White Paper: Climate-Tectonic Interactions in the Context of the Asian Monsoon for WG4.7: Tectonic-climate interactions and WG.4.5: Continent-ocean fluxes, weathering processes and linkages

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Abstract

Constraining the processes that control the Earth's climate system is a primary objective for ocean and Earth scientists. While variations in the climate linked to orbital processes have received significant attention, links between climate and solid Earth dynamics remain less well studied, in part because we lack the very long duration records required to reconstruct climate, erosion and weathering processes on tectonic timescales. As a result, the effects of mountain building on climate and vice versa are poorly understood. Growth of the Tibetan Plateau, mostly since ~50 Ma, is hypothesized to have intensified the Asian monsoon system. This in turn has a powerful effect in controlling weathering and erosion and thus the exhumation of deep-buried rocks in the Himalaya and other Cenozoic mountains across Asia. Erosion of these mountains has constructed the largest sediment bodies on Earth and buried large volumes of organic carbon, which may, along with the weathering of silicate minerals under the influence of monsoon rains, be a powerful control on atmospheric CO_2, itself a major control on climate. The potential for large feedbacks between tectonic, climatic and weathering and depositional processes is enormous, with possible influence over global climate. However, the timing of initial intensification and subsequent development of the monsoon, as well as the timing and patterns Tibetan-Himalayan surface uplift are still poorly understood and controversial, and will likely remain so without long-term weathering, erosion and depositional histories. We propose that IODP focus on retrieving these long records in critical locations that can be used to compare with tectonic and elevation histories reconstructed onshore in order to test for linkages and explore feedbacks so that better climate models, supported by improved ground-truthing, may be developed in order to prove genetic relationships and quantify feedbacks.

Research Focus

Barely recognized in the twentieth century, the interactions between climate and tectonics, modulated by erosion and deposition, have moved to the forefront of Earth science research in the twenty-first century. The growth of high terrain in Asia, including the Tibetan Plateau, and its plausible impacts on not just regional, but possibly global, climate make this region the target of choice for those who seek to understand such interactions. One of the critical obstacles to such study is the lack of long time series that record, via proxies, the history of both climate and tectonic activity. Only ocean drilling can obtain the material needed to construct time series sufficiently long to examine this history. Because the common denominator of virtually all major advances resulting from deep-ocean drilling is time series obtained from sedimentary records, we call attention to the opportunities for future drilling to make another breakthrough by sampling the margins and deep sea fans of south and eastern Asia, which contain records of both regional climate and evolving erosion and exhumation.

The Earth's climate is known to vary through geological time as a result of both external forcings, including orbital cycles and internal climatic feedbacks, as well as changing boundary conditions such as the positions of continents, growth of mountains and gateway openings and closures. Significant progress has been made in linking climate to changing solar insolation driven by orbital cycles. However, links between tectonic processes and climate have remained more conjectural because of a lack of long-duration marine sedimentary records, which have to be recovered by coring, and because of a lack of robust, appropriate proxies. The archetypal example of climate-tectonic coupling is the proposed link between the intensity of the Asian monsoon and the uplift history of the Himalaya-Tibetan Plateau, which is believed to have influenced both local and global climate during the Cenozoic. Although atmospheric scientists have demonstrated the importance of a wide, high Tibetan Plateau in controlling the climate in South and East Asia, it has yet to be demonstrated that the monsoon and Tibet have developed together over geological time. This is partially because the surface uplift history of Tibet remains controversial, and partially because the long-term evolution of the monsoon is poorly known beyond the past few million years. A long-term reconstruction of mountain building, erosion, and deposition synchronous with monsoon activity is key to testing the proposed links between climate and Tibetan evolution. Such records would enable us to evaluate the importance of other possible triggers such as the retreat of shallow seas from Central Asia, opening of South China Sea, or the formation of the Western Pacific Warm Pool

Initial studies after the Ocean Drilling Program (ODP) campaign in the Indian Ocean in the late 1980s emphasized a climate change event at 8 Ma as being the time of monsoon intensification. While, little doubt exists that this was time of climate change, the cored record in the Arabian Sea is only ~16 m.y. long in the classic offshore Oman region (e.g., ODP Site 730). In contrast, India-Asia collision dates back to around 50 Ma and the Greater Himalaya themselves are at least 22 Ma old. As a result, very few records of monsoon intensity extend as far back as the major known tectonic events, making convincing testing of climate-tectonic coupling impossible. Indeed, the community is even unclear as to whether the East and South Asian monsoons are coupled over long periods of time, as might be anticipated by some numerical models. Whether the summer and winter monsoons coevolved simultaneously also remains a question.

Proposed Work

This White Paper is submitted in support of drilling that focused on reconstructing the long-term evolution of the monsoon. Although IODP drilling is a powerful tool for monsoon research, we recognize that to reach our science goals drilling data from the continental margins and oceans must be integrated with data sets from the mountains and flood plains onshore, as well as far-field drilling on the edge of the monsoon region, if we are to derive a comprehensive understanding of tectonics-climate linkage. "Climate-tectonic" themes were highlighted in the IODP science plan, but no drilling has yet been undertaken to address this theme or to act on the recommendations of the 2008 Detailed Planning Group for monsoon studies. We argue that now is the time to make critical progress on this matter, through operations in both South and East Asia, as well as the far-field North Pacific Ocean.

Unlike earlier monsoon-oriented cruises (ODP Legs 117 and 184), which focused on oceanographic processes, the proposed new phase of drilling is designed to look at the varying compositions and volumes of clastic sediment on the Asian margins and deep sea fans in conjunction with oceanic processes such as sea level change, paleoproductivity, fresh water run-off, and upwelling. We do this to reconstruct how the environmental conditions in Asia have changed with the changing strength of the summer monsoon, as well as its relationship with tectonics and paleoceanography.

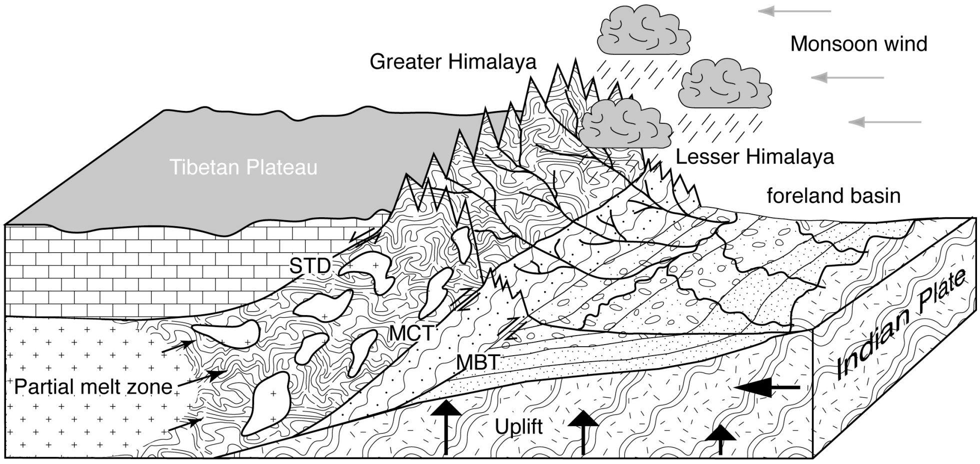
Our scientific objectives are three-fold:

(1) To use the varying chemistry and mineralogy of the sediments and sediment burial flux to reconstruct changing continental weathering intensities (and thus CO_2 consumption rates). A major problem is that there is little consensus about what makes a good chemical weathering proxy, although some are more favored than others. The chemistry or mineralogy of eroded sediments is not only controlled by chemical weathering intensity, but also by physical erosion rate, which is further complicated by rock uplift rates, provenance, and chemical weathering rates. If provenance can be shown to be stable then Sr isotopes, clay mineralogy and the degree of depletion of water-mobile elements can be used to quantify weathering. Quantitative understanding of the factors that control chemical and physical weathering is central to our goal of comparing weathering to independent rainfall and plateau altitude records. Quantifying rates of chemical weathering is important if we are to model the draw-down of CO_2 by this process during the Cenozoic.

(2) To use the organic carbon and biogenic component of the sediments to reconstruct past oceanic conditions (e.g. temperature, salinity) and productivity linked to the monsoon. In this respect we envisage using traditional paleoceanographic methods in key areas, such as the Oman margin, where there is an established link between oceanography and monsoon intensity, but current records are of insufficient duration. We suggest that appropriate areas in South and East Asia should be chosen based on the results of climatic simulations, which would also suggest the best climatic parameters to target for measurement by proxies. A multi-proxy approach is necessary to generate a robust and widely acceptable reconstruction and precisely evaluate leads or lags between tectonic and climatic events.

(3) To assess the erosional impact of the changing monsoon on the Himalaya and eastern flanks of the Tibetan Plateau. We propose to quantify the flux of eroded rock particles from the mountain sources to the continental margins during the Cenozoic. In contrast to Objective 1 we focus on the physical erosion at the Himalayan front and in the gorges of Eastern Tibet. Specifically we want to know where erosion is taking place, how quickly the sources were exhumed and how much rock was delivered to the continental margins in any given time period. This latter task will be achieved by constraining the volumes of sediment estimated from regional seismic stratigraphy and dated by drilling, combined with thermochronology work on the detrital minerals that allows source exhumation rates to be measured. In order to isolate the erosive effects of the monsoon from other processes, we need to correct for the effects of sealevel variation, because we know that this causes temporary storage of sediment

on the flood plain and shelf after erosion, followed by resedimentation into the deep ocean basin when sealevel falls.



Schematic model showing that while plateau uplift may cause monsoon intensification the monsoon summer rains cause focused erosion in the Himalaya and this in turn drives exhumation patterns and controls the orogenic structure. Sediments eroded from the mountain front form the submarine fans of the Indian Ocean. STD = South Tibetan Detachment, MCT = Main Central Thrust, MBT = Main Boundary Thrust.

In targeting the long term development of the monsoon we do not forget orbital scale variations, which can be useful for isolating the erosive effects of climate from those driven by tectonics. Glacial periods are typically associated with weak summer monsoon rains and the switching in climate especially since 2.7 Ma allows us to assess the effect of monsoon intensification on weathering and erosion. Furthermore, we aim to test the modeling prediction that the amplitude of orbital cycle response increased as Tibetan elevation increased towards the present day.

Each phase of the proposed work targets a specific part of the monsoon system and Himalaya-Tibetan Plateau, but together drilling across the Asian margins will allow us the continental scale perspective required to understand this phenomenon. The Indus Fan is the primary erosional repository for the western Himalaya and Karakoram and drilling this fan complements the earlier drilling on the Oman margin. Drilling in the Bay of Bengal will provide erosion history in the eastern and central Himalaya where the South Asian monsoon is strongest. A major goal is to understand when the Greater Himalaya began to form and how that relates to monsoon intensification.

Although the greatest erosion is in South Asia we do not forget the East Asia monsoons and the rivers draining eastern Tibet because the tectonically driven growth of the plateau is proposed to be the primary trigger for monsoon intensification. By looking at the basins in East and SE Asia we hope to isolate Tibetan erosional signals from the Himalayan flux that dominates the Indian Ocean. Coring the sediments delivered from SE Tibet will enable us to examine changing continental weathering in Indochina and SE Tibet, and also to test models for drainage evolution in East Asia. One hypothesis suggests that progressive surface uplift of Tibet has forced the re-organization of these rivers, by transferring headwater drainage from one to another. In particular, the Red River has been proposed to have lost large areas of headwater drainage. Reconstructing the history of river evolution can help us to understand the timing and patterns of Tibetan uplift, and is also essential to using sediment budgets in any one delta as a measure of monsoon-driven erosion intensity. Because this drainage evolution also impacts the Yarlung Tsangpo, this influence extends also to the Bengal Fan.

We also need to understand the sediment flux from Tibet into the East China Sea. Drilling in East China Sea combined with continental drilling in terrestrial basins in China will date the onset of flow from the Yangtze River (possibly captured away from the Red River) and provide information on the climate history of eastern China and the incision of gorges in Sichuan and Yunnan on the flanks for the Tibetan Plateau.

Outcomes

This proposed program of drilling would result in a new, tectonic-scale spatial-temporal reconstruction of evolving erosion rates and patterns, as well as environmental conditions for both South and East Asia over the course of the Cenozoic. When compared to oceanographic records of upwelling, productivity, and sealevel change these cores will allow us to assess any proposed land-sea linkages. In particular, we can test whether phases of monsoon intensification correlate with erosional events or not, and also if they coincide with periods of surface uplift reconstructed from Tibet itself. In addition, by quantifying the precipitation, exhumation rate and erosional-depositional flux from South Asia we can test models that suggest a major feedback between the solid Earth and climate via erosionally modulated exhumation. Are the Himalayas largely triggered by monsoon-driven erosion or by solid Earth plate tectonic forces? Reconstruction of spatial-temporal changes in terrigenous fluxes in the East Asia will tell us how drainage has evolved on the continental scale as progressive uplift of the Tibetan Plateau occurred. By looking at evidence of clastic fluxes linked to gorge incision in eastern Tibet, we shall be able to extend the constraints on the timing of plateau uplift that have been derived in a number of limited locations onshore.