The Asian Monsoon and its Impact on Weathering and Erosion in the Western Himalaya since the Miocene

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The Asian monsoon is controlled in part by the evolution of topography in Asia that has since the start of collision of India with mainland Asia, likely around 50–60 Ma. Feedbacks between the solid Earth and climate have been suggested to govern the structural and tectonic evolution of the mountains, and in particular the exhumation of the Greater Himalayas and the formation of the Lesser Himalayan duplex. New marine sediment cores from the Arabian Sea collected by IODP Expedition 355 now allow the relationships between climate and erosion to be investigated since 11 Ma spanning the critical climatic transition after 8 Ma. There is a coherent change in bulk sediment Nd isotopes to more primitive, Karakoram-derived sediment between 20 and ~9 Ma followed by a long term trend to more Himalayan values from that time to the present. This may reflect the progressive exhumation of the Lesser Himalayan Crystalline Series after weakening of summer monsoon rains, beginning at 8 Ma. This environmental change is reconstructed from the carbon isotope character of plant waxes, consistent with similar data from the foreland basin. Detrital zircon U-Pb data confirm the general shift of relative erosion away from the Karakoram towards the Lesser Himalaya since the Miocene. Sands deposited on the submarine fan since 2 Ma are very similar to those in the river mouth at the present time, but not during the LGM, which instead is more similar to the older Miocene sediments. Hematite/goethite values derived from spectral analysis of the core steadily increase after ~8 Ma and especially after 6 Ma, suggestive of drying climate with a reversal to wetter conditions starting ~1.5 Ma.

Keywords: Monsoon, Erosion, Himalaya, Weathering

Variations in paleovegetation and transport of terrigenous matter reconstructed by terrestrial plant biomarker compositions in sediments from IODP Site U1423 over the last 4 Ma

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The objectives of our study are to reconstruct long time-scale variations in paleovegetation in the East Asia and transport of terrigenous material to the East Asian marginal sea, and to evaluate long time-scale biogeochemical cycles in the marginal sea during the Pliocene to Pleistocene (over the past 4 million years). Sedimentary plant remains such as spore/pollen and plant mega-/mesofossils are commonly used for reconstructing paleovegetation, and recently, plant-derived organic molecules, biomakers, are also applied. In the present report, we focus on terrestrial plant biomarkers such as plant wax-derived *n*-alkanes as well as terrestrial plant terpenoids, in which structures vary depending on taxonomic differences. Moreover, we compare between the data for plant biomarkers and spore/pollen in the same samples.

The sediment cores studied were recovered at Site U1423 in the eastern part of the Japan Basin at 41º 41.95’ N, 139º4.98’ E by Integrated Ocean Drilling Program (IODP) Expedition 346. Lipids were extracted with dichloromethane / methanol, and separated to aliphatic, aromatic and polar fractions. Lipids were identified and quantified by GC/MS.

Concentrations of long chain *n*-alkanes increase from ~1.7 Ma. This result implies that plant waxes were more efficiently transported by eolian dust due to global cooling during the early Pleistocene. Triterpenoids such as α-amyron, β-amyron and friedelin, and diterpenoids such as sugiol and dehydroabietic acid were mainly identified in all samples. The plant terpenoid concentrations were found to increase from ~1.3 Ma. The sugiol is found to be consistently abundant, although the remarkable decreasing spikes are observed during 3.5 - 3.3 Ma and 1.25 –1.05 Ma. The relative abundances of ferrugiol is higher during ca. 3.5 - 3.0 Ma and ca. 1.3 - 0.6 Ma. The sugiol and ferrugiol are known to be derived from Taxodiaceae and Cupressaceae. Thus, these families were possibly abundant in Hokkiado and/or the Japan Sea side of northern Honshu Island over the 4 million years. The relative abundances of dehydroabietic acid, which is typical conifer biomarker, frequently varied and several increasing peaks are observed for 4 million years. Interestingly, the increasing peaks of dehydroabietic acid are found to be correlated to those of the relative abundances of Taxodiaceae estimated by pollen analysis. Such increasing peaks of pollen-based Taxodiaceae abundances are presumably related to Asian monsoonal climate such as warm and humid conditions. From these results, it is suggested that the indicator using dehydroabietic acid, rather than sugiol and ferrugiol, is more sensitively respond against the monsoonal climatic changes. Gymnosperm / angiosperm ratios estimated by terpenoid / diterpenoid ratios increase during 3.0 - 1.5 Ma, which is concordant with results of conifer / broad-leaf wood ratios based on pollen compositions. Thus, gymnosperm-dominant paleovegetation in land areas around Site U1423 might be distributed during the Pliocene to early Pleistocene.

Keywords: paleovegetation, biomarker, Japan Sea off Hokkaido

Evolution of the Japan Sea hydrographic system during Mio-Pliocene, inferred from radiolarian data (IODP Exp. 346, Site U1425)

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The Middle Miocene (ca. 15 Ma), is a climatic transition from a warm to a colder phase promoting growth and stabilization of an East Antarctic ice sheet. Cause of such cooling remain controversial; however, a higher carbon sequestration and drawdown of CO_2 are likely the main contributors. Since then, the climate of Earth record a progressive cooling, excepting the Pliocene warmth, which lead the establishment of the Greenland Ice Sheet (ca. 2.7-3.2 Ma). During this interval, climate changes are mainly paced by the obliquity cycle (41 kyr) until ca. 1 Ma, when a change in the dominant orbital cyclicity occurred.
On the other hand, tectonic activity also has influences on local to regional climatic/oceanographic system. The Northwest Pacific region is characterized by active tectonism, which drastically modified its paleogeography. In this context, the Japan Sea, a back-arc basin opened by a continental rifting during the Early to Middle Miocene (ca. 25–13 Ma) is one of the consequences of such activity. In modern condition, it is known that the Japan Sea is connected to adjacent marginal seas and the Pacific Ocean by four straits shallower than 130 m. The tectonic activity of this area drastically modified the Japan Sea paleogeography for older time interval such as the sill depth of its key straits. Past studies show that during the late Miocene and Pliocene, only the Tsugaru Strait connecting to the North Pacific was opened and this strait was likely deeper during Mio-Pliocene. Therefore, by studying paleoeaconographic records in the Japan Sea, a relative impact of tectonic and global climatic events on the local hydrographic system could be evaluated.
In 2013 the IODP Expedition 346 retrieved sediment cores at different sites in the Japan Sea. In this study, we have analyzed 138 core sediments samples collected at Site U1425. This site is situated in the middle of the Yamato Bank. We selected this site because the past 10 Myr could be traced continuously without hiatuses, enabling continuous data acquisition.
Radiolarians are one of the planktic micro-organism group bearing siliceous skeletons. Their species comprise shallow to deep water dwellers, sensitive to changes in sea water physical/ecological properties forced by climate changes. Their fossils are known for well preserved in the deep-sea sediments of the North Pacific. Therefore, in this study we propose to reconstruct major changes in the Japan Sea hydrography since the late Miocene, using radiolarian fossils as an environmental proxy.
As a result, shallow water radiolarians suggest relatively warm condition between ca. 7 and 9.5 Ma. Because it has been thought that only the Tsugaru strait (northern strait) of the Japan Sea was open during this period, our data infer northern shift of the subtropical front, or the presence of a shallow strait in area south of Tsugaru Strait. The situation is also complex for the intermediate water radiolarians. Indeed, our data suggest that the sill depth of the connecting strait likely control the exchanges of water masses with the North Pacific, highlighting importance of regional tectonism, although the opening of the Bering Strait seems also to influence the hydrography of the Japan Sea.

Keywords: Neogene Climate, Japan Sea, Sill depths, Hydrographic changes

An Indian Ocean record of the evolution of the South Asian Monsoon circulation

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The South Asian Monson (SAM) is one of the most extreme features in Earth’ s climate system, yet its initiation and variations are not well established. The SAM is a seasonal reversal of winds accompanied by changes in precipitation with heavy rain during the summer monsoon. It is one of the most intense annually recurring climatic elements and of immense importance in supplying moisture to the Indian subcontinent thus affecting human population and vegetation, as well as marine biota in the surrounding seas. The seasonal precipitation change is one of the SAM elements most noticed on land, whereas the reversal of the wind regime is the dominating driver of circulation in the central and northern Indian Ocean realm. International Ocean Discovery Program Expedition 359 aimed to resolve the evolution of the South Asian Monsoon by tracing back in time its sedimentary signatures and by resolving changes in the ocean circulation system in the archipelago of the Maldives.
Data from the Maldives Inner Sea provide an archive that reveals an abrupt onset of the SAM-linked ocean circulation pattern and its relationship to the long term Neogene climate cooling. In particular it registers ocean current fluctuations and changes of intermediate water mass properties for the last 25 myrs that are directly related to the monsoon. Dating the deposits of SAM wind-driven currents yields an age of 12.9 Ma indicating an abrupt SAM onset, over a short period of 300 kyrs. This coincided with the Indian Ocean Oxygen Minimum Zone expansion as revealed by geochemical tracers and the onset of upwelling reflected by the sediment's content of sedimentary organic matter. The sedimentary signature of the dust influx to the Maldives, the seismic stratigraphy of the carbonate platform, and the sediments recovered indicate that there was a winter monsoon between 12.9 and 25 Ma, but that ocean currents were weaker. Abrupt SAM initiation favors a strong influence of climate in addition to the tectonic control, and we propose that the post Miocene Climate Optimum cooling, together with increased continentalization and establishment of the bipolar ocean circulation, i.e. the beginning of the modern world, shifted the monsoon over a threshold towards the modern system.

Keywords: monsoon, indian ocean, miocene, iodp expedition 359, maldives

Five million year record of summer monsoon winds and continental aridity from The Maldives carbonate platform (IODP Site U1467)

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Strong winds and the proximity of arid source-areas result in a large flux of desert dust from the continents to the Arabian Sea in summer. This research identifies the main controls on dust influx into the northern Indian Ocean over the last 5 million years by analyzing the first high resolution marine sediment record from The Maldives carbonate platform (IODP Expedition 359; Site U1467), an area strongly affected by the monsoon seasons. Here we present variations in the concentration of specific normalized elements (e.g. Fe/Al, Si/Al), from X-ray fluorescence spectrometry, reflecting variations in the dust flux. We investigate the degree of coupling between the new dust record and Earth’ s climate in the northern hemisphere. This research paves the way for understanding hominin migration pathways from Africa to Asia.

Keywords: monsoon records, dust, ITCZ, Maldives, hominin migration routes

Tropical western Pacific hydrology during the last 6000 years based on charcoal records from Borneo

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Tropical western Pacific region is a heat source of Earth’ s surface and potentially plays a major role in global climate change. Precipitation in Borneo is controlled by both El Nino-Southern Oscillation and the East Asian winter monsoon associated with latitudinal migration of the intertropical convergence zone. In this study, we generated a 6200-year long charcoal record from three different sites in northwestern Borneo that shows large fluctuation in charcoal abundance. Two different sites at 460 km distance show common abundance peaks, suggesting that climate change regulated wild fire frequency. The abundance peak appeared every several hundred years, showing a 560-year periodicity. The peaks correspond well to those of the frequency of El Niño-induced flooding in an Ecuadorian lake (Moy et al., 2002) from 4000 to 1500 year BP, but the correspondence is not significant in other periods. There is no clear correspondence with the East Asian summer and winter monsoon records. We suggest that multi-centennial scale changes in the frequency of El Niño was a factor controlling precipitation in northwestern Borneo and the frequency of wildfires in the peatlands.

Keywords: Tropical, Climate, Charcoal

East Asian winter monsoon fluctuation revealed by ice-rafted debris occurrence in the northern Japan Sea

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Asian monsoon is composed of summer and winter monsoons. The East Asian winter monsoon (EAWM) over the Japan Sea is typically characterized by cold, dry northwesterlies from the Siverian High. These cold winds cool the surface water along the far eastern coast of Russia and promote the formation of a young deep-water mass (Japan Sea Proper Water: JSPW). According to modern global warming, the formation of JSPW has been deduced, and oxygen concentration of the JSPW was reported to be reduced. Therefore, it is very important to understand the fluctuation of EAWM on glacial-interglacial and millennial time-scales. Previous studies on modern- and paleo-oceanography indicated that surface water temperature in the northeastern Japan Sea and sea-ice condition (ice-rafted debris (IRD) occurrence) in the northern Japan Sea are good proxies of the EAWM. Previous studies, however, reconstructed the EAWM fluctuation only for the past 160 ka. Thus, IRD counting is applied for the sediment cores of MIS 6 to MIS 12 at IODP Exp. 346 site U1422 in the northern Japan Sea. The result indicates clear fluctuation with much IRDs during MIS 6, late MIS 7, MIS 8 and early MIS 10, and low IRDs during mid MIS 7, MIS 9 to mid MIS 10 and MIS 11-12. There are fluctuation in much finer time-scale suggesting the presence of millennial time-scale fluctuation of the EAWM.

Keywords: ice-rafted debris, winter monsoon, sea ice

Japan Sea oxygen isotope stratigraphy and monsoon signals recorded in sedimentary color variation of IODP Site U1427

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Oxygen isotope stratigraphy in the Japan Sea has not well been developed because the oxygen isotope variation recorded in the Japan Sea sediments is distinct from the so-called “standard” isotope curve. Owing to its semi-enclosed geographical setting, limitation of seawater exchange due to low sea level during the glacial periods made surface environment and isotope record quite different from open ocean. Another difficulty is discontinuous occurrence of fossil foraminifera in the deep sea sediments, which is mainly due to drastically varied deep water oxygen and carbonate saturation levels. In this study, we have tried to construct the Japan Sea oxygen isotope stratigraphy using shallow sedimentary sequence at Site U1427 retrieved from 330 m water depth, which contains well-preserved fossil foraminifera. Comparison of the benthic oxygen isotope records at Sites U1427 and U1429 (the East China Sea) using correlative tephra layers as stratigraphic constraints revealed that negative peaks at U1427 correspond to positive peaks at glacial maxima at U1429. Based on this comparison and microfossil data, we constructed isotope stratigraphy at Site U1427 for the last ~1 Myr. We also tried to correlate sedimentary color variations at shallow and deep sites. Combined with correlative tephra layers, sedimentary color variations in shallow and deep sites are well correlated in orbital- and millennial-scale. We will discuss sedimentary color variations and relationship between shallow and deep sedimentary sequences.

Keywords: Integrated Ocean Drilling Program, Japan Sea, sea level change

Variations in East Asian summer monsoon in the last 400 ky deduced from results of Mg/Ca-sea surface temperature and oxygen isotope of IODP Site U1429

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The East Asian summer monsoon (EASM) system involved in the hydrological cycle and in latent heat and energy transport, and thus plays a crucial role in the regional and global climate system. Modern summer sea surface salinity in the northern part of the East China Sea (ECS) is mainly controlled by the freshwater discharge of the Yangtze River, which reflects East Asian summer monsoon (EASM) precipitation in South China. Site U1429 was drilled by Integrated Ocean Drilling Program (IODP) Expedition 346 in the northern ECS to reconstruct the Yangtze River discharge in high temporal resolution (~100 year resolution). A ~200 m long sediment succession was recovered, which covers the last 400 ky based on a benthic foraminiferal oxygen isotope record. A record of oxygen isotope of seawater ($\delta^{18}O_w$), a proxy that is related to salinity change and Yangtze River discharge, was reconstructed, based on high-resolution Mg/Ca and oxygen isotope ($\delta^{18}O_{pf}$) of the planktic foraminifera *Globigerinoides ruber*. As the surface water in the northern ECS is formed by mixing salty Kuroshio water (high $\delta^{18}O_w$) and freshwater from the Yangrze River (low $\delta^{18}O_w$), the $\delta^{18}O_w$ of U1429 is interpreted as reflecting mixing ratio between Kuroshio water and freshwater.
The results of U1429 indicate that both $\delta^{18}O_{pf}$ and Mg/Ca are dominated by 100 ky (eccentlicty) cycle with 41 ky (obliquity) and 23 ky (precession) cycles. The $\delta^{18}O_w$ shows variations that have been in concert with Chinese speleothem oxygen isotope records on millennial to orbital scales except for 100 ky cycles that is not found in the Chinese speleothem record. As the the $\delta^{18}O_w$ of U1429 follows the global mean $\delta^{18}O_w$ on 100 ky cycles, this cyclicity originates from global ice volume change maybe through the Kuroshio water. On the other hand, the prominent 23 ky cycles in U1429 $\delta^{18}O_w$ may reflect the variations in the freshwater discharge, supporting that the EASM is reglated by summer insolation in the Northern Hemisphere.

Keywords: East Asian summer monsoon, IODP Exp.346, East China Sea

Formation of the Holocene mud belt in the inner shelf of the East China Sea: controlled by changes in sea level and climate

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Mud sediments deposited on the shelf of the East China Sea (ECS) during the Holocene have been widely linked to sea-level and climatic changes. Previous studies on the geochemical compositions and geophysical properties of such mud sediments from the gravity cores drilled off the coast of Zhejiang-Fujian, China, suggested that these fine-grained sediments in the ESC deposited continuously with high sedimentation rates from the mid- to late Holocene. High-resolution paleoclimatic records have been reconstructed based on multi-proxies, however the interpretation of these proxies are different from site to site. For example, the changes in grain size of fine sediments, located in the north (Core PC-6; 29º 34.92'N, 122º37.92'E) and south (Core MZ01; 26º32.82'N, 120º50.94'E) of the mud belt have been used to indicate the strength of the coastal currents that mainly controlled by the intensity of the East Asian Winter Monsoon (EAWM); while the variation in the similar signals occurred in Core MD06-3040(27º 43.36'N, 121º46.88'E), located in the central zone, has been applied to demonstrate the fluctuations in the intensity of East Asian Summer Monsoon (EASM). These ambiguities also been represented by the discrepancy in sedimentary provenance: rare earth element signals of Core EC2005 (27˚25.0036'N, 121˚ 20.0036'E) indicate that the mud sediments were dominantly transported by coastal currents (related to the EAWM) and derived from the Yangtze River since ~10 ka; whereas clay mineral records from Core MZ02 (28º10.13'N, 121º53.40'E) indicate Taiwanese rivers contributed 60% sediments during 6.2-2.4 ka via Taiwan currents (related to the EASM). In spite of these disputes, the mud deposits occurred during the highstand in sea level when a low energy shelf environment developed since ~7 ka. Furthermore, when we compare the sedimentation rates of these mentioned sediment cores, we find that the depocenter located in the central part of the mud belt (close to Core EC2005), thus we proposed that the development of such mud belt is in response to the Zhejiang-Fujian coastal currents combined with Taiwan currents. In summary, the formation of the Holocene mud belt in the ECS is more complex than expected and future work on the sediment patterns of the modern and Holocene mud belt is in progress.

Keywords: Monsoon, East China Sea, Holocene, Mud belt

Millennial-scale variability of East Asian summer monsoon precipitation during the last 6 kys is caused by N-S oscillation of precipitation front associated with westerly jet movement

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Precipitation by East Asian summer monsoon (EASM) plays a dominant role in the hydrological cycle of the area and exerts significant impact on lives of people living there. Thus, it is important to understand time-scale and magnitude of the variability and their controlling factors. Centennial- to millennial-scale variability of EASM precipitation could have been especially significant judging from Chinese historical records, but its magnitude, spatial distribution, and controlling factor(s) are largely unknown.

In this study, we estimated movement of EASM (precipitation) front in Yangtze River drainage basin during the last ~6 kys based on reconstruction of provenance changes of fine silt fraction of the sediments, representing suspended particulate (SPM) from Yangtze River, using cores from Yangtze Delta and the Mud Belt along the South China coast. The results show centennial- to millennial-scale NW-SE oscillation of EASM front with NW ward penetration during 6-5.1, 3.5-1.8, and 0.2-0 ka, and SE ward retreat during 5.1-3.5 and 1.8-0.2 ka, respectively.

We compared the result with N-S oscillation of westerly jet over the Japan Sea during the Holocene by Nagashima et al. (2013). The result suggests the oscillation of EASM front is in parallel with oscillation of the westerly jet, supporting the idea that subtropical westerly jet bounds the northern limit of EASM precipitation.

We also reconstructed flood and heavy precipitation record in SW Japan during the last 6 kyrs using SG-12 cores from Lake Suigetsu, and compared the record with the provenance changes of SPM discharged from Yangtze River. The comparison revealed a striking similarity between temporal changes in flood and heavy rain frequencies in Lake Suigetsu, SW Japan and temporal changes in provenance of SPM discharged from Yangtze River.

The observed relationships suggest that N-S movement of westerly jet has been controlling millennial-scale changes in EASM intensity through modulating the position of EASM front, and southward shifts of westerly jet and EASM front have caused more rain and frequent floods in SE part of South China and SW Japan.

Keywords: East Asian summer monsoon, precipitation front, westerly jet, Yangtze River, Lake Suigetsu, Holocene

