Depositional Process of the Ebenebe Sandstone and the Implication for the Paleogene Evolution of Southeastern Nigeria Sedimentary Basin

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The Paleocene Imo Formation holds the key to understanding the Paleogene evolution of southeastern Nigerian sedimentary basin. The Formation contains one prominent sandstone member (the Ebenebe sandstone) that is encased by marine shales.

This study integrates indications from lithofacies, textural and paleocurrent analysis to infer the depositional processes of the Ebenebe sandstone.

Results of the analysis shows that the sandstone body display a proximal-fluviatile and distal-marine character and consists of a lower abruptly progradational wave-dominated shoreface facies that is overlain progressively by tidal and tidally-influenced, cross-bedded sandstone facies. Basinwards, the sandstone interfingers with estuarine central basin and marine shales.

An overall similarity in lithofacies organization and interpretation is established between the Paleocene and the Campanian-Maastrichtian sandstones of southeastern Nigeria.

This similarity suggests a progressive southward migration of the depositional systems. This indicates that the reported episodic and asymmetrical subsidence of the Campanian-Maastrichtian Anambra-Afikpo basin complex progressed into the Paleogene.

Acknowledgement : We gratefully acknowledge constructive reviews of Prof. C.S. Nwajide and Dr. O.I Chiaghanam of Department of Geology, Anambra State University, Uli Nigeria, who served as very useful sounding board for some of the ideas herein expressed.

Evidence of enhanced continental weathering during oceanic anoxic event 2 (OAE 2) in the western Panthalassa (proto-Pacific) Ocean

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Mid-Cretaceous is characterized by intensified oceanic anoxia (Oceanic Anoxic Events: OAEs) that raised global deposition of organic black shales. The "Weathering hypothesis" that might have occurred during the middle Cretaceous has received wide attention because it may have played a crucial role in causing the OAEs. In this model, the cause of OAEs is explained by a following chain reaction, (1) global warmth and increase in atmospheric CO_2 enhanced weathering of continental crust, (2) enhanced land weathering led excessive influx of nutrients from continents to oceans, (3) eutrophication enhanced primary productivity, (4) the excessive primary producers consumed dissolved oceanic oxygen that finally led to the OAEs. Several studies, in fact, revealed a causal relation between enhanced weathering and OAEs in northern Tethys region. This study explores, for the first time, the degree of continental paleoweathering during OAE 2 in the Panthalassa Ocean. The extent of hinterland paleoweathering was determined using the geochemical weathering index (W values) of mudstones from the Aptian to Campanian Yezo Group, exposed in Hokkaido, northern Japan. The W values obtained for the Yezo Group were in the range 30–50, which is equivalent to the W values of recent soils that developed under temperate mid-latitude climates. The W value increases from the Aptian to the Cenomanian, and then decreases towards the Campanian. The fluctuations in the W values are concordant with paleotemperature fluctuations (oxygen isotope) reported from the Exmouth Plateau. This agreement indicates that the change in paleotemperature governed the weathering rates of the East Asian continental crust. In addition, high-resolution measurements of W values around the OAE 2 interval revealed an abrupt increase in hinterland weathering rates during OAE 2 that ceased simultaneously with the termination of OAE 2. Moreover, the increase in the W value slightly predates the onset of OAE 2 (ca. 100–500 ka). Therefore, this preliminary result is consistent with the weathering hypothesis in two respects. As assumed in the weathering hypothesis, enhanced hinterland weathering is actually linked with the OAEs, and hinterland weathering did precede the onset of the OAEs. Previous studies revealed that weathering of continental crust increased during OAEs in the Tethys and proto-North Atlantic oceans. Our data suggest that a similar phenomenon also operated in the open ocean; i.e., in the Panthalassa Ocean. This indicates that enhanced hinterland weathering during the Middle Cretaceous was a global and pervasive event that caused OAEs.

Sedimentary processes inferred from 3D ground-penetrating radar analysis of braid bars (Abe River, central Japan)

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We clarified the three-dimensional variation in the sedimentary facies of braid bars with various geomorphologic conditions, based on interpretation of ground-penetrating radar (GPR) profile. The surveyed bars are in the Abe River, located in Shizuoka Prefecture of central Japan. The river rises from the Akaishi Mountains (at 2000m) and flows 51 km to the Pacific Ocean. The Akaishi Mountains consist of Eocene–Miocene sedimentary rocks, where large rockslides and avalanches sometimes occur. The Abe River is thus characterized by a short flow length and high sediment discharge. Recently, ten-years return period flood occurred in the study area in September 2011. The exceptional flood reworked and deposited the surveyed bars. In the study area, the bars is approximately 600 m in length and 300 m in width and the grain size of sediment on the surface of bars is granule-pebble including <5 % cobbles and 25-40 % sands.

A GPR survey was conducted using a 250 MHz antenna with a depth of penetration up to 2.5 m below the bar surface after the flood. GPR profiles were collected from three bars with different geomorphologic conditions (sites 1, 2, and 3). The bar surveyed at site 1 is an alternate bar located at 21.25 km apart from the river mouth, where the channel width is 200 m and the river bed gradient is 1/85. Site 2 is located at 15.5 km from the river mouth, where the channel width is 400 m and the gradient is 1/150. Two or three rows of bars are found in the channel. The bar surveyed at site 2 is formed in the downstream shadow of a prominent rock bank. Site 3 is 2.5 km from the river mouth, where the channel width is 500 m and the gradient is 1/250. Linguoid bars are observed at this site. The bar surveyed at site 3 is comprised of two bars and exhibits a compound bar.

Major radar facies are distinguishable in the GPR profiles of the three sites. Inclined reflections mainly occur in the front and margin of the bar and represent accretion of a bar. Continuous horizontal to subhorizontal reflections are found at the head and upper parts of the bar and are formed by the aggradation of plane bed. Trough-shaped reflections make up the internal structure of channel fills and are formed by dunes. The GPR profiles also vary among the three sites and indicate different depositional processes. At site 1, large channel fills accrete laterally in the bar margin, and the bar downstream accretion is modest. The bar at site 2 is comprised of thin planar or gently inclined strata and might been deposited by sheet flooding from the river flow that turned at the back of the rock bank. At site 3, the bar appears to be the most active among the three sites. Multiple downstream and lateral accretions of the bars are evident in the profile.

The GPR profiles revealed that the braid bars were formed by channel cutting, channel filling, and migration and accretion of the bars. Additionally, the facies variation found at these sites is due to the difference in the geomorphic conditions, especially the degree of stability of the channel.

Depositional environment and structural deformation controls on sandstone distribution in unstable shelf edge deltas - Paleogene Lower Wilcox Guadalupe Delta, Texas, USA

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The Wilcox Group in Texas is a thick sequence (about 2000 m) of clastic sediments deposited along the Gulf Coast during early Paleogene time. Shelf margin growth-faulting favored rapid sedimentation and accumulation of thick (tens of meters) deltaic deposits in the downthrown compartments. This study describes the stratigraphic and sedimentological character of the lower Wilcox Guadalupe Delta as examined in detail in cores and interpreted from well-logs. Sedimentary structures and trace fossil associations indicate a transition of depositional environments from fluvial-dominated and tide-influenced deltas to wave-dominated deltas as the system prograded basinward. Current ripples, organic matter, low trace fossil abundance and diversity, synsedimentary microfaulting and soft sediment deformation structures suggest deposition in a fluvial-dominated delta front environment. Upward-coarsening sequences with lenticular, wavy and flaser bedding support a tidal environment interpretation. Sand streaks in mud, wave-ripple lamination and cross-beds with mud or carbonaceous drapes are common. Low diversity, low density trace fossil suites that contain both dwelling and feeding structures suggest shallow brackish water conditions. As the shoreline advanced during deltaic progradation, relatively more sediment was deposited on the downthrown side of the faults and reworked along shore by wave processes. The sedimentary succession in the downthrown basin is characterized by repeated vertical stacking of shoreface sequences and pronounced increase in sediment thickness adjacent to the fault. The shoreface successions display an alternation of fair-weather suites with storm beds. The fair-weather assemblages are represented by thoroughly bioturbated muddy sandstones with *Cruziana* ichnofacies. Storm-dominated intervals are characterized by sharply-based or erosive hummocky cross-stratified sandstones. The intensity of burrowing is highly variable depending on the severity and frequency of the storms. The change in depositional environment from tide and fluvial-influenced to wave-dominated deltas in growth-faulted compartments indicates that significant volumes of sediments were trapped on the outer shelf. However, sandy deep water deposits suggest the existence of different coeval mechanisms of sediment transport, such as canyons at the shelf edge.

The shelf edge to slope to basin-floor clinoforms and turbidite variability of the southernmost Neuquen Basin outcrops: Jurassic Los Molles Formation, Argentina

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This study describes the clinoforms and turbidite-system architecture of the southernmost Neuquen Basin margin. Excellent Jurassic outcrop of the Los Molles Formation in northern Patagonia expose continuous shelf to slope to basin floor deposits for kilometers, with visible 2-300 meters high basin-margin clinoforms. Using a high resolution digital elevation model (DEM) and satellite images, ground photo-panels and sedimentary measured sections the deposits were correlated over 20 x 20 km, along depositional dip and strike.

At the shelf edge the deposits are meter-thick structureless or cross-stratified sandstone to conglomerates, with abundant silicified wood that incise in places into the underlying muddy slope deposits. Slope deposits are dominated by thin laminated or structreless mud with thin (cm) sandstone beds. Isolated, up to5-10 m thick, erosionally based sandstone and conglomerate units with abundant mud clasts are encased in mudstones are interpreted as slope channels. Toward the base of the slope, turbidite channels have a lower thickness -to-width ratio, and they become laterally more extended (hundreds of meters). On the basin floor the deposits are interpreted as basin-floor turbidite channels and lobes based on their low relief (rarely erosional at the base) and lateral continuity for kilometers. These deposits are dominated by structureless and normally graded sandstone beds which are dm to m thick. Mapping of the individual 10-15 m basin-floor lobes shows the changes in facies from proximal to distal from dominantly structureless amalgamated and non-amalgamated sandstone beds to dominantly normal graded and laminated sandstone beds. Bed thickness increases from about 15 cm on average to 30 cm and then decreases again to 15 cm from proximal to distal. Grain size shows a more complex pattern but in general is also increasing and then decreasing form proximal to distal. On the basin floor there are also thick beds (up to 3-4 m) of pebble-conglomerate debris flow and mud flow deposits, that are more common in the older deposits (below the turbidite lobes) but also present within the lobe units.

Lower to Middle Jurassic Los Molles Formation has been previously interpreted as syn-rift to post rift deposits. The architecture of the Neuqen Basin margin shows trends which are generally valid in many basins with a wide range of grain size and similar tectonic setting.

We thank Statoil for generous support of the students and field research. Field discussions with Mason Dykstra highly improved our understanding of the deposits.

Rates of progradation revisited; a case study from the coastal plain at Moruya, southeastern Australia

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Holocene progadational coastal barriers (also called strandplains) are depositional environments, comprising a sequence of relict foredune ridges, which provide a repository of stratigraphical and sedimentological information. The ridges preserve a record of progradation. It is necessary to consider the overall barrier morphology in order to interpret chronological data, however. The prograded barrier at Moruya in southeastern Australia consists of a sequence of 60 distinct relict foredune ridges formed during the mid to late Holocene as a Palaeozoic bedrock valley infilled after sea-level stabilised 1-2 metres above its present level on this coastline. In this study, the morphology of a transect across this plain is described using high resolution elevation data (LiDAR) and Ground Penetrating Radar (GPR), and an Optically Stimulated Luminescence (OSL) chronology is developed to explore rates of shoreline progradation. The sand comprising the oldest ridge was deposited within 100 years of 7200 yrs BP, the published age at which sea level stabilised during the highstand. A large foredune dominates the seaward margin of the ridge sequence estimated to be 180-200 yrs BP. Incremental progradation of the barrier is apparent from relict beachface reflectors extracted from GPR, and volumetric calculations from LiDAR provide new insights into height variations between ridges and changes in embayment size. OSL dating indicates a linear trend of progradation from 7200 yrs BP to present at an average rate of 0.27 m/yr and implies that individual ridges were active for an average of around 110 years. This is in contrast to the earlier radiocarbon-based chronological evidence which had been interpreted to indicate a decelerating rate of progradation with little shoreline build-out since 3500 yrs BP. The OSL and radiocarbon chronologies are compared and inferences about the processes of barrier formation are discussed.

The importance of the Avaldsnes High in development of the laterally extensive Upper Jurassic reservoir in the giant Johan Sverdrup field, North Sea, Norway

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Introduction. The Johan Sverdrup discovery made by Lundin (PL501 Operator) and partners Statoil and Maersk Oil in 2010 is one of the 5 largest oil finds ever made on the Norwegian continental shelf. The discovery well, located on the southeastern part of the Utsira High in the North Sea, has since been followed by more than 30 appraisal wells.
The main reservoir is the Upper Jurassic Draupne Sandstone, which is dominated by coarse to very coarse sandstones with outstanding average permeability, in excess of 30 Darcies. The Avaldsnes High, on the east side of the field, appears to have played a key role in the laterally extensive accumulation of these high quality reservoir sands, at a distance of more than 10 km from the palaeoshoreline.

Methods. This paper presents the results of a detailed facies analysis of more than 440 meters of conventional core, combined with petrographic, biostratigraphic, isotopic, petrophysical, FMI, MDT and DST analysis.

Results. The Draupne Sandstone can be subdivided into a basal Kimmeridgian interval and a main Tithonian interval.
The Kimmeridgian interval mainly occurs west of the Avaldsnes High. It is heterogeneous, ranging from fine sandstone to conglomerate, and was deposited on a shoreface during an initial marine transgression. At that time the Avaldsnes High was probably a partially emergent island in the area of the Johan Sverdrup field.
The Tithonian interval is draped across an area of more than 200 km^2, including the entire Avaldsnes High in the area of the oil field. This interval is relatively homogeneous, dominated by coarse to very coarse, often gravelly sandstone of shallow marine origin, deposited in response to continued transgression. Locally, along the western basin-margin, conglomerates were deposited in fan deltas.
Various depositional models are discussed for the Avaldsnes High but the most likely interpretation is that it acted as a shallow marine platform during Tithonian transgression and associated subsidence. Sand was probably transported to the area by strong littoral currents from the southeast. Locally-derived coarser, immature sediments from exposed parts of the Avaldsnes High south of the field were supplied during strong storm events. A shallow water depth combined with wave action and tidal currents assisted in keeping the fines in suspension, allowing only coarse sand to be deposited. A modern example is found in the Breaksea Spit along the northeast coast of Australia. Sediments west of the Avaldsnes High may, in contrast, have been sourced mainly from the Utsira High in the west.
Conclusions. The Avaldsnes High initially existed as a partially emergent island but was transgressed during the Tithonian, where it became a submarine platform that allowed laterally extensive deposition of coarse sand. The main depositional processes on the platform were littoral drift combined with wave action and tidal currents, in addition to storm-induced gravity flows. These processes resulted in sand with excellent reservoir qualities being distributed across an extensive area.

Acknowledgements: Thanks are directed to colleagues at Maersk Oil, Lundin and Ichron for fruitful discussions. All the analysis and interpretations of those from the Avaldsnes High area are made by Maersk Oil, Lundin and Ichron only.

Stratigraphic variations of terrigenous organic carbon ratios in flood and slope failure sediments of marine area, examples from the modern natural disasters of Japan

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Understandings the modern depositional processes of sea-floor sediments are important in paleoseismic studies based on deep-sea turbidites, because turbidity currents are caused not only by slope failure during submarine earthquakes, but also by flood and storms. Large typhoons pass through the Japanese islands during summer and autumn, and submarine mega-earthquakes also occur around the Japanese islands. In this study, stratigraphic variations of muddy sea-floor sediments, which were deposited as results of flood and slope failure caused by the modern natural disasters, such as the 1596 Keicho-Bungo earthquake, the 1889 Totsukawa Flood, the 1959 Isewan Typhoon, the 2003 flood by Typhoon no.10 (Etau), the 2004 off-Kii Peninsula earthquakes, and the 2011 Kumano flood by Typhoon no.12 (Talas), were examined using terrigenous organic carbon (TerOC) ratios with stable carbon isotope analysis.

Flood-induced turbidite mud by the 2003 Typhoon no.10 and the 1959 Isewan Typhoon were characterized by high TerOC ratio. Turbidite mud by the 1889 Totsukawa Flood has the highest peak of TerOC ratio in the base of turbidite, which include wood fragments, and high TerOC ratio through the mud. TerOC ratios of the lower part of thick turbidite mud by the 1959 Isewan Typhoon, the 2003 Typhoon no.10 and the 2011 Typhoon no.12 were lower than those of middle and upper parts of the turbidite mud, and TerOC ratios of middle and upper parts of turbidite mud were high and stable. These results suggest that the lower part of flood-induced turbidite was formed by erosion and deposition of sea-floor sediments during the early stage of flood. We consider that the middle and upper parts were formed by continuous supply and deposition of terrigenous materials from river mouth during the flood.

Slope failure sediments by the 2004 off-Kii Peninsula earthquakes show low TerOC ratio. This result suggests that the sediments were considered to be remobilized and deposited on the sea floor near the slope, which contains marine plankton. Slope failure sediments by the 1596 Keicho-Bungo earthquake is characterized by upward decreasing of TerOC ratio. This result suggests that the turbidity currents were caused by collapse of delta slope sediments, which contain both terrigenous and marine organic carbon.

These stratigraphic variations of TerOC in turbidite mud reflected depositional processes by flood and slope failure indiced turbidity currents. Therefore, the stratigraphic variations of TerOC ratio might be important information, when we use analyses of deep-sea turbidites in paleoseismic studies.

Acknowledgements: This research was supported in part by Grant-in-Aid for Scientific Research from the Japan Society for the Promotion of Science (2540125).

Impact event and radiolarian faunal turnover across the middle-upper Norian transition in the Late Triassic

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The Late Triassic was characterized by several marine and terrestrial biotic turnover events prior to the end-Triassic mass extinction. The causes of the end-Triassic mass extinction and these Norian to Rhaetian biotic turnover events are still the subject of debate. Catastrophic processes such as widespread eruption of the Central Atlantic Magmatic Province flood basalts and extraterrestrial impacts have been proposed to account for the biotic turnover events. Our previous studies have revealed that the Sakahogi section in central Japan contains an impact ejecta layer in the Late Triassic, which was derived from an extraterrestrial impact event. This ejecta layer is characterized by platinum group element (PGE) positive anomalies, Os isotope negative excursion, and abundant occurrences of Ni-rich magnetite grains and microspherules.

Here we report middle to upper Norian radilarian biostratigraphy from the Sakahogi section across the impact ejecta layer. Based on the radiolarian biostratigraphy from the Sakahogi section, three radiolarian zones are recognized in ascending order as follows: *Capnodoce-Trialatus* zone, *Trialatus robustus-Lysemelas olbia* zone, and *Lysemelas olbia* zone. Detailed high-resolution sampling and biostratigraphical data allowed us to data precisely the ejecta layer, which occur in the base of the radiolarian *Trialatus robustus-Lysemelas olbia* zone. Our biostratigraphc analysis suggests that there was no mass extinction of radiolarians across the impact event horizon. Only one species became extinct at the ejecta horizon and the extinction rate of radiolarians (extinct species divided by total species at the same level) is estimated to be about 5% at the horizon. Major turnovers of radiolarians occur above the ejecta horizon within the *Trialatus robustus-Lysemelas olbia* zone. Biostratigraphic analysis shows that 20 radiolarian species became extinct in this zone and the extinction rate is estimated to be 83%. This turnover is associated with a deposition of spicular chert, suggesting temporal changes in marine ecosystems after the impact event. Given that the average sedimentation rate of the middle to upper Norian chert succession is 1.3 mm per thousand years, this turnover occurred 600 kyr after the impact event. Thus the meteorite impact did not direct cause of radiolarian extinction event.

Depositional architecture of a Holocene fissure ridge developed along a left lateral strike-slip fault segment: A case from Eastern Anatolia, Turkey

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Most of the travertine fissure ridges have been exposed in extensional provinces. In contrast, fissure ridge formation along strike-slip fault zones is quite limited. Aim of this contribution is to evaluate depositional architecture of a travertine fissure ridge in frame of left-lateral strike-slip movement zone. To achieve this aim, Travertine Fissure Ridge (HTFR) exposed near the Hacılar village along the Karlıova-Bingöl Segment (KBS) of the East Anatolian Fault System (EASF), which is a NE-trending sinistral strike-slip megashear belt, was investigated using depositional architecture and associated tectonic, geochemical and U-series age data.

The EASF form a tectonic boundary between the Palaeozoic to Mesozoic metamorphics and Pliocene Solhan volcanics. The Bitlis metamorphics are seperated into a lower and upper group. The lower group is composed of high grade metamorphics (e.g., gneiss, amphibole schist), while the upper group is formed of low grade metamorphics such as micaschist, quartzite and marble. These brecciated rocks covered unconformably by basaltic-andesitic pyroclastics.

At Hacılar, travertine precipitation occurred at two fissure ridges in elevations between 1560 and 1585 m above sea level. One of the fissure ridges has been destroyed because of human occupation. The second one, here called as the Hacılar Travertine Fissure Ridge (HTFR), located ~1 km southwest of the village was studied in detail. The NE- striking HTFR arose on a conjugate fault (i.e, Riedel shear) developed between strike-slip fault pair delimiting the main fault zone in the studied area.

The ridge is 510 m long, 7 m high and 80 m wide at the base. Along the ridge axis, single fissure, multiple fissures arranged in en-echelon or bifurcated fissures occur. Individual fissure aperture varies from 3 to 12 cm. Fissure walls are sealed by vertically banded, light coloured, 1-2 cm thick and compact travertines.

At some points along the fissure axis, 15 to 220 cm long bowl-shaped spring orifices can be observed. In several spring orifices, pisoids, up to 2 cm in dimension are attached to the fissure wall, which are the most probably resulted from bubbling hot waters.

Fissure flanks consist of bedded travertines. Crystalline crust travertine layers, the most common type of bedded travertines, precipitated on the slope surfaces of from the turbulent flow of hot spring waters. In some cases, the upper surfaces of the crystalline crust beds are ornamented by microterrace pools. Growth of the crystalline crusts is probably controlled by high levels of supersaturation as a result of rapid CO_2 degassing. Beds dip away from the ridge axis with angles up to 40° and reach up to 10 cm thick.

Sr values are high (7104 to 16.292 ppm). The $\delta^{13}C$ and $\delta^{18}O$ values are +5.3 to +6.1 (‰ VPDB), and -18.6 to -15.0 (‰ VPDB), respectively. Along the ridge axis, recent to 6.965± 0.089 ka U-Th ages, corresponding to the Holocene (Marine Isotope Stage - MIS 1), were obtained from the vertically banded travertine samples.

In conclusion, The HTFR resulted from the upwelling hydrothermal fluids that circulate in the brittle carbonate bedrock along the left-lateral strike slip movement of the KBS during Holocene.