Core-to-Core Symposium

"IODP Legacy Cores" as archives of warm periods in the geological past

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Core-to-Core Symposium

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21st Century Drilling Project - Building capacity in the digital domain using scientific ocean drilling legacy material

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The International Ocean Discovery Program (IODP) and its predecessors has provided the international scientific ocean drilling community with a wealth of legacy archives, are stored in three IODP core repositories and several databases. Greater utilisation of legacy archives is anticipated during the International Ocean Drilling Programme (IODP[3]), especially as it now easier to generate digital cores to use as a primary data (e.g., with Code for Ocean Drilling Data, or CODD; Wilkens et al., 2017). There is significant scope for integrating these “virtual cores” with data derived from re-analysis of physical legacy core stored in IODP[3]s core repositories. This integration offers a future pathway to increase capacity and utilisation of legacy material.

The 21st Century Drilling Project aimed to test best practices for the re-analysis and integration of physical and digital IODP/ODP/DSDP legacy material through four global workshops hosted at all three core repositories. These workshops aimed to test best practices for training of early career scientists in hands-on core analysis and address the scientific objectives to trace changes in ice-rafted debris (IRD) and biological responses to shifting Antarctic fronts in the Southern Ocean due to Miocene ice volume variability. To achieve this, the four linked workshops targeted five sites spread across the Indian, Atlantic and Pacific Ocean sectors of the Southern Ocean.

The first workshop was hosted as part of J-DESC’s RECORD ReC23-01 at the Kochi Core Centre (Japan) in August 2023, and investigated DSDP Site 266 (Indian

Sector). Two ECORD MagellanPlus 21st Century Drilling Workshops were held at the Bremen Core Repository (Germany) in April and November 2024, investigating respectively ODP Site 704 and ODP Sites 1090 and 1092 (Atlantic Sector). The final USSSP 21st Century Drilling workshop was held in February 2025 at the Gulf Coast Repository (USA), investigating ODP Sites 1095 and 1096 (Pacific Sector). The target sites were carefully chosen to address the scientific objectives while ensuring coverage of sites across IODP's history. This range meant we could identify potential differences in the analytical requirements of legacy material depending on the cores' age.

During the four workshops, we brought together 68 early career-to-experienced researchers from a wide range of IODP and non-IODP countries. Though linked by common goals, each workshop had its own specific focus and developed a path tailored toward participant needs and site-specific requirements. By conducting the workshops sequentially, we could evaluate and adapt our approaches as needed. Here, we will illustrate initial highlights of best practice approaches for investigating digital and physical legacy material to provide powerful research and training opportunities for the next generation researchers engaged with the international scientific ocean drilling community.

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The Japan Sea paleoceanography and paleoclimatology during the Miocene (ReC23-03) and plan for Kochi Core Scool 2026

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In the ReC23-03 “The Japan Sea paleoceanography and paleoclimatology during the Miocene”, we focuse on understanding the short-time scale oceanic environmental changes in the warmer-than-present condition. We are especially focusing on; 1) centennial to millennial scale oceanographic changes recorded in laminated sediments, 2) rapid warming event (~10.8Ma; Tortonian Thermal Maximum [1]) and subsequent changes in oceanographic condition.

To understand the past oceanographic changes and their mechanisms properly, we utlized the Miocene Japan Sea sediments recovered from five sites, Sites 794, 795, 797 (drilled by ODP Leg 127 in 1989 [2]) and Sites U1425 and U1430 (drilled by IODP Exp. 346 in 2013 [3]), which makes depth trancects.

The non-destructive analyses and sampling party of ReC23-03 were conducted in 2024, and analyses based on 20 sample requests are still ongoing. Members regularly exchange updates of their results, and ReC23-03 workshop will be held in this March. We are also working on revising existing age models and improving inter-site correlations.

Together with cores used in ReC23-01, cores used in ReC23-03 will be utilized at the Kochi Core School 2026 in November. We will present some of potential target intervals (laminated sediments, seliceous-calcareous boundary, and orbital-scale chages) for Kochi Core Scool 2026. We aim to identify paleoclimatic features common to both ReC23-01 and ReC23-03.

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Long-term Miocene climate signals from bulk carbonate isotopes at DSDP Site 266

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Deep Sea Drilling Project (DSDP) Site 266 (56°24.13′S, 110°6.70′E; 4,173 m water depth), located on the southern flank of the Southeast Indian Ridge, provides an important archive of Southern Ocean paleoceanographic change. To refine oxygen isotope stratigraphy and reconstruct long-term environmental evolution, we analyzed bulk carbonate $\delta^{13}C$ and $\delta^{18}O$ together with calcium carbonate ($CaCO_3$) content from sediment samples collected throughout Hole 266 during the ReC23-1 sampling party in 2023.

Carbonate content is nearly absent above ~150 mbsf but reaches up to 90% below this depth, indicating a major lithological transition from carbonate-dominated sediments in the early–middle Miocene to diatom-rich sediments in the upper interval. Bulk carbonate $\delta^{18}O$ values range from ~0.5‰ to 2‰, with heavier excursions exceeding 3‰. Between ~200 and 245 mbsf, $\delta^{18}O$ values are generally lighter, followed by a progressive increase toward 150 mbsf, suggesting a long-term cooling trend from ~180 to 150 mbsf.

Bulk $\delta^{13}C$ records display a broad positive excursion between ~200 and 260 mbsf. This interval likely reflects enhanced carbon burial and/or changes in deep-water ventilation under relatively warm climatic conditions. Pending refinement of shipboard biostratigraphy, this positive $\delta^{13}C$ excursion may correspond to the middle Miocene Monterey carbon isotope excursion. These results provide new constraints on Miocene carbon-cycle dynamics and paleoceanographic evolution in the southern Indian Ocean.

Middle to Late Miocene paleoceanographic evolution of the southern Indian Ocean (ODP Site 752) inferred from nannofossil assemblages and carbon isotopes

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The Middle to Late Miocene constitutes a critical time interval on a global scale. Due to a global continental reorganization, a near-modern monsoonal wind system was established in the Indian Ocean (IO). This period is further characterized by a series of climatic successions, linked to the Middle Miocene Climatic Transition (MMCT), and a northward displacement of the Westerlies region during the Late Miocene. However, the role of this processes over surface ocean dynamics in the southern IO remains poorly understood. Here, we investigated Ocean Drilling Program (ODP) Site 752, located on the west flank of Broken Ridge (30° 53.475ˈS/93° 34.652ˈE), which represents a key location to investigate the interaction between the abovementioned processes and the surface ocean in the eastern sector of the southern IO across the Middle to Late Miocene.

Our nannofossil data revealed that the period comprehened between 7.31 – 16.06 Ma was characterized by five assemblages (Cluster 1-5) and two sub-assemblages (Cluster 5a-5b). Sea surface conditions were inferred based on the main nannofossil assemblage constituting each cluster. Subsequently, the paleobiological data were compared with a set of global/regional climatic and geochemical data to better understand the main factors controlling the surface ocean dynamics at ODP Site 752 during the Middle to Late Miocene.

Additionally to the paleobiological data, carbon speciation (total organic carbon and total inorganic carbon) and isotopic analyses (on bulk organic and benthic foraminifera) were performed at Site 752. This allows to track variations in ocean productivity and changes in the nutrient cycle and their relation to the changes observed in the nannofossil assemblage across the Middle to Late Miocene.

Our results indicate, that during the Middle Miocene the surface southern IO was characterized by low-nutrient and high surface temperature conditions. After the MMCT, and concomitantly with a global decrease in $\delta^{18}O$, the surface ocean underwent a change towards a more nutrient-rich and lower temperature system. Specifically, maximum nutrient conditions were recorded at ~9.9 Ma, coeval with the establishment of the Late Miocene Cooling. Furthermore, the comparison between our paleobiological data and eNd records available for Site 752 indicated that a shift towards lower surface nutrient conditions occurred between ~10.7 – 9.9 Ma, as result of the enhanced Pacific Ocean waters influx into the southern IO realm. Additionally, the comparison of the assemblage data against $\delta^{13}C$, TOC, and TIC measured at ODP Site 752 allowed to disentangle the local processes driving changes in the IO surface water conditions.

Miocene marine Os isotope variations in Indian Ocean

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We reconstructed osmium isotope ratios ($^{187}Os/^{188}Os$) of Indian Ocean seawater over the past 20 million years using sediment cores recovered from Sites 752A and 707A. Our new dataset clearly captures a gradual increase in the $^{187}Os/^{188}Os$ ratio from 0.72 at ~15 Ma (middle Miocene) to 1.02 at 0.3 Ma (late Pleistocene). The gradual increase has been widely recognize at sites worldwide, suggesting that Indian Ocean sediments faithfully preserve seawater Os isotopic signals.

A transient decrease in Os isotopic composition (to 0.69) around 17 Ma was also observed, corresponding to the well-known mid-Miocene Os isotope minimum identified in the Pacific[1], which is likely linked to the eruption and emplacement of the Columbia River Flood Basalt, one of the youngest large igneous provinces on Earth. Compared with Pacific records, the Os isotopic values at Site 752A are slightly lower but exhibit a parallel long-term trend, suggesting basin-scale differences in seawater Os composition. This offset may reflect hydrographic factors such as variations in ocean circulation and water-mass exchange between the Indian and Pacific Oceans.

As the spatial and temporal coverage of marine Os isotope records expands, these data are expected to provide a robust global chemostratigraphic framework comparable to that based on Sr isotopes. Because the residence time of Os in the ocean has been estimated at 10-50 kyr, much shorter than that of Sr, regional Os isotope variations may preserve valuable information about past ocean connectivity and basin restriction.

In summary, the Os isotopic record of Indian Ocean sediments broadly reflects secular variations in the global seawater Os isotopic composition, serving as a useful chemostratigraphic proxy, while detailed interbasinal comparisons are likely to capture information on ocean connectivity and circulation.

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Turn over of the oceanographic and environmental conditions of Baffin Bay with the Oligocene-Miocene transition: results from IODP Expedition 400, U1607 site

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IODP Site U1607, drilled at 739 m water depth on the northwestern Greenland shelf, recovered 978 m of predominantly fine terrigenous sediments containing abundant and well-preserved aragonitic bivalves. These shells constitute an exceptional archive for reconstructing past environmental and oceanographic conditions in Baffin Bay. Strontium isotope stratigraphy performed on the bivalves indicates an age range spanning the Late Oligocene to Late Miocene. This interval encompasses several major global climatic transitions, including the cooling associated with the Oligocene– Miocene boundary and the Mid-Miocene climatic optimum. Its high-latitude location makes it particularly valuable for understanding regional responses to global climate change.

This study presents stable oxygen and carbon isotope compositions together with elemental ratios measured in bivalve shells from Site U1607 to reconstruct climatic variability in Baffin Bay. In addition, neodymium (Nd) isotope analyses were performed on the same samples to investigate changes in ocean circulation associated with these environmental shifts.

The $\delta^{18}O$ record displays a general downcore decrease consistent with an estimated paleotemperature increase of approximately 6 °C between the Late Oligocene and Late Miocene. Variations in Ba/Ca ratios, used here as a proxy for nutrient availability, broadly parallel the $\delta^{18}O$ trend and indicate relatively nutrient-rich conditions during the Late Oligocene followed by progressive nutrient depletion through the Miocene. These geochemical signals suggest coupled changes in temperature and productivity in Baffin Bay during this interval. Preliminary Nd isotope results provide additional constraints on water-mass sourcing and circulation patterns. The εNd values point to mixing between at least two distinct sources, one of which is most consistent with North Atlantic waters and appears to dominate during the Late Oligocene. This influence decreases through the Miocene, resulting in progressively less radiogenic εNd signatures.

Taken together, these geochemical records provide a comprehensive reconstruction of Oligocene–Miocene oceanographic and environmental evolution in Baffin Bay. They offer new insights into the sensitivity of high-latitude marine systems to global climatic forcing and contribute to a better understanding of Arctic–North Atlantic interactions during a key transitional interval in Earth's climate history.

Biomarker Preservation and Paleoclimate from Late Neogene Marine Sediments from DSDP Site 467 offshore Los Angeles

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The Neogene encompasses warm periods of Earth's History that provide analogues for future warming. In southwestern North America, concerns regarding future warming are compounded by uncertainty about whether the current drying trend will continue. Today, the cool California current and upwelling results in sea surface temperatures (SST) of ~14˚C while past warmer states might have fed convection and increased rainfall. With the goal of resontructing hydrocliamte and vegetation history of SW North America, we revisit Deep Sea Drilling Project Site 467, outside the Santa Barbara Basin (33°50.97'N, 120°45.47'W, 2,127.8 m water depth), drilled in 1978 in the early days of DSDP. We identify and quantify marine and terrestrial biomarkers in 108 samples spanning 16.7 to 3.6 Ma. We identified the loss of preservation of alkenones below 413 mbsf (5.0 Ma) and loss of glycerol dialkyl glycerol tetraethers (GDGTs) below 587 mbsf (7.9 Ma). The alkane fraction includes an uncharacterized complex mixture, indicating maturation and biodegradation. In contrast n-alkanoic acids were abundant throughout the profile, suggesting post-deposition production. Although preservation curtails the record, GDGTs indicate cooling from 23 to 17°C from 8.2 to 3.6 Ma consistent with regional alkenone reconstructions. In this core, alkenones are only preserved in the Pliocene and yield estimates around 25°C that appear warm-biased, suggesting preferential loss of $C_{37:3}$. The loss of biomarkers can potentially be atributed to the changing Oxygen Minimum Zone offshore shouthern California, which contracts/expands according to changes in the strength of upwelling driven by the notherly winds blowing along the coast. The uncharacterized complex mixture in the *n*-alkanes fraction and dominant C_{16} and C_{18} *n*-alkanoic acids may indicate migrated oil from the Monterey Formation, which is later biodegraded in situ, through the porous unconsolidated Miocene carbonates due to the site's proximity to the Monterey Formation. Elsewhere reports of reduced organic carbon burial in the middle Miocene presents a challenge for efforts to use organic biomarkers to reconstruct this relatively recent warm climate analogue. The potential underreporting of null results from biomarker studies leads to duplicate efforts to extract the same sediments in multiple biomarker laboratories, which we seek to avoid by being clear about the recoveries and implications in DSDP Site 467. Shore-based expeditions utilizing legacy core materials should focus on the cores‘ recovery, sites‘ oceanographic settings, and depositional settings to ensure ideal outcomes, especially for those participants who use proxies that are prone to degradation or loss.

Global changes in the test size of Oligocene planktic foraminifera *Paragloborotalia opima*

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Oligocene planktic foraminifera is characterized by low diversity, hampering detailed understanding of the paleoceanography. The extinction of *Paragloborotalia opima* at 26.9 Ma is an important Oligocene biohorizon [1], and the species is differentiated from an ancestral species *Paragloborotalia nana* only by test size (larger *P. opima* and smaller *P. nana*). Previous study at Integrated Ocean Drilling Program (IODP) Site U1334 in the eastern equatorial Pacific revealed that the maximum test size of *P. opima-nana* plexus increased from 0.44 mm (~30.8 Ma) to 0.68 mm (~27.2 Ma) [2], which coincided with the increased abundance of the species [3]. However, changes in the species' test size outside of the equatorial Pacific have not been studied well and the relationship between the test size and the abundance have not been clearly understood.

In this study, several deep-sea sediments were selected to derive test size variations in *P. opima-nana* plexus: Deep Sea Drilling Project (DSDP) Site 317B (33.4–22.7 Ma) in the South Pacific, Ocean Drilling Program (ODP) Site 707A (28.2–26.5 Ma) in the Indian Ocean, and IODP Site U1406 (30.4–26.0 Ma with hiatus between 27.7 Ma and 26.6 Ma) in the North Atlantic. At DSDP Site 317B, maximum size of *P. opima-nana* plexus increased from 0.25 mm (~30.7 Ma) to 0.47 mm (~27.5 Ma), which is consistent with the increasing trend at IODP Site U1334. In turn, maximum size ranged from 0.24 mm (~27.4 Ma) to 0.37 mm (~28.0 Ma) at ODP Site 707A in the Indian Ocean, which did not show size increase observed in the Pacific Ocean (DSDP Site 317B and IODP Site U1334). Similarly, maximum size ranged from 0.23 mm (~28.7 Ma) to 0.35 mm (~28.2 Ma) at IODP Site U1406 in the North Atlantic. Therefore, IODP Site U1334 in the equatorial Pacific recorded by far the largest population of *P. opima-nana* plexus, supporting that productivity is a major constraint on the species' test size [2]. In addition, this study highlights potentially different trends of the species' test size between the Pacific, Indian, and Atlantic Oceans. In the presentation, the relationship between the test size and the abundance will also be discussed.

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Antarctic Atmospheric–Ocean–Ice Sheet reorganization during the Middle Miocene Climate Transition

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While the broad features of the Middle Miocene Climate Transition (MMCT) are well documented (*1*), the detailed oceanographic evolution of southern high-latitude regions remains poorly constrained, particularly regarding the timing of Subantarctic Mode Water (SAMW) formation. SAMW forms through deep winter convection, driven by intensified winds and strong winter cooling in the Subantarctic Zone between the Subtropical Front (STF) and Subantarctic Front (SAF) of the Southern Ocean. Its formation is crucial because enhanced SAMW ventilation links the high and low latitudes and contributes to the renewal of global thermocline waters. Furthermore, the establishment of SAMW ventilation would have strengthened the thermal isolation of Antarctica and likely served as a key driver of global cooling and the carbon cycle during the MMCT. Reconstructing the evolution of SAMW therefore provides essential constraints on both the timing and the mechanisms through which interactions among the cryosphere, atmosphere, and ocean generated feedbacks in the global carbon cycle. However, most previous studies have relied on deeper marine sediment cores (> 1300 m water depth), which provide limited insight into intermediate-water ventilation and therefore cannot resolve the evolution of SAMW.

In this study, we present new neodymium isotope (ε_{Nd}) and foraminiferal geochemical records from ODP Site 1120 (~550 m water depth) on the Campbell Plateau, southwest Pacific (*2*). The data reveal an abrupt reorganization of the upper-ocean ventilation at ~14.2 Ma, shifting from a stratified, subtropical water-dominated state to a mode characterized by vigorous, wind-driven SAMW formation. This reorganization was tightly coupled to the expansion of the Antarctic Ice Sheet (AIS) and the intensification of Southern Ocean winds. The 14.2 Ma onset of Antarctic ice–ocean–atmospherere reorganization would promoted atmospheric CO_2 drawdown and strengthened Antarctica's thermal isolation, driving a key positive feedback that amplified AIS regrowth and global cooling.

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Dust sources to the Arabian Sea and their record of continental hydroclimate

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Mineral dust plays and important role in Earth's climate as it affects radiation budget, regional hydroclimate and provides nutrients to the Arabian Sea and further afield. Dust accumulating in deep sea sediment has the potential to provide long uninterrupted records of past changes in hydroclimate. However, to read these records properly it is important to be able to trace these dust deposits to their origin. Dust records from the Arabian Sea have long been used to reconstruct past changes in continental hydroclimate. However, this ocean basin is encircled by many arid and dust-producing regions and its dust record has been variously attributed to East Africa, the Arabian Peninsula, Mesopotamia and further east into southwest Asia. We use geochemical methods (Sr and Nd isotopes) to fingerprint major dust producing regions on the Arabian Peninsula and southwest Asia and distinguish them from those of Africa. Furthermore, we employ high-resolution remote sensing observations over a four-year interval to map dust activation frequency in the Horn of Africa. We find that dust activity in this region is dominated by the Afar Triangle, showing that aridity and mean wind field alone are poor predictors of dust activation and that a supply of readily deflated sediments associated with ephemeral water bodies in endorheic basins is key. Lastly, we report the results of a dust-based palaeo study of hydroclimate change from the western Arabian Sea covering the middle Pliocene and late Quaternary.

Shelf Ecosystems Crossed a Tipping Point During the Early-Middle Pleistocene Transition: Climate Stories from Foraminifera in Legacy Cores

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The Early-Middle Pleistocene Transition (EMPT; ~1.25–0.6 Ma) represents a fundamental shift in Earth's climate system. This climatic reorganization is exemplified by an increased severity of the glacial phases and the transition from a 41,000-year glacial-interglacial alternation to a quasi-100,000-year one. The EMPT occurred without significant modifications in the orbital forcing, suggesting that internal Earth feedbacks played a crucial role.

A key episode during the EMPT is the so-called "900-ka event" (~940–866 ka), which coincides with the first prolonged glaciation of the Pleistocene and the establishment of the 100-kyr cyclicity. Traditionally considered as part of the natural climate variability, the ecological repercussions of this event in shallow marine areas are still poorly constrained.

In this study, we present new high-resolution evidence indicating that shortly after the 900-ka event, a major threshold for continental shelf ecosystems was crossed. The multi-proxy analysis of an expanded EMPT sedimentary sequence from IODP Site U1460 (southwestern Australian shelf) revealed a rapid ecological restructuring centered at 850 ka with lasting consequences. The study area is influenced by the interaction between the warm, oligotrophic Leeuwin Current and the cooler, oxygen-rich Leeuwin Undercurrent, both of which are modulated by the sea level–driven Sahul–Indian Ocean Bjerknes Mechanism.

This study tracked the complete trajectory of this newly discovered ecological reorganization (named LC850), from the pre-destabilization conditions, through the actual transition to a new equilibrium state, highlighting the speed at which an ecosystem´s restructuring can occur. As climate models increasingly account for tipping elements, our results also emphasize the importance of understanding past abrupt transitions, such as the LC850, in order to forecast potential future responses to the anthropogenic forcing.

From Weathering to Warm Oceans: The Silicon Cycle in IODP cores

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Understanding Earth's response to past warm climates is essential for constraining future climate trajectories. Marine sediment cores recovered through IODP and its legacy programmes provide unique archives to investigate the coupled evolution of ocean chemistry, biogeochemical cycling, and climate feedbacks during periods of elevated global temperatures. In particular, the silicon (Si) cycle links continental weathering, marine productivity, nutrient availability, and carbon cycling, thereby providing a powerful framework for interrogating warm-age Earth system dynamics.

This contribution synthesizes recent advances in silicon isotope ($\delta^{30}Si$) systematics across marine and terrestrial environments to highlight key mechanisms that can be investigated using IODP core material. Biogenic silica preserved in marine sediments - such as sponge spicules and diatomaceous opal - records variations in dissolved silica availability and nutrient utilization, offering insights into ocean circulation, productivity, and redox conditions during past warm intervals. At the same time, the fidelity of biogenic silica archives is strongly governed by post-depositional processes. Experimental and micro-analytical investigations of the diagenetic transformation from amorphous opal-A to opal-CT demonstrate that late diagenetic recrystallization can modify primary $\delta^{30}Si$ signals. Constraining these mechanisms is critical for robust proxy application in long sedimentary records.

Complementary laboratory experiments and modern analogue studies further elucidate silicon isotope fractionation during low-temperature silicate weathering and secondary mineral formation. The precipitation of amorphous hydroxyaluminosilicates and hydrous ferric silicates, key intermediates in reverse weathering reactions, regulates ocean alkalinity, atmospheric CO_2, and nutrient fluxes. Observations from alpine periglacial environments illustrate how climate-driven changes in weathering regimes are sensitively recorded in Si isotope signatures, providing process-level constraints relevant to marine sediment archives.

Together, these approaches demonstrate how IODP cores can be used to integrate oceanic, continental, and diagenetic processes, enabling a mechanistic understanding of the silicon cycle and its role in climate feedbacks during past warm worlds.

Learning from Legacy Data: Unlocking High-Resolution Climate Proxies with Foundation Models

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Decades of scientific drilling have produced a vast archive of marine and terrestrial cores, a “legacy” that holds untapped potential for understanding past warm periods. While High-resolution X-ray fluorescence (XRF) core scanning has become a standard for these archives, transforming this semi-quantitative data into robust quantitative paleoclimate proxies remains a challenge. Conventional calibration models are often site-specific and fail to generalize to new geological settings. This limits our ability to revisit and fully utilize legacy collections. To bridge this gap, we introduce MAX (Masked Autoencoder for XRF), a self-supervised foundation model trained on over 55,000 XRF spectra from diverse expeditions.

Unlike conventional models that often fail due to the heterogeneity of legacy materials, MAX pre-learns universal spectral characteristics, such as positions of atomic emission lines, from thousands of diverse sediments. This foundational knowledge differs from site-specific calibrations by allowing the model to interpret complex XRF spectra even with limited ground truth data. We demonstrate that MAX achieves high-accuracy proxy quantification (total organic carbon and $CaCO_3$) using only one-third of the calibration samples required in conventional methods, effectively unlocking high-resolution climate records from legacy cores where extensive resampling is restricted. By reducing the barriers to re-analyzing existing archives, foundation models like MAX offer a powerful pathway to extract new climate insights from the legacy of past drilling expeditions.

Furthermore, we present our initiative to compile a global database of over 234 legacy cores/sites. Its completion shall enhance MAX’s ability to generalize across more geological settings, machine series and applications. Meanwhile, its metadata offers a good opportunity to build AI agents for assisting researchers in extracting information from references for extensive legacy data collections.

Poster presentations

The role of Biostratigraphy in SciOD Legacy Expeditions

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Three 21st Century Drilling workshops were held in Bremen (BCR, April 2024 and Nov 2024) and College Station (GCR, Feb 2025). The BCR workshops were funded by Magellan Plus and run as mini Legacy Expeditions (MAG+01 and MAG+02) and the GCR workshop was structured as a teaching opportunity so participants could develop their own Legacy Expeditions in the future. These follow a pioneering workshop held in Kochi (RECORD 01-23). Legacy "expeditions" are held in repositories to 1) refine shipboard data (e.g., re-describe core; refine age models) and 2) add new datasets not available when drilled (eg., scanning XRF, SHMSL, SHIL).

Biostratigraphy is fundamental to determining the age of sediments. Astrochronology and other tuning methods are dependent on biostratigraphic (and magnetostratigraphic) datums provided shipboard and post-cruise to refine age estimates and create the high-resolution studies that characterize modern paleoceanography. With the shift to using primarily legacy material for deep ocean

paleoceanographic studies, we highlight some lessons learned and propose best practices for evaluation of older drill cores.

Sample collection, preparation, picking and species determination requires a lot of time and specialized training and experience. It is also conducted as a group effort since there is a lot of overlap between the fossil groups. We conducted BCR Workshops 1 and 2 as though they were shipboard experiences; samples were taken, washed, dried, split and analyzed in real time. BCR Workshop 1 was 5 days long and so it took until the second day before biostratigraphic analyses could really be conducted in earnest. BCR Workshop 2 was 8 days long. Although review of existing datums and updating of existing age models was conducted at the BCR, the teams continued to analyze samples at home to finalize the biostratigraphy, meeting regularly. .

Team BCR1 met up in Summer 2024 in London. They updated datums to GTS2020, determined additional foraminiferal datums based on coiling, and confirmed the likelihood of a mid-Miocene hiatus, although very slow sedimentation cannot be ruled out. Team BCR2 met regularly on zoom. Datums were updated to GTS2020. Nannofossils were improved for the Miocene at ODP Sites1090 and 1092. Foraminifera and nannofossils indicate Oligocene age at 1092. Magnetostratigraphy re-interpretation depends on a finalized XRF- based splice, another product of the workshops. The GCR Workshop was focused on preparing participants to plan a legacy expedition, which included a brief review of the basics of biostratigraphy and magnetostratigraphy and practice creating age models using datums.

Finalizing age models was challenging due to limited time and participants' other commitments. To overcome this, we recommend building in more dedicated working time by extending workshops and funding follow-up (post- expedition) meetings. An Expedition Project Manager would provide consistency and a logistics lead who could also manage publication plans. Decades of IODP experience show that post-cruise collaboration is key, and Legacy Expeditions should retain this structure for success.

Western Pacific Warm Pool perspective of prolonged El Niño-like conditions during the Late Miocene

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The Late Miocene is characterised by warmer-than-present conditions with temperatures comparable to those predicted for 2100. It is important to understand how equatorial Pacific climate systems such as the El Niño Southern Oscillation (ENSO) were impacted during interval of past global warmth, such as the Late Miocene. The presence of Late Miocene permanent El Niño-like conditions in the equatorial Pacific remains ambiguous, with several studies proposing either 1) a permanent Late Miocene El Niño-like state (e.g., Ravelo et al., 2014), 2) alternating El Niño-like (9.6-6.5 Ma) and La Niña-like (6.5-6.1 Ma) conditions (e.g., Nathan and Leckie, 2009; Drury et al., 2018), or 3) modern thermal gradients since ~12 Ma (e.g., Zhang et al., 2014). As modern ENSO causes significant precipitation and temperature anomalies around the globe, reconciling these disparate views of prolonged El Niño-like conditions during the Late Miocene is a key step towards understanding the potential global impacts of long-term warming in the equatorial Pacific.

Clarification of the status of permanent El Niño-like conditions in the Late Miocene was hindered by low-resolution data in the Western Pacific Warm Pool (WPWP), exacerbated by the scarcity of archives suitable for high-resolution work in the WPWP region. The recovery of International Ocean Discovery Program (IODP) Site U1488 during IODP Expedition 363 to the WPWP provided the key sedimentary sequences needed to resolve this issue. We generated high-resolution (2.5 kyr) mixed layer, thermocline and benthic foraminiferal stable oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotope stratigraphies to reconstruct the evolution of water column structure in the WPWP between ~10 and 6 Ma. We integrate our new WPWP records with high-resolution foraminiferal data from the eastern equatorial Pacific (Drury et al., 2018). Our initial findings provide insight into the extent of prolonged El Niño-like conditions during the Late Miocene, and how these conditions may have impacted heat transport and carbon cycling in the equatorial Pacific Ocean.

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Single-Chamber Mg/Ca Paleothermometry: Cleaning Procedures of Miocene Foraminifera Tests at ODP Site 752

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The Miocene Climatic Optimum (MCO) was a period of warmer global temperatures, approximately 3-4°C higher than today, accompanied by reduced sea ice volumes. Indian Ocean Sub-Antarctic Mode Water (SAMW), which forms primarily south of 30°S, serves as a significant return path for deep waters, migrating and mixing northward at Intermediate Water (IW) depths. The SAMW is a key pathway for nutrient transport to lower latitudes, but in warmer climates with reduced sea ice, increased nutrient trapping in the Southern Ocean can decrease this nutrient flux. To investigate these dynamics, we focus on ODP Site 752, located in the southeastern Indian Ocean (IO) at a modern water depth of 1086.3 m on Broken Ridge, as a key site for understanding changes in IW conditions during the Middle to Late Miocene (15-8 Ma).

In this study, we use benthic and planktonic foraminifera to reconstruct temperature variability through the water column and investigate influxes from cooler water masses associated with increased SAMW intensity. Miocene foraminifera served as a test case for single-chamber Mg/Ca paleothermometry, with Laser Ablation–Inductively Coupled Plasma–Mass Spectrometry (LA-ICP-MS) analyses carried out at the NAWI Graz Geocenter to establish a cleaning protocol. Since no standardized cleaning procedure currently exists for Miocene samples from the IO, various cleaning steps were tested based on the protocol of Petersen et al. (2018)[1]. For this study, we used different trace element-to-calcium (TE/Ca) ratios, such as Al/Ca, Mg/Ca and Mn/Ca, to develop a functional cleaning protocol. Specifically, we used tests from *Cibicidoides mundulus* and *Cibicidoides wuellerstorfi* as representative for bottom-water species, and *Globorotalia menardii* as representative of thermocline species.

We present a cleaning protocol for single-chamber Mg/Ca analysis using Miocene foraminifera from ODP Site 752 and evaluate the effects of varying the number of methanol steps within the protocol on foraminiferal tests. Additionally, we observed a shift in the Mg/Ca ratios of *G. menardii* tests toward more negative values when not ablating through the entire thickness of the test wall, corresponding to a temperature shift of up to 15°C. In contrast, this shift has not been observed in benthic foraminifera.

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Seismic reflection profiles for inferring the past change of bottom currents: a case study of Shatsky Rise

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Understanding the long-term evolution of deep-ocean circulation is fundamental to reconstructing Earth's climate system. Conventional paleoceanographic reconstructions rely largely on geochemical and micropaleontological analyses of drill cores, which provide high-resolution temporal records but limited spatial coverage and only indirect constraints on current pathways and strength. Seismic reflection profiling offers a complementary perspective by imaging sedimentary architecture continuously across basin scales, enabling direct assessment of depositional patterns shaped by bottom currents.

Bottom currents modify deep-sea sedimentation through erosion, lateral transport, and selective deposition, producing characteristic features such as thickness gradients, contourite accumulations, sediment waves, and unconformities. The geometry and internal reflector organization of these deposits record variations in current intensity and sediment supply over geological timescales.

Here we apply this framework to high-resolution multichannel seismic (MCS) data acquired in April 2024 across the southwestern flank of Tamu Massif (Southern High), Shatsky Rise, in the northwestern Pacific Ocean, extending onto the adjacent abyssal plain. This large igneous province hosts a ~150-Myr sedimentary succession. Seismic depth-migrated images reveal systematic lateral variations in sediment thickness, regionally traceable unconformities, and reflector reorganization indicative of alternating phases of bottom-current intensification and weak-current pelagic accumulation. Integration with ODP Leg 198 Sites 1213 and 1214 provides chronostratigraphic control, allowing stratigraphic changes to be placed within a basin-scale paleoceanographic context.

These results demonstrate how seismic stratigraphy can extend bottom-current reconstructions beyond point-core observations and provide new spatial constraints on the evolution of deep Pacific circulation over Cretaceous–Cenozoic timescales.

Geochemical signatures of the Chicxulub impact and Deccan Trap volcanism in Indian Ocean IODP Cores

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The end of the Cretaceous is characterized by two major events in Earth history. The first is the asteroid impact that occurred ~66 Ma at Chicxulub in Mexico, which defines the Cretaceous-Paleogene (K-Pg) boundary [1]. The second is the Deccan Trap flood basalt volcanism in the Indian subcontinent, which occurred ~1 million years across the K-Pg boundary [2]. A high abundance of platinum group elements (PGEs), such as Osmium (Os), Iridium (Ir) and Ruthenium (Ru), has been identified in K-Pg boundary clay layers worldwide [1,3]. A decrease in the osmium isotope ratio ($^{187}Os/^{188}Os$) in marine sediments is regarded as one of the most reliable geochemical signatures of these events and has been widely used for stratigraphic correlation of the K-Pg boundary [4]. However, long-term $^{187}Os/^{188}Os$ records across the K-Pg boundary are currently limited to the North Pacific, the South Atlantic, and the Gubbio section in Italy [5], leaving a significant geographic gap.

Here, we present high-temporal resolution data of PGE concentrations and $^{187}Os/^{188}Os$ ratios in two marine sediment cores from the Indian Ocean. The first core was obtained from the International Ocean Discovery Program (IODP) Hole U1514C in the Mentelle Basin off southwest Australia (33°7.24'S, 113°5.48'E). At the biostratigraphic K-Pg boundary, we identified a pronounced PGE concentration peak, a CI chondrite-like PGE composition, and a clear decrease in the $^{187}Os/^{188}Os$ ratio. These features indicate a stratigraphically complete K-Pg boundary that preserves the geochemical evidence for the Chicxulub impact. The second core was obtained from the Ocean Drilling Program (ODP) Hole 761B in the Wombat Plateau off northwest Australia (16°44.23'S, 115°32.10'E). At the biostratigraphic K-Pg boundary, increases in Ir and Ru concentrations and a decrease in the $^{187}Os/^{188}Os$ ratio were observed. However, based on biostratigraphic constraints and correlation with Hole 761C, the K-Pg boundary interval in Hole B appears to be incomplete. On the other hand, the $^{187}Os/^{188}Os$ ratio variations in the Maastrichtian interval are consistent with those reported from the Pacific and Atlantic Oceans [5]. In particular, a marked decrease in the $^{187}Os/^{188}Os$ ratio at ~66.3 Ma coincides with the timing of major eruptive phases of the Deccan Traps [6]. This study highlights the scientific value of IODP core archives and provides a foundation for future researches on the end of the Cretaceous in the Indian Ocean region.

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Reconstructions and inter-hemispheric comparison of monsoonal activity (in a deglacial context)

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Monsoonal activity and precipitation patterns in southeast Asia and northwestern Australia are driven by thermal gradients between the ocean and the continents, and the position of the Intertropical Convergence Zone (ITCZ). A micropaleontological assessment of sea surface temperature (SST), upwelling, (export) productivity and bottom water oxygenation (BWO) allows the inter-hemispheric reconstruction of monsoonal activity. During the most recent deglaciation from the last glacial maximum to the Holocene (Termination 1), and specifically the Younger Dryas (YD; 13-11 ka PB) as well as Heinrich Stadial 1 (HS1; ~19-15 ka BP), important global changes, and inter-hemispheric see-saws in monsoonal activity have been postulated from a multitude of Quaternary proxy-records [1]. For this proposed project we intend to sample species of benthic and planktonic foraminifera from surface sediments and sediment cores for proxy calibration and inter-hemispheric reconstructions for the YD and HS1. Two key study areas have been identified for this purpose from existing proxy data: 1) In the northern South China Sea (SCS; ODP 1146) changes in upwelling related to the southeast Asian summer monsoon (ASM) are postulated, and 2) on the northwestern continental shelf of Australia (NWA; U1461), including the Timor Sea (TS), changes of SST and productivity related to the Australian monsoon (AM) are reconstructed. The NWA, TS and SCS have the proximity to the Indonesian Throughflow (ITF) with warm surface waters in common. We attempt to reconstruct the inter-hemispheric see-saw with a micropaleontological approach. We will deliver innovative proxy data on the onset and/or pacing of the most important forcings of ASM and AM such as supra-regional ITCZ reconstructions and changes in SST and BWO with implications for the ITF during YD and HS1. Foraminiferal elemental ratios such as Mg/Ca and the stable isotopic composition will inform us about changes in SST, bottom water temperatures, (export) productivity and BWO. Laser Ablation ICP-MS (LA-ICP-MS) and electron probe micro-analysis (EPMA) will allow us to refine and validate calibration approaches for the targeted elemental ratios. We will reconstruct intensity and temporal changes of ASM and AM during YD and HS1 from sediment cores from the SCS and NWA. We will use LA-ICP-MS and EPMA to study ontogenetic changes in individual foraminifera and diagenetic effects with an overall effort to strengthen calibrations and reconstructions.

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Chemical composition around hiatus of ODP Site 752 at Broken Ridge based on Micro XRF mapping analysis (ReC23-01)

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The ReCoRD (Repository Core Re-Discovery) Program, ReC23-01 were conducted in 2024. The sediments obtained from ODP Site 752, located on an isolated ridge in the Indian Ocean were used. The sediments recovered from Site 752 contained concretion at Paleogene age when hiatus or lower sedimentation rate was suggested by the age model [1].

Micro XRF mapping analysis is a useful tool to reveal sediment composition which recorded past oceanographic changes. However, this method was usually not applicable to 1.5 m long legacy cores obtained by international ocean drilling program. In this study, we utilized M6 JETSTREAM provided by Bruker Corporation, which could conduct non-destructive measurement for 80 cm × 60 cm wide area and could measure 1.5 m long archive half cores directly. In addition, using the specialized method of JETSTREAM, high elevated intervals such as concretions can also be measured simultaneously with background sediments.

We measured the concretion and the surrounding sediments together using specialized method of JETSTREAM, and revealed high-resolution elemental maps of concretion and surroundings sediments. However, above-mentioned specialized method was only applied to an section contained concentration. As a results, XRF mapping results cannot comparable with other sections, which specialized method was not used during the measurement.

In this study, we also measured standard samples under various measurement settings. Using the results of standard samples, we estimate difference come from machine settings and conduct calibration for the XRF mapping results of Site 752.

The calibrated XRF mapping results clearly shows that each element (Ca, Fe, Mn) is concentrated on different part on and around the concretion. The Ca concentration is higher at an interval above a concretion, which may suggest high calcareous productivity during the sedimentation period.

Our results highlight the potential of geochemical imaging of legacy ocean-drilling cores, with implications for sedimentology, stratigraphy, provenance, paleoclimatology, paleoecology and many other geoscience subdisciplines.

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