The Holocene/Anthropocene Transition in the Mississippi River Delta

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This talk will examine how the Mississippi River Delta (MRD) transitioned from a system dominated by Holocene dynamics, to one dominated by Anthropocene dynamics. Whereas during the Holocene, rates of relative sea-level rise were relatively modest (often <1 cm yr^{-1}), and relatively constant over regional (1-50 km) spatial scales, during the Anthopocene, rates of relative sea-level rise were greater (>1 cm yr) and substantially more variable over the 1- 50 km spatial scale. Whereas during the Holocene, the course of the Mississippi River was driven largely by patterns of sediment infilling that drove avulsions, during the Anthropocene the course of the Mississippi River has largely been driven by needs for flood control and economic efficiency. Anthropocene and Holocene dynamics merge in subsurface flow, where levees influence the maximum stage of the Mississippi River, and the historic distribution of sandy channels influence pattern of groundwater flow. The early stages of Anthropocene development of the MRD were marked by nearly 4,900 km2 of land loss, about 20% of the deltas area. Looking forward, many plans to restore the Mississippi River involve Anthropogenic activities designed to partially mimic Holocene-era sedimentary dynamics. These involves the formation of artificial crevasses, designed to carry 100 to 2,000 m^3 s^{-1} of freshwater that distribution sediment across 10s to 1000s of km^2. The efficacy of these systems at providing ecosystem services can be further enhanced by the creation of artificial bars and barrier that enhance sediment trapping and retention. Ultimately, the sustainability of the MRD will require managing the interactions between hydrologic, sedimentary, economic and cultural factors.

Keywords: Mississippi , Groundwater , Restoration

Late Holocene to Present shoreline change at the mouths of the Mekong River delta

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The Holocene Mekong River delta prograded rapidly in a relatively sheltered bight in the South China Sea under the influence of high fluvial sediment supply 5300 to 3500 years ago, developing from an estuary into a delta. This bight infill led to increasing exposure of the prograding shoreline of the delta to ocean waves, resulting in a greater wave influence on the patterns and types of shoreline. In the eastern half of the delta where the river's sediment supply debouched into the South China Sea through several distributary mouths, deltaic progradation has been characterized by the construction of numerous sets of sandy beach ridges. The growth pattern of this sandy river-mouth sector over the last 2500 years has been determined from OSL dating of these beach-ridge deposits, while the most up-to-date shoreline trends (1950-2014) have been highlighted from the analysis of maps and satellite images. The OSL ages show that the total delta area remained nearly constant till about 500 yr BP, following which the mouths sector underwent significant accretion that may reflect changes in catchment land-use as well as in monsoon rainfall and attendant river water and sediment discharge. Since 1950, the trend has been dominantly one of accretion but punctuated by two periods of erosion. The first (1965-1973) occurred in the course of the second Indochina war, and the second more recently from 2003 to 2011, followed by mild recovery between 2011 and 2014. These temporal fluctuations most likely reflect changes in sediment supply caused by the vicissitudes of war and its effect on vegetation cover, as well as variations in monsoon rainfall and discharge, and, for the most recent period, massive sand mining in the river and deltaic channels. Continued accretion of the mouths sector has gone apace, over the recent multi-decadal period, with large-scale erosion of the muddy shores of the delta in the western South China Sea and the Gulf of Thailand, thus suggesting that the mouths sector may be increasingly sequestering sediment to the detriment of the rest of the delta shoreline. Fine-tuned analysis of the spatial pattern of change in the mouths sector shows marked variations that may reflect alongshore transport variations associated with gradients in wave energy caused by the multiple river mouths in a context of increasingly depleted sand supply. Accretion in the mouths sector is likely to be impacted in the coming years by large-scale channel bed sand mining, compounded by sediment trapping by recent dams in China. The overall current status of the entire Mekong delta shoreline, dominated by land loss, highlights increasing vulnerability to perturbations in sediment supply driven by human activities over the last few decades.

Keywords: River delta, Vulnerability, Sediment supply, Mekong

Risk trends in Vietnamese river deltas: Manifestations of environmental change or socio-economic transformation?

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Vietnam's Mekong and Red River deltas are often numbered amongst the global hot spots of environmental risk. Climate change and regional hydropower development are typically listed as the main risk drivers. What is much less understood, however, is how the country's socio-economic and political transformation process is changing the vulnerability of the population in the two deltas. The paper therefore analyses key risk trends in both deltas by examining, first, the role of changing hazard patterns and, second, the contribution of shifting vulnerability. It draws on empirical results collected in over six years of research in Vietnam, based on two long-term projects. The analysis brings to light an antagonistic pattern: While the political leadership is keen to frame deltaic environmental risks as being driven by external forces (notably climate change and upstream hydropower), the data suggests that locally driven environmental degradation as well as socio-economic marginalization and weak institutions play a much more immediate role in driving up natural hazards and social vulnerability, respectively. The paper discusses whether these local drivers of risk emerged "despite of" or "because of" Vietnam's pronounced socio-economic and political transformation process in relation with doi moi-reforms. The article concludes with debating the relevance and transferability of the findings for other delta environments in Asia and beyond.

Keywords: Risk, Vulnerability, Vietnam, Deltas

Modelling floodplain inundation of the Mekong Delta using a regional hydrodynamic model with a view to future scenarios

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With a very flat, low-lying topography and immediate proximity to the coast, deltas are one of the most hazardous regions for flooding. Flooding does provide an important resource to distribute fertile sediment in these regions, but can also result in devastating loss of life and property, with perhaps the most potent recent example being the 2008 Irrawaddy Delta floods. Therefore, careful management of appropriate flooding is vital to ensure sustainable management of these delicate systems.
Deltas are becoming increasingly populous with an estimated 500 million people now living on them, with much of the growth in mega cities. Yet, these regions also provide an essential agricultural resource, resulting in a concentration of resources and people, and thus a high flood risk. This risk is growing disproportionately in developing countries, where most of the world's most populous deltas are located. Future projections of sea level rise, subsidence and sediment delivery are predicted to significantly increase the risk in many of the world's deltas. Flood inundation modelling of deltas at an appropriate scale can be applied to improve our understanding of the hazard. This work provides initial results of flood simulations on the Mekong Delta using a computationally efficient hydrodynamic model (LISFLOOD-FP) applied at the regional scale with freely available data.
The Mekong Delta, the world's third largest delta, is densely populated and considered Southeast Asia's most important region for agricultural production. However, it is increasingly exposed to coastal erosion, subsidence and reduced sediment delivery, and thus there is a need to investigate the potential impact these pressures might have on future flood hazard. To enable this investigation it is first necessary to develop an efficient but sufficiently accurate hydrodynamic model of the delta.
Simulations were run across resolutions of 540m and 270m for a 6 year period between 2001 and 2007. Topographic data was taken from a custom bare earth version of SRTM developed at the University of Bristol, where a vegetation correction factor is obtained from ICEsat and MODIS data. River width data was supplied by the GWD-LR database. Further calibration data including gauge readings and bed elevation was supplied by the Mekong River Commission. Where bed elevation was unavailable a number of different methods were applied to estimate channel depth. These included a hydraulic geometry relationship approach and interpolating existing bed elevation along delta plain gradients. Tidal influences were considered by including several nearby gauges as downstream boundary conditions. Validation of results was achieved using satellite-derived flood inundation maps from the MODIS platform. Performance was also compared to other flood inundation models of the delta, including CaMa Flood. Results show that LISFLOOD-FP has considerable skill for the simulated period, with limitations largely occurring from terrain errors in the SRTM data.
This work demonstrates the potential of a regional scale hydrodynamic model to simulate flood hazard in deltas, providing an important resource towards assessing flood risk within these regions. It is envisaged that this work will enhance the representation of flood hazard in the risk portfolio of these complex systems. Further work is planned to run the model across a number of deltas under future scenarios that included sea level rise, subsidence, population growth, sediment delivery and runoff change.

Keywords: Mekong Delta, LISFLOOD-FP, Floodplain Inundation, Flood

Food and nutrition security trends, determinants and challenges in tropical mega deltas

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It is estimated that more than 20% of the global population remains food insecure (FAO, et al 2015, Wheeler and von Braun, 2013). Due to a rise in consumption and rapidly increasing population, food demand may increase by at least 70% by 2050 (Royal Society, 2009). The challenge of meeting this increased demand is exacerbated by demographic changes, political instabilities, and environmental change, including the impacts of climate change (Poppy, 2014). These challenges are particularly pertinent to the densely populated tropical mega deltas of the global south, dubbed the ‘rice bowls’ of the world.
In the last 20 years many developing countries have made considerable progress towards improving food security and nutrition. However, progress across countries and dimensions of food security have been uneven (FAO, 2014). For example, in countries home to major tropical deltas such as Bangladesh and Cambodia, about a third of children are still classified as undernourished (IFPRI, 2015). While challenges to food security in the context of environmental and climate changes have been studied widely, limited evidence exists for their implications for food and nutrition security in tropical deltaic regions. Delta areas are particularly vulnerable to food insecurity and malnutrition due the specific environmental, climatic and human development factors affecting agricultural production and fisheries. These include coastal flooding and storm surges, deforestation, changes to river flow patterns and water tables, increased soil salinity and water quality degradation. Due to the large number of people living in Deltaic regions and their importance in regional food production, there is a pressing need for a better understanding on how environmental factors affect food security and malnutrition.
This study explores the potential impacts and challenges posed by environmental and climate change on food and nutrition security in three tropical mega-deltas: the Amazon, the Ganges-Brahmaputra and the Mekong delta. Socio-economic, agricultural production, environmental, nutritional, health related and demographic datasets for each region for the period 2000-2015 will be used and analysed to assess the impacts of contextual environmental variables on food security and nutrition. This includes an assessment of how these relationships vary in strength of association between the 3 deltas.. In addition, existing socio-economic- and climate change scenarios and modelling results are used to assess potential changes in food and nutrition security under plausible future pathways of development and impact. Results are framed in the context of relevant targets of the proposed Sustainable Development Goals and describe the challenges for food security and policy implications for each mega-delta.

Keywords: Delta's, Food security, Environmental change, Nutrition, Climate Change

The GDVI –A blueprint for spatial vulnerability assessments in deltas facing multiple hazards

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Disasters continue to exact a heavy toll on humans, ecosystems and economies, thus undermining ongoing efforts to achieve sustainable development. River deltas host dense populations, feature rich biodiversity and are hot spots of both agricultural and industrial production. But due to their ecological and economic importance, they are increasingly recognized as central to research and policy-making in the context of regional sustainability. Being located at the interface between the land and the ocean, the long-term sustainability of deltas is increasingly under threat due to the impacts of a range of natural and man-made threats, including large-scale human interventions as well as a range of environmental hazards (e.g. sea level rise, floods, storms, droughts, salinity intrusion, etc.). Understanding risks associated with these hazards, including both drivers of exposure and vulnerability of deltaic social-ecological systems (SES), and identifying hotspots at the sub-delta scale is hence becoming increasingly important for the development of spatially-targeted adaptation options.
Drawing on a holistic SES-centered risk and vulnerability framework as well as a “library” of environmental, socioeconomic and governance-related indicators (Sebesvari et al., forthcoming), we developed the Global Delta Vulnerability Index (GDVI) as a blueprint for delta risk and vulnerability assessments worldwide. Relevant indicators to be included in the indicator library were identified by means of a systematic review of peer-reviewed (and grey) literature combined with expert consultations during a series of stakeholder workshops in three model deltas, the Amazon, the Ganges-Brahmaputra-Megna, and the Mekong delta. In the library, indicators are organized in a modular structure, i.e. according to their relevance for different environmental hazards, hence being responsive to the specific multi-hazard settings of a given delta SES while also considering the interactions between the hazards in a given location. Based on these preliminary steps we followed a largely sequential, multi-stage workflow to construct the GDVI for the above mentioned model deltas. Important modeling stages include data acquisition and pre-processing (identification and treatment of outliers, missing data and multi-collinearities), normalization, (weighted) aggregation, sensitivity analysis (e.g. impact of indicator choice, etc.) and visualization. Further, for one of the deltas a validation of the resulting risk against observed loss and damage information was carried out.
Results show that risk, exposure and vulnerability are very heterogeneous both between and within the three deltas, with varying contributions of the underlying indicators. The highest level of risk and exposure was observed in the Mekong delta, followed by the GMB and the Amazon, while vulnerability of the coupled SES was found to be particularly high in the Amazon. Both facts have crucial policy-making implications since (a) interventions aiming at reducing risk must be spatially targeted, and (b), due to its relatively high level of vulnerability, risk might increase dramatically in the Amazon delta if exposure to natural hazards increases in the future, hence calling for improved preparedness.
The presented work is part of a global project called ‘Catalyzing action towards sustainability of deltaic systems (DELTAS)’ funded by the Belmont Forum and the 2015 Sustainable Deltas Initiative, endorsed by ICSU.

Keywords: Deltas, Social-ecological systems, Spatial vulnerability assessment, Amazon, Ganges-Brahmaputra-Megna, Mekong

Connectivity in river deltas: Channel-wetland exchange, process couplings, and implications for water, sediment, and nutrient transport

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River deltas are highly dynamic landscapes composed of networks of channels and wetlands and subject to natural forcings such as waves, tides, and wind, and to multiple natural and anthropogenic stressors. Deltas are thus vulnerable to changes in sea level, subsidence, and extreme events such as storms, all of which pose significant risks to the large populations living in coastal areas. The delivery of water, sediment, and nutrients is fundamental to land growth and for maintaining a healthy and diverse ecosystem. Such delivery highly depends on the physical and process couplings in the delta system. Yet, portions of the delta (channels, wetlands, shoreline) are usually studied in isolation and process couplings are not quantified.
We present a framework for studying connectivity in river deltas based on field observations collected on Wax Lake Delta in Louisiana (USA) and numerical modeling. We show that wetlands are an important part of the delta hydrological network as up to 50% of the channel discharge is transferred from the channels to the wetlands. This value varies depending on the relative roughness of wetlands and channels, the discharge magnitude, and the tidal cycle, which we quantify by applying a numerical model under a range of conditions. Couplings among water depths, tides, wind, and discharge at different locations of the delta are quantified with an information theory approach, specifically by computing mutual information and transfer entropy from time series data. These metrics quantify the degree of information shared and transferred among variables and thus detect synchronization and forcing dominated couplings in the delta and associated scales.
The implications of connectivity on delta functioning are discussed in terms of land growth, potential for nutrient removal, and travel times through the system as a function of network structure.

Keywords: deltas, networks, connectivity

The hydrology and hydrochemistry of deltas and their significance to deltaic hydrochemical/diagenetic processes and deltaic ecology

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Once a delta has aggraded/prograded to become emergent above the level of high tide its hydrology and hydrochemistry generally are complex. This is particularly the case for large deltas because they are comprised of a diverse suite of landforms and stratigraphic units, a range of water sources of different hydrochemistry, and a range of hydrologic recharge/discharge mechanisms. Deltas set in the various possible tidal ranges and climate types provide further variation on the dynamics of hydrology and hydrochemistry. In the midst of standard salinity gradients and intra-annual variations resulting from seasonal river inflows, the size and complexity of the delta, and the size of an estuary where a delta may reside, there are important localized interactions between the different open water bodies around deltas, such as river to sea interactions, or sea to estuary to river interactions. Whether adjoined by seawater or open estuarine waters (into which the delta has been prograding) or dissected by distributary channels with waters that can vary seasonally from marine to brackish to freshwater, the core of a delta may contain a freshwater lens similar to that under an oceanic island that interacts hydrologically on its margins with the open ocean or with an enclosing estuarine water body or with the river channels. The freshwater lens has a saline/freshwater contact similar to the Ghyben-Herzberg saline and freshwater relation.

Local areas on the subaerial delta plain, comprising contrasting mud-floored lagoons/ponds or sandy cheniers, or abandoned channels, are affected by river inflow, or rain, or evaporation, and develop salinities and hydrochemically specific surface and near-surface water bodies and groundwater bodies, respectively, that perturbate the salinity/hydrochemistry of the main body of the delta groundwater. The delta is characterised by fluctuating watertables and hydrochemistry of groundwater and the marine and estuarine water between wet and dry seasons, the dynamics of discharge, intrusion and seepage that occur between the delta groundwater and marine or estuarine water, and the wetlands on the delta. The various water bodies and their hydrodynamic and hydrochemical characteristics and interactions are underlying determinants of the biota resident on the deltaic wetlands and determinants of diagenetic products that occur within a delta. Western Australian deltas and intra-estuarine deltas serve as case studies of the hydrology and hydrochemistry of deltaic systems.

Keywords: deltas, intra-estuarine-deltas, Western-Australia, hydrology, hydrochemistry

Delta channel network complexity for quantitative delta classification and vulnerability assessment

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Deltas are landforms that deliver sediment, water and nutrients from upstream basins to the shoreline through interconnected pathways of channels that self-organize to a variety of stunning and complex patterns. The question as to what information about the forming processes (river, tide, and wave energy, vegetation, sediment properties, flow characteristics, etc.) might these patterns encode is fundamental to developing a quantitative approach to delta classification and advancing the still-in-use qualitative approach of *Galloway* [1975] and *Orton and Reading* [1993]. In our recent work [*Tejedor et al.*, 2015a,b] we introduced a graph theoretic framework for analyzing delta channel network complexity from a topologic (channel connectivity) and dynamic (flux exchange) perspective and proposed a TopoDynamic complexity space where deltas can be uniquely positioned. Here we examine the potential of this framework, together with field, numerical and experimental deltas towards a systematic approach to delta classification and inference. Specifically, we show that sediment parameters (grain size and cohesiveness; acting also as surrogates for vegetation) leave a distinct signature on the channel structure in river-dominated deltas simulated by a morphodynamic model (Delft3D) -- deltas with coarser incoming sediment tend to be more complex topologically (increased number of looped pathways) but simpler dynamically (reduced flux exchange between subnetworks), giving hope for classification. This is encouraging and calls for further analysis of simulated and field deltas and possible expansion of the dimension of the TopoDynamic complexity space to introduce additional discriminatory metrics. Comparison of the “delta width function” (channels at a radial distance from the apex) with the time-evolving shoreline of simulated deltas provides insightful new information about delta formation. Finally, entropy-based metrics of delta complexity are analyzed for both field and simulated deltas to examine how complexity might relate to delta vulnerability (where vulnerability here is defined by the relative effect of upstream flux perturbations to the shoreline) and an inverse relationship is reported.

Keywords: Delta Classification , Graph Theory, Complexity , Vulnerability

Development of large scale fluvio-deltaic morphology: a long-term modeling study

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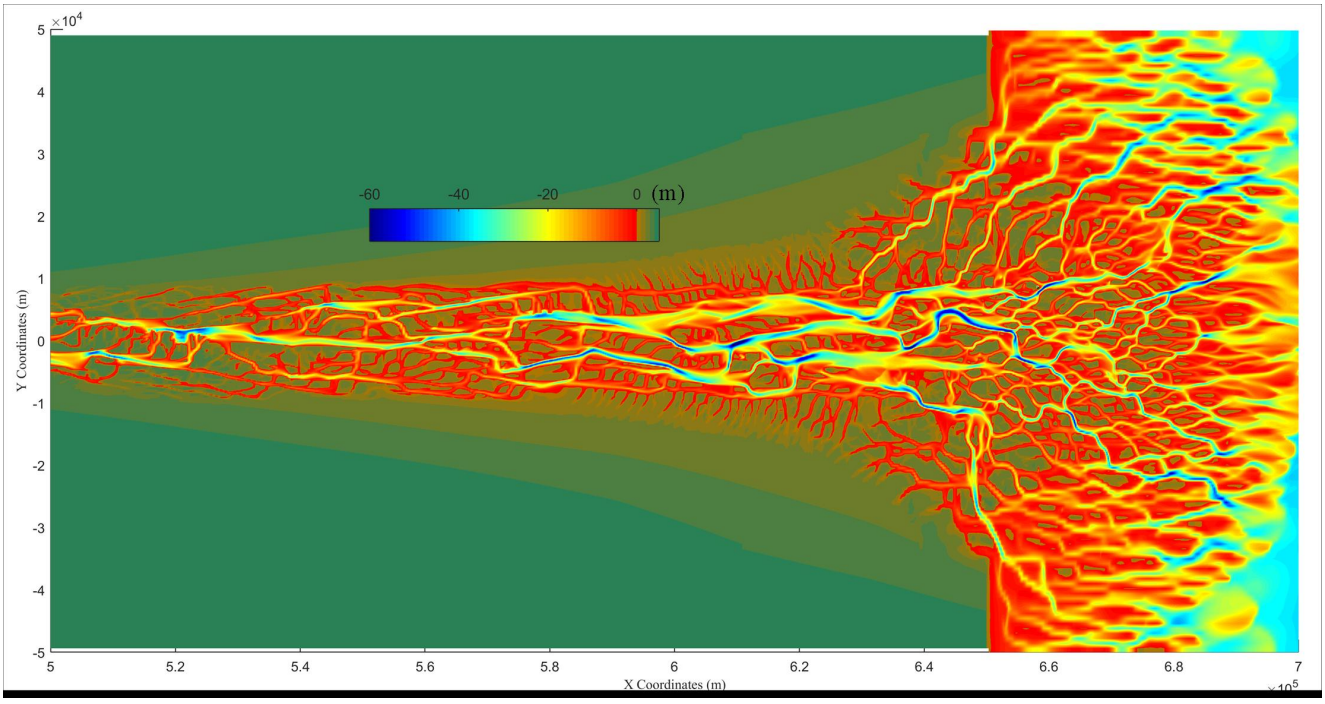
To investigate initial delta development and forcing controls, this study uses a process-based morphodynamic model (Delft3D) to simulate long-term (millennial time scale) morphodynamic development of a schematized large-scale fluvio-deltaic system (700 km long and 100 km wide) forced by high river discharge and strong tides. The model couples water motion, sediment movement, and bathymetric updating enhanced by a morphological acceleration technique which bridges the time scale gap between hydrodynamics and morphology (Roelvink, 2006). Model results (Figure 1) suggests that (1) river flow magnitude and sediment supply exerts strong controls on deltaic morphodynamic development and associated channel pattern; (2) estuarine bank erodibility plays a role by supplying sediment and providing space for channel migration and sand bar formation; and (3) initial basin geometry and shelf slope also have impacts on the deltaic morphodynamic development. The sensitivity simulations to varying governing factors thus help to unveil the basic controls on deltaic morphodynamics and provide guidelines to understand delta in nature.

Keywords: Estuary, Delta, Morphodynamic



Sediment Grain Size Trends throughout Delta Networks

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Commonly a network of channels forms once a feeding river channelbelt enters a low-gradient coastal plain, creating the classic delta planview morphology. This area is a zone of net deposition and consequently mass loss in the longitudinal direction. Tank experiments and subsurface data show that mass loss leads to down-channel sediment fining as deposition preferentially removes coarser particles (Paola and Martin, 2012). Understanding grainsize depositional trends is important for assessment of subsurface characteristics and importantly impact local subsidence rates and shallow groundwater flow.
We hypothesize that downstream fining trends are more pronounced 1) if rivers commonly experience overbanking and floodplain inundation, and 2) in deltas with a complex distributary networks.
We use a numerical model that describes fluvial transport with a simple geomorphic mass balance approach. It models a main channel belt as a 2D longitudinal profile that responds dynamically to changes in channel geometry, water discharge, sediment load, and grain-size distribution based on first-order, physics-based principles. Sediment flux is described with a modified Exner equation by separate erosion and sedimentation components. Erosion flux along the main flowpath depends on river discharge and channel slope, and is independent of grain-size. Depositional flux in both longitudinal direction and in lateral direction into the floodplain depends on stream velocity and on grain-dependent settling rates.
Model experiments show distinct thinning of deposits, and fining of grainsize downstream the fluvio-deltaic floodplain. An abrupt coarsening of the deposits and change in overall downstream fining trend occurs at the land-ocean boundary, associated with a decreased transport capacity and a rapid acceleration of sediment settling rates in the marine domain.
Preliminary scenarios with increased flood dynamics display a more rapid mass extraction and efficient sorting downstream, due to the upstream settling of sediment otherwise funneled downstream during bankful conditions.
A more complex delta distributary network dramatically affects mass extraction rates and associated overall fining trends. In addition, repeated occurrences of rapid grainsize coarsening are observed at distributary nodes.
Already these simple experiments provide new insights in grainsize distribution patterns in delta floodplains, but major advances can still be made by improving the simple modeling approach to a more sophisticated channel floodplain coupled model including tidal processes.

Keywords: numerical modeling, floodplain, grain size patterns, delta

Rock-barred deltas –an addition to the types of coastal deltas with examples from eastern Australia

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Modern delta classification has addressed that deltaic sedimentation and landform building is dependent on fluvial delivery of sediment to the coast and the building of deltaic coastal landforms by the interplay of oceanographic and fluvial processes resulting in a ternary classification that recognises wave-dominated deltas, tide-dominated deltas, and fluvial-dominated deltas. Granulometry and delta asymmetry also recently have been addressed in expanding the initial ternary delta classification. This paper explores a type of delta that currently is not captured by the classification of the present ternary system, nor by the partitioning of deltas according to their dominant granulometry. It is one where river flow has been prevented from forming one of the coastal landforms of deltas (digitate, lobate, or current-aligned shoals/islands) because they have been barred by barriers such as rock islands. These delta-lands *are still deltas*. This we term a “rock-barred delta”. The Queensland coast as the sedimentary receptor for a range of rivers deriving from a 3500 km long highland (the Great Dividing Range) forms the framework for rock-barred deltas in that 1. the Great Dividing Range is continental-scale watershed; 2. numerous short rivers arise from this watershed; 3. the region has a high-rainfall climate; 4. the geological grain of the coast is comprised of N to NNE-trending rocky coastal strike-ridges and N to NNE-trending near-shore rocky coastal islands that form the obstructions to delta development; and 5. the Great Dividing Range as source material for riverine and coastal sediments yields sand and mud, and often mud > sand. The characteristics of rock-barred deltas are: 1. a triangular delta-plain that represents a valley tract almost to wholly filled with sediment; 2. a partial barrier of bedrock islands and peninsulae that bar the fluvial accumulations from the open ocean and perturbate oceanic waves; and 3. a tidal zone of low-tidal sand and/or mud flats, mangrove-vegetated mud flats, and high-tidal saline mud flats. In many aspects, the rock-barred deltas have features in common with traditional deltas, with the main difference being the seaward geometry because of the barriers, peninsulae, and nearshore islands. Bedrock island obstructions, however, do not stop tide-dominated delta landforms being developed in the interior of the delta-land, nor fluvial processes influencing development of fluvial landforms in the interior of the delta-land.

Keywords: delta, classification, rock-barred, eastern Australia

Sediment Flux to Ganges-Brahmaputra-Meghna Delta

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The Ganges-Brahmaputra-Meghna (GBM) is one of the youngest fluvio-tidal-deltaic systems in the world. It encompasses with a very dynamic sedimentation process that receives sediment accumulation both from the Himalayas and the natural tidal effect of the Bay of Bengal.Water and sediment discharges are highly skewed to the monsoon resulting 80% of the annual water discharge and 95% of the annual sediment load is come out during the monsoon months of June to September. Bed material, flow condition, geological setting and land use patterns profoundly govern the amount of sediment input and its transport processes. Furthermore, human interventions massively influence the flow pattern and sediment dispersion, which plays an important role in GBM delta formation processes. Several dam construction (planned and executed) and river-linked-project (proposed) at the upper riparian system would influence the flow and sediment input in the GBM systems.
A number of attempts had been taken by many researchers for budgeting the total annual sediment flux of this river systems during the last century. The total sediment flux of the GBM basins is not obvious from literatures as it ranges from 1.06 to 1.67 billion ton of combined mean annual sediment flux stated in several documents. Previous measurements are too old and that also do not represent the present value since a large number of human interventions have been executed in the upper riparian during the last two decades. Also, estimation of the sediment flux vary from river to river because of different measurement methods, time and inter annual river variabilities. Moreover, these measurements were not conducted in the same time series and there was a seasonal effect on the estimation. From literature, it is observed that the Brahmaputra has a mean annual sediment flux of 387 to 650 million tons, on the other hand, the Ganges sediment ranges from 196 to 480 million tons. For the Upper Meghna river systems, the estimation is more dispersed where a maximum mean annual sediment flux of 20 million tons was documented. There is a distinct variation in the mean annual sediment flux of the GBM basin and the reason behind this fluctuation is not clarified yet. Future prediction of sediment flux is very important to assess the sustainability of this delta and accurate quantification of present sediment load is a pre-requisite for this. Any attempt to predict future sediment load in this region needs information about the present-day condition. As a result, it is very important to have reasonable estimate of current sediment flux based on reliable field measurement that will provide the basis of prediction for future sediment fluxes in the GBM system. This kind of prediction is important to support the long-term planning strategies like Bangladesh delta plan 2100 (BDP2100).
Considering all these, a field measurement (4 times a year) programme is planned for the three major river system (at strategic section) of GBM basins—the Ganges, the Brahmaputa and the Upper Meghna, respectively. The measurements will be conducted by using ADCP that considers the Doppler effect of sound waves scattered back from particles within the water column.Sediment concentration obtained from ADCP will be calibrated with the sediment concentration obtained from the water sample collected during the measurement. Moreover, the available sediment concentration data during the last 30 years collected by Bangladesh Water Development Board (BWDB) will be used to determine the trend of the sediment flux. This will be the first of this kind of sediment measurement to compute the sediment flux in the GBM delta and is expected to constitute the basis of all future sediment related research in this region.

Keywords: GBM delta, Sediment Flux, ADCP

Sediment storage and dispersal system of west and southwest Taiwan deltas: millennial to decadal time-scale changes

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The natural setting of Taiwan with high mountains, steep slopes, high gradients of rivers, frequent earthquakes, erodible lithology, and heavy rainfall represents an ideal environment to determine the sediment dispersal from land to the sea over various time scales. Sediment transport from the small mountainous rivers can provide a large amount of sediment into the ocean. These small mountainous rivers of west and southwest Taiwan on the active narrow margin not only transfer terrigenous sediment to the ocean but also have the impact on both the short-term and long-term characters of the coast and seafloor (Syvitski and Saito, 2007; Milliman et al., 2007). Sediment storage, remobilization, and cycles of erosion may be accelerated in this tectonically active region. The west and southwest Taiwan deltas trapping sediments over time scales from millennia to decades showing about 4,700 km^2 of subaerial delta and 2,400 km^2 of the subaqueous delta. To assess the sediment storage in the deltas, the volumes of subaerial and subaqueous deltas were calculated since the last maximum flooding surface in 7 ka to present. Based on the 80 core sites and 112 radiocarbon dates, the volume of sediment deposited over the last 7 ka can be estimated. The volume in the west and southwest Taiwan deltas since 7 ka is 201.1 km^3 and the accumulation rates have been high with averaging about 0.4 cm/yr. Besides, the modern (<100 years) sedimentation rates in average in the Taiwan Strait are ranging about 0.28-0.4 cm/yr (Huh et al., 2011; Hsu et al., 2014). However, the sediment trapping efficiency of the delta region is decreasing at present. The water depth of historical nautical charts allowed the reconstruction of the paleo-bathymetry and paleo-shorelines. The regional deepening and minus volume evaluation indicate the erosional/transport environment and seafloor instability at present. The extreme climate events and human activities in the west and southwest Taiwan may keep delta shrinking in the coming decades.

Keywords: Small mountainous river delta, Accumulation rate, Sediment dispersal system, Taiwan

Delta deposits at the Tsengwen River mouth, western Taiwan

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Taiwan is located in the fold and thrust belts due to the island arc collision action, and the coastal plains along the western coast has been subsiding. Subisidence rate along the western coast is estimated to be approximate 5 mm/yr based on topographical survey and ages of coastal deposits (Ching et al., 2011). Sedimentary facies analysis and measurement of grain size and loss on ignition (LOI) were performed for two borehole core sediment with 250 m long obtained from the Tsengwen River delta, western Taiwan to investigate evolution of the depositonal systems located at tectonically subsiding coasts. Additionally, a new borehole core sediments, 300 m long, was taken near the river mouth in 2015. In the present study, we report the characteristics of the depositonal systems especially the deltaic system on the basis of these cores. The thickness of deltaic deposits showing upward-coarsening succession is about 100 m. Maximum median grain size is 0.3-0.4 mm and LOI is usually less than 6 %. Depositonal age of the deposits may have been during the last 8-9 ka.

Keywords: Sea-level change, Tectonically subsiding lowland, Delta

Estimation of natural and anthropogenic impacts on groundwater resources of Pintung delta plain using numerical spatiotemporal modeling

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This study applies a numerical spatiotemporal dynamic model to estimate the natural and anthropogenic impacts on groundwater resources, and to identify the unstably vulnerable areas which need intensively monitor. The methodology of this study can be divided to six parts: (1) estimate temporal-spatial pattern of pumpage and recharge using coupled analysis of groundwater hydrograph fluctuation and isotope; (2) simulate spatiotemporal groundwater level using numerical model and regard that as actual observed data; (3) compute groundwater storage hydrograph according to observed groundwater level for inverse evaluating the temporal distribution of pumpage and recharge under multiple irrigation practices; (4) apply principle component analysis with observed groundwater level for inverse evaluating the spatial distribution of pumpage and recharge; (5) compute the spatiotemporal distribution of pumpage and recharge and simulate the corresponding groundwater level; and (6) assess the insufficient monitoring areas determined by higher evaluated error of pumpage and recharge. This study applies the established method on the groundwater system of Pintung delta plain. Results show that, the weighted average precise percentage of inverse evaluated temporal-spatial distribution of pumpage and recharge using PCA reaches 95.24%. The spatiotemporal distribution of pumpage and recharge is extremely non-uniform in Pintung plain that annual over-exploitation of shallow groundwater aquifer in tail fan reach 2.89×10^8 m^3. Furthermore, the assessing outcome show that, the area with higher differential value of harmonic mean pattern of leakage rate and with higher groundwater fluctuation amplitude has higher spatial evaluated error. These unstably vulnerable areas are mostly located at the intersection of upstream river and delta boundary and the intersection of downstream river and geological non-homogeneous demarcation.

Keywords: principle component analysis, estimation of pumpage and recharge, numerical groundwater modeling, hydrograph analysis, isotope, vulnerability assessment

Provenance variability associated with East Asian Summer Monsoon precipitation change recorded in the inner shelf deposit of the East China Sea during the middle and late Holocene

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Hydroclimate variations associated with the East Asian Summer Monsoon (EASM) precipitation exert significant impacts on lives of people inhabiting within the Yangtze River drainage and the coastal zone of South China. Seasonal shift of main precipitation area is attributable to the reposition of northern limit of summer monsoon, which would lead to provenance and composition changes of suspended materials transported by the Yangtze River. Consequently, the interannual- to millennial -scale variability in the position of rain belt mentioned above could be recorded in the long-term change in compositional variation of the sediment originated from the suspended materials from the Yangtze River. The inner shelf sediments of the East China Sea (ECS) is of primary importance to study provenance changes of terrestrial materials from the Yangtze River. Because of this expectation, we examined provenance changes in MD06-3040 core sediments recovered from the inner shelf of ECS in association with spatial variability of EASM precipitation.
Provenance of sediment particles were evaluated on the basis of the electron spin resonance (ESR) signal intensity and crystallinity index (CI) of quartz. Comparison the core sediments taken from core MD06-3040 with Yangtze Delta core and modern Yangtze River sediments suggests that the Yangtze River would be a predominant source of the mud belt on the inner shelf of ECS. The ESR value in fine silt fraction of core MD06-3040 samples showed larger values compared to the ESR value in coarse silt fraction during 6.5 to 6 cal kyr BP, 6 to 4 cal kyr BP, and 1.8 to 1 cal kyr BP. The ESR values in both fine silt fraction and coarse silt fraction of core MD06-3040 samples have similar results during 4 to 1.8 cal kyr BP and 1 to 0 cal kyr BP. Moreover, detailed examination of quartz provenance within the Yangtze River drainage using ESR and CI enable us to discriminate the sediment contributions from the upper-middle reaches (northern tributaries) versus lower reach (southern tributaries) of the Yangtze drainage. This observation suggested that variability of the main location of EASM precipitation (EASM front) on multi-centennial to millennial-scale has been detected from this result which showed heavier precipitation in the middle-upper reaches(NW part of the drainage) with contribution from southeastern side of lower reaches (Lakes Dongting and Poyang) and few local rivers during 6 to 4 cal kyr BP, and in the middle-upper reaches(NW part of the drainage) during 4 to 1.8 cal kyr BP, 1.8 to 1.0 cal kyr BP, and 1.0 to 0.6 cal kyr BP.
Modal grain size in fine silt of core MD06-3040 showed notable decrease at times of smaller contribution from EASM precipitation within the Yangtze drainage, such as 6 cal kyr BP, 5.3 cal kyr BP, 4.5 cal kyr BP, 3.7 to 3.3 cal kyr BP, 2.2 cal kyr BP, 1.4 to 1.3 cal kyr BP, which also coincide with the higher value of reconstructed SSS derived from paired measurement of Mg/Ca and $\delta^{18}O$ of foraminifera calcite in core MD06-3040. Such coincidence of low Yangtze discharge events and minima in grain size suggest that the Yangtze River discharge supplied by EASM precipitation should be a dominant control on the Yangtze River discharge, and accordingly influence deposition of Yangtze-derived sediment on the inner shelf of ECS and ECS salinity.High precipitation is correlated with higher contribution of material from the upper and middle reaches of the Yangtze drainage since 6 cal kyr BP.

Keywords: EASM precipitation, Yangtze discharge, East China Sea

Transportation and sedimentary process of fine detrital particles in the Yangtze delta during the late Holocene based on ^{14}C ages of shell fossils, benthic foraminifera, and organic carbon and their paleo-climatological implication

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The Yangtze River is one of the largest river in the world and discharges large amounts of water and sediments into the East China Sea. Such an abundant sediment supply resulted in development of the Yangtze delta during the late Holocene. Initiation and evolution of the Yangtze delta have been discussed using inland and subaqueous sedimentary cores around it.
At present, more than 90 % of the sediments discharged from the Yangtze River are transported in the form of suspended particulate material (SPM). It is generally believed that a part of SPM (= fine detrital particles) shed from the river mouth deposited in the delta and the rest is carried southwestward along the coastline of Southeast China and eventually deposited to form the “Mud Belt”. However, less attention has been paid about how detrital particles discharged from Yangtze were transported and deposited within and around the Yangtze delta.
We drilled the Yangtze delta to reconstruct changes in SPM provenance and examine their relation with climate changes within the Yangtze drainage basin. We conducted ^{14}C dating of shell fossils, benthic foraminifera, and organic carbon to establish the age model. Contrary to our expectation, the result suggests complicated process and/or history of deposition of fine grained detrital particles within the Yangtze delta. We will discuss implications of the result to the sedimentation of fine detrital particles in the Yangtze delta and its possible linkage with the climate change within the Yangtze drainage basin during the late Holocene.

Keywords: Yangtze River, Sediment transportation, 14C dating, Late Holocene, Paleoclimatology

Holocene sea level history in the broad Yangtze River Delta derived from high resolution sediment archives

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The Lower Yangtze River region is one of the key areas of China cradling Neolithic cultures (including early rice domestication), the most representative sites including Kuhuqiao (8-7 ka B.P.) and Hemudu (7-5 ka B.P.) in Ningbo-Shaoxing plain (basin) along the east coast. Over the last few decades, a great deal of work has been carried out to understand how early human settlements coped with Holocene environmental and sea level changes in this critical region. However, reconstruction of sea level history in coastal China has often been hampered by lacking of high resolution records with diagnostic proxies. Existing data retrieved from different regions show great discrepancy and contradiction.
In this study, we chose Ningbo-Shaoxing plain (basin) as the target area for Holocene sea level re-construction. This is because the Ningbo-Shaoxing plain is sheltered to both the north and south by mountain ranges, minimizing the influenced from fluvial and tidal processes, as oppose to the nearby areas such as the Qiantangjiang estuary. This geographic setting would have enabled a relatively continuous and uniform sedimentation during the Holocene, as oppose to the delta and estuary region where sedimentation is often truncated and interrupted by facies changes. As a result, high resolution chronology in Ningbo-Shaoxing plain can be performed and diagnostic paleoenvironmental proxies can be applied.
Eleven core have been recovered from the basin, with lengths ranging from 20m to 40m. High-resolution geochronology of the sediments is established by AMS 14C dating of seeds and plant debris. Dating results suggest that the cores covers age ranges from the Last Glacial Maximum to the present. Sedimentological, biological and geochemical analyses have been carried out to re-construct the environmental history since early Holocene. Of particular interest is the high-resolution sea level history. Combined with archaeological records nearby, the study provides critical information about 1) the timing when marine transgression first arrived in the Ningbo-Shaoxing basin; 2) the timing when sea level reached high stand; 3) the mode of sea level rise; 4) the timing and mode of land initiation, propagation and human occupation. Most importantly, our study sheds some light on the understanding of how Neolithic human beings coped with environmental changes, particularly with sea level changes in this coastal region.

Keywords: Sedimentology

Sea level change and its influence on the Hemudu Culture in the South Yangtze River Delta during the Holocene

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The Neolithic settings of Ningbo-Shaoxing Plain (basin) is famous for the early adoption of cereal cultivation during the Holocene, such as Hemudu Culture. Ningbo-Shaoxing basin is located in the south Yangtze River Delta near the east coast of China. As noticed by many work carried out in this region, the sea level change was one of the most important challenge for the early settlements during the early to middle Holocene. However, there still lacks a unified understanding about the sea level change history.

As Ningbo-Shaoxing basin is sheltered by the north mountain ranges from direct erosion of tidal process, we retrieved a series relative continuous sediment cores with uniform lithology, to understand the land and sea interaction in this basin. In this study, one core located away from, but close to the Tianluoshan site (a representative site of Hemudu Culture) was chose, as a natural sedimentation. Among many different proxies, diatom is a well-known biological indicator of fresh and marine environment. Nevertheless, in previous studies, there is rare systematic study about diatom at this area. Besides, X-Ray Fluorescence (XRF) scanning can provide different geochemical elements curves in the sediment in a high-resolution and semi-quantitative way.

In this study, diatom, XRF scanning and grain size analyses was carried out, based on a high resolution AMS ^{14}C chronology frame. This study assesses the timing when sea transgression reached this area and when sea retreated, also the pattern of sea level change during the early to middle Holocene. The result shows that during the period of sea level rise, there were several short-term periods influenced by fresh water input, which was indicated by predominately fresh diatom species than marine species. Moreover, Calcium content from XRF scanning has a significant correlation with the relative abundance of marine diatom species, which may provide a high resolution sea level history. These results may make important contribution to the understanding of how early settlements adapt to sea level change in this area.

Keywords: sea level , diatom, XRF

Three dimensional morphological changes and ^{137}Cs dating in the Yellow River (Huanghe) delta during 1976-2012

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The Yellow River (Huanghe) is a major sediment supplier to the Bohai Sea and the Yellow Sea. Since 1976 the river's channel has been located on the east side of delta complex and has built out broad sedimentary lobe. To understand the sedimentation of the subaqueous delta, extensive bathymetric and high resolution seismic profiles, vibrocores and a borehole core in the survey lines were collected in 2012. The morphological change along with ^{137}Cs profiles of cores were used to establish the present sedimentary frame of delta front slope and to examine sediment dispersal in the west of Laizhou Bay in this study. Sedimentation and morphological change in the area were examined on the basis of (1) the morphological change between 1958/1976 and 2012 and (2) analyses of sediment cores including radionuclides (^{137}Cs and ^{210}Pb), sediment structure and texture. The morphological change shows the distribution of sedimentation since 1976, and this also was validated on basis of analysis of cores. About 80% Yellow River-derived sediment deposits in the subaqueous delta during 1976-2012. The morphological change also reveal the present morphology of subaqueous delta that exceeds previous estimated boundary, and this also was validate on basis of analysis of ^{137}Cs in cores. The ^{137}Cs onset depths corresponding to the depths of lithological changes and morphological changes indicate that it can be a proxy to track the dispersal of Yellow River-derived sediments in the study area. Synthesis of bathymetry, seismic profiles, ^{137}Cs profiles and surface sediment pattern show that a depocenter occurs in the south frank of Yellow River delta in the west of Laizhou Bay. The deposition probably results from the headland eddy that formed with the morphological change.

Keywords: Morphological change , Sediment cores, Cs-137

Fluvial to tidal transition in the Mekong River delta, Vietnam

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The Mekong River delta extends from its apex at Phnom Penh in Cambodia to the Vietnamese coast, and from the Saigon River mouth in the east to Cape Camau in the west. The delta plain area exceeds 50,000 km^2. The delta has prograded more than 200 km during the last 6–7 ka. The middle Holocene sea-level highstand is recognized at ~2 m above present sea level in this region. The delta owes its great size to the combination of a huge sediment supply and a stable sea level for the last 6–7 ka. The area around the mouth of the Mekong is meso-tidal with a maximum tidal range of 3.2–3.8 m. Tidal effects are obvious in the water level as far as ~100 to 150 km upstream from the river mouth throughout the year, but particularly in dry seasons. The zero meter level of the river channel thalweg is ~600 km upstream, in Cambodia. Freshwater and sediment discharges from upstream occur mostly in the wet season from May to November; however, ocean tides exert strong influences in the dry season, including re-suspension of sediment in river channels.
To better quantify the influence of river discharge and tides on river-bottom sediments, we collected >250 surface samples from distributary channels across the entire delta in Vietnam from the border to the five river mouths during the dry season (January–May 2015), and from one distributary channel from the border to the river mouth during the wet season (October 2015) with simultaneous CTD measurements. In the dry season, river- and tide-dominated areas can be spatially distinguished by the sedimentary facies (grain size and sedimentary structures) of channel bottom sediments. Tidal rhythmites (sand-mud couplets) are common as far as ~100 km upstream from the river mouths, and mud balls are often found in the middle reaches of distributaries. The spatial distribution of river- and tide-dominated areas is closely linked to channel morphology. The thalwegs of river channels show deepening trends, with large variations, downstream from the border and suddenly change to shallowing trends near their mouths. Coarse sediments are found mostly in regions with a deepening trend and sand-mud couplets are found in regions with a shallowing trend. During the wet season, most of the rivers are occupied by freshwater, and the 0.5 pss salinity line is only ~5 km upstream from the river mouth. Nevertheless, sand-mud couplets are recognized up to ~100 km upstream from the river mouth in this freshwater environment.

Keywords: Mekong River, fluvial-tidal transition, estuary

Holocene tidal changes around the Mekong River Delta, Vietnam

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Numerical simulation was conducted to reconstruct tidal changes taken place within and around the Mekong River Delta during the Holocene. The paleobathymetry used in this study was based on GIA model and was modified by removing thick Holocene deposits existent in major deltas facing the South China Sea, e.g., Mekong, Red, Chao Phraya, and Pearl river deltas. A preliminary result shows that semi-diurnal tidal currents were developed at the inner portion of the paleo Mekong estuary during the mid-Holocene transgressive stage, suggesting stronger influence of tides on the delta formation than at present.

Keywords: delta, South China Sea, paleotidal modeling, Holocene transgression

Holocene intra-estuarine deltas of south-western Australia –testing and extending delta classification

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An *intra-estuarine delta* is a delta that occurs wholly within an estuary. The prefix 'intra' emphasises that these deltas are sedimentary accumulations *within* the estuary. They are relatively small in comparison to open-coastal deltas. South Western Australia provides excellent examples of relatively large estuaries with numerous inflowing rivers and a large number of intra-estuarine deltas which can be used for testing and exploring the classifications of deltas.
In the estuaries of south-western Australia, with asymmetric distribution of wave climates, and/or differential shelter from wind and wind-waves, intra-estuarine deltas do not readily conform to the idealised pattern of delta development and cannot be readily classified using traditional delta classification. For instance, they may show geomorphic asymmetry in response to their orientation to wave climates and wind, so that they may be wholly wave-dominated, or partly wave-dominated in one part, and fluvially dominated in another part of the delta system. In an estuary with symmetrical delta-land development a symmetrical stratigraphy usually develops but with asymmetry in evolutionary development the deltaic stratigraphy may be laterally asymmetrical.
To deal with such variations and to highlight them, we have developed a classification approach for intra-estuarine deltas, an approach that we believe also can be applied to open-coastal deltas. The classification involves identifying the delta attributes and systematically applying descriptors for these attributes in terms of delta size (megascale, macroscale, mesoscale), plan-form (lobate, cuspate, digitate, birds-foot, palmate, elongate, crenulate, rectangular, fretted, symmetrical, asymmetrical), internal landforms, , delta origin or genetics (*viz.*, wave-dominated, tide-dominated, fluvially-dominated, and whether the delta is monogenetic, *e.g.*, wholly wave-dominated, or poly genetic, *e.g.*, part wave-dominated and part fluvially-dominated), and homogeneity/heterogeneity of the stratigraphy. A full classification of an intra-estuarine delta is achieved by including all the attributes described above as adjectival descriptors. In south-western Australia, for instance, the Deep River intra-estuarine delta is a mesoscale, monogenetic wave-dominated, internally geomorphically asymmetric and stratigraphically asymmetric. The Preston River intra-estuarine delta, another example, is macroscale, polygenetic tide- and fluvially-dominated, internally geomorphically asymmetric, and stratigraphically asymmetric. The Harvey River intra-estuarine delta is macroscale, monogenetic fluvially-dominated, internally geomorphically and stratigraphically symmetric. As such, an intra-estuarine delta system, or even an open-coastal delta system can be classified systematically to separate and expand the diversity of delta types worldwide.

Keywords: deltas, intra-estuarine deltas, classification, south-western Australia, estuaries

Determining the geoheritage significance of deltas using the Geoheritage Tool-kit

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Geoheritage is the heritage value assigned to features of a geological nature, encompassing Globally, Nationally, State-wide to Regionally, and locally significant features of Earth Science. Sites of geoheritage significance are intrinsically important or culturally important, offering information or insights into the evolution of the Earth, or into the history of Earth Science, or that can be used for research, teaching, or reference. Features of geoheritage significance can range from the small scale such as crystals to the large scale such as mountain ranges and drainage basins. While there has been a focus on geological features of geoheritage significance in the record of rocks, palaeontology, minerals, and landscapes, there has been little emphasis placed on the geoheritage significance of deltas.
In terms of geodiversity and geoheritage values, deltas provide a rich assortment of geologic, geomorphic, sedimentologic, mineralogic, and biogenic attributes, not only in regards to the features within the deltas themselves, but also in the geology, geomorphology, and hydrology of the immediately surrounding landscape that borders them or (if in an estuary) that frames them. Deltas provide a wealth of features of geoheritage significance: from the large scale expressed as delta types and stratigraphic sequences to the small scale of sedimentary products and diagenesis. Consequently, they lend themselves to qualifying as sites of geoheritage significance. This is especially the case in that deltas derive from and reside in various types of geologic, geomorphic settings, and oceanographic settings which results in a wide variety of delta types; they occur in a wide range of climates from tropical to temperate, and from humid to arid, which also results in a wide expression of delta types stratigraphically, sedimentologically, and geochemically/mineralogically.
The Geoheritage Tool-kit has been developed to systematically catalogue and evaluate different aspects of geology, assign them as to category of geoheritage site, rank them as to size, and then evaluate individual features or package of features as to their significance. The Geoheritage Tool-kit can be systematically applied to deltas to help identify Internationally and Nationally significant deltas as a basis for management and geoconservation. Applying the Geoheritage Tool-kit to deltas worldwide and to specific case examples in Australia shows a range of environmentally significant deltas.

Keywords: delta, geoheritage, Geoheritage Tool-kit, geodiversity

