

# **Magnitude and timing of erosion of the north-eastern Tibetan Plateau from geomorphology and low-temperature thermochronology**

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The lateral expansion of high topography of the northern and eastern Tibetan Plateau is important to both our understanding of the mechanics of plateau growth and to tectonic and climate feedback mechanisms related to plateau uplift and regional climate changes affecting central and southern Asia. In particular, the initiation of fault-bounded range and basin structures in northeastern Tibet has been used as a proxy for the development of high mean elevations at the northern plateau margin. However, poor timing constraints of faulting activity and erosional histories make current linkages between orogenesis, exhumation/sedimentation and climate tentative.

New apatite (U-Th)/He ages from several fault blocks of the northeastern Tibetan Plateau are mid-late Miocene at low structural positions and early Cenozoic/late Mesozoic at progressively higher structural positions. Preservation of Mesozoic ages suggests that mean exhumation of the plateau surface has generally been limited to less than a few kilometers since India/Eurasia collision commenced in middle Eocene time. Greater exhumation of up to several kilometers only occurs where rivers have deeply incised into uplifted and/or tilted fault blocks. Helium ages collected on vertical (elevation) transects within fault blocks give information about the timing and magnitude of individual exhumation events. Data collected from the West Qinling range near Linxia Basin show two periods of accelerated cooling beginning at ~ 45 Ma and between ~ 15-5 Ma. These two events are similar in magnitude and associated with not more than a few kilometers of erosion during each episode. Ages from three transects in the Kunlun Range collected above the eastern Qaidam Basin show one period of accelerated erosion beginning at ~ 40 Ma and lasting until at least 20 Ma. Ages from samples collected within transpressional fault blocks exposed along the Kunlun Fault have uniformly younger ages that indicate rapid exhumation between at least 19 – 7 Ma.

Well-developed, low-relief erosion surfaces are commonly preserved in many fault blocks and are often tilted or offset by fault motion. We associate a period of slow-cooling during late Mesozoic time with the development of this geomorphic surface. The depth of the partial-retention zone for helium identified on vertical transects also suggests that 1-2 kilometers of cover has been stripped from these erosion surfaces since at least Eocene time. We suggest that easily erodable sedimentary cover probably overlain this Mesozoic bedrock

erosion surface and has since been reworked and deposited into later (Cenozoic) sedimentary basins. Overall, a few kilometers of erosion of the northeastern Tibetan Plateau margin differs significantly from  $> 10$  km of erosion of southern Tibet since collision. We relate the small magnitude of Cenozoic erosion to slow, protracted or episodic surface strain rates. Therefore, the pattern of surface faulting may not relate to any single phase of major elevation gain of the plateau. Slow surface strain and a relatively arid climate could effectively limit any feedback mechanisms between erosion and orogenic growth- two principle differences between northern and southern Tibet despite similarities in their extreme mean elevation and regional topographic gradients.

## **Thermochronology of Mineral Grains in the Red and Mekong Rivers, Vietnam: Provenance and Exhumation Implications for Southeast Asia**

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Samples of sand were taken close to the mouths of the Red and Mekong Rivers and analyzed to determine the provenance and exhumation history of their source regions. U-Pb dating of detrital zircon grains shows that the main sources comprise crust formed within the Yangtze Craton and during the Triassic Indosinian Orogeny. Indosinian grains in the Mekong are resolvably younger (210–240 Ma) than those in the Red River (230–290 Ma), suggesting preferential erosion of the Qiangtang Block of Tibet into the Mekong. The Red River has a higher proportion of 700–800 Ma grains derived from the Yangtze Block. <sup>40</sup>Ar/<sup>39</sup>Ar dating of muscovite grains demonstrates that rocks cooled during the Indosinian Orogeny are dominant in both rivers, although the Mekong also shows a large grain population cooling at 150–200 Ma that is not seen in the Red River and which is probably of Qiangtang Block origin. Conversely, the Red River contains a significant mica population (350–500 Ma) eroded from the Yangtze Craton. The high-grade metamorphic rocks exposed in the Cenozoic shear zones of southeast Tibet-Yunnan are minority sources to the rivers. However, apatite and zircon fission track ages show evidence for relatively rapid, recent exhumation for most detrital grains, especially in the Red River. The dominant sources were exhumed through the shallowest 5–3 km of the crust since ~25 Ma after initial Indosinian metamorphism. The thermochronology data exclude Tibet as a major sediment source, but are consistent with erosion from gorges that incise the eastern flank of the plateau, as well as from the Central Highlands of Vietnam in the case of the Mekong. Average Neogene exhumation rates are 105–190 m/m.y. in the Red River basin, which is within error of the  $178 \pm 35$  m/m.y.

estimated from Pleistocene sediment volumes. However, an average rate of 60–110 m/m.y. in the Mekong basin is much more than the  $20 \pm 5$  m/m.y. calculated from sediments, and indicates that much of this catchment is not eroding. Data from the Mekong River favors tectonically driven rock uplift causing gorge incision as the dominant control on erosion, with precipitation being an important secondary influence.

# **The Sedimentary and Tectonic Evolution of the Yinggehai-Song Hong Basin and the Southern Hainan Margin, South China Sea; Implications for Tibetan Uplift and Monsoon Intensification**

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The Yinggehai-Song Hong Basin is one of the world's largest pull-apart basins, lying along the trace of Red River Fault Zone in the South China Sea. South of Hainan Island this basin cross-cuts the rifted margin of the northern South China Sea. In this paper we present for the first time a regional compilation of multichannel seismic reflection data from both the strike slip and rifted margins. The basins started to open after ~45 Ma, especially after ~34 Ma. The Yinggehai Basin was folded and inverted in the Middle Miocene, after 21 Ma in the north and 14 Ma in the south, before rapidly subsided again after ~5 Ma due to continued tectonism. This subsidence has caused shale diapirism, especially driven by associated sedimentation in the late Pliocene (2.6–2.0 Ma). Extension along the adjacent south Hainan margin shows preferential lower crustal extension, suggestive of lower crustal flow increasing towards the continent-ocean transition during break-up. Sediment supply is reconstructed to peak in the Middle Miocene, then falls between 14 and 10.3 Ma, to reach a low in the Late Miocene. However, rates rose again in the Pliocene-Pleistocene. The Red River sediment budget is incompatible with climate models that propose stronger monsoon rains starting at 8 Ma, or with large scale river capture away from the Red River after ~10 Ma. Both lines of evidence point to major uplift in the Red River drainage being Middle Miocene or older. The recent, pre-industrial Red River carried much more sediment than the average Pleistocene accumulation rate, indicating modest sediment buffering onshore, at least in recent geologic time.

## **The Asian Monsoon: Present scenario and Unresolved Issues**

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The Asian monsoon is a large scale feature of the climate system affecting one of the most densely-populated Asian and African regions. The monsoon is the lifeline to the people of Asia as region's water needs for agriculture and domestic use are largely dependent on the monsoon rainfall. Thus monsoon constitutes a critical resource for the region's largely agrarian economies. A good monsoon means a booming Asia whereas a failed or an over intensified monsoon will cause misery to the large component of the region's population. Considerable efforts have been made toward high resolution (high density sampling of the marine cores) reconstruction of proxy records of monsoon that have helped in the understanding of monsoon evolution, its variability over various time scales, and forcing factors that drive the monsoon on orbital and sub-orbital time scales. However, there are still unresolved questions as to the timing of the advent of monsoon and driving mechanisms of the monsoon variability. There are different propositions that suggest the beginning of the Asian monsoon some time between 30 and 7.5 Ma. While the marine records indicate a major shift in the monsoon system between 9 and 8 Ma, the continental records suggest a range from 22 to 7.5 Ma during which time the monsoon may have evolved. The model studies, on the other hand, put the origin farther back in time at ~ 30 Ma. Thus to resolve this issue, a coordinated effort is required to analyze high resolution marine cores from high sedimentation areas as well as continental records of continuity. Numerous recent studies have shown that monsoon has varied at orbital (eccentricity, obliquity and precession) and sub-orbital (centennial to millennial) time scales. The centennial to millennial scale changes in the monsoon have been linked to both the internal (linked to North Atlantic Oscillation, ENSO, etc.) and external (solar) forcings, but mechanistic links of monsoon variability to these forcing factors require further studies. The testing hypotheses regarding the monsoon variability seen in the paleo records is an active research area that is rapidly growing.

## **Thermochronometry of the Red River Shear Zone: Implications for Tectonic Extrusion**

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Since collision began at ~60 Ma, Indo-Asian convergence has been accommodated by a variety of mechanisms including underthrusting of India beneath Eurasia, contractile thickening of the Eurasian lithosphere, and eastward lateral extrusion of continental blocks along lithospheric-scale strike-slip faults. In particular, two models have emerged that are striking in their contrasting assumptions. One asserts that the lithosphere can be approximated as a thin viscous layer and as such shortens and thickens diffusely in response to collisional forces. Another view is that the lithosphere is sufficiently rigid to localize strain along lithospheric-scale shear zones and thus a significant portion of Indo-Eurasian convergence may have been accommodated via lateral extrusion of blocks along major strike-slip faults.

The Red River shear zone (RRSZ), exposed as a semi-continuous belt of gneissic massifs from NW Yunnan to Vietnam, plays a central role in the extrusion hypothesis. Much recent attention has been focused there to test predictions of the extrusion model, particularly the proposed link between left-lateral shearing along the RRSZ and seafloor spreading in the South China Sea. Magnetic anomalies in the South China Sea have been interpreted as indicating that seafloor spreading occurred between 32 and 16 Ma at a rate of ~4 cm/yr. Numerous geochronological studies report evidence for late Tertiary ductile, left-lateral shearing along the RRSZ. However, these data indicate only that high-temperature deformation occurred either during or subsequent to that period. Thermal histories derived from  $^{40}\text{Ar}/^{39}\text{Ar}$  thermochronometry suggest that diachronous initiation of strike-perpendicular extension occurred along a 500 km segment of the RRSZ, from 25 Ma in the southeast to 17 Ma in the northwest. This relationship suggests that the onset of transtensional faulting propagated northward along the RRSZ at ~4 cm/yr, consistent with the rate of spreading of the South China seafloor, but does not directly link seafloor spreading to left-lateral strike-slip motion along the RRSZ. In situ Th-Pb ion microprobe dating of monazite inclusions within garnets grown during high-temperature deformation permits us to directly assess the timing of amphibolite grade metamorphism and synchronous left-lateral shearing.

Monazite prograde thermochronological results from the northern segments of the RRSZ in Yunnan, China, indicate that garnet growth occurred between 34–21 Ma and are the first to document that metamorphism and left-lateral shearing occurred during the late Oligocene. Results from the portion of the RRSZ within Vietnam are complicated in part by Tertiary overprinting of rocks that had experienced amphibolite metamorphism during the Indosinian orogeny (~220 Ma). The period during which left-lateral deformation is now constrained to have occurred along the RRSZ (i.e., 34–17 Ma) is essentially coincident with spreading of the South China seafloor (i.e., 32–17 Ma). This temporal and kinematic link between left-lateral shearing along the RRSZ and opening of the South China Sea supports the view that Indochina was extruded from Asia as a block along lithospheric-scale strike-slip faults.

## **Geochemical characterization of intertidal sediments of Halong-Bay, NE-Vietnam**

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The geochemical composition of the intertidal sediments of Halong Bay and the Song Hong Delta is crucial for deciphering this complex system in terms of interactions between geological, geochemical and biological processes. The composition of the sediments is highly effected by the Song Hong with its huge sediment load of up to 1300 mg/L [1], the tidal characteristic of the Gulf of Tonking and the mangrove system, enriching fine-grained material as well as organic matter and acting as sink for certain pollutants [1, 2, 3].

For the geochemical characterisation of the tidal flat sediments a total of 40 samples have been collected from four different sites (HL, DC, DS, DV) within the intertidal areas. The sample locations differed in sediment input, agricultural activities, industrialization and urbanization of the hinterland. At each location samples of about 1.5-2 kg sediment of the uppermost 15-20 cm were collected along traverses covering the whole intertidal zone from the end of the supratidal up to the beginning of the subtidal area. The distances between each sample point varied between 25 to 50 m.

To characterize the geochemical composition of the sediments, the contents of major elements (SiO<sub>2</sub>, TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, MnO, MgO, CaO, Na<sub>2</sub>O, K<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub>) and up to 23 trace elements were determined by XRF. Additionally, LOI was determined. Quality controls on precision and accuracy of the data were assessed.

The major constituents of the sediment fraction < 63 µm of all 40 samples are SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub>, whereas SiO<sub>2</sub> is the most abundant major oxide with a range of concentrations between 51.95 wt.-% (DS) and 80.55 wt.-% (DC). The Al<sub>2</sub>O<sub>3</sub> contents range between 9.65 wt.-% (HL) and 20.30 wt.-% (DS) and those of Fe<sub>2</sub>O<sub>3</sub> between 2.5 wt.-% (DC) and 8.26 wt.-% (DS). Values of K<sub>2</sub>O and MgO vary between 0.7 and 3.5 wt.-%. TiO<sub>2</sub>, MnO, CaO, NaO and P<sub>2</sub>O<sub>5</sub> have contents mainly less than 1 wt.-%. The range of the LOI lies between 6.64 wt.-% (DC) and 13.58 wt.-% (DC). The trace elements Ba, Rb, Zn and Zr were always present with contents > 100 ppm. Additionally, in some traverse points the concentrations also

of V, Ce, Cr, Sr, Pb were > 100 ppm. With mainly less than 10 ppm Hf, Mo, Ta, U and W were determined. Most of the trace elements follow the same distribution of depletion and enrichment within the traverses as Al<sub>2</sub>O<sub>3</sub>. When comparing all four sample traverses, DS and DV have a similar geochemical composition with distinct higher trace element contents than the HL and DC samples. The composition of HL and DC is also similar. Normalizing the data against the element contents of the upper continental crust according to Wedepohl[4], a variety of elements are strongly enriched in all four sample sites. Especially elements usually derived from anthropogenic inputs like As, Co, Cr, Cu, Mo, Ni, Pb, W and Zn are highly enriched in the sediments.

## References

- [1] EISMA, D. (1998): Intertidal Deposits. River Mouths, Tidal Flats and Coastal Lagoons. 525 S., CRC Press LLC (Marine Science Series), Florida.
- [2] MACFARLANE, G.R., PULKOWNIK, A., BURCHETT, M.D. (2003): Accumulation and distribution of heavy metals in the grey mangrove, *Avicennia marina* (Forsk.) Vierh.: biological indication potential. *Environmental Pollution* 123, 139-151.
- [3] MACHADO, W., MOSCATELLI, M., REZENDE, L.G., LACERDA, L.D. (2002): Mercury, zinc, and copper accumulation in mangrove sediments surrounding a large landfill in Southeast Brazil. *Environmental Pollution* 120, 455-461.
- [4] WEDEPOHL, K.H. (1995): The composition of the continental crust. *Geochimica et Cosmochimica Acta* 59, 1217-1232.

## **The East Asian Record of Miocene Climate and Tectonics**

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Since the early Eocene climate optimum approx. 50 Million years ago, the Earth's climate system has drifted from extreme warmth with ice free poles to glacial conditions with extensive polar ice caps. The Miocene climatic transition (approx. 17 to 8 Ma), which started with an extended period of global warmth (Miocene climate optimum) and ended with the establishment of permanent ice sheets in Antarctica, marked a crucial step in Cenozoic cooling. This cooling may have been related to the uplift of the Tibetan Plateau and associated drawdown of CO<sub>2</sub> from the atmosphere by enhanced continental weathering, intensification of the East Asian Monsoon, restriction of zonal ocean passages and the buildup of a proto-Western Pacific Warm Water Pool. Stable isotope records in oceanic sequences initially revealed a prolonged  $\delta^{13}\text{C}$  excursion („Monterey“ event) that was characterized by low frequency fluctuations, suggested to approximate long eccentricity cycles in the earth's orbit. The apparent co-variance between deep ocean  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  gave support to the hypothesis that periodic increases in organic carbon burial drove atmospheric CO<sub>2</sub> drawdown and favoured cryosphere expansion. However, high resolution sediment records spanning this critical climatic transition are still extremely scarce, because deep water sedimentary successions have all too often been strongly affected by carbonate dissolution, burial diagenesis or hiatuses caused by deep sea currents. The complete, carbonate-rich, high sedimentation rate Miocene sedimentary sequences of the South China Sea offer the unique possibility to directly link changes in terrigenous flux from the Asian continent to high resolution marine carbon and oxygen isotope records. The record of ODP Site 1146 already allowed reconstruction of this critical interval of climate change in unprecedented details (Holbourn et al. 2005). Further drilling of South East Asian sediments along depth transects from the shelf to the deep sea will undoubtedly provide new insights into the relation of  $\delta^{18}\text{O}$  variations to sealevel and into the processes driving long- and short-term climate changes, in particular the influence of SE Asian tectonic evolution on Miocene global cooling and the swift reversals in ocean overturning that coincide with rapid warming events.

## **Internal structure of the Korea Strait shelf mud off SE Korea and the Holocene relative sea-level change**

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The Korea Strait shelf mud (KSSM) off SE Korea consists of over 60-m thick recent mud, deposited since the early Holocene (ca. 8000 yr BP). The structure of the central part of the KSSM, interpreted from multi-channel sparker profiles, was corrected for the velocity effect of shallow gas to better determine the overall geometry of the KSSM. The central part of the KSSM can be divided into three seismic units: the bottom (ca. 8000 – ca. 5200 yr BP) and top (ca. 2600 yr BP to present) units, characterized by aggradation and the middle unit (ca. 5200 – ca. 2600 yr BP), exhibiting oblique progradation. The Holocene relative sea-level curve, derived from the internal reflection patterns of the KSSM, was corrected for the depth of wave base that controls base level for fine-grained sediments. The sea-level curve is composed of four distinct stages: stage 1, corresponding to the bottom unit, characterized by a gradual rise to about 80 m below the present level; stages 2 and 3, corresponding to the middle unit, characterized by a short, rapid rise to about 35 m and a following fall to about 55 m, respectively; and stage 4, corresponding to the top unit, characterized by a gradual rise to the present level. The Holocene relative sea-level curve lies significantly deeper (-80 m) than the global sea-level curves. This is probably in part due to local tectonic movements, responsible for the widespread normal faulting along the landward part of the area, which caused syn- and/or post-depositional deepening of the KSSM.

Keywords: Holocene sea-level change; mud belt; coastal onlap; wave base; shallow gas, velocity pull-down

## **Flux and Fate of Asian River-derived Sediments in the Western Pacific Marginal Seas**

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Rivers are the major carriers for delivering large amounts of land-derived freshwater, sediment, and natural elements to the global ocean. Collectively, the global rivers annually discharge about 35,000 km<sup>3</sup> of fresh waters and  $22-22 \times 10^9$  tons of solid and dissolved sediment to the ocean. Among them, approximately 70% has been delivered from Asian large rivers (e.g. Yellow, Yangtze, Pearl, Red, Mekong, and Ganges-Brahmaputra, etc) and numerous small mountainous rivers (e.g. rivers in Taiwan, Indonesia, and Papua New Guinea, etc) into the Western Pacific marginal seas, e.g. Yellow Sea, East China Sea, and South China Sea. As a result, Asian rivers, especially those large rivers, play important roles in not only controlling the physical and biogeochemical features of the Asian estuaries and Western Pacific ocean margins, but also in impacting on the evolution and culture development of Asian society.

Field studies show nearly 50% of Asian large river-derived sediment has been deposited in the lower reach of the river mouth, forming many extensively distributed subaerial delta plain, and rest of them discharges into the adjacent ocean. Among those being discharging into the ocean, nearly half of them has been found to be longshore-transported several hundreds kilometers from the river mouth. There is very little or few percent of the total sediment discharge has been found to be across-shelf transported into the deep ocean.

In contrast, sediment from small rivers has a very different fate. Some major small mountainous rivers in active margins (e.g. Kaoping, Choshui, Lanyang, etc), usually do not form deltas and are mainly controlled by episodic events, contribute more than 50% of global terrigenous sediments to the sea. However, more than 80% of their sediment discharges are transported directly to the shelves or deep canyons mainly via gravity/turbidity or hyperpycnal flows, which are distinctly different from the above large rivers that discharge to passive margins or shallow marginal seas.

## **Tertiary deformation of continental SE Asia and possible links with South China Sea tectonics: where do we stand ?**

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More than 20 years ago, Tapponnier and co-workers formalized the extrusion hypothesis: a large part of continental SE Asia (Sundaland) was extruded away in response to the collision between India and Eurasia (e.g. Tapponnier et al Geology; Peltzer et al., JGR; Tapponnier et al. 1986). Such extrusion would imply several hundreds of kilometres of left-lateral displacement along the Red River fault zone linked with the opening of the South China marginal sea. The extrusion hypothesis focussed the attention of many earth scientists because of its implications, not only on the regional geology, but also on the rheology of the continental lithosphere: deformation can be localized along few main discontinuities and particularly large strike-slip shear zones.

A lively debate is still opposing the “pros” and the “cons” of the extrusion hypothesis. This debate has focussed on several issues of the East Asia deformation history: 1) How much left-lateral displacement occurred along the Red River fault zone? When? 2) Are such left-lateral displacements linked with the opening of the South China Sea? 3) Did the sense of shear switched to right-lateral along the Red River fault zone? When? Is the fault still active? 4) What are the Tertiary deformations of the Sundaland and South China blocks on both sides of the Red River fault zone? Is lower crustal channel flow taking place from Tibet to Yunnan? Since when?

Our continuous field work in Asia since two decades allows us to bring clear answers to several of these questions while some other stay open. The aim of our talk will be to synthesize the progress made on the Tertiary deformations of SE Asia and discuss what could be the critical targets for future onshore and offshore studies.

## **Deciphering an orogen's evolution from its sediment record: examples from the Himalaya**

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The detrital record of material eroded from a mountain belt and stored in adjacent sedimentary basins, can provide invaluable information on an orogen's evolutionary history, especially where information in the mountain belt itself is overprinted by later metamorphism. Isotopic techniques applied to single detrital grains have proved of particular value, particularly for sediments of mixed provenance where "whole rock" studies can produce only an averaged signal. The advent of double and triple dating, using different techniques on the same grain, has allowed a more complete cooling history of a detrital mineral to be determined. Here, techniques are illustrated with examples from onshore studies of Himalayan-derived sediment which are located in regions pertinent to understanding the evolution of the Bengal and Indus Fans. They could be of equal value implemented on Red River sediments, both on- and offshore.

Potential Bengal Fan provenances include the Himalaya-Tibet region (both Gangetic and Brahmaputra drained), Indo-Burman ranges, and Indian craton. Characterisation of these sources allows their recognition in the Bengal Fan. Isotopic fingerprinting of the Palaeogene and Neogene sediments of the Himalayan foredeep allows characterisation of the palaeo-Gangetic sediments to be deduced and provides information on the early exhumational history of the southern flank of the Himalaya. We present results which document onset of Himalayan erosion in the Eocene<sup>1,2</sup>, and a magnetostratigraphically dated section from 21-5 Ma which dates the timing of transfer of exhumation into the footwall of the MCT at 16 Ma<sup>3</sup>, with erosion of the Lesser Himalaya since at least 11 Ma<sup>4</sup>. Tertiary sediments of the Indus-Tsangpo Suture Zone and Tethys Himalaya should reflect palaeo-Brahmaputran sediments from its upper reaches. Work by myself and others<sup>5-7</sup>, on the characterisation of these sediments in southern Tibet will be discussed. Work by Allen et al.<sup>8</sup> provides the first comprehensive characterisation of the sediments of the Sunda arc accretionary complex in the Indo-Burman ranges (IBR) Burma, Chittagong Hill Tracts (CHT) Bangladesh, and in the Andaman Islands, where it is proposed that early Bengal Fan sediments may be offscraped and preserved<sup>9</sup>. CHT provenance, determined from seismic data, Ar-Ar, fission track and Sm-Nd analyses, documents Himalayan provenance. IBR and Andaman analyses are ongoing.

To the west, the route of the palaeo-Indus remains controversial<sup>10</sup>. The Palaeogene

Molasse of the Indus Suture Zone is interpreted by Clift et al<sup>11</sup> to be palaeo-Indus deposits, whilst Sinclair and Jaffey<sup>12</sup> consider the rocks to be the products of internally drained basins, with the palaeo-Indus not routing along the suture zone until the Neogene. Our current project (lead: PhD student A. Henderson) combines extensive mapping and facies analysis of the Tertiary Molasse in Ladakh, with isotopic analyses of the detrital minerals, in order to distinguish between these two hypotheses, and to document the early erosional and exhumation history of the orogen in this area. The Neogene route of the palaeo-Indus is no less complicated. Previous studies suggest river capture at 11 Ma<sup>13,14</sup>. However, data from the detrital record in the foreland basin shows a major increase in arc-derived material since 18 Ma. Detrital Ar-Ar lag time data indicate rapid exhumation of a subordinate metamorphic source region at that time, either the Nanga Parbat region or, less likely, the Asian plate. We interpret that the river draining into the foreland basin cut back in to the arc and further north at that time, capturing the Indus River<sup>15</sup>.

<sup>1</sup>**DeCelles, P. et al.** 2004. *EPSL* 227, 313-330.

<sup>2</sup>**Najman, Y. et al.** 2005. *Geology* 33, 309-312.

<sup>3</sup>**White, N. et al.**, 2002, *EPSL*, 195, 29-44.

<sup>4</sup>**Najman, Y. et al.** 2006, *Geophysical Research Abstracts* 8, abstr no: *EGU06-A-00466*

<sup>5</sup>**Aitchison, J. et al** 2002, *J. Asian Earth Sci.* 21, 251-263

<sup>6</sup>**Wang, C. et al**, 2002. *Terra Nova* 14, 114-120.

<sup>7</sup>**Zhu, B. et al**, 2005. *J. of Geology* 113, 265-285.

<sup>8</sup>**Allen, R. et al** 2005. *J. Asian Earth Science* 26, 123.

<sup>9</sup>**Curry, J.** 2005. *J. Asian Earth Sciences* 25, 187-232

<sup>10</sup>**Najman, Y.** 2006. *Earth Science Reviews* 74, 1-72

<sup>11</sup>**Clift et al**, 2000. *Eos* 81, 277-281.

<sup>12</sup>**Sinclair, H & Jaffey, N** 2001. *J. Geol. Soc London* 158, 151-162

<sup>13</sup>**Cervený et al.** 1989. *GSA Special Publ.* 232, 129-136.

<sup>14</sup>**Abassi, I & Friend, P.** 1989. *Z. F. Geomorph.* 76, 75-88.

<sup>15</sup> **Najman et al**, 2003, *GSAB*, 115, 1265-1277

## **Strain rates and palaeo-stresses in the Ailao Shan-Red river ductile shear zone.**

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On the Earth surface, deformation is mostly localized in fault zones in between tectonic plates. In the upper crust, deformation is brittle, the faults are narrow and product earthquakes. In contrast, deformation in the lower ductile crust corresponds to larger shear zones. If it is relatively easy to measure in situ deformation rates at the surface of the crust using for example GPS data; it is much more difficult to determinate in situ values of strain rate in the ductile crust. Such strain rates can only be estimated in paleo-shear zones.

We have applied a new direct method to obtain local strain rates on shear zones, coupling quantification of deformation and geochronology, on the Ailao-Shan - Red River Shear Zone (ASRRsz) in SE Asia. For this ~1000 km long shear zone, large-scale fault rates determined in three independent ways are 3.3 to 6 cm/yr. between 35 and 16 Ma, corresponding to strain rates between  $1.17 * 10^{-13} \text{ s}^{-1}$  and  $1.52 * 10^{-13} \text{ s}^{-1}$  for a 10-km-wide shear zone.

In outcrops where several generations of syntectonic dykes are present, the strain rate can be measured by quantifying the deformation and the age of each dyke. On one hand, we used a method of surface restoration to quantify the stretching and the minimum shear strain  $\gamma$  of boudins trails corresponding to the deformed dykes. The undeformed dykes make an angle of 30° with the shear direction that is taken as a reference for the initial angle prior to deformation of the other dykes. The more deformed dykes yield values of  $\gamma$  between 4.7 and 6.7. On the other hand, we determined the emplacement age of each dyke, by using an ion microprobe to determine the Th-Pb age of monazites. The more deformed dykes give an age of  $29.9 \pm 0.5$  and  $29.9 \pm 0.4$  Ma, while the undeformed dyke yield an age of  $22.5 \pm 0.2$  Ma. Moderately deformed dikes yield intermediate ages of  $24.2 \pm 0.4$  and  $26.2 \pm 0.5$  Ma. Such minimum shear strains and ages yield minimum strain rates of 2.8 to  $3.1 * 10^{-14} \text{ s}^{-1}$ . The fact that these strain rates are 4 to 5 times smaller than those calculated at larger scale can be due to the fact they are minimum estimates, that the shear zone could be wider than 10 km, that

deformation was not uniform at the scale of the shear zone, or a combination of these factors. In rocks from the same shear zone, the mean sizes of recrystallised quartz grains within mylonitic quartz ribbons vary between 70 and 120  $\mu\text{m}$ . This correspond to shear-stresses between 15.6 MPa and 23.4 MPa if applying the experimental piezometer of Stipp and Tullis (GRL, 2003). If these estimates are paired with the corresponding temperature of deformation estimated from quartz LPO's, and introduced in a classical power flow-law most samples yield strain rates between  $2.10 \cdot 10^{-14}\text{s}^{-1}$  and  $1.15 \cdot 10^{-13}\text{s}^{-1}$ , with one value at  $8.07 \cdot 10^{-13}\text{s}^{-1}$ . Such results are compatible both with the minimum estimates deduced from the deformation of the leucocratic dykes and the large-scale estimates. The highest strain rates value corresponds to the highest estimate of temperature of deformation ( $> 550^\circ\text{C}$ ) thus suggesting that deformation was not uniform at the scale of the shear zone but faster in hotter zones. Such values of strain rates and stress are furthermore in good agreement with numerical models taking into account the large-scale fault rate, the fact that the fault is lithospheric, and shear heating both in the brittle and ductile deformation fields (Leloup et al., 1999, G.R.L.)

## **The seaward extension of the Red River Fault Zone and its activity history**

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According to the geophysical and geological information, as well as the analogue modeling experiments, the RRFZ is supposed to split into two main branches along its seaward extension due to clockwise rotation. One branch is composed of the East Vietnam fault, Wanan fault and Lupar fault, which is also the present boundary fault of Indochina block; the other branch is through WNW-trending Zhongjiannan fault to Paleo-Tinjar fault, and the Tinjar fault is the present boundary fault of Nansha block (or Dangerous ground). Thus the Zengmu basin locating at the end between above two boundary faults was supposed to be formed by the clockwise rotation and divergence of the seaward extension of the RRFZ. Dating of the sediments in Zengmu basin suggests that the rifting of the basin started from late Eocene (Chen, 2002) at about 46Ma (Hutchison, 2004). This means that the RRFZ begin left-lateral slip at around 46Ma, which is consistent with the beginning of rapid rifting in the Yinggehai (or called ‘Song Hong’) basin. Inversion structures developed in the northwest of Yinggehai basin and the west of Qiongdongnan basin suggest that the Indochina changed motion at around 30Ma to make a narrow strike-slip zone southwest of Vinh Nihn fault in the Hanoi basin (Rangin et al., 1995) and a compression in the Yinggehai, Qiongdongnan and Zengmu basin. The inversion ceased at about 15.5Ma in Yinggehai basin and roughly the same time in Qiongdongnan basin, so we conjecture that the RRFZ stopped left-lateral slip at around Middle Miocene. On the other hand, the compressive inversion happened in the northwest of Beibu Gulf basin in very short time period around 10.4Ma suggests that the compressive stress comes from northwest and point to the dextral movement of the South China block along the RRFZ. At roughly the same time, along No.1 fault, the right boundary fault of the Yinggehai basin there is a depocenter migration and broadening of basin, suggesting a new phase of activity. Thus from sedimentation evidence, the activity of the RRFZ could be divided into at least three stages: sinistral slip associated with clockwise rotation from ~46 to 30Ma, a narrow sinistral slip stage from 30-15.5Ma and dextral slip stage after 10.4 Ma.

## **High and Dry in Central Tibet Since the Late Oligocene**

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The Tibetan plateau is the largest region of extreme elevation on Earth, and exerts a first-order control on climate and continental tectonic processes in central Asia. The timing of high elevation gain in Tibet remains controversial, with estimates ranging from 40 million to <7 million years (Ma) ago. New oxygen and carbon isotopic analyses of modern and ancient carbonate from the Nima and Zhada Basins indicate that the high elevation and dry climate of central and southern Tibet were established by 26 Ma. The maintenance of high elevation (4.5-5 km) for at least the past 26 Ma suggests that any flow of lower crust from beneath central Tibet must have been balanced by the northward insertion of Indian crust.

## **Late Quaternary evolution of the Sunda Shelf and outlook for IODP activities**

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Previous research of the Kiel working group on the Sunda and Vietnam Shelf was based principally on late Quaternary sea-level fluctuations and the corresponding sedimentary architecture. The Sunda Shelf as one of the largest shelf areas in the world offers excellent conditions for the reconstruction of the last glacial cycle by its extension, low gradient, high supply of terrigenous organic-rich sediment, tectonic stability. From detailed sediment core and seismic transects in the central (Natuna islands) and northern (off the Mekong Delta) sectors we developed a depositional model of the last glacial cycle and a high-precision sea-level curve for the deglacial sea-level rise after the Last Glacial Maximum (LGM). Detailed AMS-<sup>14</sup>C datings of terrestrial and coastal deposits provided the high-resolution age control.

The deposits during sea-level fall prior to the LGM lowstand and the subsequent deglacial sea-level rise correspond to four systems tracts: (1) wide, partly detached prograding deltaic clinofolds indicate forced regression related to a regressive systems tract; (2) sparse shoreline deposits and widespread soil-formation refer to a lowstand systems tract; (3) rapidly backstepping coastline-related deposits form a confined transgressive systems tract without stacking patterns and are mainly restricted to paleo-valley systems; (4) a thin marine mud cover extends as a condensed section over the whole shelf area as the base of a highstand systems tract. Correlation with the global sea-level curve has provided the age frame within which the units and surfaces of the last glacial cycle and also older sediment bodies have been identified.

The stratigraphic architecture on the Sunda Shelf over the last glacial cycle is the result of three major factors: (1) rapid sea-level changes; (2) locally pronounced physiography; (3) changes in sediment supply that determined the distribution and accumulation pattern.

The major regression after the Eemian (marine isotope stage 5e) highstand around took place stepwise down to the LGM lowstand with a total sea-level drop of more than 120 m. Regressive deposits are controlled by minor sea-level fluctuations around the general falling-trend with periods of some thousands of years before reaching the LGM lowstand at -122 m around 23000 cal yr BP. Deglaciation started with a possible initial rapid rise of more than 6 m around 20500 cal yr BP followed by a moderate sea-level rise up to -96m until 14600 y BP. Between 14600 and 14300 cal yr BP sea-level rose during this highly accelerated phase from -96 to -80 m corresponding to meltwater pulse 1A. After slower and more uniform rise during the early Holocene the highstand was reached around 6000 cal y BP with a sea-level

exceeding the modern one not more than 2.5 m.

Investigations should be extended now down to the Pliocene to address the multifaceted issues on formation and evolution of sedimentary strata in modern tropical epeiric seas during a period of major changes in sea level and climate. Direct response to sea level changes is stored in sedimentary archives deposited under shallow marine to terrestrial conditions. The most cogent objectives for drilling this modern tropical shelf by the use of Mission-Specific Platforms should be elaborated during this workshop.

## **Electron spin resonance (ESR) signal intensity and crystallinity of eolian quartz from Asian deserts and their implications for dust provenances**

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It is generally considered that the major sources for the Asian dust lie in the deserts of northern and northwestern China. However, relative contributions of dust particles among different sources to the eolian sediments of north China remain controversial. To investigate the spatial difference of modern deserts and specify the major sources of eolian deposits preserved in terrestrial and marine sediments, we employ ESR signal intensity and crystallinity index (CI) of eolian quartz as two potential indicators to trace the provenances of Asian dust. Surface samples were taken from nine deserts in north China and south Mongolia, and 9 loess samples were taken from the loess deposits in Vladivostok and the Chinese Loess Plateau. Since the ESR signal intensity and crystallinity of quartz may be different in clay-, silt- and sand-size fractions, we first carry out grain size separation and evaluate the difference of ESR signal intensity and crystallinity among different size fractions. Because only fine dust particles (<16  $\mu\text{m}$ ) can be transported regionally or globally, we focus on the fine quartz particles for further ESR and XRD analyses.

Estimated ESR signal intensity exhibits different value between fine fraction and other grain size fractions. The ESR signal intensity of fine fraction in all samples is higher than that of other grain size fractions. The crystallinity index exhibits a higher value in the fine fraction than other size fractions, except for one sample from Taklimakan desert. The ESR signal intensity and CI of fine quartz exhibit spatial discrepancies among those deserts. The highest and lowest ESR signal intensity values are identified from the Gurbantunggut desert and the Taklimakan desert, respectively. The CI of fine quartz from the two deserts are also different, with high values in the Gurbantunggut desert and low values in the Taklimakan desert. Another two notable deserts are the Tengger desert which is adjacent to the western loess plateau, and the stony/sandy desert in south Mongolia. Fine quartz from the Tengger desert is characterized by low ESR signal intensity and higher CI, whereas fine quartz from the Mon

desert has moderate ESR signal intensity and low crystallinity index. Difference in the ESR signal intensity and crystallinity index is also evident among other deserts. Spatial discrepancies among those deserts are evident, implying that the fine quartz of each desert is originated from different mother rocks. Applicability of the two indicators (ESR signal intensity and CI) for tracing dust provenances can be tested by two examples: loess deposits in the Vladivostok and loess/paleosol samples from the Chinese Loess Plateau.

## **Outline of IODP Proposal #605Full2 “Onset and evolution of millennial-scale variability of Asian monsoon and its possible relation with Himalaya and Tibetan uplift”**

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IODP proposal #605 Full2 is proposed by an international community in East Asia that include Ryuji Tada, Takuya Itaki, Ken Ikehara, Takeshi Nakajima from Japan, Jang Jun Bahk, Sang Hoon Lee from Korea, Youbin Sun, Hongbo Zheng from China, and Sergey Gorbarenko from Russia. It is ranked 4th at SPC this year and has high possibility to be drilled in the near future once site survey will be completed. Below is the abstract of the proposal. In the workshop, I will briefly introduce the scientific background and outline of the proposal, and would like to discuss the way to enhance possible linkage with other proposals.

It is well demonstrated that Asian monsoon varied with the Dansgaard-Oeschger Cycles [DOC]. Recent studies further suggest that such variability may have been caused by oscillations in westerly jet circulation between two different modes of meandering. Because topographic effect of Himalaya and Tibetan Plateau [HTP] is considered as the probable cause of different modes of the westerly jet meandering, and increasing evidences suggest final uplift of HTP commenced during Plio-Pleistocene, it is hypothesized that Plio-Pleistocene uplift of HTP, and consequent emergence of the two discrete modes of westerly jet meandering is the cause of the millennial-scale variability of the Asian monsoon and amplification of the DOC.

In this project, we aim to collect the geological evidence necessary to test this hypothesis through drilling in the Japan Sea and northern part of the East China Sea. We propose to drill two latitudinal transects in the Japan Sea to monitor the behaviors of the westerly jet and winter monsoon. We also propose to drill at the northern part of the East China Sea to monitor the Yangtze River discharge history that should have been reflecting variations in summer monsoon intensity. The southern transect will be used to reconstruct the behavior of the subpolar front and examine its relationship with the westerly jet and the sea level changes. Whereas the northern transect will be used to identify ice-rafted debris [IRD] events and reconstruct temporal variation in its southern limit, which we consider as winter monsoon proxies. Finally, we arrange two depth transects to reconstruct the ventilation history of the sea. We will examine the relation between the ventilation in the sea, and the nature of the influx through the Tsushima Strait and/or winter cooling.

Through the proposed drilling, we hope to 1) specify the onset timing of orbital and millennial-scale variabilities of East Asian monsoon and westerly jet, and reconstruct their evolution process and spatial variation patterns, and 2) reconstruct orbital and millennial-scale paleoceanographic changes in the Japan Sea during the last 5 m.y. to clarify the linkage between the paleoceanographic changes in the Japan Sea and variabilities of East Asian monsoon and/or sea level changes. Comparison of the obtained results with the uplift history of HTP will enable us to test the idea that topographic evolution of HTP was responsible for creation of bimodality in westerly jet circulation that caused amplification of millennial-scale variability of Asian monsoon.

## **Intertidal sediments, sedimentary provinces and sediment-microorganism interactions in the Ha Long Bay, Red River Mouths, Northern Vietnam**

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The present sedimentation in the Ha Long Bay is dominated by the Red River System. This relatively short river transports a high amount of sediment load (~ 12 kg/m<sup>3</sup>) to the estuaries of the river. Sedimentological research was aimed to quality the sediment composition, the sources of the sediment and sedimentary changes throughout the deposition. Further work was concentrating on the geochemical composition and sediment-organism interactions.

Sediment samples were collected along 4 traverses from the lowest to the highest water line, the distance between the sampling points was 30 - 50 m. The position of two traverses (HL and DC) was in the northern part of the Ha Long Bay, two further traverses (DS and DV) were situated in the southern part of the bay.

The grain sizes of all samples range from silt to fine sand and are characterized by a normal distribution. Quartz, feldspars, biotite, muscovite and several heavy minerals are the main constituents of the sediments. The carbonate content ranges from 1 to 2 wt.-%, the TOC concentrations from 0.8 to 6 wt.-%.

Transportation of the sediments has occurred along different distances. The HL profile is the most fluvial one. Also the sediments of the DC traverse have not been transported over long distances, but in addition to the fluvial source they may have a second source. The DS profile is the most marine one, sediments from the DV traverse contain substantial percentages of terrestrial materials with a short transport way. C/N ratios and the abundances of major and trace elements will be used to substantiate these classifications.

Micropalaeontological studies suggest that several taxa of the mostly cosmopolitan rotaliid foraminifera genera *Ammonia*, *Elphidium*, *Eponides*, *Discorbina*, and *Asterorotalia* seem to be sensitive in-situ monitors of marine pollution caused by exploitation of Late Triassic coal-seams which led to a remarkable increase of As- and Zn-concentration in the clayey sediments. Microbial cells and biofilms attached to these - mainly foraminiferal nutrients - quite probably initiate biomineralization reactions of foraminiferal test at biofilm /surface interfaces. Especially high concentrations of As and Zn are known to be stressful and dangerous factors for microorganisms initiating toxic effects in microbial cells. The resulting morphological foraminiferal deformities include wrong coiling, aberrant chamber shape and size (particularly inflated last chambers), poor development of the last whorl, twisted chamber

arrangement, additional chambers, protuberances, multiple apertures, irregular keel, twinning, and lack of sculpture.

## **Fingerprinting Individual River Basins using the $^{40}\text{Ar}$ - $^{39}\text{Ar}$ Incremental Heating Technique on Bulk Sediment**

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Resolving the provenance of fine-grained terrigenous material remains critically important for understanding problems related to climate and tectonics. A technique is outlined that uses the  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  incremental heating method to fingerprint bulk fluvial sediment entering the northeast Pacific Ocean for the goal of tracking sediment source and transport changes in the marine environment through time. We show that reproducible age spectra are obtained from individual rivers. Of the 33 samples analyzed, 23 samples display age “plateaus” - an interesting finding considering the sediment is multi-age and polymineralic. Two tests are illustrated to confirm the validity of the technique and address why polymineralic detritus might yield concordant age steps. The first model tests, in light of bulk mineralogy and diffusion of silicates, whether measured K/Ca spectra (determined from  $^{39}\text{Ar}$  and  $^{37}\text{Ar}$ , respectively) are reasonable considering typical values seen in K- and Ca-bearing minerals. The model shows that the bulk mineralogy is reflected in the outgassing K/Ca spectra and that plagioclase is likely to be driving the age plateaus, followed by potassium feldspar. Secondly, a simple model is invoked to predict bulk sediment ages in order to address the hypothesis that bulk sediment  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  plateau ages are representative of the average age of crystallization of rocks from a given river basin. The model takes into account rock exposure area, crystallization age and K-content of rock types within river drainages. Modeled and observed ages are very similar when topographic and lithologic complications are accounted for. Initial results documenting downcore provenance change in the northeast Pacific will also be presented illustrating the utility of the technique in the marine realm. Overall, this technique shows considerable promise, not only as a fingerprinting tool for individual terrigenous sources in the oceans, but also for understanding erosion and sediment transport related to climatic and tectonic processes in the fluvial environment.

## **Intertidal sediments, sediment-organism interactions and sedimentary provinces in the Halong Bay, Northern Vietnam.**

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The sedimentation in the Halong Bay/Northern Vietnam is dominated by the Red River System. This relatively short river transports a high amount of sediment load (12 kg/m<sup>3</sup>) to the estuaries of the river. Sedimentological research was aimed to qualify the sediment composition, the sources of the sediment and sedimentary changes throughout the deposition. Further work was concentrating on the geochemical composition and sediment-organism interactions.

Sediment samples were collected along four traverses on intertidal flats in the Halong Bay area. Every traverse was from the lowest to the highest water line, the distance between the single sample points was 30 – 50 m. The geographical position of the first two traverses, the HL- and the DC profile, was in the northern part of the Halong Bay. Two traverses, the DS and the DV profile were collected in the southern part of the bay. The research methods are grain-size distribution, TOC, DC and N content, the mineral composition, the clay minerals and the geochemistry.

All traverses contain fine-grained clastic sediments. The composition and the grain sizes show a normal distribution of intertidal estuarine sediments and ranges from silt to fine sand. The mineralogy contents quartz, feldspars, biotite, muscovite and several heavy minerals. The carbonate content ranges between 1 and 2 wt-%. The sediments are characterized by a high content of organic matter. The TOC ranges from 0,8 to 6 wt-%.

Transportation of the sediments has occurred along different distances. The HL profile is the most fluvial one, with a higher sand content and a high amount of quartz. Sediments of the DC traverse have not been transported over long distances, but in addition to the fluvial source they may have a second source. The DV and the DS profiles are richer in fine grained fractions. The DS profile is the most marine influenced one. The TOC content and the C/N

ratio also support this suggestion. The TOC in the DV traverse is coming partly from terrestrial material, with a short transport way, the C/N ratio is higher. This could mean that the organic matter comes also partly from rivers or from terrestrial material.

A correlation between Si/Al and the Si/Fe ratio shows similar results. The HL profile shows a short transport distance. The constituents of the samples of the DS and the DV traverse are transported over a greater distance, but have the same source as the samples of the HL profile. The sediments of the DC traverse have been transported over a short distance, but the sediments are poorer in iron than those of the other traverses. This means that the sediments are coming from another source, or some chemical processes are at work in these sediments which enlarge the iron content. The samples of the HL traverse have ratios of Si/Al and Si/Fe which are similar to Chinese loess.

Benthic foraminifera of the marine dominated sediments show a quite wide range of test deformations which may have been caused by pollution such as heavy metal contamination or other anthropogenic influences. Due to recent world-wide studies they are obviously sensitive in situ-monitors of sediment pollution (comp. poster Lichtschlag et al.).

## **Deciphering the history of Himalayan erosional flux from Ganges-Brahmaputra delta sediments: Insights on source-to-sink sediment dispersal and their implications for deep-sea fan deposits**

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Thick sediment sequences deposited by the Ganges and Brahmaputra rivers in the delta of Bangladesh provide excellent high temporal-resolution records of Himalayan erosion and river-course dynamics. Specifically, these deltaic records are helping to unravel complex erosional responses to well-documented changes in the South Asian monsoon. Using the Sr and Nd isotopic composition of several boreholes throughout the delta, we are reconstructing the provenance history of sediments during the Holocene and into the last glacial maximum (LGM). Results show changes in provenance timed with shifts in the strength of the Southwest Asian monsoon in the early Holocene and at the LGM. Since each river drains a different set of Himalayan lithologies, we find that the various regions of the Himalaya differ in their response to millennial-scale (monsoonal) and glacial-interglacial time scale climate changes. In particular, we note an increase in High Himalayan Crystalline Series (HHC) input correlated with maximum monsoon intensity in the early Holocene. This provenance shift is also associated with an increase in sediment loading to the delta at that time. During the LGM, little to no sediment input from the Tibetan Sedimentary Series (TSS) is delivered to the delta, despite it being a major component at other times. Although the cause is uncertain, this suggests that the Tsangpo reach of the Brahmaputra was not contributing sediment to the downstream transport system. Finally, Bengal Fan records from the Tertiary indicate that lithologies drained by the Ganges dominate the sediment load on longer timescale. In contrast, we find a general pattern of high TSS input during the late Quaternary, indicating a potential strengthening of the effects of the monsoon on Tibet, or an increase in the relative importance of the Brahmaputra in delivering sediment to the margin. Ongoing isotopic measurements continue to help us determine the causes of these observed shifts in sediment delivery to the Ganges-Brahmaputra delta. Taken together, though, isotopic data from the delta, shelf, and fan comprise a complex sedimentary archive, one that reveals a more dynamic Himalayan erosion-transport-deposition system than suggested by past notions of a simple on/off

monsoon control. Furthermore, the delta appears to provide a record of Himalayan erosional flux that is unique from that reconstructed from fan deposits, implying that the delta acts as an important filter and gateway between the source areas and deep-sea repository.

## **Late Miocene and mid-Pliocene Enhancement of the East Asian Monsoon As Viewed from the Land and Sea**

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The late Miocene onset of the Indian monsoon and the late Miocene and middle Pliocene enhancement of the East Asian monsoon appear to be the result of coeval uplift episodes in the Himalayan-Tibetan region. A decrease of the abundance ratio of planktonic foraminifera *G. sacculifer*/*G. ruber* and increase of *Neogloboquadrina* approximately 8 Myr at ODP site 1146 in the South China Sea indicate lowering of the surface temperature and increased productivity, which are interpreted to have been caused by an intensified influence of the East Asian winter monsoon winds. In the Arabian Sea, monsoon-driven upwelling indicated by the appearance and abundance of planktonic foraminifera *G. bulloides* and radiolaria increased remarkably at ~ 8 Myr. Wind-blown sediment started to accumulate over a wide area of the Chinese Loess Plateau at ~ 8 Myr, about the same time as a pronounced pulse of eolian dust to the North Pacific, as revealed at ODP site 885/886, indicating onset of widespread aridity in the Asian interior. At 3.6 Myr the accumulation of eolian sediment increased by about an order of magnitude, both at proximal settings in China and in the distal North Pacific Ocean. The planktonic foraminifera *Neogloboquadrina* also underwent a further increase in abundance in the South China Sea at this time.

Existing evidence from inland Asia and the surrounding seas suggests a late Miocene onset (or significant intensification) of the East Asian and Indian monsoons, the reason being their link with the uplift of the Himalayas and the Tibetan Plateau. The first increase in mean sediment flux to the Indian Ocean at 11 Myr and strong peak beginning between 9 and 8 Myr indicates the rising of the Himalayas. That rise could have reached sufficient height to produce a rain shadow in Central Asia, causing aridity and providing a source of dust to be transported eastwards into north China and the North Pacific. Further rapid uplift of the entire Tibetan Plateau at 3.6 Myr, as evidenced by the extensive conglomerates of that age on the north flank of the Plateau, resulted in further aridity in the basins of central and eastern Asia, an enhanced East Asian monsoon, and a second, late Pliocene, pulse of terrigenous sedimentation in the Indian Ocean.

## **Climatic and Tectonic Evolution of Eastern Asia: Evidence from the Ulleung Basin, Southwestern East Sea / Japan Sea**

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We propose to examine four climatic and tectonic problems in eastern Asia by drilling a single deep hole in the Ulleung Basin in the southwestern East Sea/Japan Sea. The proposed site is in 2220 m of water and will recover approximately 3.9 km of hemipelagic sediments, distal turbidites, mass-transport deposits, sediment-sill complexes and 200 m of volcanic basement. We shall also determine the age, paleomagnetic character and geochemistry of the igneous basement. The sedimentary cover will be analyzed to characterize the temporal variations in lithology, chemistry and microfauna since early Miocene basin opening. Structural data will constrain the modern and paleo-stress regimes in the Ulleung Basin. We plan to test hypotheses regarding: (1) the strengthening of monsoonal conditions in eastern Asia since the early Miocene, (2) the timing and nature of changes in water circulation in the East Sea/Japan Sea and their relationship to gateway development in the Korea/Tsushima Straits, (3) tectonic evolution of the Ulleung Basin and implications for the interactions with adjoining plates and subduction systems, and (4) back-arc volcanism and consequences for geochemical balances and subduction petrogenesis. Our proposed drilling addresses a number of primary scientific objectives highlighted by the IODP science plan. Our paleoceanographic-climatic objectives, in particular, complement high-resolution work proposed by other workers in the East Sea/Japan Sea. However, our longer-term record will allow competing models for climatic-tectonic that propose coupling of the Monsoon and Tibet at either 8.5 Ma or 16–18 Ma to be tested. The absence of such long-term climatic records currently prevents models for solid Earth-atmospheric interaction from being assessed.

## **Changes in the Asian monsoon system caused by mountain uplift in a climate model**

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In order to study the effect of progressive mountain uplift on the Asian monsoon system, a series of experiments with mountains of 0% (no mountain), 20%, 40%, 60%, 100% (control run), 120%, and 140% of the standard (present-day) heights were performed by using a coupled ocean-atmosphere-land surface model. The land-sea distribution and vegetation are the same for all experiments and all mountains in the world are varied uniformly for simplicity.

It is found that the southwesterly summer monsoon flow from the Indian Ocean becomes strong by mountain uplift and transports moisture toward East Asia, which results in movement of precipitation area to the inland of the Asian continent and formation of the baiu rainband from the South China Sea through Taiwan to Japan. These changes in the precipitation pattern causes increase of freshwater discharge to the adjacent seas by rivers in the East Asia. Combined effect of the increase of river runoff and precipitation results in decrease of sea surface salinity (SSS) in the Bay of Bengal, the South China Sea, the East China Sea and the Sea of Japan. In contrast with the decrease of SSS, increase of SSS is induced in the Arabian Sea due to increase of evaporation and decrease of precipitation and river runoff.

The summer upwelling region in the Indian Ocean also changes from the eastern region off the Sumatra and Java to the western region off Somalia and Oman in association with the changes in the wind fields by mountain uplift. Sea surface temperature decreases in the western coastal region and increases in the eastern equatorial and coastal regions, corresponding to the shift of the upwelling region.

## **Korean IODP (K-IODP) Activities**

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Korea joined the ODP in 1996 with Canada and Australia. The PacRim Consortium, consisting of organizations from Australia, Canada, Chinese Taipei and Korea was established January 1997, and Korea had participated this consortium as a one-twelfth membership until the end of ODP.

In 2004, Korea constructed Korean IODP (K-IODP) Project Team to effectively manage IODP activities. The primary governing arm of the K-IODP organization is the K-IODP Council. The chairperson of the Council is the president of the Korea Institute of Geoscience and Mineral resources (KIGAM) and members consist of representatives of research institutions, universities, other organizations or administrations related to the geoscience community. The K-IODP Council as the ultimate decision making body, is responsible for the K-IODP budget and selection of K-IODP Scientific Committee (SciCom) members, and revision/amendment of the K-IODP articles. The K-IODP Scientific Committee and Secretariat are under the K-IODP umbrella. K-IODP SciCom selects the panel members and to discuss issues such as revision of K-IODP articles and K-IODP structures. It also gives recommendations for shipboard scientists and evaluates IODP-related research proposals. The K-IODP Secretariat is from the KIGAM. The main role of Secretariat is to support K-IODP Council and SciCom, to administer the KODP budget, and to manage national office. Korea is planning to join the IODP this coming May as a Asian Consortium to expand the research field and to enhance the cooperative work with the other international member countries. As a contributing participant, Korea will have a right to send scientists on IODP cruises, to access samples and data, and to be involved with the planning process for future cruises. For these purposes, MOMAF (Ministry of Maritime and Fisheries) selected KIGAM as a representative institution through the public subscription. KIGAM will take a role of main participating organization, but with many other research institutions, universities and private companies also get involved in the K-IODP.

The main task of K-IODP is to do research on the ODP and IODP samples, to recruit scientists for IODP cruises, to write a drilling proposal on the East Sea and other areas within the Korean jurisdiction, and to look for other international partners to join Asian Consortium.

**The history of East Asian monsoon and climate during the last 140,000 years: ODP Sites 1143 and 1144, South China Sea.**

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The Asian monsoon system is a major component of both regional and global climate, its evolution is linked with the uplift of the Himalayan-Tibetan orogen, the The East Asian monsoon system is characterized by strong summer and winter monsoonal circulation, unlike the Indian Monsoon, which shows strong summer and weak winter circulation. Moreover, an important tele-connection between Asian monsoon and high-latitude climate has been confirmed by the comparison and correlation between high-resolution studies of low- and high-latitude records.

The location of the South China Sea between the Asian continent and the Pacific Ocean makes it ideal to record 1. the paleoceanographic responses to summer and winter monsoon, and 2. the changes in continental input related to climate changes because the basin receives sediment material from three of the largest rivers in the world, namely Mekong, Red, and Pearl river.

ODP Leg 184, which represents the first Ocean Drilling Project campaign to the South China Sea, recovered an almost complete sequence of hemipelagic sediments from lower Oligocene to Holocene. The sediments represent simple and monotonous mixing of nannofossil ooze and detrital clays derived from Asia, via the Pearl and Red Rivers on the northern margin and via the Mekong, Molengraaf and directly from Borneo on the southern margin. Post cruise analyses have produced high quality datasets, consisting of stable isotopic, mineralogical, geochemical, and micropaleontological data.

A multi proxy study, including mineralogy, grain size analysis, inorganic and organic geochemistry, was carried out on sediment samples from ODP Sites 1143 and 1144. The goal was to reconstruct the sedimentation and climatic history of this region during the last 140,000 years, when sea level variations interacted with monsoon variability. Along with glacial-interglacial variability, both records show proofs of intense and short lasting cold periods and correlate with loess records in China and marine records from the North Atlantic.

Here, the outcomes of the study of ODP Sites 1143 and 1144 will be discussed and compared to the newest results in the study of the Asian monsoon system with the goal of showing the great potential of further studies in this particularly interesting area.