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Outcrop and Seafloor Sedimentation Study of Parts of Afikpo and Offshore Niger Delta Basins

Hope Chibuzor Chuku*
Department of Earth Sciences, Ajayi Crowther University, Oyo, Oyo State, Nigeria

Abstract: The study was specifically carried out on channel and deltaic sediments of outcrops in Afikpo Basin South East Nigeria and seafloor sediments offshore Niger Delta Nigeria to determine sediments distribution, grain size, deposition and preservation.The outcrop sections in Afikpo Basin were studied by visual observation and photographing of lithostratigraphic architectures during the field work. Empirical technique was used to predict seafloor facies from multibeam bathymetry and acoustic backscatter data collected in the study area. Side scan sonar and echo sounder seafloor data from the Niger Delta Basin were also used to predict sediment types and deposition trend derived during geophysical seabed survey using onboard instrumentation offshore. Mud covers a wide range of backscatter variance because it can be found trapped in pockets on the seafloor. Gravelly-muddy sand was found close to the seabed surface, and it has very low to medium-bathymetry variance. Mud (silt and clay) covers 61 percent of the study area. Sandstone reservoir outcrops showing mouth bar architecture occurred at Akpoha Town east of Afikpo town. The field work on outcrop established the rock types as sandstones and shales, well rounded sediment, pink to pinkish white colour, well sorting, cross bed and herringbone structures, Kaolinitic materials found as matrix and quatz minerals present, Bioturbations, matrix, drape materials, and bedding plain (sharp or gradational). It was revealed that sediments on the seabed vary from gravelly-muddy sand, muddy sand, and mud. The ridges have relatively low bathymetric relief (2-3m). The trend of deposition of these sedimentary units as seen from geoacoustic sensors imageries and outcrops within the study areas shows a coarsening upward sequence. This is typical of a deltaic and shallow marine depositional setting which shows different environments affected by variety of processes ranging from wave, currents, tidal and other fluvial process.

Keywords: *Sedimentation, Afikpo Basin, Outcrops, Seafloor Sediments, Niger Delta Basin, Distributary Channels*

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INTRODUCTION

The Cretaceous Afikpo sedimentary Basin in Southeastern Nigeria contains rocks of fluvial, deltaic and shallow marine origin. The outcrop sections and the Afikpo River were studied by visual observation and photographing of important features during a field mapping exercise. The seafloor data from the Niger Delta Basin were also used to infer depositional environments based on bathymetry imageries. The study was specifically carried out on Alluvial, channel and deltaic deposit to determine the lithofacies and their stratigraphic relationships with a view to drawing inferences on the geology, provenance, depositional history and environment of deposition of the sedimentary bodies within Afikpo town, Akpoha, Ndi-Owerre and Akanuibiam town in Ebonyi State. Niger Delta has recently received tremendous attention from both the oil companies and the academia for several decades due to increasing hydrocarbon discoveries

*Correspondence concerning this article should be addressed to Hope Chibuzor Chuku, Department of Earth Sciences, Ajayi Crowther University, Oyo, Oyo State, Nigeria E-mail: hopechibuzor@yahoo.com

in the region, to maximize its exploitation from offshore province, there is the need to properly understand the processes of sedimentation and the consequent depositional architecture for proper situating of drilling rigs, pipelines, jackets, cables and production platforms (Chuku & Ibe, 2015); (Momta, 2018); (Chuku & Ibe, 2015). Outcrop studies have long been employed as a mechanism of studying analogues and understanding petroleum fields (Collinson, 1970); (Ekwenye, 2020); (Chuku & Umoh, 2023). Traditionally, the surficial facies of the seafloor is determined by collecting a suite of bottom samples, analyzing the samples for grain size and/or determining rock type, and then mapping the results by interpolating or extrapolating the gaps between samples (Dartnell & Gardner, 2004); (Daukoru, 1975). Once the type of depositional system and the accommodation history of a hydrocarbon field are derived from subsurface data, appropriate outcrop analogue(s) can then be identified (Alexander, 1993); (Bonne, 2014). Outcrop analogue studies have been undertaken both qualitatively and more recently quantitatively. Traditional quantitative studies (Dreyer, 1992); (Chapin, 1994); (Bryant & Flint, 1992); (Clark & Pickering, 1996); (Reynolds, 1999) have been focused on the collection of outcrop data to populate inter-well reservoir model areas by stochastic, object-based methods (Floris & Peersmann, 2002); (Arnot & Good, 1997). Given that direct measurement of these parameters is limited to a few wells it is necessary to extrapolate their distribution (Chuku & Umoh, 2023). As geology is a first order control on petrophysics, it follows that an understanding of facies and their distribution is central to predicting reservoir quality and architecture (Pringle, 2004); (Boboye, 2021). Depositional facies is a fundamental control on petrophysics (Chuku & Umoh, 2023). However, facies scale heterogeneities are not resolvable using current seismic methods, and well data provide little or no data on 3D geometries beyond the well bore (Pringle, 2006) and (McCaffrey et al., 2005). The advent of high-resolution multibeam echosounders (MBES) in the last decade has provided a new technique to efficiently map large areas of the seafloor at meter-scale horizontal, and centimeter-scale vertical resolutions (Clarke, 1996); (Hughes, 2000); (Chuku & Umoh, 2023).

LOCATION OF STUDY AREA

The two major rivers (Niger and Benue rivers) in Nigeria are of significance in the distribution of sediments in the east and western offshore area of the country. The Niger River is active and supplies sediments toward the western part of the Niger Delta, whereas, the Benue River concentrates sedimentation in offshore (Figure 3) area (Momta, 2018); (Barnes & Lisle, 2013). There are seafloor evidences of the occurrence of recent sediments of river channels that served as conduits for transporting sediments from the continent to the seafloor (Chuku & Ibe, 2015). These sedimentation processes are still active today and sediments keep building out along the shores and on the continental shelf of the Niger Delta. The seafloor occurrence of shallow marine facies will serve as analogue to the outcrop exposures of marine sandstones in the Afikpo Basin (figure 1). We will look at the outcrop evidence of fluvial and marine sandstones at Afikpo Town, and trace the course of the Cross River from Afikpo (Figure 2) to the coastal town of Calabar where presently these sediments are deposited into the estuaries and open marine environments (Momta, 2018). Offshore Niger Delta Basin and Afikpo Basin were chosen for this study because of the need to unravel the geological state of seafloor for subsea facilities installations and paleo sedimentary processes, made possible by seafloor data, including high-resolution multibeam bathymetry and acoustic backscatter, sediment samples, seafloor photographs, and seismic profiles (Figure 3).

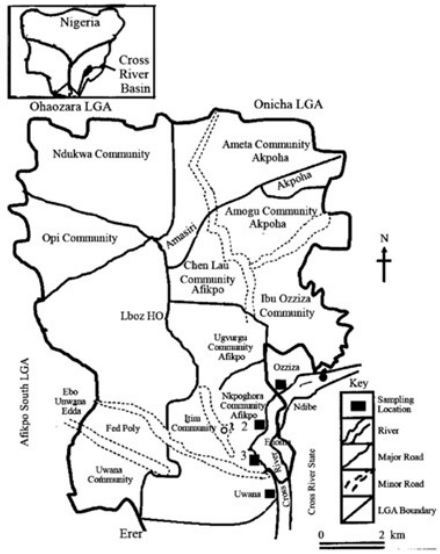

Figure 1 *Location of Study Area (Adapted after Ogbonnaya, 2012)*

Figure 2 *The river configuration within Afikpo town, Ebony State Nigeria Adapted after (Adapted after (Momta, 2018))*

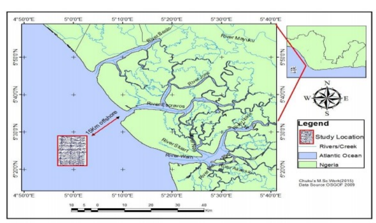

Figure 3 *Map of the study location offshore Niger Delta (Adapted after Umoh et al., 2023)*

METHADOLOGY

On 23rd November, 2019, personnel and geophysical equipment on the vessel, proceeded to location. Setting up of geophysical equipment commenced immediately. Dry tests were conducted on the geophysical sensors and were confirmed. Before the commencement of the survey, sound velocity reading was obtained and inputted in Echo Sounder, Side Scan Sonar, Sub bottom Profiler and Magnetometer, after which they were deployed. Test run of some lines were done for the purpose of patch test (Chuku & Umoh, 2023); (Chuku & Odigi, 2019). The survey grid was 500m by 500m (fig 4) for the location and line survey kicked off at about 13:54hrs on 23rd November, 2019 and data recorded in all deployed sensors (fig 5). The side scan sonar and magnetometer were towed from the stern with 45m and 86m cable out respectively, while the sub bottom profiler was towed on the mid stern with a chain out of 10m. The DGPS and gyrocompass were interfaced with eiva navigation software for acquisition of both position and directional data for the survey.

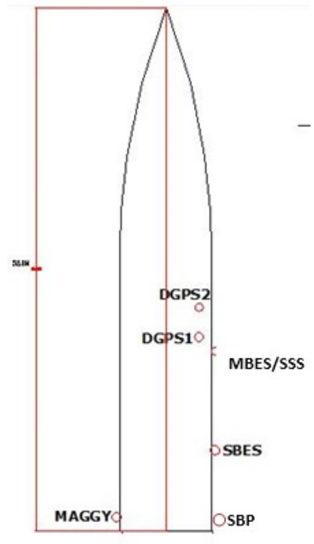

Figure 4 *Schematic diagram of MV SED, showing the sensors offsets (After (Chuku & Ugwueze, 2023))*

The side scan sonar was towed from the stern with 45m and 86m cable out respectively, while the echo sounder was side-mounted by the survey vessel.

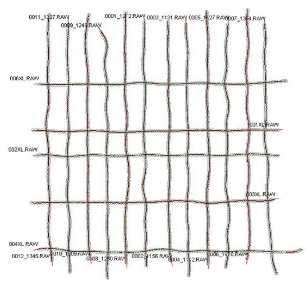

Figure 5 *Navigation Track Plot of the study Location*

Approximately 27 linear kilometers of sub bottom profiler, side scan sonar and echo sunder data were surveyed using Geo acoustics SSS 941 Tow fish with Geo acoustics. The accurate positioning of the side-scan sonar, sub bottom profile and echo sounder track line was accomplished by means of a kongsberg sea path 330 receiver (DGPS), the backscatter of the surface sediments (side- scan sonar), couple with sea bed sample has enable the distinction of the sea floor lithofacies (fig 6). Bed forms captured from the sea bed scan were matched with the topographical features to deduce the processes shaping the sea floor environment of the study area.

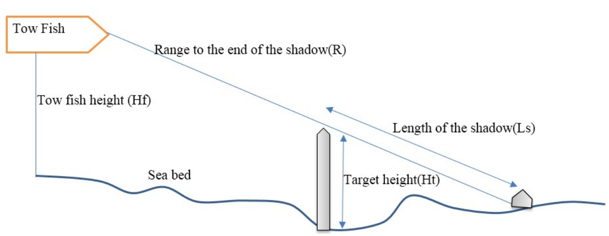

Figure 6 *Target height measurements above sea bed (Modified after (Chuku & Ibe, 2015))*

During the outcrop mapping exercise, three (3) outcrop sections of the Amasiri Sandstone were described from Akpoha to Afikpo, using critical location descriptions. The field investigation comprises of locating oneself in the field (area of study, North East Afikpo, Ebonyi State Nigeria), taking notes of the lithological features of the outcrops and describing them. Some of these features are; rock type, the height, colour, dip, strike and dip direction of each bed in the outcrops. The noting of textures, grain size, mineralogy, sorting, sedimentary structures, tectonic structure, fossil content, bedding plain (sharp or gradational), GPS location reading and photographing of the outcrops were done (fig 7). While on the field, measurement of the thickness of the different outcrop encountered was estimated (Chuku &

Umoh, 2023).

Figure 7 *Multi-story/storey sandstone body at Mac Gregor College Hill Sandstone body/Formation*

- Cross beds present
- Deposit is oval in shape (Geometry Oval)
- Paleo cement direction is East West
- Multi-story/storey sandstone body

RESULTS AND DISCUSSION

Outcrop Facies Evaluation

Delta-Lobe Deposits :The marine portion of the outcrops in Afikpo marks a transition from a more fluvially influenced sedimentation to a deltaic process. This is evident in the isolated lobes of sandstone outcrops that occur within Akpoha area west of Afikpo Town (Figure 8). It may possibly be a

Figure 8 *Deltaic deposits in lobes: Sandstone is underlain by Marine ShaleDeltaic environment*

Figure 9 *Deltaic deposits in lobes: Sandstone is underlain by Marine ShaleDeltaic environment*

Figure 10 *Deltaic deposits in lobes: Sandstone is underlain by Marine ShaleDeltaic environment*

mouth-bar deposit that occurred towards the end of a distributary channel. It consists of two facies units: a shale bed overlain by cross-beded facies of sandstone (Figure 9). The sandstone is underlain by mudstones and shale portraying a coarsening upward sequence in grain size typical of a deltaic environment. A shoreface shallow marine section is observed in the Cretaceous age Amasiri sandstone (Afikpo Basin) showing a large lateral extent of more than 6 km with thickness greater than 120 m (Figure 11, 12 and 13).

Figure 11 *Barrier bars (Regressive)*

Figure 12 *Sandstone: It is laterally extensive and runs parallel to paleo-coastline*

Figure 13 *Shallow marine section*

The deltaic front environment is highly unstable due to the variety of processes operating within this realm. Marine and fluvial influence accounts for the depositional styles within the marginal marine.

Seafloor Sedimentary Analogue of Offshore Niger Delta Basin

Seafloor Facies Prediction The combination of hypotheses, rules, and variables in the hierarchical decision tree produced a map of predicted seafloor facies for the study area. Seafloor facies varies from sand, silt, muddy sand and others. The classification predicted the distribution of seafloor facies, gravelly-muddy sand, muddy sand, and mud.

Figure 14 *Side scan sonar data showing seafloor sediments types*

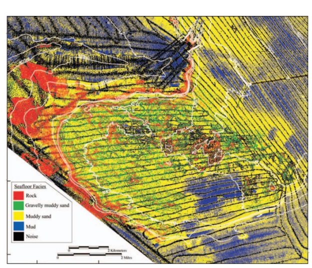

Figure 15 *Side scan sonar data showing seafloor sediments types*

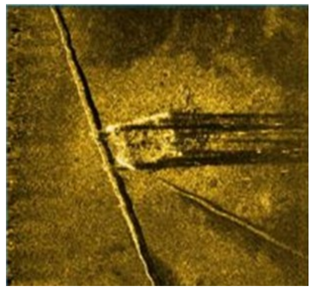

Figure 16 *Side scan sonar data showing seafloor sediments types*

Sediments correlated with very high backscatter, low to very high-backscatter variance, and medium to very high-bathymetry variance. Sandstone has very high-backscatter because its extremely high acoustic impedance scatters all of the incident energy (Figure 14). Sediment has a wide range of backscatter variance because many outcrops are diverse areas with exposed rock and sediment pockets that absorb some of the acoustic energy. Sediment has medium to very high-bathymetry variance because exposed rock outcrops can have a wide range of relief. Gravelly-muddy sand can slightly have lower backscatter than sandstone, medium to high backscatter variance, and very low to medium-bathymetry variance (Figure 15). This sediment facies does not return as much acoustic energy as sandstone because some of the signal is refracted into the sediment and absorbed. Gravelly-muddy sand has medium to high-backscatter variance because the sediment is found close to the seabed surface, and it has very low to medium-bathymetry variance because the sediments are found on the plain topography as well as on the transitions zones from the flat to steep seafloor. Muddy sand correlated with the largest range of backscatter, backscatter variance, and bathymetry variance of all the facies in the study area. Muddy sand has a wide range but lower backscatter than gravelly-muddy sand because its fine grain size scatters less acoustic energy and allows more penetration, thus more volume absorption. Muddy sand is found more in the study area, on the steep eastern flanks of Niger Delta Basin, as well as on the smooth, uniform inner continental shelf (Figure 16). Mud correlated with the lowest backscatter but has a wide range of backscatter variance and bathymetry variance. Mud is similar to muddy sand, although, it has the lowest backscatter because it absorbs most of the acoustic energy because of the high water content and low density of particles in the size range of the acoustic wavelength (1.5 cm). Mud also covers a wide range of backscatter variance and bathymetry variance because it can be found trapped in pockets on the seafloor. The predicted facies classification of the study area shows that seafloor has a more complex distribution of sediment composition (Figure 18). Sediment exposures were predicted on the seafloor throughout the area. The most prominent area on the eastern edge of the field protrudes above the surrounding seafloor by as much as 3m (Figure 19). Gravelly muddy sand and muddy sand are found within the northeast of the study area. Pockets of ridges composed of individual pebbles (Figure 18) trend north to south on the Eastern side. The ridges have relatively low bathymetric relief (2-3m) compared to the larger outcrops but trend for some meters. Gravelly-muddy sand was predicted to be in small patches throughout the study area and only covers 5m or 10 percent of the study area (Figure 18). This predicted facies is generally found close to the river mouths where eroded sediments have been identified. Muddy sand is the most prevalent sediment type predicted, covering 200m or 40 percent of the study area (Figure 17). This facies is found on the lower energy regime portion of the area, in pockets within the higher energy area (Figure 18). Predicted mud dominates the north east portion. Mud was also predicted on the seafloor in small pockets within the southeast as well as in bathymetric lows in the central portion and southern portion of the seafloor. Predicted mud covers 55m or 61 percent of the study area (Figure 17).

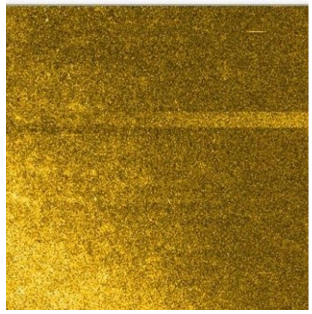

Figure 17 *Side scan sonar and echo sounder data extracts showing seafloor sediments distribution*

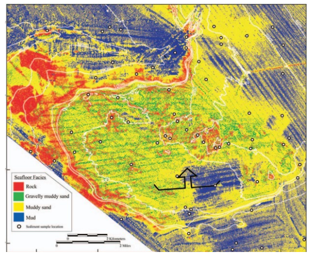

Figure 18 *Side scan sonar and echo sounder data extracts showing seafloor sediments distribution*

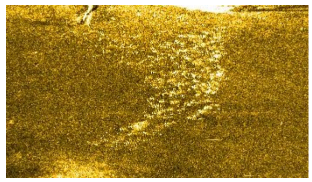

Figure 19 *Side scan sonar and echo sounder data extracts showing seafloor sediments distribution*

that were recently deposited within the open sea and reworked to confer the various architecture and configurations of the deposits). The deltaic front environment is highly unstable due to the variety of processes operating within this realm. Marine and fluvial influences account for the depositional pattern within the marginal marine. Studies on modern sedimentary environments revealed that vertical profiles of grain size from a specific environment have certain characteristics. Hence, prograding deltas and barrier bar deposits have coarsening upward grain size trends.

CONCLUSION

Afikpo Basin South Eastern Nigeria comprises of sediments of fluvial, deltaic and marine origin. Ancient fluvial sediments in the area contain both braided stream and point bar channel sedimentary units. Similar sediments are also observed on the seafloor due to recent fluvial sedimentary process that is continuously transporting sediments from the rivers into the open sea in the offshore of the western Niger Delta through the Esravos, Forcados and Benin Rivers. Depositional pattern of these sedimentary units as seen from geoacoustic sensors imageries and outcrops within the study areas shows a coarsening upward sequence. This is typical of a deltaic and shallow marine depositional setting. Generalized, depositional model for these fields shows different environments affected by variety of processes ranging from wave, currents, tidal and fluvial process. Almost all the sediments were derived from the continent and deposited within the shallow marine environment through distributary channels. The sediments upon arrival within the shores are reworked by wave action to form seafloor dunes. The ancient and recent sediments identified in the areas form the major sources of sand used for construction purposes.

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