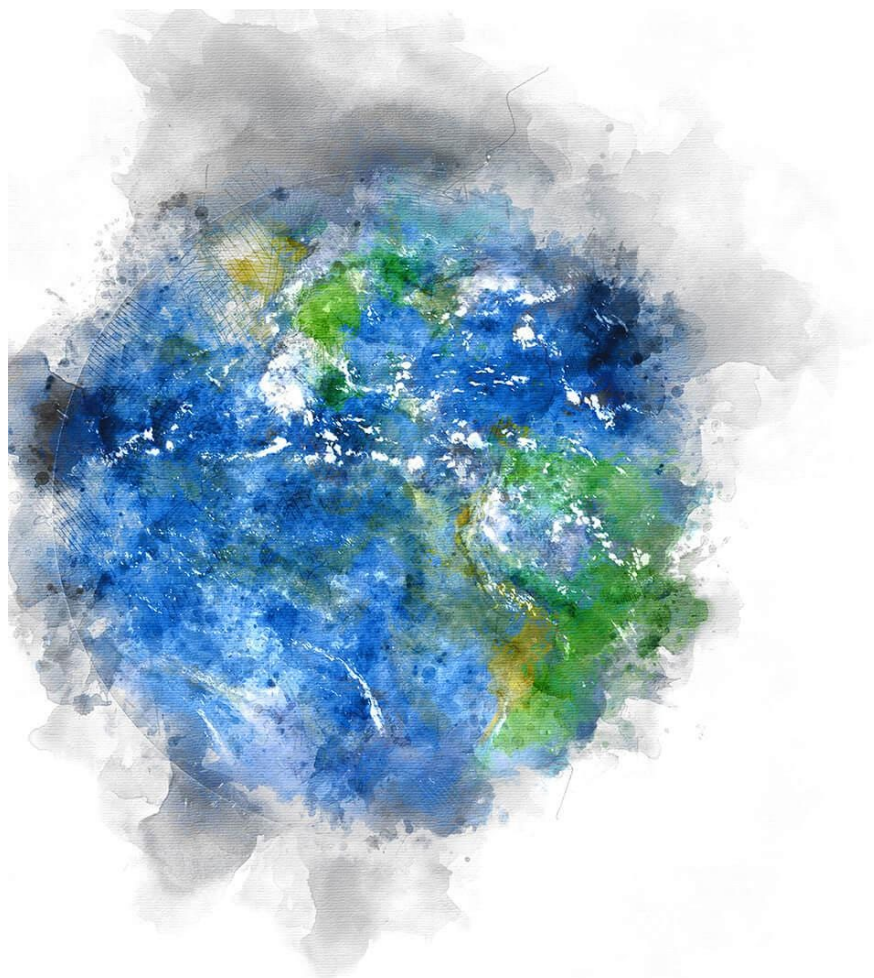


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(**COST CA23150** - pan-**EURO**pean **Blo**Geodynamics network)

Scientific Kick-off Meeting
Bratislava, Slovakia
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SESSION 1: TECTONICS & LANDSCAPE

INVITED TALK

PLANETARY HABITABILITY AND PLATE TECTONICS

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Earth, the only planet on which life is known to have originated appears unique in many ways, including the presence of abundant surface water, a large moon, long-lived magnetic field and plate tectonics. *Yet, which of these and other characteristics are essential for its long-term habitability?*

Changes in the climate and environment are driven by multiple sources, operating on many timescales, from slow changes in the Sun's strength, which eventually will make our planet inhabitable, to instantaneous processes (impacts) that shaped the young Earth but also influenced life evolution dramatically in much more recent times. Small body impacts and variations in global volcanism related to plate tectonics, plume-sourced hotspot and kimberlite volcanism, magnetic field and orbital changes (Milankovitch cycles) have all been experienced by mankind. Conversely, harsh Snowball Earth climates ended long time ago *but how close may Earth have come to becoming inhabitable in the past?*

In this lecture I focus on plate tectonics as a driver for environmental and climate change. Plate tectonics regulates interior temperatures, but also atmospheric greenhouse gas concentrations and surface temperatures via sources (mainly volcanic CO₂ degassing) and sinks (silicate weathering and carbonate deposition). Subduction enables recycling of volatile elements between the surface and the mantle and is probably essential for sustaining planetary habitability. Plate tectonics has not been identified on other terrestrial planets where cooling largely occurs by conduction through a stagnant lid. Because the questions of *when*, *why* and *how* plate tectonics started are debated, an improved understanding of Earth's evolution is critically needed.

TECTONIC CONTROLS ON GLOBAL BIODIVERSITY DISTRIBUTIONS

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The global distribution of biodiversity exhibits patterns that suggest control by environmental and geographic factors including climate, mountainous topography, and tectonic activity. There are two main pathways by which tectonic activity drives biodiversity. First, is through surface uplift, subsidence and roughening of topography, which interacts with climate to create new habitat, encouraging local colonization or speciation and higher regional species richness. Second is through tectonic deformation of topography which fragments habitat, separating populations, leading to vicariant speciation and higher species richness. These two pathways can be described as enhanced environmental heterogeneity and tectono-geomorphic disruption, respectively. We attempt to disentangle the relative importance of these pathways for plant species richness. By building a model for environmental heterogeneity based on modern topography and climate models, we can estimate the expected plant richness. The difference between this estimate and the observed richness is interpreted as the component due to tectono-geomorphic disruption. We find that this excess component of richness is nearly always positive and is locally a factor of up to ten above that expected by environmental gradients alone. We conduct a categorical analysis, comparing the excess richness to active tectonic and geomorphic domains and find a close correspondence between the patterns of excess richness and recent tectonic and geomorphic activity. In particular, we find that biodiversity hotspots overwhelmingly fall in areas of tectono-geomorphic activity, even after accounting for environmental heterogeneity, supporting the hypothesis that transient, tectono-geomorphic disruption is an important control on speciation rates and the distribution of biodiversity.

TECTONICS-SURFACE PROCESSES INTERACTIONS DURING THE WILSON CYCLE

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The links between crustal tectonics, mantle dynamics and surface processes such as erosion, sediment transportation and deposition coupled to climatic variations have been long recognized as the main drivers for the evolution of orogens and sedimentary basins. Understanding their complex interactions is challenging because of their wide range of spatial and temporal scales. In this study, we analyze the surface fingerprints of distinct crustal and mantle processes that are linked to the specific stages of the Wilson cycle, and we will particularly focus on the drivers of surface evolution, in terms of subsidence and uplift patterns. We aim to better understand the feedback mechanisms between tectonics, mantle melting and surface processes during the Wilson-cycle, including the evolution of continental rifts, oceanic subduction and collision zones.

This study is based on conducting and analyzing a series of thermo-mechanical models by 2D/3D ELVIS and comparing the model results with geological and geophysical observational data from orogen-sedimentary basin systems. Depending on the rate of tectonic processes and the mantle thermal properties different surface processes rates alter the timing and flux of mantle melting, and by that primarily modify the style and further rates of tectonic processes. The topographic evolution of subduction zones is also governed together by surface and deep Earth processes. Enhanced sediment subduction lubricates the subduction interface and by water release weakens the overlying mantle. Forearc and back-arc sedimentary basins are sensitive proxies for variable plate and interface rheologies. Lower surface processes rates enable a more efficient stress transfer between the plates facilitating back-arc extension. Whereas higher sediment subduction fluxes contribute to enhanced melting. The competition between the slab-pull force, upper plate strength and melt-induced weakening are all linked to variations of the subduction velocity and topography.

TESTING THE GLACIAL ISOSTATIC ADJUSTMENT AS A CAUSE OF AN EARLY PLEISTOCENE RIVER NETWORK REARRANGEMENT IN THE BALTIC AREA

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As the EUROBIG project integrates specialists across scientific disciplines, this contribution aims to use the kick-off meeting venue to discuss the interaction between the earliest Quaternary continental glaciations of Europe, the induced lithospheric deformation by isostatic adjustment, and reorganization of riverine depositional systems in the forebulge. Notably, this period involves striking changes of biosphere. We investigated a fluvial succession in Lithuania (NE Europe), presumed to be of Early Pleistocene age, underlying the region's oldest preserved till. This succession shows a marked shift in palaeotransport direction—from SE to NW—observed at multiple sites and unlikely to result from simple river avulsion or planform change. To test whether glacial isostatic adjustment (GIA) in the forebulge caused this river network reorganisation, we used the ICEAGE normal-mode modelling software (Kaufmann, 2004), simulating a spherical, compressible Earth with radially variable rheology, as recommended by Lambeck et al. (2010). Six model configurations tested different lithospheric thicknesses and lower mantle viscosities. Ice sheet extents were derived by visually comparing Batchelor et al. (2019) with the ANU-ICE model (Lambeck et al., 2010). We selected ANU-ICE time steps that resemble the late Gauss and early Matuyama extents in Batchelor et al. (2019), and an additional, larger ice extent reaching ~150 km NW of the study area. We modelled a 285,000-year scenario covering four glacial cycles of increasing magnitude, with 40 kyr and 100 kyr periodicities, including deglaciation and interglacial phases. Deformation was analysed along a transect from NW Norway to SW Belarus, intersecting the current GIA uplift maximum and Lithuanian sites. Results show that smaller ice sheets generated SW-directed tilting, while the largest induced up to 0.0015° NW-directed tilting during deglaciation—consistent with the latest pre-glacial drainage direction. Future work will evaluate the impact of modelled tilting on river evolution and explore additional scenarios with varied parameters.

Acknowledgment: The postdoctoral project CosmoLith is carried out under the “New Generation Lithuania” plan (Nr. 10-036-T-0008) financed under the European Union economic recovery and resilience facility instrument NextGenerationEU.

NEW ^{10}Be -DERIVED CATCHMENT-WIDE DENUDATION RATES SHED LIGHT ON THE UPLIFT HISTORY OF THE MALÁ FATRA MTS. (WESTERN CARPATHIANS)

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Knowledge of temporal and spatial evolution of mountain chains is an important key to resolve the interactions of geosphere and ecosystems. The evolution of uplift may have crucial impact on correlations of mammal biostratigraphic stages across the Europe, as the mountain chains represent major barriers for faunal migration. Hence, the kick-off meeting of the EUROBIG project represents an ideal venue for discussing new results on the spatial and temporal variations in river incision and near-surface denudation across the Western Carpathians. Taking the Lúčanská Malá Fatra Mountains (central Slovakia) as the key study area, we integrate cosmogenic nuclide (^{10}Be) analysis with high-resolution digital elevation models and apply the Stream Power Incision Model (SPIM) to reconstruct uplift history and associated geomorphic responses. Slope-break knickpoints extracted from river longitudinal profiles reveal spatially heterogeneous, multi-phase tectonic activity.

Based on ^{10}Be concentrations measured at the ASTER AMS laboratory (CEREGE) and processed with the CRONUS calculator, we determined a mean catchment-averaged denudation rate of 109.02 ± 3.13 m/Ma across 14 basins, and a corresponding mean erosion coefficient (K) of $1.51 \pm 0.05 \times 10^{-6}$ m/a. These values inform SPIM calibration and indicate a significant uplift signal around 7 Ma, consistent with thermochronological and sedimentary records. This study provides new quantitative constraints for reconstructing the Late Cenozoic landscape evolution of the Western Carpathians.

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SEA LEVEL CHANGE AND SURFACE UPLIFT IN THE AEGEAN CONTROLLED BY CRUSTAL DYNAMICS

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One of the most important challenges in identifying records of sea level variation in actively stretching tectonic regions, such as the Aegean-Anatolia, is to consider the role of long-term tectonics. Surface topography variation with respect to a reference baseline may be clearly documented in the geological record. Here, we present results of numerical experiments of lithospheric extension that demonstrate surface topography and landscape evolution controlled by crustal flow. Model results are compared and contrasted against the stratigraphic data from the graben systems in western Anatolia and the Cyclades in the Aegean. Our results show that localized flow may drive a few hundred meters of surface uplift on the horsts of the extended terranes. This may explain why rapidly stretching areas are not below sea level and are supported by dynamic topography induced by lower crustal flow.

NEOGENE PALAEOGEOGRAPHY OF SW ANATOLIA INFERRED FROM TECTONIC- SEDIMENTATION-CLIMATE INTERACTIONS

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The neotectonics of western Anatolia were characterized by the development of extensional basins. Interpretations of the origin and history of these basins have been based on regional tectonic inferences rather than detailed stratigraphic analysis of the basin-fill architecture, thus the timing and tectonic nature of the post-orogenic episodes of crustal deformation in the western Taurides remain controversial.

Recent studies of the terrestrial filling of these post-orogenic basins show a strong synchrony that has led to the recognition of three pulses of crustal extension that caused changes in the basin paleogeography and stratigraphic architecture. The development of the basins commenced in the Vallesian, involving alluvial fan, alluvial and lacustrine deposition. A second pulse of rifting occurred in the late Ruscinian, dividing the basins longitudinally; the lacustrine environment expanded, coastal peat-forming marshes developed and abundant mammal fauna appeared in the early Villanian. While the lake gradually shrank due to the progradation of deltas, a third pulse of rifting created new normal faults that further divided the basins into narrow half-graben basins at the end of the Villanian. The third pulse of rifting is estimated to have accounted for 10% of subbasinal crustal extension but caused the greatest changes in basin paleogeography and drainage patterns.

These were the first regional case studies of post-orogenic continental basins using detailed basin fill analysis and mammal biostratigraphy, providing a reliable time-stratigraphic framework for rifting pulses. Therefore, the study tests the applicability of this framework by stratigraphically analyzing adjacent orogenically related extensional basins. This comparative study is a contribution to a better understanding of the development of the orogenic top extensional basin sequence in SW Anatolia, addressing some regional controversies and providing new insights into the tectonic history and paleobiogeography of the region, and draws analogies to the Alpine Orogeny and other branches of the paleo-Mediterranean belt.

DYNAMIC TOPOGRAPHY AND THE MANTLE FORCING ON CLIMATE

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Global topography plays a fundamental role in shaping climate, influencing atmospheric circulation and precipitation patterns through orographic effects. While much of Earth's topography arises from isostatic support due to variations in crustal and lithospheric thickness and density, a significant portion of up to $\pm 1\text{-}2\text{km}$ results from dynamic forces driven by slow yet vigorous mantle convection. Despite decades of research on the spatial and temporal evolution of such 'dynamic topography', its impact on global climate remains unexplored. In this study, we address this gap by quantifying the influence of mantle-induced dynamic topography on present-day atmospheric circulation and precipitation patterns. Using an Earth Model of Intermediate Complexity forced with different models of global dynamic topography, we isolate the mantle's contribution to climate patterns. Our findings reveal prominent climatic effects linked to mantle dynamics, particularly along the American Cordillera, the East African Rift System, and other regions across latitudes which are critical to biodiversity and the evolution of life. These results uncover a hitherto unknown connection between Earth's deep interior and surface environments, with the mantle dynamics as active driver of climate processes, enhancing our understanding of the Earth System. By linking mantle dynamics to global climate, our study offers new opportunities for paleoclimate investigations and insights into how geodiversity and biodiversity have co-evolved throughout Earth's history.

UHP METAMORPHISM IN GREECE: PETROLOGIC DATA FROM THE RHODOPE MOUNTAINS

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In Greece, UHPM rocks occur in the Rhodope area, one of the major tectono-metamorphic units located in NE Greece. This region consists of different metamorphic complexes involved in the Alpine collisional history between the Eurasian and African plates (e.g., Krohe & Mposkos, 2002-GSLSP, 204, 151). In Rhodope, a Jurassic UHP metamorphism is confirmed in the uppermost Kimi and the underlying Sidironero complexes (e.g., Mposkos & Kostopoulos, 2001-EPSL, 192, 497; Perraki et al., 2006-EPSL, 241, 672).

UHP metamorphism is evidenced by the presence of octahedral microdiamond inclusions (3 to 10 μm) in protective garnets, within the metapelitic gneisses. Microdiamonds probably formed from a supercritical fluid under extreme P-T conditions. The latter is strengthened by the presence of composite inclusions consisting of CO_2 , calcite, and microdiamonds. Other UHP indicators include: 1) quartz rods and rutile needle exsolutions in metapelitic garnet, suggesting a former titaniferous super-silicic (majoritic) garnet formed at $P > 4\text{GPa}$) oriented quartz lamellae in eclogitic clinopyroxene having been exsolved from a former super-silicic UHP precursor; and 3) coesite pseudomorphs in garnet, where radial cracks around multi-crystalline-quartz aggregates are indicative of the former coesite existence (e.g., Mposkos & Krohe, 2006-CJES, 43, 1755).

Jurassic UHP rocks are overprinted by late Jurassic/early Cretaceous HP granulite facies metamorphism ($P > 1.5\text{GPa}$; $T \sim 900^\circ\text{C}$). In the Eastern and Western Rhodope, exhumation of these rocks occurred along different P-T paths. In the eastern Rhodope (Kimi Complex), UHP rocks re-equilibrated under relatively static annealing conditions and emerged at the surface in the Eocene. In the western Rhodope (Sidironero Complex), these rocks have been subjected to an overprinting Eocene MP to HP metamorphism, followed by exhumation along a major shear zone at $\sim 40\text{ Ma}$. In either case the final exhumation period revealed the rocks at the surface setting the protoliths on erosion and brittle tectonics that shaped the landscape in Rhodope.

DYNAMICS OF LOW MOUNTAIN RANGES DROVE A BIODIVERSITY BURST IN SE DURING THE MIOCENE-CLIMATIC OPTIMUM

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While proven for the highest ranges such as the Andes, the Himalayas, and the Cordilleras, it remains poorly understood whether and to what degree low mountains such as the Dinarides, the Apennines, and the Carpathians affect the climate variations and species dispersal across the mountain range. Although their present-day topography is significantly lower, the Dinarides in SE Europe seem to comprise a record of variable climatic conditions, depositional environments, and species distribution across the mountain range, similar to the Earth's largest ranges. Previous geological data imply that mountain growth drove regional contrast, i.e. arid vs humid conditions and fauna distribution across the Dinarides during the Miocene Climatic Optimum (MCO). However, the analysis of causal relations is greatly hampered by the uncertainty about whether the basins across the mountain range were coeval due to poor age constraints.

This study focuses on sedimentological and geochemical analysis, systematic dating (U-Pb geochronology of carbonates and zircons via LA-ICP-MS), analysis and revision of paleontological material from saline-type lake successions across the Dinarides. After completing the study's first phase, our new data with the existing datasets provides a range-wide correlation. This demonstrated coeval evolution of the saline-type lakes in the internal and freshwater lakes along the flank facing the Adriatic Sea, implying contrasting arid and humid climatic conditions, respectively. As a consequence, freshwater lakes represent the most prominent species-richness hotspot of continental Europe, while the biota along the arid flank is conspicuously less diverse. This implies that the Dinarides' topography blocked the moisture-rich westerly winds from the Adriatic Sea and induced aridification along the lee side during MCO across the range. As a next step, the occurrences of all aquatic and terrestrial biota of Dinaridic intramountainous basin will be quantified and calibrated by new radiometric data to estimate changes in biodiversity and its drivers.

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CLASSIFICATION OF TECTONIC COAL DESTRUCTION TYPES USING CONVOLUTIONAL NEURAL NETWORKS

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Tectonic coal destruction is a key geological phenomenon that significantly affects the safety and efficiency of coal mining operations. Accurate classification of coal destruction types provides vital insights into underground geological structures and supports risk assessment in mining engineering. Traditional methods for analysing coal samples are often manual, subjective, and time-consuming. To address these limitations, this study investigates the application of convolutional neural networks (CNNs) to automatically classify coal destruction types using image data.

In this research, we utilised the first standardised image dataset of tectonic coal destruction types, constructed both domestically and internationally. The dataset contains 1031 labelled images collected by experts in the underground environments of three coal mines and their subsidiary sites. Each image is categorised into one of five destruction classes: Nondestructive coal, Destructive coal, Strongly destructive coal, Pulverised coal, and Fully pulverised coal. The dataset reflects a high level of authenticity and reliability, making it suitable for deep learning applications.

We designed and trained a custom CNN architecture to classify the images into their respective categories. The model was evaluated using standard performance metrics such as accuracy, precision, and recall. Preliminary results demonstrate strong classification performance, particularly in distinguishing between highly similar destruction types.

SESSION 2: CLIMATE & CARBON CYCLE

INVITED TALK

CLIMATE STABILITY: MECHANISMS LEADING TO GREENHOUSE AND ICEHOUSE REGIMES

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Under volcanism activity, astronomical forcing, and a spatially inhomogeneous input of solar radiation, the climate system responds dynamically to redistribute energy and matter until reaching a stationary state. This redistribution is governed by complex nonlinear interactions among subsystems—such as ice sheets, sea ice, atmosphere, ocean, and vegetation—which can amplify or dampen initial perturbations across a wide range of temporal and spatial scales.

In this talk, we will discuss several examples of feedback mechanisms acting at different scales and leading to either greenhouse or icehouse regimes. We will focus on the role of the long- and short-term carbon cycles in shaping the final stationary climatic state, and on the challenges involved in modelling the complex spectrum of variability of the climate system.

INVITED TALK

BIOGEOSPHERE: MULTIPLE SULFUR ISOTOPES TRACK THE ADVENT OF PHOTOAUTOTROPHY IN THE PALEOARCHEAN (CA. 3.4-3.5 GYR AGO)

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Free energy from chemical disequilibria in crustal environments – chemolithoautotrophy – sustained the last universal common ancestors (LUCAs) of all life. If the LUCA relied on the reductive Acetyl-CoA metabolic pathway via abundant H₂ (e⁻ donor) and CO₂/bicarbonate (e⁻ acceptor), they were confined to hydrogenous (H₂-producing) metalliferous (ultra-)mafic alkaline hydrothermal (>50°C) systems. With the appearance of photoautotrophy a new plentiful e⁻ donor (Corg) was provided. This allowed early life to exploit Sulfur (S) compounds as an energy source. Here, we report new multiple S-isotope (32S, 33S, 34S; Δ33S) data from authigenic sedimentary sulfides in Eoarchean-Paleoarchean sedimentary rocks from Isua (West Greenland) and South Africa (Barberton) to trace this early metabolic evolution. We pinpoint in time and space when life began to influence the marine S cycle, and make inferences about the biogeodynamic changes in the early Archean that set the stage for the eventual appearance of the Eukaryotes.

DEVELOPMENT OF A NEW BIOGEODYNAMIC TOOL FOR EXPLORATORY CLIMATE MODELLING

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Exploring the dynamical structure of the Earth climate following a “biogeodynamical approach” requires running simulations over long time scales and for a wide range of initial conditions. Simulations need to include interactions among the climatic components such as a dynamical atmosphere and ocean as in general circulation models, a representation of vegetation, sea and continental ice, the whole adaptable under different plate tectonic configurations for deep time modelling. However, due to their high computational costs using CMIP-like models is not feasible. Here, we propose a newly developed biogeodynamical modelling tool that allows for running simulations over multi-millennial time scales in a reasonable amount of CPU-time.

Starting from the MITgcm coupled atmosphere-ocean-sea ice setup, we developed a global ice sheet model based on the shallow-ice approximation, where the surface mass balance is computed as in Tsai and Ruan, 2018. A hydrological model pysheds is used to generate the runoff map and considers the ice-sheet isostatic correction. Finally, offline coupling with BIOME4 a vegetation model and PANALEISIS a paleogeographical reconstruction model is performed. This coupled setup allows for exploratory studies of global-scale nonlinear interactions among the climatic components.

Throughout Earth's history these interactions evolve and balance differently under the effect of various types of forcing, hence leading to a large range of climatic steady states for different paleogeographical reconstruction times, and potentially revealing the presence of tipping mechanisms. Here, we show a present-day validation of this coupled setup against observations and CMIP6-model results, and how we plan to apply it to selected time frames in deep time.

SODIUM INCORPORATION INTO BELEMNITE AND BIVALVE CARBONATE: A NOVEL SEAWATER CALCIUM PROXY?

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The long term major element chemistry of seawater is controlled by a balance of Earth surface weathering, mid-ocean ridge hydrothermal circulation and sedimentary depositional fluxes, and provides an important integrated record of these processes throughout Earth history. However, there is a limited range of proxies that can be applied to derive this information, and they often come with large uncertainties or with limitations on the achievable resolution of the record. The concentration of calcium ions is essential for determining carbonate mineral saturation state, but has been particularly problematic to determine directly. The Na/Ca ratio of planktic foraminiferal calcite has been proposed as a novel record of Na/Ca in seawater, which, because of the very long residence time of Na, mostly reflects changes in the calcium ion concentration. Here we present a ~27 Myr early Jurassic dataset of belemnites and bivalves covering both the Sinemurian-Pliensbachian and early Toarcian events. Whilst these organisms lack a calibration to independent measures of seawater calcium concentrations, their Na/Ca ratios are broadly comparable between the two groups for the same time interval, record a similar range compared to Cenozoic foraminifera, and vary in a way that is compatible with our understanding of biogeochemical change during the events covered by the record. This suggests that Na/Ca in these groups holds some promise as a high resolution proxy to determine seawater calcium concentration prior to the advent of abundant and well preserved planktic foraminifera tests.

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GEOLOGICAL CARBON CYCLE IN DIGITAL EARTH SISTERS

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Over geological timescales, Earth's climate is regulated by a long-term stabilizing mechanism known as the carbon-climate feedback. This feedback is driven by a dynamic balance between two opposing carbon fluxes: (a) The release of CO₂ from Earth's interior through volcanic degassing and (b) The removal of CO₂ from the atmosphere via silicate weathering and carbonate formation at the surface. This balance, first formalized by Walker (1981), plays a crucial role in maintaining habitable surface conditions over millions of years. However, carbon cycle models often focus on Earth's current state and do not fully capture the coupling between deep Earth processes, surface dynamics and climate evolution. To address this, the aim of my PhD project is to compute these key fluxes, degassing and weathering, using numerical models based on first physical principles. The goal is to test the hypothesis of a long-term balance between these fluxes, under a range of planetary conditions. These fluxes will then embed in digital siblings of the Earth, fully integrated 3D digital planets developed as part of the ERC Pandora project. Pandora is an international and interdisciplinary initiative that combines geodynamics, surface processes modelling, climate and eco-evolution simulations to investigate how interior-surface interactions shape planetary habitability. At first, equilibrium between these fluxes is not reached in our initial simulations, suggesting that additional sources or sinks of carbon may need to be considered in the system. True Polar Wander (TPW), a geophysical process in which the entire solid Earth shifts relative to planet's rotation axis, can influence degassing and weathering by shifting continents into different climate zones. This process, linked to the supercontinent cycle, may therefore impact the long-term carbon cycle.

THE IMPACT OF PALAEOGEOGRAPHIC BOUNDARY CONDITIONS ON EARLY CENOZOIC CLIMATE SIMULATIONS

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Studying warm climates of the geological past is essential to improving our understanding of the Earth's climate and carbon cycle under elevated atmospheric CO₂ levels. A major challenge in simulating past climates lies in the accurate reconstruction of the palaeogeography – the spatial distribution of land, mountains, oceans, and their bathymetry. However, the impact of palaeogeography and its uncertainty on modelled paleoclimates and model-data misfits is poorly quantified. Here, we quantify the impact of palaeogeographic boundary conditions on the simulation of early Cenozoic climates (66 to 34 million years ago) using the IPSL-CM5A2 Earth System Model. We performed a series of palaeoclimate simulations for key time slices, such as the early and middle Eocene climatic optima (EECO and MECO), using the most recent palaeogeographic reconstructions and with varying atmospheric CO₂ concentrations. We tested alternative palaeogeographic scenarios, with particular focus on the different reconstructions of the Neo-Tethyan region and the India-Asia collision. In addition, we evaluate the impact of using different global reference frames, including the latest palaeomagnetic reference frame of Vaes et al. (2023, Earth-Science Reviews). We show that the choice of reference frame and palaeogeographic reconstruction can significantly impact global ocean circulation as well as regional temperature and precipitation patterns. To assess how palaeogeography affects model-data comparisons, we compared model predictions against available palaeoclimate proxy records. We find that changes in palaeogeographic boundary conditions lead to notable differences in the reconstructed position of proxy sites. This may affect interpretations of past climates based on proxy records, such as reconstructions of latitudinal temperature gradients or climate sensitivity calculations. Our findings highlight the importance of palaeogeography for palaeoclimate modelling, and we discuss how future improvement of palaeogeographic reconstructions may contribute to advancing our understanding of past climates and the carbon cycle.

HYDROGEN ECONOMY, MYTH OR REALITY

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The energy system is essential for every economy, but at the same time the concept of sustainable development as a guiding principle needs balance with nature. The challenges of sustainability require a long-term perspective together with integration of many elements. One of them and the most important is energy. Although many alternative sustainable energy corridors may emerge, one of the pathways towards zero carbon emission is the replacement of fossil fuels by renewable energy. Among the many candidates, hydrogen is considered as the future clean fuel. When it burns it releases only water, without any contribution to the carbon footprint. However, access to the clean hydrogen is difficult and followed by some controversy. Most of the currently produced hydrogen is from fossil fuels, termed either as grey or blue hydrogen. The difference between them is that the carbon is captured and stored for the blue, and the grey is produced without the above. There are other forms of hydrogen like green, obtained from electrolysis by using surplus renewable energy sources.

Some researchers have shown that natural (geologic) hydrogen might be in abundance. Fuel explorations in the past were not focused on the hydrogen so we might be surprised how much hydrogen lies in the ground. Evidence from the literature and calculations suggest that hydrogen could be more prevalent than initially considered and in more geological environments than have been previously realised. The recent discoveries of large cache of hydrogen in Mali and Albania, in some aspects resemble the beginning of the oil era in the mid of 19th century. The scientists have been started to write a scenario for hydrogen economy. It is possible solution to move the global energy system towards a sustainable trajectory.

FROM PASTORALISM TO GEOBIOLOGY: THE CONTRIBUTION OF ANIMAL LIFE TO EARTH SURFACE DYNAMICS

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Pastoralism is a land use that has significant impacts not only on human nutrition and economic production, but also on the physical and biochemical evolution of the Earth's surface. Grazing behaviour, mobility patterns, defecation, and direct interactions of animals with the soil play a decisive role in soil structure, nutrient cycles, vegetation composition, and erosion processes. These interactions can lead to the reorganisation of landforms, the formation of microhabitats, and changes in ecosystem functions over time. While the discipline of geobiology aims to understand the effects of biotic factors on geological processes, pastoral systems provide one of the most concrete examples of this relationship in the field. This study assesses the impact of pastoral systems on earth dynamics and argues that livestock should be considered not only as biological but also as geological agents. Particularly in arid and semi-arid regions, the topographic and biochemical changes observed as a function of grazing intensity and continuity provide important clues for understanding human-interactive geobiological processes. In this context, a holistic approach to assessing the interactions between livestock production and land systems is crucial both for sustainable land management and for understanding nature-culture relationships.

SPECIES DIVERSITY IN ECOLOGICAL BALANCE AND GEOBIOLOGICAL FEEDBACKS

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The stability and functionality of ecosystems are contingent upon the biodiversity they contain. Species diversity plays a pivotal role in determining the complexity of ecological networks. Moreover, it has been demonstrated that biodiversity is instrumental in ensuring the stability of fundamental Earth system processes, including but not limited to the formation of soil, the cycling of nutrients, the hydrological cycle, the flow of energy, and the balance of atmospheric gases. Geobiological approaches that have emerged in recent years have facilitated a more profound comprehension of the interactions between living organisms and the geosphere. In particular, the role of biotic actors such as microorganisms, plants, and soil invertebrates on earth systems has become a central focus. The present study analyses the effect of species diversity on ecological balance and the resulting geobiological feedback mechanisms. It has been demonstrated that as species diversity increases, the resistance of ecosystems to environmental stress factors increases and post-disturbance recovery processes accelerate. To illustrate this point, it is important to note that plant species diversity has been shown to support organic matter accumulation and water infiltration in the soil through different root structures and mycorrhizal relationships. In contrast, microbial diversity plays a critical role in terms of the continuity of carbon and nitrogen cycles. The loss of species instigates cascading reactions within intricate feedback systems, thereby endangering the equilibrium of Earth's ecosystems. In this context, an interdisciplinary approach to the study of the multi-layered interactions between ecosystem components is of particular importance in terms of protecting biodiversity, especially in the face of pressures such as climate change, land use change, and pollution. This standpoint has the potential to facilitate the emergence of nature-based solutions and the development of sustainable land and resource management policies.

THE IMPACT OF PALAEOGEOGRAPHIC RECONSTRUCTIONS ON PHANEROZOIC CLIMATE SIMULATIONS

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Throughout the Phanerozoic, Earth's climate has alternated between greenhouse and icehouse states, largely driven by shifts in continental configurations that influence weathering processes and, consequently, global climate. Geodynamic factors play a key role in these transitions, and intermediate-complexity Earth System Models are valuable tools for exploring the associated parameter spaces. These models rely on topographic boundary conditions derived from palaeogeographic reconstructions, where elevation and slope strongly affect silicate weathering rates. However, differing reconstruction methodologies can yield substantially divergent results. Among these, the digital elevation models (DEMs) by Scotese and Wright (2018) are widely used, despite notable discrepancies relative to other reconstructions. To evaluate the influence of palaeogeographic reconstructions on climate model outcomes, we compared outputs from PlaSim-GENIE simulations for 45 time slices across the Phanerozoic, using both the PaleoMap and PANALEISIS (Vérard, 2019) DEMs. These simulations, spanning pCO₂ levels from 0.25 to 16 times pre-industrial concentrations (280 ppm), generated lookup tables for the spatially resolved global carbon cycle model SCION (Mills et al., 2022). This approach enabled the exploration of a broad parameter space governing Phanerozoic climate shifts. Preliminary results indicate that incorporating degassing forcing from the PANALEISIS palaeogeography enables even simple inorganic carbon cycle box models to better reproduce atmospheric CO₂ variations inferred from proxy data. Furthermore, climate simulations using PANALEISIS within SCION more successfully replicate the Hirnantian Glaciation, while simulations constrained by PaleoMap yield pCO₂ levels too high to account for glaciation during this interval. These differences may reflect PANALEISIS's more robust treatment of plate boundary evolution, grounded in plate tectonic principles.

SESSION 3: LIFE EVOLUTION & BIODIVERSITY

INVITED TALK

PLANETS AND LIFE: EVOLVING TOGETHER THROUGH TIME

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Biodiversity is not static, it evolves over time, often in connection with Earth processes. We emphasize that while many global biodiversity hotspots are found in mountainous regions, not all mountains host exceptional levels of diversity. This paradox points to the importance of understanding not only the presence of gradients and new habitats created by mountain uplift, but also the geological processes that continuously reshape their connectivity. Traditional explanations based on climate and topography only partially account for plant diversity patterns. We argue for a broader focus on tectonic and geomorphic processes, which generate disturbances at landscape scale and can trigger rapid diversification of species. Biodiversity hotspots often emerge from such dynamic settings, where fast diversification follows major environmental reorganisations illustrated with two case studies. First, in the Hengduan Mountains of Asia, complex tectono-geomorphic activity drives mixing and isolation cycles that fuel speciation. Second, Madagascar is a hotspot of endemism despite lacking active tectonics, where geomorphology fosters diversity through reorganisation of river valleys. These modern patterns may even help the interpretation of ancient evolutionary bursts of the Ediacaran and Cambrian radiations: global-scale disturbances such as "Snowball Earth" associated with unique climatic and geomorphological upheaval may have triggered unparalleled diversification of marine organisms. These analogies suggest that certain geodynamic conditions repeatedly foster diversification by alternating phases of connectivity and isolation. Can we then define general rules for how life evolves in response to planetary dynamics? Simulation-based approaches help link Earth's dynamic systems to global biodiversity patterns and serve as a window into life's long-term response to planetary change.

INVITED TALK

STUDYING THE EVOLUTION OF BIODIVERSITY IN ITS PALEOENVIRONMENTAL CONTEXT USING PHYLOGENETIC DIVERSIFICATION MODELS

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The evolution of biodiversity is highly dependent on the environmental context in which it operates. I will present phylogenetic diversification models specifically designed to investigate the association between paleoenvironmental conditions and the diversification of life. A meta-analysis across tetrapods in the Cenozoic reveals a positive association between temperature and diversification rates, providing support for abiotic versus biotic controls on diversification. When accounting for spatial heterogeneity in diversification dynamics, these models accurately predict present-day levels of species richness across latitudes. I will present current efforts to integrate direct information from the fossil record into these models, and discuss current gaps as well as potential future developments in the field.

EXPLORING BIODIVERSITY AND ECOSYSTEM COMPLEXITY THROUGH AI AND IMMERSIVE TECHNOLOGIES IN MIDDLE-LEVEL LEARNING CONTEXTS

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This study explores the integration of artificial intelligence (AI), simulations, and immersive technologies to support deeper engagement with biodiversity and ecosystem dynamics in middle-level educational settings. Through inquiry-driven and interactive approaches, participants investigate ecological systems and their evolving patterns. Virtual habitat simulations on platforms such as Minecraft Education Edition and EcoMUVE provide dynamic representations of wetland and forest environments. For example, a simulated Sultan Marshes scenario enables observation of climate-related impacts on migratory bird populations, encouraging systems-based ecological reasoning. To analyse long-term environmental changes, AI-powered tools like Google Earth Engine are used to track satellite data from regions such as the Gediz Delta between 2000 and 2023. These analyses facilitate exploration of land-use shifts and biodiversity decline through real-world datasets. Conversational AI agents—including ChatGPT and Bard—are employed in role-based activities, allowing users to assume expert perspectives (e.g., ornithologists) when addressing issues like pollution or disrupted migration routes. Strategy-oriented platforms like Classcraft incorporate AI-generated ecological scenarios, prompting collaborative solutions and integrative thinking. Immersive tools such as Google Expeditions, WWF Free Rivers, and Merge Cube further enhance conceptual understanding by enabling interactive modelling of habitats—such as bird nests and beehives—highlighting the complexity of interspecies relationships. By combining ecological inquiry with advanced technologies, this interdisciplinary approach promotes critical thinking, ecological literacy, and a systems-oriented understanding of life sciences within contemporary learning environments.

MEGACLIMATE AND DIFFERENTIAL EXCITABILITY OF DIVERSITY — THE THREE TIME SCALES OF MAMMALIAN MACROEVOLUTION

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Biological evolution is driven by the interplay of external physical forcing and internal population (in broad sense) dynamics. The influence of various factors depends on the temporal and spatial scales of evolution, as well as on the taxonomic level of the evolving entities. Therefore, multiscale approaches are needed to map the interactions between changes in species diversity (macroevolution) and Earth systems, such as climate. Here, we explore the fossil record of large mammals as documented in the NOW (New and Old Worlds) database and compare the reconstructed diversity trajectories to climate fluctuations at scales greater than 0.5 Ma. Using species diversity trajectories reconstructed by applying a Bayesian approach for three mammalian orders through the Cenozoic — Carnivora (excluding Pinnipedia), Perissodactyla, and Artiodactyla (excluding Cetacea) — we performed Haar fluctuation analyses, which yielded distinct scaling patterns of diversification as a function of time scale. The structure functions allowed us to distinguish three separate time-scaling regimes with two distinct crossovers in mammalian macroevolution. Additionally, the slopes of the scaling functions revealed differential sensitivity of species diversity to global temperature fluctuations at time scales longer than 4 million years, well within the megacclimate regime. Therefore, the scaling analyses revealed the invariant generality of distinct macroevolutionary regimes while also revealing taxon-specific differences in the sensitivity of species diversity to long-term climate change.

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(BURNING) POST-COAL-MINING WASTE HEAPS: A BIOGEO-DIVERSITY MARKER OF “ANTHROPOCENE”

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Post-coal-mining heaps (dumps) stand for a long-living, commonly inalienable elements of the environment of coal basins worldwide. This makes these commonly large, anthropogenic objects – often comparable to volcanoes – a marker of “Anthropocene”. At once, they pose a collection of different biotopes. Several years of observations in the Upper Silesia region allowed to preliminarily identify numerous plant species thriving in the local, numerous heaps. Following this, we began a detailed study of plant communities growing close to fumarolic vents. This included the phytosociological and floristic method in 3 burning heaps. Example interesting species confirmed include the most *Spergularia* (possibly *S. salina*) recorded in the “Wrzosek” heap at Pszów. Of the mosses one worth mentioning is *Aulacomnium palustre*, confirmed at Borowa II heap in Ruda Śląska but possibly also present among persistent, hydrous vent in the “Szarłota” heap at Rydułtowy. The nominally tropical grass, *Digitaria sanguinalis*, was observed in its vicinity. Mosses most commonly seen within the heap fumaroles are *Leptobryum pyriforme*, *Ceratodon purpureus* and *Campylopus introflexus*. The latter is a known, highly invasive species and a separate phytogeochemical study of it is planned. Environmentally important liverwort representative, *Marchantia polymorpha* – known to be a pioneer species in wildfire-affected areas – is preliminarily identified at Rydułtowy, Ruda Śląska (Szyb Andrzejka), and one of the “Chwałowice” mine heaps at Rybnik. Other potentially marker vegetation include *Petrorhagia saxifraga*, *Veronica arvensis* and *Caliergonella cuspidata* (Rydułtowy), *Centuria* (“Marta Waleska” dump at Łaziska Górne); *Puccinellia distans*, *Eragrostis minor* and *Atriplex* (Czerwionka-Leszczyny). The nitrophilous plants from “Szarłota” include *Solanum nigrum* and *Rubus*. Some of these species may represent garden fugitives.

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EVIDENCE OF PROTEROZOIC LIFE IN THE UKRAINIAN SHIELD

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Evidence of Precambrian life is scarce and obscure, comprising both direct evidence in the form of potential remnants of organisms and indirect geochemical indicators of life's presence. In the Ukrainian Shield, the oldest potential remains of ancient microbial organisms were discovered in metamorphosed Paleoproterozoic (ca. 2.1 Ga) sediments (Yatsenko et al., 2019). Another possible example is represented by unusual structures in ca. 2.1 Ga sandy sediments described as burrows produced by the first multicellular animals (A. Berezhovsky, personal communication). However, amphibolite-to-granulite-facies metamorphism that affected the entire Shield has made identification of biogenic remnants difficult.

Microbial mats represent the first well-preserved biogenic structures found in clay deposits of the Bilokorovychi basin, dated between 2.0 and 1.8 Ga. However, the Precambrian biota in the Ediacaran sediments of the Moldova-Podillya Basin is especially numerous and diverse, represented by casts, moulds, and imprints of soft-bodied organisms (e.g., Palij, 1976; Velikanov et al., 1983; Uchman and Martyshyn, 2019; Grytsenko, 2020; Francovschi et al., 2021). Besides these, numerous vendotaenids and other microfossils are also found (Gnilovskaya et al., 1988; Golubkova et al., 2021). A large variety of fossils allows direct correlation with other Ediacaran deposits worldwide.

Thick siliciclastic and chemogenic sedimentary successions of various ages, ranging from Mesoarchean to Neoproterozoic, enable the tracing of biogenic and environmental geochemical indicators and their linkage to changes in the tectonic environment. The location of the Ukrainian Shield in central Europe and its easy accessibility make it an ideal place for biogeodynamic studies.

MODELLING THE CO-EVOLUTION OF LIFE, CLIMATE AND LANDFORMS

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Life, climate, and landforms interact to shape the patterns of biodiversity we observe on the Earth's surface. Models serve as valuable tools for testing our understanding of how these complex systems form and function. While advances have been made in modelling these systems, the focus is typically on just one component—either the landscape, climate, or evolutionary processes. To gain a deeper understanding of how tectonic and climatic processes influence evolutionary patterns, there is a need to develop coupled numerical tools. In our contribution, we introduce our coupled eco-evolutionary and landscape evolution model called AdaScape. We will demonstrate the functionality of this model through two examples. The first example focuses on differentiating between tectonic and climatic histories of the central Andes and their influence on the timing of plant speciation. The second example examines how island morphology affects the levels of micro-endemism, using Madagascar as a case study. Finally, we will share our future perspectives on modelling the co-evolution of life, climate, and landforms.

CNN-BASED CLASSIFICATION OF NATIVE PLANT SPECIES FOR BIODIVERSITY APPLICATIONS

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Accurate identification of plant species is essential for biodiversity conservation, ecological monitoring, and educational purposes. In this study, we employed Convolutional Neural Networks (CNNs), a class of deep learning algorithms widely used in image recognition tasks, to classify native plant species. A publicly available dataset consisting of high-quality plant images was used for training and evaluation. The dataset includes visual representations of various species, offering a valuable resource for building image-based classification models.

We applied standard preprocessing steps such as resizing, normalization, and data augmentation to enhance the generalizability and performance of the CNN model. The architecture was designed to automatically learn spatial hierarchies of features from the input images, avoiding the need for manual feature extraction. The model was trained and validated using a stratified split of the dataset to ensure class balance.

Our results indicate that CNNs can effectively distinguish between different plant species based on their visual patterns, textures, and structural attributes. The trained model achieved satisfactory classification accuracy, demonstrating its potential to support semi-automated or fully automated plant identification systems in field applications. The use of deep learning in this context contributes to reducing the dependency on domain experts, especially in regions where botanical expertise is limited.

This study not only showcases the utility of CNNs in biodiversity-related image classification tasks but also supports their integration into user-friendly applications for educational tourism, citizen science, and conservation initiatives. Future work will focus on expanding the dataset and experimenting with more advanced CNN architectures to improve model robustness and scalability in real-world scenarios.

LIVING LAB ON REFORESTATION ON FOREST DISASTER AREAS

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The current extent of forest damage in South Westphalia, Germany, is dramatic. Regionally adapted reforestation strategies must be found, particularly for the large areas of pure spruce stands that have been destroyed by climate change-intensified drought events and pest infestation. These strategies aim to create a resilient, multifunctional forest of the future that combines ecological diversity and economic viability. Following a forestry industry that has been strongly focused on the timber industry in recent decades, innovative strategies for forest use should increasingly increase and economically evaluate all other added values, including the ecosystem services that are often provided free of charge. In this context, new business models and income opportunities for forest owners should also be identified. All people often benefit from healthy, diverse and attractive forests in very different ways, so that multifunctional forests should be considered when reforesting.

The project's living lab approach aims to develop regionally adapted, practical solutions on a landscape scale and resolve potential conflicts of objectives and use. Local stakeholders are actively involved in order to establish a joint research and demonstration infrastructure and achieve inter- and transdisciplinary networking.

The project "ReForm-regioWald" (in German: Resiliente Forst-/Offenlandsysteme für eine multifunktionale regional angepasste Wald-Bioökonomie; in English: Resilient forest/open land systems for a multifunctional, regionally adapted forest bioeconomy) is part of a set of projects on climate resilient forest and wood research, implementation, and networking actions.

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PLANT SILICON DRIVES PLANT COMMUNITY PROPERTIES AND ECOSYSTEM STRUCTURE

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Silicon (Si) concentration in plant tissues is considered a functional trait that can provide multiple morpho-physiological benefits to plants. However, it is still unclear whether and how these individual benefits extend to plant community processes and ecosystem functioning. We investigated how plant Si concentration is associated with plant community properties and the ecosystem structure of herbaceous communities in Israel. We sampled 15 sites across Mediterranean and desert ecosystems and built models to evaluate how plant silicon concentration is associated with variables such as species richness, biomass production, plant cover, and functional diversity. Sites with lower susceptibility to drought had significantly more Si-accumulating grass species and higher soil Si availability. Models with plant Si concentration instead of soil Si, always performed better, although those considering Si concentration variation had overall stronger associations with community properties than only mean Si concentration. For instance, up to 51% of plant Si concentration variation was explained by climate, biomass production, and species richness, combined. Still, mean plant Si concentration and plant cover combined explained up to 42% of plant functional diversity. Our results suggest that plant Si concentration serves as a proxy for understanding the ecological properties and functioning of arid and Mediterranean ecosystems. In light of various global change scenarios, enhancing our understanding of Si as a plant functional trait could help bridge existing knowledge gaps and improve ecological modelling, thus enabling more accurate forecasts of changes in plant distributions.

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VARIATION IN PLANT IONOMES ACROSS BIOCLIMATIC REGIONS AND FUNCTIONAL GROUPS

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Plant chemical composition is a trait gaining increasing importance in plant ecology. However, there is limited research on the patterns and drivers of its variation among different plant functional groups and bioclimatic regions. We conducted an analysis of ionomes utilising X-ray fluorescence on 83 plant species from four distinct functional groups (grasses, legumes, forbs and woody species); we marked plots across 15 sites located in both the desert and Mediterranean bioclimatic regions. The primary factors influencing variations in ionomes are predominantly attributed to bioclimatic factors rather than soil composition. Across all functional groups, plants from the Mediterranean region are characterised by greater association with calcium, whereas desert plants exhibit a higher affinity for strontium (Sr), suggesting its potential role in drought tolerance. Among functional groups, grasses uniquely exhibit distinct ionic features, primarily due to their higher silicon (Si) concentrations. Plant species' affinities for certain elements and their interactions are likely driven by physiological constraints, whereas variations within a functional group are mostly driven by environmental conditions. We conclude that interactions among elements form physiological phenotypes shaped by natural selection under large-scale environmental variability, making plant ionome composition an important plant functional trait.

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SESSION 4: GEOCHEMISTRY & NUTRIENTS CYCLE

INVITED TALK

SULPHUR CYCLING ON THE EARLY EARTH: INSIGHTS FROM ANCIENT SULPHATE AND SULPHIDE MINERALS

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Earth's geochemical cycles represent emergent phenomena that result from complex interactions between geological and biological processes, and exhibit dynamic persistence as their functionality persists through time while material components have changed [1]. Explaining the foundational processes in modern geochemical cycles thus requires insight into their evolutionary history, all the way back to the Archean eon (4.0 to 2.5 billion years ago) when major microbial metabolisms evolved. Here, I will explore what we have learned about the earliest sulphur cycle through the study of sulphate and sulphide minerals preserved in Palaeoarchean (3.6 to 3.2 billion years ago) greenstone belts of South Africa, Australia and India. I will highlight how rare occurrences of the mineral baryte (BaSO_4) have provided key evidence for photochemical reactions of volcanic sulphur dioxide in the anoxic Archean atmosphere, and discuss the roles of microbial sulphate reduction and sulphur disproportionation metabolisms in both local and global Palaeoarchean sulphur cycles. A compilation of sulphur isotope data from various Archean chemical and clastic sedimentary successions suggests locally elevated seawater sulphate levels in baryte-forming environments ("sulphate oases"), coupled to a stronger signature from microbial sulphate reduction. In contrast, baryte-free environments show isotopic signatures that are more consistent with sulphur disproportionation pathways, indicating major differences in local biogeochemical sulphur cycles as early as 3.2 billion years ago.

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THE ROLE OF EPICONTINENTAL SEAS IN GLOBAL NUTRIENT CYCLES

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Shallow marine and marginal marine sediments are biogeochemical reactors, where redox sensitive reactions occur in short diffusive contact with the overlying ocean. Given the magnitude of the fluxes and the proximity to the overlying water column, these chemical reactions have a disproportionate impact on global biogeochemical cycles. Tectonic changes that drive changes in bathymetry and the distribution of shallow epicontinental seas can vastly expand the regions that are covered in these biogeochemical 'hot zones'. In this talk I'll explore the changes in the distribution of shallow epicontinental seas over the last 70 million years and discuss the impact that these have had on the global sulfur, nitrogen and iron cycles. The marine biogeochemical sulfur cycle shifted dramatically around 50 million years ago, which has been argued to coincide with a change in the distribution of shallow seas and a change in the locus of pyrite burial, which is the dominant sink for sulfur in the ocean. I will discuss data that shows how different depositional environments impact the sulfur isotopic composition of pyrite and posit how this may have changed over the last 70 million years, driven by tectonic reorganisation shallow environments. These same tectonic drivers shifted the location of denitrification, which resulted in changes to the global nitrogen cycle; the coupled measurement of nitrogen and sulfur isotope ratios may help track the changes driven by tectonic reorganisation of shallow burial environments. Finally I will speculate about the impact this would have on iron recycling and iron delivery to the ocean, which is a key limiting nutrient for primary productivity. Taken together it is clear that there remains much to learn about the role of tectonic drivers in modulating shallow biogeochemical cycling of key nutrients and the impact on their global biogeochemical cycles.

THE EVIDENCES OF DEEP MELTING PROCESSES IN XENOLITH BEARING MAFIC ROCKS IN SOUTHERN THRACE REGION, TÜRKİYE: THE NEW INSIGHTS FOR PERIDOTITE AND THE PYROXENITE SOURCE MELTING

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Xenolith bearing mafic rocks with late Miocene age are widely distributed in southern Thrace region. Primitive mantle - normalised multi-element diagrams of these mafic rocks display OIB signature and specific incompatible element ratios such as Nb/La (1.65-2.05) Nb/U (37.81 -48.74), Zr/Ba (0.45-0.72) further indicate that mafic rocks were originated from the OIB-like component, besides, xenoliths (0.1191-0.1379) and the host rocks (0.1279-0.1439) have the similar ¹⁸⁷Os/¹⁸⁸Os isotopic compositions.

Geothermobarometric analyses of clinopyroxenes (Putirka, 2008) from host basalts express that the melting source resides at an estimated depth of around 85 km. These depth calculations and the melting from deep or shallow mantle sources provide significant support to the mantle dynamics and also interior evolution of the earth. The volcanic activity causes emissions of mantle-related gases to the atmosphere. The cycling of volatiles such as water and CO₂ between the mantle and the surface is a critical aspect of biogeodynamics, based on the development of hydrothermal systems, which are essential for mineral deposits and the distribution of economically important elements.

High Nb/U, Gd/Yb ratios, Re-Os isotopic compositions, and the REE-based melting model, starting from the primitive xenoliths (from study region) and pyroxenite source (Van Nostrand, 2015) reveal that single source melting is not capable of producing the mafic lavas, instead, these rocks appear to be originated from the melting of the deeper part of the mantle, likely involving the contributions from both of the sources, rather than shallow asthenosphere.

Extensive magmatic activity leads to significant consequences, melting from the two distinct mantle sources produce different heat flow, help us to understand temperature changes that effects the different species by different ways. Further, O isotope studies provide invaluable insights into biogeodynamics process.

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SESSION 5: ULTRA-LONG-TERM HABITABILITY & HUMAN SOCIETY

INVITED TALK

SUPER-EARTHS AND SUB-NEPTUNES, STRANGE BUT HABITABLE?

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Over the past decades, planet characterization has become a central pursuit in exoplanetary science. The growing catalog of exoplanets reveals a striking diversity in sizes and mean densities, with planets with radii in between Earth and Neptune emerging as the most common types—despite lacking analogs in our Solar System. The interior structures and formation histories of these super-Earths and sub-Neptunes and thus their potential to be habitable worlds remain debated. While the observed lack of planets with radii around 2 Earth radius suggests that sub-Neptunes retain thick H/He envelopes above rocky interiors, while super-Earths are their stripped counterparts, alternative formation scenarios propose distinct origins for these two types of planets inside and outside the water snowline.

However, recent evidence suggests that sub-Neptunes are surprisingly water-poor, even when formed beyond the snowline, challenging the classical formation models. This shifts the focus toward understanding the chemical and thermal evolution of their atmosphere. In this context, global chemical equilibrium models have emerged as powerful tools to interpret observed atmospheric compositions and connect them to formation histories and bulk composition of these planets.

I will present our evolving understanding of super-Earths and sub-Neptunes, emphasizing a new generation of coupled interior–atmosphere models that account for compositional and chemical interactions. These models are essential for interpreting atmospheric observations, understanding the formation environments, and the habitability of super-Earths and sub-Neptunes.

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ARE “EARTH-LIKE HABITATS” COMMON?

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Astrophysical and geophysical factors necessary for the evolution of terrestrial planets with N₂-O₂-dominated atmospheres, so-called Earth-like Habitats (EH), will be discussed. The basic requirements of planetary environments where aerobic organisms can grow and survive include atmospheric limitations of millimeter-to-meter-sized biological complex animal life-forms based on physical limits and O₂, N₂, and CO₂ toxicity values. It will be shown that the life-time of the protoplanetary disk and accretion processes of the growing protoplanets set the initial parameter stages for terrestrial planets, including the further evolution to hypothetical EHs. Important factors like a planet's thermal evolution, the right tectonic regime, and the fraction of ocean-landmass necessary for aerobic lifeforms will also be addressed. One can expect that many terrestrial planets inside the habitable zone for complex life will have internal heat budgets and tectonic regimes that are not ideal for plate tectonics. Nitrogen is a necessary element in the building blocks of life; therefore, a long working geobiological N₂-cycle and a functioning C-cycle are fundamental factors in the long-term evolution of EHs and hence aerobic complex lifeforms. A recently derived formula that includes the main relevant processes and parameters of EHs will be presented so that one can estimate the expected maximum number of EHs in the galaxy. Future observations of the atmospheres of terrestrial exoplanets with space observatories such as LIFE or HWO can then be used to further constrain the obtained values.

WATER-INDUCED BUOYANCY IN THE MANTLE TRANSITION ZONE STABILISES SURFACE OCEAN MASS ON ROCKY (EXO)PLANETS

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The spinel phase (wadsleyite, ringwoodite) in the mantle transition zone (MTZ) of rocky (exo)planets, can contain up to 1–2 wt% of water. However, whether these water reservoirs in the MTZ are filled is debated and, as the result, water content in the MTZ of rocky exoplanets remain uncertain. We test water stability in the MTZ numerically by using newly developed thermodynamic model of hydrous MTZ melting combined with 2D numerical hydro-thermomechanical-chemical geodynamic MTZ models with phase transitions and hydrous melt formation and percolation in the mantle. Numerical models predict that water-induced buoyancy of hydrated MTZ regions triggers development of hydrous plumes containing both solid and partially molten domains. On time scales of some tens million years, these plumes rise to and interact with olivine-spinel transition. Positive Clapeyron slope of this transition causes cold plume upwellings to slow down until their temperature rises enough to cross the transition. Depending on the water content and temperature of plumes, this crossing may trigger water release from the spinel phase as a porous fluid, which rapidly rises upward in form of either hydrous diapirs or porosity waves. We conclude that, due to the intrinsic positive buoyancy of hydrated mantle compared to dry rocks, mantle transition zone of rocky planets operates as a transient water reservoir. Relatively small amount of water (<0.2 wt%) should be therefore characteristic for the MTZ of rocky exoplanets, which may play a key role in stabilizing surface ocean level. At appropriate planetary water fraction, this stability can enable long-term coexistence of surface ocean with extensive dry land area, which, in addition to plate tectonics, is one of the key requirements for ultra-long-term habitability and development of intelligent technological life forms on rocky (exo)planets (Stern and Gerya, 2024, Scientific Reports, 14, 8552).