Abstracts for Geological Survey Seminar no. 267*

Deltas: their Dynamics, Facies and Sequences with special references to sea-level changes and human impacts

Preface & Asian Delta Programs of the GSJ

Yoshiki SAITO[1]

A delta, which consists of a low-lying area found at the mouth of a river, is an important feature of coastal topographies. In particular, large Asian rivers form huge deltas in South, Southeast, and East Asia. More than 60% of the world population lives in deltas, and more than 80% of the world's total area with rice paddies is in Asia. Deltaic lowlands in Asia are important also to the study of sedimentology and global sediment flux. Rivers in southern Asia and Oceania contribute about 70-80% of the world sediment flux from the land to the ocean. These huge sediment deposits have formed large deltas during the Holocene, and this region is considered the present depocenter in the world.

The purpose of this workshop is to summarize current knowledge of deltas in the East and Southeast Asian region, and to establish networks among Quaternary scientists, sedimentologists, and geological oceanographers for delta studies in this region. Recently, Japanese scientists have had several opportunities to promote international cooperation on delta studies in Asia. This workshop will provide a forum for broader exchange of present knowledge and discussion of future tasks among scientists.

The Geological Survey of Japan has been conducting delta programs since 1996. The foci of these study programs are dynamic sediment processes, sediment facies, sequence stratigraphy, human impacts, and the influence of sea-level rise on large river deltas in Asia: the Huanghe (Yellow River), the Changjiang (Yangtze River), the Zhujiang (Pearl River), the Song Hong (Red River), the Mekong River, and the Chaophraya River deltas. These programs are conducted in cooperation with the Department of Mineral Resources of Thailand, the National Center for Natural Science and Technology, Vietnam, the Institute of Marine Geology, Tongji University, and East China Normal University in China, and other national institutes and universities, together with the National Institute for Environmental Studies and the Geographical Survey Institute in Japan and Niigata University, Nagoya University, and other Japanese universities. These programs are supported by the Global Environmental Research Fund of the Environment Agency of Japan.

The Research Programs

Effects of Environmental Pollution Load through Large Rivers on Marine Ecosystem in the East China Sea (Phase 1 : FY 1996- FY 1998, Phase 2 : FY 1999- FY 2001). Responsible Institute: National Institute for Environmental Studies

Study on Comprehensive Assessment for Impacts of Sea-Level Rise (Phase 1 : FY 1997- FY 1999, Phase 2 : FY 2000- FY 2002) Responsible Institute : Geographical Survey Institute

This workshop is the third international workshop organized by our group to be held in Japan. The first meeting was held as a session of the International Symposium on Quaternary Environmental Change in the Asia and Western Pacific Region, held at the University of Tokyo from October 14-17, 1997. The session name was "Coastal dynamics : late Quaternary changes of deltas and continental shelves", and it was convened by Y. Saito, M. Umitsu, and W. W-S. Yim. Post-meeting publication of the session will appear as a special issue of the Journal of Asian Earth Sciences (vol. 18, no. 4, 2000). The second meeting was the Prof. K.O. Emery Commemorative International Workshop on Land-Sea Link in Asia, held in Tsukuba, from March 15-19, 1999. The proceedings were published by JISTEC-GSJ at the workshop (Saito et al., eds., 1999, 487 pages). This third workshop is part of an interim report on our programs.

This workshop is being held under the auspices of the Active Geological Process Panel of the Geological Society of Japan ; the Research Group on Coastal Environment and Morphodynamics of the Association of Japanese Geographers ; the Sedimentological Society of Japan ; IGCP Project 396 : "Continental Shelves in the Quaternary"; IGCP Project 437 : "Coastal Environmental Change During Sea-Level Highstands"; IGBP-LOICZ-Japan and Inter MARGINS-Japan.

([1]Marine Geology Department, GSJ)

Keywords : delta, Asia, global change, human impact

* This seminar was held at the Geological Survey of Japan in Tsukuba, on March 16-17, 2000.

World Delta Studies - A New Assessment of Some Key Problems: Age Dating, Land Subsidence, Sea-Level Change And Human Pressures

Daniel Jean STANLEY[1]

Multidisciplinary investigations have been made on different Holocene deltas located in diverse climatic, geographic and geologic settings by Smithsonian Deltas-Global Change Program teams during the period 1985 to 2000. Our comparative studies, for example, have focused on groupings of radiocarbon dates acquired at the base of Holocene sediment sections of many deltas (50). These show that the majority of delta systems were initiated during deceleration in the rate of sea-level rise at about 8000 to 6500 years ago (Warne and Stanley, 1994). Moreover, on the basis of archaeological identification, we find that humans began to occupy many of these environmentally-rich depocenters within 500 years of their initiation along different world coastal margins (Stanley and Warne, 1997). However, comparisons of different deltaic systems have raised salient new problems that now warrant attention and discussion by participants of the *Deltas Workshop* in Tsukuba, Japan (March, 2000).

One problem we have identified pertains to dating of Holocene sections above the deltaic base. Specifically, both conventional and AMS radiocarbon methodologies provide age results that are commonly unsatisfactory. Dates are often erratic in mid- and upper core sections; they are commonly inverted stratigraphically (i.e. not systematically younger upsection); and they are usually more than 2000 years too old, even at present deltaic plain surfaces (Stanley, 2000). Analyses of hundreds of radiocarbon dates obtained in the Nile (Egypt), Yangtze (China P.R.), Mississippi (U.S.A.), Ganges-Brahmaputra (Bangladesh, India), RhUne (France) and Rhine-Meuse (The Netherlands) indicate anomalous ages in all of these systems. This observation, to a large extent, results from progressive incorporation of old carbon in younger sections, i.e. as older sediments in temporary storage along fluvial valleys are eroded and reworked during floods and subsequently displaced farther down valleys toward the sea (Stanley and Hait, 2000). These episodic downslope-to-coast, estop and goi transport and contamination events are thus recorded at core sites by inversion upsection of radiocarbon dates, many of which are too old and do not reliably date the time of final deposition (Stanley and Chen, 2000).

Difficulty in dating Holocene sequences requires serious attention in view of the low elevation of deltaic surfaces. Such plains are vulnerable to the interaction of natural factors such as sediment compaction, land subsidence and rising sea level. Sea level has been rising at a rate of somewhat >1.0 mm/year, while the amount of land motion (usually subsidence) can vary within a single deltaic area (e.g. ~1.0 to 5.0 mm/yr in the Nile), and from delta to delta (to >20 mm/yr in the Mississippi). Together, these factors lead to relative sea-level rise requiring strategies to protect against accelerated coastal erosion and salt water incursion into delta plains. Radiocarbon dates that are too old lead to measurements of sediment accretion and relative sea-level rise that are too low. Thus, to establish a realistic chronostratigraphic base for deltaic sections, there is a need to use several dating methods (isotopic and others) and archaeological identification concurrently (Stanley *et al.*, 1999). Obtaining accurate dates of Holocene sequences is essential for calculating reliable rates of sediment accumulation and of land subsidence relative to sea level, measurements critical for implementing coastal protection measures.

During the past 7 millennia, most Holocene deltaic systems record natural phases of deltaic plain construction and seaward progradation (e.g. recent ebirdfooti phase of the Mississippi delta) as well as of destruction (e.g. distributary channel avulsion, lobe migration and coastal erosion of relict lobes of the Nile, RhUne and many others). However, it now appears that during the past 2 centuries, *human* pressures in many systems we have examined have become more important than, and override, *natural* processes thus modifying the original deltaic architecture. The Nile has become a classic example of a system where human artificial alteration has accelerated the destruction phase of an entire deltaic depocenter (Stanley and Warne, 1998). Here, extensive diversion of water by barrages, dams and a complex irrigation network has resulted in cut-off of most fresh water and sediment reaching the sea. Salt is no longer flushed from the plain surface, and erosion of selected sectors of the deltaic margin has accelerated. Increasingly, wetlands are artificially reduced in size as they are converted to agricultural land. As Nile populations have rapidly grown during the past 3 decades (now locally reaching >1000 persons/km^2), waters that reach wetlands carry larger amounts of agricultural, municipal, industrial wastes. As a result, ever smaller lagoon and marsh areas have become markedly more polluted, reducing much-needed fish catches. The modern Nile is an example of a delta that no longer functions in a natural manner.

Most fluvial systems elsewhere have also been dammed, or their water flow systems modified and reduced, resulting in decreased sediment loads that entrain deltaic destruction phases. We find that water diversion and channelization projects on deltaic plains (e.g. Nile, Rio Grande) are usually even more important than damming *per se* (Stanley, 1996). It is quite evident that as humans continue to migrate onto the worldis deltas, such systems will be artificially modified at an increasing pace. Of course, river water control measures are required for basic human needs, yet there is an equally important need to maintain healthy delta development. We have now entered a new phase of delta investigations that emphasizes environmental balance, the effects of which will be felt by many. Collaborative multi-disciplinary scientific studies of deltas are essential to resolve the geological and ecological problems highlighted in this presentation. The *Deltas Workshop* presents a valuable opportunity to explore growing human-versus-nature conflicts and to provide constructive solutions to problems raised here.

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([1]Smithsonian Institution, USA.)

Keywords : delta, global change, human impact, Smithsonian Institution

This keynote paper had been listed in the preliminary program but could not been presented because the author had not been able to visit Japan. The editorial board admitted the importance what the author proposed in the paper, so that this is documented without the actual presentation by authors's.

Holocene Sea-Level Changes and Glacio-Hydroisostasy

Masao NAKADA[1] and Jun'ichi OKUNO[1]

Observations of late Pleistocene and Holocene sea-level variations contain information for establishing the tectonic histories of continental margins, island arcs, and oceanic islands, as well as for estimating the mechanical response of the Earth to changes in surface loading by ice and meltwater. A separation of the parameters that define these various processes is possible in principle by examining records of sea-level changes over different time periods from geographically widespread sites. For example, sea-level changes at sites near the former ice load (locations in the near field) exhibit a quite different dependence on the various parameters defining the Earth's response and the ice load's geometry through space and time than do sea-level changes at sites far from the ice sheets (the far field).

Sea-level changes in the far field are characterized by a rapid rise during the melting phase from about 20 000 years before present (yr BP) to about 6000 yr BP. In the postglacial phase from about 6000 yr BP to the present, however, sea-level changes caused by the melting of the late Pleistocene ice sheets are very sensitive to island size and the geometry of the coastline, and have a significant spatial dependence over distances of less than 100 km. These variations are associated with the viscous response of the Earth to meltwater loading. By using the spatial dependence of sea-level changes, it is possible to separate the tectonic and glacio-isostatic components of the observed Holocene sea-level changes.

In this talk, we discuss the concept of hydroisostasy using the observed sea-level changes along the west coast of Kyushu, Japan. In this area, submerged archeological sites from the Jomon period of the mid-Holocene (underwater Jomon sites with ages of 6000-5000 yr BP) have been observed. These underwater Jomon sites are reasonably explained by sea-level variations due to meltwater loading. These observations also provide important constraints on lithospheric thickness and asthenospheric viscosity. We will also show the sea levels predicted using glacio-hydroisotasy for the sites discussed in this workshop.

([1]Kyushu University)

Keywords : hydroisostasy, sea-level change, glacioisostasy, Asia, Holocene

Depositional Environments of the Deltaic Sedimentary Body at the Mouths of the Han and Imjin Rivers, West Coast of Korea

Geon Hong MIN[1] and Yong Ahn PARK[2]

There are three big subtidal sedimentary lobes at the mouths of Han and Imjin rivers, west coast of Korea (northeastern margin of the Yellow Sea). The deposits of the three lobes can be divided into two seismic stratigraphic units (Sequence A and Sequence B). Sequence A can be further divided into three subunits (Subunit A-1, A-2, and A-3).

The lowermost sequence, Sequence B, is composed of reddish to brownish sandy sediments deposited in the paleoriver mouth during the pre-Holocene (late Pleistocene), whereas the unconformably overlying sequence, Sequence A, is composed of typical macrotidal marine sediments middle to late Holocene in age.

Such sedimentary environmental changes as those between Sequence A and B are well supported by regional erosion contacts shown in the seismic profile, and by sedimentological characteristics of sediments from deep cores. In particular, three subunits of Sequence A (A-1, A-2, and A-3) are described in ascending order in relation to sedimentary depositional history and process. Subunit A-1 is characterized by olive gray muddy and clast-bearing yellowish sandy sediments showing some stacked ripple laminations, reactivation surfaces, and herringbone cross laminations. Subunit A-1 may have been deposited in a tide-influenced shallow-water environment during a middle Holocene transgression.

Subunit A-2 is dominated by cross-stratified sandy layers and muddy sediments with rhythmic tidal beddings that may have been deposited in a subtidal environment during progradation and/or aggradation during a late Holocene transgression period. Subunit A-3 is composed of nearshore tidal sand ridges and alternating sand/mud deposits. Such alternating sand/mud deposits prograde offshore and are indicative of subtidal deposition during the late Holocene.

([1]Petroleum and Marine Research Division, KIGAM, Korea, [2]Department of Oceanography, Seoul National University, Korea)

Keywords: Han River, and Imjin River, river mouth sand body, Holocene trasngression

Holocene Evolution of the Huanghe (Yellow River) Delta, China

Yoshiki SAITO[1]

The Huanghe (Yellow River) has a length of 5464 km and a watershed 7.52 × 10^5 km^2 in size. Its sediment discharge rate, about 1.0-1.1 billion tons/yr, is the second largest in the world. The Huanghe Delta is characterized by elongated delta topography and huge sediment discharge in the present delta and by frequent lateral changes in the delta lobe and developed cheniers (shelly ridges) on the delta plain. The Holocene Huanghe delta complex is divided into ten superlobes based on cheniers and the historical remains that bound superlobes. Nine superlobes are located by the western Bohai Sea, and one superlobe is by the Yellow Sea.

Detailed analyses, including more than fifty AMS radiocarbon dates, of three borehole samples (H9601, H9602, and ZK-228) taken from the present Huanghe delta, together with radiocarbon dates previously reported from Holocene cheniers, provide a high-resolution picture of the Holocene evolution of the Huanghe delta and its relationship with cheniers on the delta plain. Chenier formation and delta progradation are linked, and controlled by sediment supply and course shifts of the lower reaches on the alluvial fan formed by the Huanghe.

Paleosediment discharge of the Huanghe can be estimated from deltaic sediment volume in coastal areas. Based on the paleogeographic map, borehole data, and detailed radiocarbon dating, the estimated past sediment discharge from 6-1 ka was only about one tenth of the present amount. This rapid increase is thought to be the result of human activities, such as deforestation, in the Loess Plateau. The increase in sediment discharge caused the Huanghe delta topography to change from strand-shaped to an elongated shape.

([1]Marine Geology Department, GSJ)

Keywords: Huanghe, Yellow River, delta, chenier, paleohydrogy

Human Impact on the Yellow River Delta Regime and its Consequences

Zuosheng YANG[1], Yoshiki SAITO[2]
and John D. MILLIMAN[3]

Water and sediment discharge from the Yellow River into the sea have been steadily decreasing since the 1970s. Average annual water discharge during the 1990s (1990-1999) at Lijin gauge, located about 105 km from the estuary, was only 27% of the discharge from 1950 to the 1960s, and sediment discharge measured only 33% of what it had been from 1950 to the 1960s. The river-flow cutoff first happened at Lijin gauge in 1972, and it has become more and more serious. There were a maximun of 226 no-flow days at Lijin gauge and 333 no-flow days in the estuary in 1997. The Yellow River is now a seasonal river.

The rapid reduction in water and sediment supply to the Yellow River delta area has caused serious environmental problems. The delta coast undergoes strong erosion. The newly formed wetlands of the delta have been eroding away at a rapidly increasing rate of 10 km^2/yr since 1996. The storm-buffer function of the wetland is declining in effectiveness, putting the coastal dams in an endangered state. Shrimp hatcheries are disappearing. The number of food organisms available for shrimp and fish has declined dramatically. Shrimp production during the 1990s in the Bohai Sea has decreased 20.2% compared to the 1960s. Saltwater intrusion into groundwater has increased, causing the deterioration of the ecological environment of the delta land. Nutrient input into the sea has decreased sharply, and the possibility of a disastrous pollution event occurring has increased.

The main reason for the reduction in the Yellow River water and sediment supply to the sea is the rapid increase in the quantity of water consumed in the river basin. More than 200 large irrigation systems and eight large water reservoirs and hydroelectric installations have been built along the main channel of the river. Water consumption has increased to five times more than it was during the 1960s, and 85% of the water consumed goes to irrigation. More than 30 billion cubic meters of Yellow River water are consumed annually, comprising 55% of the total water resources of the river basin.

The strong water-regulating effect of the reservoirs is the second major reason for the environmental degradation. And the decrease in precipitation during the last 10 years is ranked third among the reasons for reduced flow.

The largest reservoir, called Xiaolangdi and located in the middle channel of the Yellow River, is expected to be completed in 2000. It will have a water storage capacity of 12.65 billion cubic meters and a sediment storage capacity of 9.75 billion tons. Therefore, the water and sediment supply from the Yellow River to the delta area will be reduced even more in the future. The environmental problems due to the delta-regime change caused by human activities may become even more serious.

([1]Ocean University of Qingdao, P.R. China, [2]Marine Geology Department, GSJ, [3]College of William and Mary, USA)

Keywords: Huanghe, Yellow River, Human impact, dry-up

Clay Mineralology of the Yangzte Delta, China: Interpreting Late Quaternary Sea-Level Fluctuations, Climate Change, and Sediment Provenance

Zhongyuan CHEN[1] and Zhanghua WANG[2]

The present study focuses on the temporal distribution of clay minerals in a new, complete, type core, ZX-1, from the south-central part of the Yangtze delta plain. The continuous sedimentation, along with a suitable sedimentation rate, ensures that this high-resolution clay-mineral study will increase our understanding of environmental change during the late Quaternary. Four diagnostic clay-mineral suites were marked upward from the core bottom: Zone I, kaolinite and illite (late Pleistocene); Zone II, kaolinite and chlorite (early Holocene); Zone III, illite, smectite, and chlorite (early to mid-Holocene); and Zone IV, illite and smectite (late Holocene). Holocene smectite distribution has been closely linked with sea-level fluctuation, because its occurrence in Holocene sediments is related to sea invasions. Fluctuations in kaolinite and chlorite during the early and mid-Holocene are apparently associated with climatic oscillations, as verified by the pollen assemblage. The clay-mineral distribution also sheds light on sediment provenances. The terrigenous sediment sources of the late Pleistocene and early Holocene were primarily in the western highlands of the study area, and the sediments of the late Holocene were basically from the Yangtze. During the mid-Holocene, the clay-mineral suite indicates dual sediment supplements to the study area, derived both from the western highlands and the Yangtze.

([1]National Key Laboratory for Estuarine and Coastal Research, East China Normal University, P.R. China, [2]Pilot Laboratory for Urban Remote Sensing and Archaeology, Department of Geography, East China Normal University, P.R. China)

Keywords: Yangtze, Changjiang, clay mineral, Holocene, delta

Sediment Facies and Progradation Rate of the Changjiang River Delta

Kazuaki HORI[1], Yoshiki SAITO[2], Quanhong ZHAO[3], Xinrong CHENG[3], Pinxian WANG[3] and Congxian LI[3]

The Changjiang (Yangtze) River has formed a huge tide-dominated delta at its mouth since 6-7 ka, when sea level reached or approached its present position. Three borehole cores (CM97, JS98, and HQ98) were obtained in the Changjiang delta plain during 1997-

1998 to clarify the characteristics of tide-dominated delta sediments and their architecture and the progradation rate of the delta. Detailed core descriptions and sediment analyses were carried out, and 32 Accelerator Mass Spectrometry radiocarbon dates on molluscan shells and plant materials were obtained.

Core sediments were divided into six depositional units based on sediment analyses. They were interpreted as tidal sand-ridge, prodelta, delta-front, subtidal to lower intertidal-flat, upper intertidal-flat, and surface-soil deposits, in ascending order. Tidal sand-ridge deposits occurred only in JS98 and consisted mainly of several sets of an upward-fining succession. These sets were composed of poorly sorted very fine to medium sand with shell fragments and mud clasts, overlain by thickly interlaminated to thinly interbedded sand and mud. Prodelta sediments were recognized in CM97 and HQ98 and were characterized by dark gray silt to clay with occasional thin shell beds and thin coarse-silt layers. Delta-front deposits consisted mainly of thickly laminated to very thinly interbedded sand and mud. Silty to fine sand with parallel and/or ripple laminations were commonly recognized in HQ98. Subtidal to lower intertidal-flat sediments showing an upward-fining succession were composed mainly of thickly laminated to very thinly interbedded sand and mud with few shell fragments. Upper intertidal-flat deposits consisted of thinly interlaminated sand and mud deposits containing plant rootlets. The surface soil was characterized by dull brown clayey silt, including abundant plant rootlets and snail shells. The prodelta to delta-front units showed an upward-coarsening succession covered by an upward-fining succession from the uppermost part of delta-front unit to the surface-soil unit. Sedimentary structures such as thinly interlaminated to thinly interbedded sand and mud and bidirectional ripple laminations indicated that tides strongly influenced the formation of these sediments.

The sediment facies and their succession and the high-resolution radiocarbon dating made possible the determination of the accumulation rate of the core sediments and the progradation rate of the delta. The accumulation rate of core sediments was 1.1 m/ka during the deposition of prodelta sediments. In contrast, high accumulation rates, more than 3.5 m/ka, prevailed during the deposition of the delta-front to lower intertidal- to subtidal-flat sediments. The delta has prograded more than 240 km during the last 6 ka, with an average progradation rate of 48 km/ka. Progradation rates increased abruptly to from 34 to 76 km/ka at ca. 2 ka. A possible cause for this increase was a depocenter change from the middle reaches, which had broad floodplains and lakes, to the delta area.

([1]Department of Geography, University of Tokyo [2]Marine Geology Department, GSJ, [3]Laboratory of Marine Geology, Tongji University, P.R. China)
Keywords: Yangtze, Changjiang, Holocene, progradation, delta, paleohydrogy

Harmful Dinoflagellate Cysts Found in Surface Sediments and a Core Sample Collected Offshore from the Changjiang River Mouth, China

Kazumi MATSUOKA[1], Yoshiki SAITO[2], Hajime KATAYAMA[2], Yutaka KANAI[2], CHEN Jianfang[3] and ZHOU Huaiyang[3]

A palynological study was carried out on nine surface-sediment samples and a core sample collected offshore from the Changjiang River mouth, China. Palynomorphs found in these samples included various taxonomic groups, such as dinoflagellate cysts, Prasinophycean phycoma, freshwater Chlorophycean *Pediastrum*, Chrisophycean archeomonads, tintinnid lorica, microforaminiferal linings, resting eggs and bodies of copepods, and acritarchs. The results of this study are as follows:

1) The occurrence of *Pediastrum* suggests that the freshwater plume derived from the Changjiang River extended to around 100 km offshore from the mouth.
2) In the surface-sediment samples, the dinoflagellate cyst concentrations, 10 to 10^2 cysts per 1 ml sediment, were approximately one tenth the concentration found in the coastal areas and inner bays of the Korean peninsula and west Kyushu.
3) Since autotrophic dinoflagellate cysts dominated all surface sediments, eutrophication did not progress extensively off the Changjiang River mouth. However, in the core samples, the increase in hetrotrophic dinoflagellate cysts upward probably reflected gradual eutrophication during the last two or three decades.
4) Some cysts of red-tide-causing dinoflagellates such as *Lingulodinium polyedrum*, *Scrippsiella trochoidea*, and the *Polykrikos kofoidii/schwartzii* complex were present in the surface sediments and also in the core samples.
5) Ellipsoidal and ovoidal cysts were probably identical to the toxic species *Alexandrium catenella/tamarense* and *A. minutum*, respectively.

([1] Faculty of Fisheries, Nagasaki University, [2]Marine Geology Department, GSJ, [3]Second Institute of Oceanography, SOA, P.R. China)
Keywords: palynomorph, dinoflagellate, Yangtze, Changjiang, delta, red tide

Numerical Simulation of Paleotides around the Changjiang Estuary at 10 and 6 kyr B.P.

Katsuto UEHARA[1], Yoshiki SAITO[2], and Kazuaki HORI[3]

Two-dimensional paleotidal simulations were carried out in order to investigate the influence of large morphological changes that occurred during the postglacial period in the region around the Changjiang estuary on tides and tidal currents of the Yellow/East China Sea. Calculations were made for two typical periods: 10 and 6 kyr BP. The former corresponds to a period when the Changjiang estuary extended southeastward for about 400 km, filling the incised valley that had been sculpted when the sea level was lower. The latter period coincides with the maximum postglacial transgression in eastern China. Special consideration was taken to reconstruct the paleotopography around the Changjiang estuary (from lat 31-33°N and long 119 -123°E), which was accomplished by using available borehole datasets. The aim was to remove the effect of the massive sedimentation that obscures the original topographic features in this area. We also simulated the coastline and bathymetry along the Jiangsu coast and Hanzhou Bay for the same reason. Sea level was assumed to be -45 m at 10 kyr BP and 0 m at 6 kyr BP, relative to the present sea level.

At 10 kyr BP, the M2 tidal amplitude within the elongated estuary exhibited an alternative distribution of maximums along the northern coast and minimums along the southern coast. The existence of two maximums can be related to the second natural mode of the estuary, while the asymmetric distribution of tidal amplitudes between the coasts may be ascribed to the Coriolis effect. The M2 tidal-current ellipses were almost linear and aligned primarily with the axis of the bay, i.e., in a NW-SE direction. This feature was also detectable along the relict submarine valley outside the estuary. Additional simulations that lowered the sea level by 45 m with modern topography revealed that the tide and tidal-current rectification due to the burial of the paleo-Changjiang estuary was limited to the area within and adjacent to the estuary.

On the other hand, at 6 kyr BP, the M2 tidal currents converge (diverge) from (to) the mouth of the estuary, forming a radial tidal-flow pattern originating from the estuary. Tidal amplitude reached a maximum value in the middle of the estuary and attenuated toward its head. These features agree with the numerical results of Zhu (1998), who estimated paleotides at 7 kyr BP using a different depth elevation model. Tides and tidal currents in the estuary at 6 kyr BP seem to have been stronger than those at present. From the analysis of the tidal-current phase pattern and from some supplemental experiments with changing sea levels, it appears that the emergence of the radial flow pattern of the tidal currents might have been caused by the southward shift of the southern tip of the Yellow Sea amphidromic system that accompanied the postglacial sea-level rise.

In the Jiangsu coastal area between lat 32.5°N and 33.5°N, the major direction of the M2 tidal current shifted from a SW-NE to E-W direction during the last 6000 years. This directional change is consistent with a paleocurrent direction estimated for the North Jiangsu region using a geomagnetic analysis (Zhang et al., 1998). The SW-NE flow pattern also appeared when an experiment was carried out using the present-day configuration, except that the sand-ridge system off the Jiangsu coast was removed. This result might indicate a relationship between sand-ridge formation and the directional shift of the tidal current.

([1]Research Institute for Applied Mechanics, Kyushu University, [2]Marine Geology Department, GSJ, [3]University of Tokyo)

Keywords : Yangtze, Changjiang, paleotide, Holocene

Paleocurrent Studies on Samples from Borehole CM-97 from the Changjiang Delta Using Anisotropy of Magnetic Susceptibility : Preliminary Results

Baozhu LIU[1], Yoshiki SAITO[1], Toshitsugu YAMAZAKI[1], Abdelaziz ABDELDAYEM[1], Hirokuni ODA[1] and Kazuaki HORI[2]

Anisotropy of magnetic susceptibility (AMS) has long been demonstrated as a useful tool in paleocurrent determination, in particular for marine, lacustrine, and tidal-flat sediments. The Changjiang delta is a typical tide-dominated delta in a mesotidal coastal environment. AMS analysis was conducted on samples from Borehole CM-97 (lat 31° 37' 29" N, long 121° 23' 38" E) in the Changjiang delta. This borehole core, about 70 m long, recorded sedimentary environments of the Changjiang estuary during the approximately 10,000 years from 11.5 ka to 1.5 ka. Sediments from this core were divided into 9 stratigraphic units, namely Unit 1 to Unit 9 from bottom to top. A total of 1272 discrete samples were obtained through sub-sampling by pressing standard 7 cm^3 plastic cubes into the working half of each section of the split core. Initial low-field magnetic susceptibility (MS) and its anisotropy were measured using a KappaBridge KLY-3S susceptibility meter. The natural remanenr magnetization (NRM) was then measured and the sample demagnetized using a three-axis 2G Enterprises cryogenic magnetometer with an in-line alternating field (AF) demagnetizer with a peak field strength of 80 mT. The majority of the samples exhibited stable magnetization with a single component heading toward the origin of the orthogonal plot. Some samples, however, did not show a credible magnetic record and were excluded from further statistical analysis. Magnetic north for each sample level was calculated from a linear fitting of declination on depth and was used for reorientation of the AMS axes to their geographic coordinates.

Following the recommendations of Ellwood et al. (1988) and Tarling and Hrouda (1993), a set of AMS parameters defining the mean magnetic susceptibility (K), corrected anisotropy degree (Pj), magnetic lineation (L), magnetic foliation (F), and the ellipsoid shape (q) were calculated and used to evaluate the magnetic fabric of the present Changjiang delta sediments. Only samples that satisfied criteria for a primary fabric were used for paleocurrent estimation using the paleomagnetically oriented maximum- and minimum-susceptibility axes. Paleocurrent directions could generally be recovered for most of the recognized 9 stratigraphic units. Absolute directions were only available for a few levels where imbrication could be recorded. The overall results can be summarized as follows: main flow directions were to the west or northwest for all stratigraphic units, i.e., a flood-tidal current dominated. This finding was in good accordance with sedimentological interpretations of units 2 to 6 as intertidal to subtidal estuarine sediments. Poor correlation, however, existed for units 7 to 9, which had been interpreted as prograding delta or delta-plain sediments without much tidal influence. Nevertheless, interbedded sand and mud layers could be recognized in sections from units 7 to 9, which perhaps explains why AMS showed a flood-tide-dominated pattern. Another possibility might be that deltaic sediments were reworked by tidal processes. For Unit 1, which was interpreted as fluvial sediments, no absolute flow direction could be inferred from the AMS data, but the reason remains to be determined. All the stratigraphic boundaries could be seen clearly from the characteristics of downhole changes in the MS and AMS parameters, which shows that AMS has great potential in sedimentological studies in addition to paleocurrent determination.

([1]Marine Geology Department, GSJ, [2]University of Tokyo)

Keywords: Yangtze, Changjiang, magnetic susceptibility, AMS, paleocurrent

Sedimentary Facies and Progradation Model of the Holocene Mekong River Delta in Vietnam

Susumu TANABE[1], Thi Kim Oanh TA[2], Van Lap NGUYEN[2], Masaaki TATEISHI[3], Iwao KOBAYASHI[3] and Yoshiki SAITO[4]

The Mekong River is one of the major rivers in the world in term of water discharge (470 km^3/y), sediment discharge (160 million t/y), and drainage area (810,000 km^2). The river forms a vast delta at its mouth on the South China Sea. The delta is located in a humid tropical region and is greatly influenced by monsoons. A monsoon-driven ocean current creates a wave up to 1 m high at the coast. A tidal range of about 3 m prevails (mesotide) at the river mouth. Ocean currents are considered to affect the morphological form of the delta. After the maximum Holocene transgression, the delta prograded from the inner part of the Indochina Peninsula toward the South China Sea.

During 1997-1998, three boreholes were obtained from the delta plain in order to study the delta development in relation to Quaternary sea-level changes. In this study, the TV1 and VL1 cores, which were located in the outer and central part of the Mekong delta plain, respectively, were described in detail, and the sand and silt contents were measured in order to study the sedimentary facies. AMS-^{14}C dating for 15 samples was done by Beta Analytic Inc.

The following sedimentary facies have been interpreted by analysis of the sediments.

The TV1 core was composed of the following seven facies in ascending order. They were 1) *basement (late Pleistocene) deposit)*: tan-colored weathered deposits with ^{14}C ages of about 43,000 yr BP on shell fragments; 2) *transgressive lag sediments*: a mixture of terrigenous deposits, such as bauxite pebbles, and marine materials, such as foraminifers; 3) *prodelta to delta-front sediments*: an upward-coarsening succession from massive clay to flaser bedded sand/mud with current-ripple lamination or double mud-drape structure; 4) *seaward margin sediments of subtidal flat*: well-sorted, fine-medium sand: 5) *subtidal flat sediments*: alternating thin sand and clay beds with wave and current-ripple laminations in flaser/lenticular sand; 6) *sand-flat sediments*: an upward-fining succession from well-sorted medium sand to very fine sand; and 7) *beach ridge-back swamp sediments*: alternating beds of sand and clay with plant fragments.

The VL1 core consisted of seven sediment facies. In ascending order, they were 1) *basement* and 2) *transgressive lag sediments*: same characteristics as with the TV1 core; 3) *shelf-mud sediments*: massive marine clay with a gradual contact with transgressive lags; 4) *prodelta sediments*: alternating sand and clay with double mud drapes and parallel lamination; 5) *delta-front sediments*: an upward-coarsening succession of alternating sand and mud, with common current-ripple laminations; 6) *tidal-flat sediments*: an upward-fining succession of sand/mud lenticular bedding; and 7) *floodplain soil*: clay with roots and covered by lateritic soil.

^{14}C dating shows that most of the deltaic sediments in the TV1 core were deposited from 2,720 to 720 cal. yr BP, and that the deltaic sediments in the VL1 core were deposited from 6,110 to 3,435 cal. yr BP. These ages indicate when the subaqueous Mekong River delta passed the borehole sites during the Holocene. The Mekong delta has prograded southeastward since the maximum Holocene transgression. Moreover, the depositional rate of the VL1 core is higher than that of TV1 core.

Thus, the following features are suggested:

1) The sedimentary facies associated with the VL1 and TV 1 cores suggest that sediments from both cores were influenced by tidal currents, but that the TV1 core was more influenced by wave and ocean currents.

2) The progradation rate of the Mekong delta decreased in the late Holocene. The progradation rate was 25.8 m/y from the VL1 site to the TV1 site and 12 m/y from the TV1 site to the present delta front, based on identified delta-front facies and ^{14}C dates.

3) The change in progradation rate occurred around 3,500-2,500 cal. yr BP.

4) The reason for this change may have been the sediment dispersal effect of longshore drift toward the south to Ca Mau Cape caused by wave action. This possibility is supported by the presence of a wave-influenced sediment facies in the TV 1 core and by well-developed beach ridges on the outer part of the delta.

([1]Shinshu University, [2]Sub-Institute of Geography, Vietnam National Center for Natural Science and Technology, Vietnam, [3]Niigata University, [4]Marine Geology Department, GSJ)

Keywords: Mekong delta, Holocene, sediment facies

Role of Remote Sensing in a Survey for Environmental Change

Yasukuni OKUBO[1], Akiko TANAKA[1], Manabu KAKU[2] and Sin SINSAKUL[3]

Remote-sensing instruments view wide ranges repeatedly, and their images provide information on changes in the regional environment. Changes in the shoreline of the upper Gulf of Thailand, which was great before 1987 and is remarkable in the comparison of the remote sensing images with the old shoreline, continued till 1992. Three alternative explanations for the cause of the changes are (1) land subsidence, probably caused by over-pumping of ground water, (2) the new artificial lakes along the upper streams of the Chao Phraya, and (3) the destruction of the mangrove forests. The Rayong area, 150 km southeast of Bangkok, faced rapid coastal erosion. The images delineate recent artificial construction along the coast, suggesting that the construction was a cause of the erosion. The mangrove forests of Phuket Island and Phang Nga Bay in the "time-series SAR composite image" are marked by a gray color with a special texture. Remote sensing should be a powerful tool for mapping beach forests. The images of the Amphoe Khlung area suggest that the wetland has undergone a rapid change. A seasonal change in plant cover may account for that change. Since the coastal change was vulnerable to tides and waves, knowledge of the sea currents and their changes are crucial for the interpretation of coastal environments. The remote-sensing images show muddy flow from the river. Therefore, analysis of that flow could give information about currents.

Consequently, extensive analysis of remote-sensing images acquired at different periods can yield information about changes in coastal environments and their possible causes.

([1]Geophysics Department, GSJ, [2]Mitsubishi Materials Natural Resources Development Corp., [3]Department of Mineral Resources, Thailand)

Keywords: Chaophraya river, Gulf of Thailand, remote sensing, SAR

A Note on the Morphodynamic Processes of Different Time Scales in the Pearl River Estuary

Chaoyu WU[1]

An estuary is a region where a river meets the sea. All present-day estuaries are geologically young since they formed when sea level reached its present level approximately 6,000 years ago. Long-term morphodynamic processes and sedimentation in the coastal zone, in response to human interference and a changing environment, is increasingly an important issue.

The Pearl River delta is located in Guangdong Province, South China. After entering the delta area, the West, North, and East rivers bifurcate repeatedly and form the network system of the Pearl River, one of the most complicated river network systems in the world. The Pearl River discharges into the South

China Sea through eight major outlets, which interact through the network and form several estuarine complexes.

Based on field observations, a hydrographic survey, historic records, navigation charts, and sediment dating, the present paper briefly describes the morphodyamic sedimentation processes for different time scales, from seconds to geological time-scales. The most recent field survey indicates that seasonal variation in the circulation pattern of the estuary varies from partially mixed to remarkably highly stratified, depending on river discharge, water depth, and tides. Spectrum and system analysis reveals the characteristics of variations in low frequency flow and water stage over periods from several days to several months. The possible driving forces are also discussed. The evolution of the estuary for the last 300 years is described using historic records and navigation charts from as early as 1723. The geologic evolution and geographic setting of the estuary have profound effects on modern morphodynamic processes. Numerical models based on physical laws, behavior models, and elaborately selected statistical models are applied to simulate the morphodynamic processes for different time scales.

Finally, an automatic marine environment observation system (PEIOS) being built in the Pearl River estuary is briefly described.

([1]Center for Coastal Ocean Science and Technology Research, Zhongshan University, P.R. China)

Keywords: Pearl river, delta, estuary

Coastal Development of the Modern Red River Delta

Tran Duc THANH[1] and Dinh Van HUY[1]

With a shoreline 145 km long, the modern Red River delta (MRRD) is considered to have two zones: a subaerial delta (late Holocene plain), with an area of 5000 km^2; and a submerged delta (avant-delta) with an area of about 1000 km^2. The sediments of the MRRD range from fine sand to clay, and the facies are mainly those of avant-delta, submerged bar, tidal flood plain, beach, beach ridge, and mangrove marsh. The deposited sediments tend to be finer on the southwest along the shore and from the low-tidal subzone both landward and seaward in the transverse profile.

The MRRD is located in a depression with the Cenozoic sedimentary thickness reaching 5000 m, the Quaternary 250 m, and the Holocene about 30 m. The sinking rate was determined to be from 0.04-0.20 mm/yr during Neotectonic time and 0.04-0.12 mm/yr. during the Quaternary. The sea level rose at a rate of 2.24 mm/yr from 1957-1989 as measured at Hon Dau Station located on the NE margin of the MRRD. The vertical depositional rate has been surveyed for the same period and was from 1-6 cm/yr. In the intertidal zone the MRRD has developed as a result of the dynamic interaction among river, tide, and waves. Every year, the Red River discharges into the coastal zone of the MRRD 111 million tons of sediment. The tide is of the diurnal type and has a maximum range of 3.5-4.0 m. The prevailing waves are from the NE and E during a NE monsoon, and from the SE and E during a SW monsoon. The mean wave height is 0.88 m and the maximum height is 5.0 m. The mangroves contribute importantly to the deposition of sediment.

Coastal accretion of the MRRD is rapid, but irregular. The delta has expanded seaward at a mean rate of 28 m/yr and a maximum rate of 100-120 m/yr at the large river mouths, where accretional convex bows or caps have been formed and extended into the sea. However, the first four shorelines have been eroded. Erosion of the Van Ly coast has been at a rate of 10-15 m/yr, with a maximum rate of 30 m/yr during the last 50 years. Along the coast, accretion has been stronger to the SW. The main distributaries of the river have moved periodically to the SW or NE simultaneously. The length of the period has been observed as 30-40 years, and at this time, the distributaries are moving to the SW. The formation, development, and destruction of sandy beach ridges close to the river mouths have influenced the direction of motion of the distributaries. Human activities such as the construction of dikes and dams, the dredging of channels, and upstream and mangrove deforestation have changed coastal landforms, sedimentary distribution, and balance. They have contributed to profound changes in coastal erosion and accretion, and increased the risk of flood, sea-dike ruptures, and salt intrusion. In particular, the sea-dike system built during the last thousand years has formed large lowland compartments inside the delta and has accelerated the very rapid but irregular expansive acretion of the tidal plain outside.

([1]Hai Phong Institute of Oceanology, Vietnam)

Keywords : Red river, Song Hong, delta, Holocene

Landforms and Environmental Change in the Lower Red River Delta

Shigeko HARUYAMA[1] and Vu Van PHAI[2]

The Red River, which is the biggest river in the northern part of Vietnam and the second largest river in Vietnam, is forming a large delta plain at its mouth in the Vinh Bac Bo. The Red River delta is a result of the interactions between natural factors and long-term human activities (during the last 2 ka), as well as the land-sea interface. These interactions are observed in relief structures such as landforms, the channel network, and artificial constructions. The accumulation rate of the Red River is high, causing the flood plain between the river and the artificial dikes on either side of the river to be 0.5-0.8 m higher than outside the dikes. Although they are being continuously changed by the alteration of the channel, bed-load sediments tend to raise the channel floor. The Red River and its distributary, the Day River, have raised beds as a result of the construction of the dikes and circle levees.

Based on the analysis of the landforms (by the interpretation of aerial photos) and sedimentary features, and the role of the dominant factors affecting their formation, the Red River delta was divided into the following geomorphological units: alluvial terraces, alluvial fan, natural levee and back marsh, higher delta, lower delta, tidal flat, lagoon, and sand ridges. In general, the dominant process in the coastal area is deposition, and the shoreline has moved seaward at various rates during modern times. However, coastal erosion is occurring south of the river mouth. The most intensive accretion is at Kim Son- Nga Son, where the average rate of accretion is 80-100 m/yr, but the rate has varied from 30-40 m/yr (from the tenth century to the present) to 100 m/yr (from the nineteenth century to the present). The accretion rate at Tien Hai- Ba Lat is about 5-7 m/yr, and reclaimed lands are increasing. From 1960 until now, the area reclaimed is about 10,000 ha. About 60 km of the shoreline from Do son to Nga Son has been eroded by wave activity and currents. The erosion has been most intense on the coast of Hai Trieu (32.3 m/yr) and Giao Phong (33.3 m/yr).

([1]Waseda University, [2]Hanoi National University, Vietnam)

Keywords : Red river, Song Hong, delta, Holocene

Mekong River Delta Progradation into the South China Sea in the Late Holocene

NGUYEN Van Lap[1], TA Thi Kim Oanh[1], Masaaki TATEISHI[2], Susumu TANABE[3], Iwao KOBAYASHI[2], Toshio. NAKAMURA[4], and Yoshiki. SAITO[5]

The Mekong River delta, one of the largest deltas in Asia, is located in southern Vietnam. The sediments from the river, dominantly silts, clays, and fine sands, have been deposited in the South China Sea and the Gulf of Thailand. Detailed mapping and sedimentary studies indicate that the maximum Holocene transgression occurred in the interval from ca. 6000-5000 yr BP, and sea level at that time was approximately 3.5 m above the present sea level. During the highstand and regressions in sea level over the last 5000 years, delta progradation has produced a great flat plain of 62,520 km^2.

Delta progradation into the South China Sea is discussed based on preliminary results from newly collected borehole cores. Six boreholes were drilled on the lower delta plain of the Mekong River delta in 1997-1998 : BT 1 lat 10°17 ' 01"N, long. 106°21 ' 34"E ; BT 2 lat. 10°08 ' 18"N, long. 106°28 ' 7"E ; BT 3 lat. 10° 01 ' 5"N, long. 106°37 ' 44"E ; DT 1 lat. 10°17 ' 4"N, long. 105°39 ' 17"E ; VL 1 lat. 10°02 ' 16"N, long. 105°58 ' 22"E ; TV 1 lat. 9°41 ' 12"N, long. 106°25 ' 32"E. Based on detailed analyses of samples from these 6 cores, latest Pleistocene and Holocene sediments were distinguished. Latest Pleistocene sediments were composed mainly of mottled, slightly oxidized, yellowish gray stiff silts, sandy silts with subangular pebbles, and laterite. These sediments were radiocarbon dated to 11,340 and 43,420 yr BP. The Holocene sediments were 13-56 m thick and unconformably overlay the Pleistocene sediments. The Holocene deposits consisted of dark gray, greenish gray clayey silts, sandy silts, and fine sands. They were characterized by parallel lamination and wavy and lenticular bedding, with shell fragments and organic matter. Radiocarbon ages on marine molluscan shells from embayment sediments were ca. 5200 yr BP at the BT 2 borehole and 5700 yr BP at the VL 1 borehole. These embayment sediments were linked to the evidence for a Holocene sea-level rise found in the northern Mekong River delta. The inner prodelta sediments were dated at ca. 4600-3400 yr BP, but near the recent coast their ages were ca. 4200-2400 yr BP. The inner delta-front sediments were dated at ca. 4590-3300 yr BP, but at ca. 3100-2200 yrs BP near the recent coast. The subaqueous inner delta-plain sediments seemed to be younger than 3300 yrs BP, but those near the recent coast were dated from 2100-1300 yr BP. These changes show rapid delta progradation and seaward migration of the subaqueous delta plain, delta front, and prodelta system of the Mekong River delta after the maximum Holocene transgression.

([1]Sub-Institute of Geography, Vietnam National Center for Natural Science and Technology, Vietnam, [2]Department of Geology, Faculty of Science, Niigata University, [3]Graduate School of Technology, Shinshu University, [4]Dating and Materials Research Center, Nagoya University, [5]Marine Geology Department, GSJ)

Keywords : Mekong river, delta, Holocene

Coastal Change and Saltwater Intrusion Related to Human Activities in the Coastal Lowlands of the Mekong River Delta, Southern Vietnam

NGUYEN Van Lap[1], TA Thi Kim Oanh[1], and Masaaki TATEISHI[2]

The Mekong River delta, one of the largest deltas in Asia, is a tide-dominated delta. Sediments dominated by silts, clays, and fine sands have been deposited in the South China Sea and the Gulf of Thailand. During the sea-level highstand and regression over last 5000 yr BP, delta progradation has produced a great flat plain of 62,500 km^2, the total shoreline of which is about 740 km long. A monsoon regime together with two different tidal patterns, semi-diurnal and diurnal, on the South China Sea and Gulf of Thailand have played an important role in the coastal change of the Mekong River delta in recent years. Since 1885, large tidal ranges of 3-4 m have contributed considerably to coastal erosion and accretion on the coast of the South China Sea. The Bo De coast, 60 km long, a well-known eroding coast, is eroding at an average rate of 30-50 m/yr, and in places at a rate of over 80 m/yr. The remainder of the delta coast is eroding at about 10-25 m/yr, including the coastal segments of Go Cong, Ba Tri and Dong Hai of Tien Giang, Ben Tre and Tra Vinh provinces, respectively. The delta coast on the western side of Camau Cape is accreting with an average rate of 50-80 m/yr, and in places at a rate of over 100 m/yr.

The low-lying Holocene coastal plains supporting freshwater wetlands are often close to or below the level reached by the highest tides. Together with the large tidal range and the wave and northeast monsoon actions, saltwater intrusion has clearly occurred for the last several decades. Saltwater intrusion has extended more than 20 km inland in more than 20 years, and saltwater has invaded the low-lying freshwater wetlands through a combination of inland extension along main channels, tidal creeks, incompletely infilled paleochannels, and artificial canals. Moreover, the extension of salt marsh and mangrove marsh environments inland along most tidal creeks has been considerable because of increasing pressures from shrimp farms along the landward fringes of the salt and mangrove marshes. Since the price of shrimp has increased rapidly in recent years, large areas of mangrove forest and rice fields in the Camau Peninsula have been destroyed in order to set up shrimp farms. The area devoted to shrimp farms has increased rapidly from 82,300 ha in 1991 to 147,000 ha in 1997. The expansion has not been managed well, and it aggravates the ongoing processes of coastal erosion and saltwater intrusion.

The main concern of this study is the rate of coastal change, especially emphasizing coastal erosion as documented during the past 100 years and saltwater intrusion during the last 20 years. Further coastal erosion and saltwater intrusion in the Mekong River delta will probably be induced by the sea-level rise as a consequence of global warming.

([1]Sub-Institute of Geography, Vietnam National Center for Natural Science and Technology, Vietnam, [2]Department of Geology, Faculty of Science, Niigata University)

Keywords : Mekong river, delta, salt intrusion, human impact

Late Holocene Sea-Level Changes and Evolution of the Central Plain, Thailand

Masatomo UMITSU[1], Sin SINSAKUL[2], Suwat TIYAPAIRACH[2], Niran CHAIMANEE[2] and Kumiko KAWASE[1]

The Central Plain, one of the largest deltaic and tidal plains in southeastern Asia, is located along the lower reaches of the Chao Phraya River in central Thailand. Landforms of the lower plain are classified as flood plain, deltaic plain, and tidal lowland. The elevation of the plain is mostly less than 5 meters in the central and southern region and 1-2 meters in the coastal region.

Holocene sediments in the central plain consist mainly of silt and clay with occasional organic matter. They are classified into four units: basal peat, marine, tidal, and fluvial, from bottom to top. The basal peat developed in places on top of Pleistocene sediments and was covered by the marine unit; it lay mainly at depths of about -5 to -10 m in the southwestern plain, and about -5 to 0 m in the eastern and northern parts of the plain. The marine unit, the so-called Bangkok clay (Nutalaya, 1983), overlay the basal peat or Pleistocene sediments; it consisted of very soft, gray silty clay. The marine unit was more than 10 m thick in the central and southern plain, and decreased in thickness toward the margins of the plain. The tidal unit consisted of gray silt or silty clay with very thin organic-rich sandy layers; it was covered by the fluvial unit. The tidal unit was 2-3 m thick in the central plain and 3-5 m thick at the margins; its thickness decreased to the south.

Some radiocarbon ages for the Holocene sediments have been obtained from the sediments of the Central Plain. The ages of the basal peat collected by the authors and reported by Somboon (1990) were between ca 8000 to 5500 yr BP, and they show that a distinct mangrove forest had developed by the early to middle Holocene. The basal peat layers were distributed from -10 m to +2 m depth, and their ages indicate the period of the Holocene transgression. Radiocarbon ages obtained from the tidal unit ranged from ca.7000 to 4000 yrs BP. These ages are also indicative of past sea-level changes.

Based on the ages and heights of basal peat and tidal sediments, the maximum height of sea level was more than 2 meters above the present sea level, and occurred around 6000 yr BP. After the sea-level high-stand, a slight regression occurred ca 4,500 yr BP. This sea-level change is similar to that shown by Sinsakul (1992). A former beach ridge is located in the southwestern part of the plain. The height of the ridge is 3-5 m a.s.l. and its age is 3420 yr BP. Late Holocene tidal sediments developed in the central and southern parts of the plain, and they show that the Central Plain expanded as the tidal plain retreated toward the south.

([1]Department of Geography, Nagoya University, [2]Department of Mineral Resources, Thailand)
Keywords: Chaophraya river, delta, central plain, Holocene, sea-level change

Sedimentary Sequences of the P.T. Borehole, Lower Central Plain, Thailand

Suwat TIYAPAIRACH[1]

The project on the Impact of Sea Level Change on Coastal Areas of the Lower Central Plain of Thailand is being conducted by a joint working group of Thai and Japanese Researchers. The deep drilling, the P.T. Borehole, was carried out at lat. 14°4 ' 20"N, long. 100° 37 ' 59"E in late 1998. The core samples were described and the sedimentary units were classified in detail based on lithology. The depositional environments of each sedimentary unit were interpreted from the sedimentary sequences. The paleogeography of this sedimentary sequence was characterized by comparison with delta models. The results of this study were used to reconstruct the history of lower Central Plain throughout the Holocene period.

([1]Department of Mineral Resources, Thailand)
Keywords: Chaophraya river, delta, central plain, Holocene

Late Holocene Delta Front Migration of the Chaophraya Delta, Thailand

Yoshiki SAITO[1], Yoshio SATO[2],
Yuichiro SUZUKI[3], Sin SINSAKUL[4],
Suwat TIYAPAIRACH[5], and
Niran CHAIMANEE[4]

Late Holocene delta progradation of the Chaophraya River delta, Thailand, is described based on delta-front sediments and radiocarbon dates from borehole and open-pit samples taken from the lower central plain in Thailand. Three borehole cores were taken from the central plain of Thailand in late 1998: Site 1 lat. 14°04 ' 20"N, long. 100°37 ' 59"E; Site 2 lat. 13°40 ' 03"N, long. 100°13 ' 20"E; Site 3 lat. 13°34 ' 11" N, long. 100°35 ' 13"E. Holocene sediments at the borehole sites were 10-13 m thick, and they unconformably covered underlying Pleistocene marine or fluvial sediments. Radiocarbon dates from the basal part of the Holocene marine sediments were ca. 4.0 ka at Site 1, 7.0-7.5 ka at Site 2, and 2.5-3.0 ka at Site 3. Other radiocarbon dates on marine molluscan shells from the basal part of Holocene sediments in pits on the central plain were from 7.0-7.5 ka. As these molluscan shells with radiocarbon dates of 7.0-7.5 ka were recovered from sediments beneath the central plain and about 5 to 10 m below the present sea level, they are linked with the Holocene sea-level rise and inundation of the central plain. Accumulation curves from age-depth plots at borehole sites clearly show the time at which the delta front of the Chaophraya delta passed each borehole site. This event occurred from 3.5-4.0 ka at Site 1 and ca. 1.0 ka at Site 3. These data and other radiocarbon dates on the delta-front facies provide continuous data on seaward delta progradation in the central plain for the last 6 ka.

([1]Marine Geology Department, GSJ, [2]Geological Museum, GSJ, [3]Mineral and Fuel Resources Department, GSJ, [4]Geological Survey Division, Department of Mineral Resources, Thailand)
Keywords: Chaophraya river, delta, central plain, Holocene, progradation

Seismic Facies, Stratigraphy, and Evolutionary Model of Late Quaternary Deposits in the Lower Central Plain of Thailand

Wichien INTASEN[1], Thawatchai TEPSUWAN[1]
and Suvit SERITRAKUL[1]

In June 1998 and March 1999, a geophysical survey with high resolution seismic reflection profiling and echo sounding systems was conducted by the DMR and CCOP along the Chao Phraya River, the Tha Chin River, the Mae Klong River, the Mae Klong Canal, the Damnoen Saduak Canal, and the Sanphasamit Canal in the western part of the lower Central Plain of Thailand. A total of 472 line-km of geophysical data were obtained.

Water depths along the survey lines ranged from 0. 3 to 60 m. Three major seismic sequences beneath the water column were classified, namely Sequence 1, Sequence 2, and Sequence 3, in descending order. Sequence 1 generally thickened seaward with thicknesses ranging from 1 to 20 m. Seismic reflection configurations within this sequence were characteristically parallel and subparallel with low amplitudes, acoustic blanking, and chaotic patterns. The sediments were interpreted to be composed of prograded fluvial sands in the bottom of the channel axis overlain by Holocene marine-estuarine muds. The topmost lithofacies within this sequence was made up of recent fine-grained fluvio-estuarine sediments near the coast and coarse-grained fluviatile sediments farther upstream, 40 km from the coast. The mud unit could be correlated with the Bangkok Soft Clay Member. Sequence 2 was separated from sequences 1 and 3 by strong reflectors at depths below the water surface of 5-30 m and 20-100 m, respectively. This sequence is about 5-40 m thick, and the seismic reflection configurations within the sequence were characteristically parallel and subparallel with higher amplitudes than in Sequence 1. It was presumed to be made up of clay and sandy clay deposited under a terrestrial environment during the late Pleistocene and could be correlated with the Bangkok Stiff Clay Member. Sequence 3, the lowermost sequence depicted on the seismic profiles, exhibited a wavy parallel pattern in the upper part. It might be a middle Pleistocene sequence equivalent to the Phra Pradaeng Member, which is composed of a thick clay bed about 10-20 m thick at the top and alternating layers of sand/gravel and marine clay in the deeper part.

The Chao Phraya delta margin is experiencing land subsidence and coastal erosion problems. Thick, soft, marine-estuarine muds just beneath the present-day flood plain may be one of the stratigraphic factors responsible for the subsidence. Extensive river-sand mining results in a negligible supply of sand to the coast. Consequently, coastal erosion at the head of the Gulf of Thailand has been accelerated. However, high urban growth rates and pressures from development in central Thailand have stimulated increasing demand for new sand and gravel deposits to mine. Sand dredging in existing river channels will be stopped, and thus a need exists to find relict or inactive deposits in nearby areas. The river-channel evolution model presented in this paper suggests that coarse channel sands and gravels were deposited during later stage of estuary infilling and are thus to be found in more mature parts of the present flood plain.

([1]Economic Geology Division, Department of Mineral Resources, Thailand)

Keywords: Chaophraya river, delta, central plain, seismic survey

The Markham Delta and Alluvial Fan Complexes of the Huon Peninsular Basin, Papua New Guinea

Niran CHAIMANEE[1]

The Huon peninsular basin is dynamic, although the extent of the dynamics and the interlocking of the different mechanisms are not very well known. It lies on the leading edge of the South Bismarck plate convergent margin, which is overriding the Australian plate along the Ramu-Markham Collision Zone. Coastal processes of erosion and sedimentation are responsible for some of the dynamics, while other dynamic processes are responsive to the tectonic situation. The formation of the Markham delta and coastal alluvial fan complexes of the Huon peninsular basin is an example of tectonically induced landforms that have been dynamic during the Quaternary.

The coastline of the Huon Peninsula in the vicinity of Lae is a low-lying plain made up of alluvium deposited by rivers. At the mouth of the Markham River, a deltaic fan of sediments has been deposited, where they sit precariously at the edge of the continental slope. Added to the mix is an east-to-west wind-generated littoral drift that has further built up sandbars and spits at the river mouth. These features are subject to rapid change, and their seaward slopes are steep and unstable. Finally, much of the coastal population here lives within striking distance of the tsunamis that occur occasionally.

Several shallow borings were performed in areas selected as geologically significant, especially along the coastal zone, and sections along road cuts and river banks were measured and described. Datable materials from the shallow boreholes and sections were collected for C-14 dating in order to establish the chronology of coastal evolution. The coastal landforms of the Markham delta plain were characterized and the alluvial fan complexes within the Huon peninsular basin were differentiated. The sediment budgets and coastline behavior accompanying these geomorphic features were evaluated. Finally, the evolution of the Huon peninsular basin and the impact of tectonic instability were elaborated.

([1]Department of Mineral Resources, Thailand)

Keywords: Markham Delta, Alluvial Fan, Huon Peninsular

Grain-size analyses to compare overbank flow, sediment entrapment and seaward bypassing in wave-dominated Holocene deltas, Veracruz, Mexico

Hiroko OKAZAKI[1], Daniel Jean STANLEY[2] and Eric E. WRIGHT[3]

Grain-size distributions are used herein to compare the relative importance of fluvial sediment input versus erosion by coastal processes in two adjacent, modern deltas, the Tecolutla and Nautla, located along the high-energy Veracruz margin, southwestern Gulf of Mexico. Both systems have been formed at the mouths of short, powerful rivers that carry their volcaniclastic loads from the adjacent Sierra Madre Oriental mountain chain down steep slopes directly to the coast. Our focus is on evaluating influence of flood overbank deposition, sediment entrapment on delta plains and effective bypassing of fluvial material to the sea. A total of 197 surficial sediment samples (Tecolutla = 96 ; Nautla = 101) were collected systematically in 11 environments (coded 1 to 11) between the delta apices and the Gulf inner shelf. Grain-size parameters (mean, standard deviation, skewness) were determined for each environment in each of the two deltas.

Comparison of textural parameters in each system indicates a general similarity in grain size across parameters in both deltas. However, evaluation of differences in parameters show that the Tecolutla [one of the most powerful rivers (1) in Mexico when in flood stage] has a larger loss of coarser fractions by overbank deposition on levees (2) and flood plain (3) than in the Nautla. Moreover, there is more effective entrapment of finer-grained fractions in the marsh (4), mangrove (5) and upper estuary (6) of the Tecolutla. As a result, sediment in the Tecolutla lower estuary (7) is somewhat finer grained and better sorted than in the Nautla.

Grain-size parameters in offshore environments [dune (8), beach (9), breaker zone (10), inner shelf (11)] reveal that sediment from marine environments is accreted onto the Nautla delta by coastal processes in the high-energy, wave-driven Gulf coast margin. This landward pulse is confirmed independently by the delta's truncated configuration and masking of volcanic and light mineral components by heavy minerals and carbonates of sand size in its lower estuary. In contrast, fluvial sediment of the Tecolutla can bypass the lower estuary to beyond the river mouth. This is indicated by the gentle cuspate form of the delta and presence of higher relative amounts of fluvioclastic light and volcanic mineral components in the lower estuary and offshore environments immediately seaward of the river mouth. The investigation reveals the extent to which grain-size analysis is a necessary adjunct for interpreting sediment source, role of overbank flow, entrapment on plain surfaces, and seaward bypassing of sediment. It is also valuable for distinguishing transport processes in different deltaic environments.

([1]Natural Museum and Institute, Chiba, [2]Smithsonian Institution USA, [3]Marine Science Department, Coastal Carolina University, USA)

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Large Scale Coastal Behavior of the Nile delta, Egypt, and its 3 D chronostratigraphy integrated into a GIS

Daniel A. DeLISLE[1], Georges DRAPEAU[2] and Daniel J. STANLEY[3]

The natural coastal behavior of the Nile delta is now being altered by human interactions up to a point where it is considered to be in a destruction phase. Egypt has been included in the world economy 150 years ago. Ever since, the Nile delta have suffered irreversible alterations. Human and economic pressures imposed the construction of major engineering infrastructures such as dams to produce electricity and regulate the flooding seasons to allow agriculture all year long. Anthropogenic modifications can be observed by the land use over the years. The four major lagoons of the Nile delta are good indicators of the increased land reclamation activities. Historical maps and recent satellite images were overlayed to determine the rate of surface decrease through the last 150 years. Lagoon coastlines were digitized and integrated into a Geographic Information System (GIS). This database allowed to monitor coastal changes using a geostatistical approach. Not only our results show rapid size decrease of the lagoons but also a trend in their lateral motion.

The geomorphological changes of these lagoons, even if altered by human activities, showed a trend which we believed was induced by differential subsidence throughout the delta. The rate varies from 1.5 mm/year on the west side, near Alexandria, to almost 5 mm/year on the east side, near Port Said. The GIS allowed the surface changes of the delta to be compared with geological information. A 3 D model of the Nile delta chronostratigraphy, for the Holocene period, was produced using the carbon datation of more than 400 samples taken from 86 boring cores, provided by the Smithsonian Institution. The profiles extracted from this model show many deltaic features such as delta fronts which were correlated with the sedimentological information of the corelogs. It was

also possible to identify the 2 major depocenters of the delta as well as the location and accumulation rates of former Nile channels.

Overall results show that lagoons alterations, even induced by human activities, are influenced by natural impacts. There is a close relation between their recent motion trends and the Holocene history of the Nile delta.

([1]Universite du Quebec a Rimouski, Canada, Current address: Ibaraki University, [2]INRS Geo-Ressource, Canada, [3]Smithsonian Institution, USA)

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