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Compound Dunes in a Tide-dominated Estuary Succession: Example from the Daban Fulani Member of Pindiga Formation, Gongola Sub-basin, Northern Benue Trough, NE Nigeria.

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Abstract

This work documents criteria for identification of compound dunes from the tidalites of the Daban Fulani Member of Pindiga Formation, Gongola Sub-basin, Northern Benue Trough, Nigeria. It is based on the study of well exposed outcrop analogue along recently constructed Gombe-Kumo road. This definition is important because tidal compound dunes and tidal bars are similar in scale and in 2D cross-section even though they originate by forward-accretion and lateral accretion processes respectively.Field measurements reveal the following characteristics for the compound dune: 1) medium to very coarse grained moderate to well-sorted cross bedded sandstones arranged in clinoforms between which thin mud-draped intervals occur; 2) the clinoforms display tangential oblique geometry with each consisting of fining-up grain size profile, large-scale planar cross bedding at its lower part and small-scale planar and trough cross bedding at its upper part with some of the small-scale cross bedded parts, displaying herringbone cross-bedding; 3) the clinoforms display sharp lower and upper contacts and range in thickness from 10 cm to 40 cm; 4) overall, coarsening and thickening-up of the clinoform sets with corresponding decrease in thickness of mud drapes is characteristic, as a result the clinoforms become amalgamated up-section; 5) the sandstones are generally not bioturbated but the mud intervals display mottled texture with up-section decrease in intensity. Compound dunes and tidal bars are deposited adjacent to each other in tide dominated systems and their peculiarities significantly impact on the prediction of fluid flow properties as well as estimation of hydrocarbon reserve especially in frontier basins.

Keywords: Compound dunes, Tide-dominated Estuary, Northern Benue Trough.

INTRODUCTION

A good account of the characteristics of compound dunes was documented by Mutti et al.(1985), though they were called "tidal sandridges". Ashley (1990) also made a detailed analysis of

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compound dunes but referred to them as "sand waves" deposited in tide dominated offshore environments. Dalrymple and Choi (2007) came to the conclusion that tidal sandridges of Mutti et al. (1985) and the sandwaves of Ashley (1990), Allen (1980), Dalrymple (1984), Dalrymple and Rhodes (1995) are all referring to the same thing. i.e. compound dunes. Even though it is a common feature of tidal deposits, its description and identification is not common especially in Gongola basin and Nigerian sedimentary basins in general. This work therefore gives detailed account of a well exposed example of compound dune within Deba Fulani Member (Zaborski *et al.*,1997) of the middle Sandy members of Pindiga Formation in the Gongola Sub-basin of the Northern Benue Trough, NE Nigeria.The objectives are to: (1) describe the characteristics of the compound dune through construction of detailed graphic log; (2) describe the geometry of the Compound dune; and (3) characterize the possible reservoir heterogeneities within the Compound dune.

Geologic Setting and Stratigraphy

The Gongola Sub-basin (Figure 1) forms the north-south trending arm of the Northern Benue Trough which is part of the mother Benue Trough formed as a result of the separation of the African plate from the South American plate in the early Cretaceous Period. The origin of the basin has been a major subject of many publications and it consist of about 6Km of sedimentary successions spanning from Albian to Palaeogene in age. The basin marked the northern extreme of the Benue Trough and is separated from the east-west trending Yola arm (Yola Sub-basin) by an area of shallow basement rocks traversed by four major NE-SW trending sinistral strike-slipsFaults of Gombe, Bima-Teli, Kaltungo and Shani while to the north is limited by the Dumbulwa-Bage High from the Chad basin (Zaborski, 1998.

The stratigraphic successions within the Gongola Sub-basin (Figure 2) from the oldest include the continental Bima Formation, the transitional Yolde Formation, the marine Pindiga Formation, the transitional Gombe Formation and the continental Keri-Keri Formation (Zaborski *et al.* 1997). Of interest to this work is the Pindiga Formation. It largelycomprises sediments deposited during a period of major marine transgression (Zaborski, 2000). Stratigraphically, the Pindiga Formation has been divided into five members namely: the basal Kanawa Member, the middle sandy members of Gulani, Deba-Fulan and Dumbulwa, and the upper Fika Member. Of interest to this work is the Deban Fulani Member of Zaborski *et al.* 1997.

Goro (2015) identified eight major facies associations within the Deban Fulani Member which include:Wave/storm - dominated prodelta to delta front facies association,Wave/storm - dominated shoreface facies association,Tide - dominated channel facies association,

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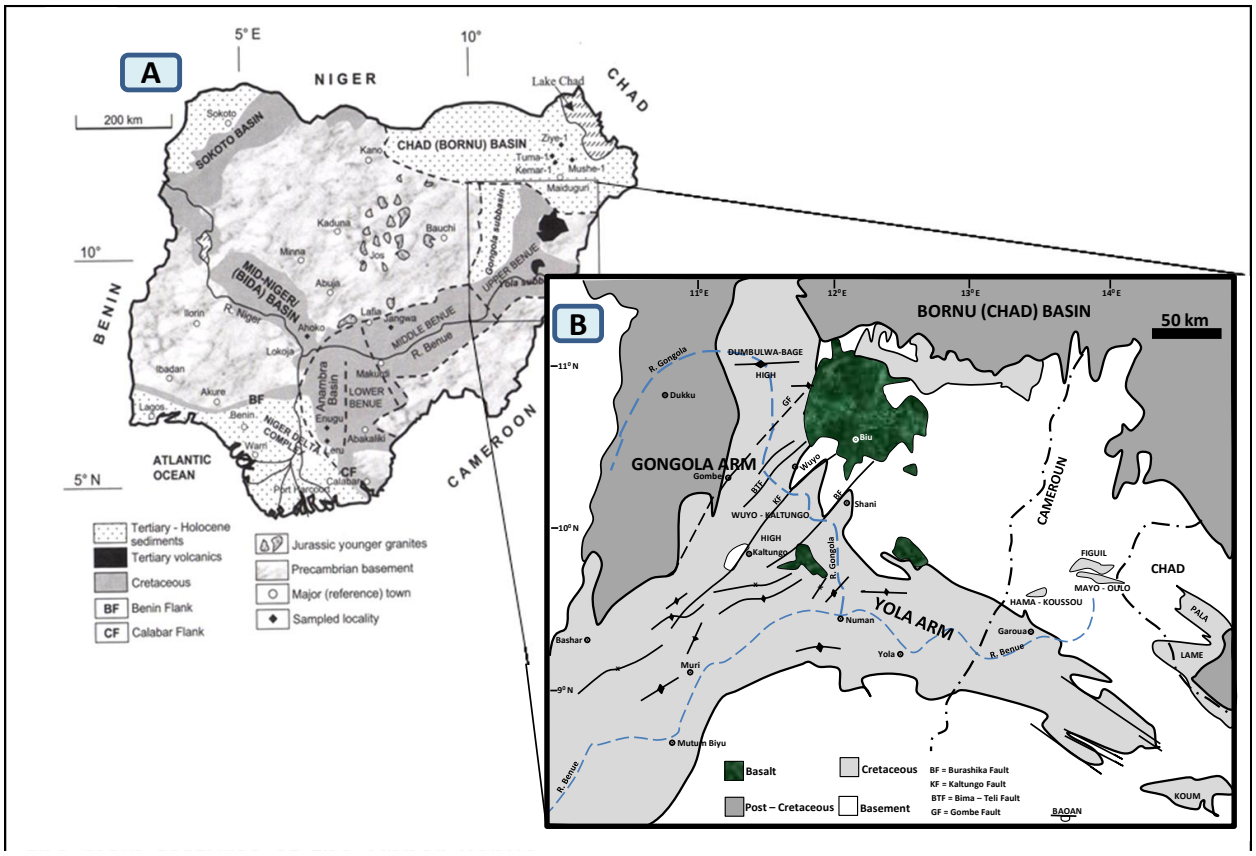


Figure 1: Simplified geological maps showing [A] Cretaceous basin of Nigeria (From Obaje *et al.*, 2004) and [B] the main features of the Northern Benue Trough (modified from Zaborski, 1998)

Age	Northern Benue Trough	
	Gongola Sub-basin	Yola Sub-basin
Tertiary	Keri Keri Formation	
Maastritchian	Gombe Formation	
Campanian	Fika Shale	
Santonian		
Coniacian	Pindiga Formation: Dumbulwa/Deba Fulani/Gulani Members	Lamja Formation Numanha Formation Sekuliye Formation
Turonian	Kanawa Member	Jessu Formation Dukul Formation
Cenomanian	Yolde Formation	
Albian - ?Upper Jurassic	Bima Formation	
Precambrian	Basement complex	

Figure 2. Lithostratigraphic successions in the Northern Benue Trough (modified from Abubakar, 2014).

Tidal sand bar facies association, Fluvial facies association, Bayhead delta facies association, Central estuary bay facies association, and Estuary mouth facies association. The compound dune described herein is associated with the tide-dominated channel facies association.

MATERIAL AND METHOD

The research is base on detailed field study of excellently well exposed outcrop within the Dampami stream section along Gombe-Kumo road, Gombe state, NE Nigeria. Data collected from the field study (e.g. measurement of sedimentary features such as thickness of beds and recording of sedimentary features such as lithology, texture, sedimentary structures, bioturbation index etc) were then used to construct a sedimentological graphic log (Figure 3). The outcome of this was then used to interpret the observation base on existing literature.

RESULTS

Field characteristics of the compound dune complex

The interval of study is approximately 7 m thick complex consisting of stacked units of individual, 10 – 40 cm thick sigmoidal shaped sandstone beds arranged in off lapping pattern similar to clinoforms (Fig. 3) displaying average leeface inclination of 34^0. Field graphic log summarizing the sedimentological features of part of the Sandy Members exposed in the Dampami stream is shown in Figure 3A, whereas a sedimentary model showing the internal characteristics of the study interval is displayed as Figure 3B. The sandstone bed-sets are interbedded with bioturbated grey mudstone intervals at the lower part of the complex (Fig. 3B, C); separated by thin mud drapes at the middle part (Fig. 3B, C) and are amalgamated without mud-rapes towards the upper part of the complex (Fig. 3B, D), giving the unit an overall coarsening and thickening-up trend. The sigmoidal shaped beds internally consists of finning-up, medium to very coarse, moderate to well sorted, graded and cross bedded sandstones. The lower parts of the beds show large-scale often planar cross bedding while the upper parts are characterized by small-scale trough as well as herringbone cross bedding and reactivation surfaces (Fig. 3B, E). The Sandstones are generally not bioturbated but the mud-draped intervals display mottled texture with up-section decrease in intensity.Thickness of mud-drapes range from 3 to 7 cm.

The interval of study is bounded at its base by a sharp, erosional surface and at its top by a planar surface marked by thin ferruginous crust interpreted as a transgressive surface (Goro, 2016). The upper boundary is overlain by bioturbated, dark grey mudstone (Fig. 3 A, B). The underlying unit is a succession of sandstones composed internally of abundant concave-up erosional surfaces and trough cross bedding (Fig. 3A).

Discussion

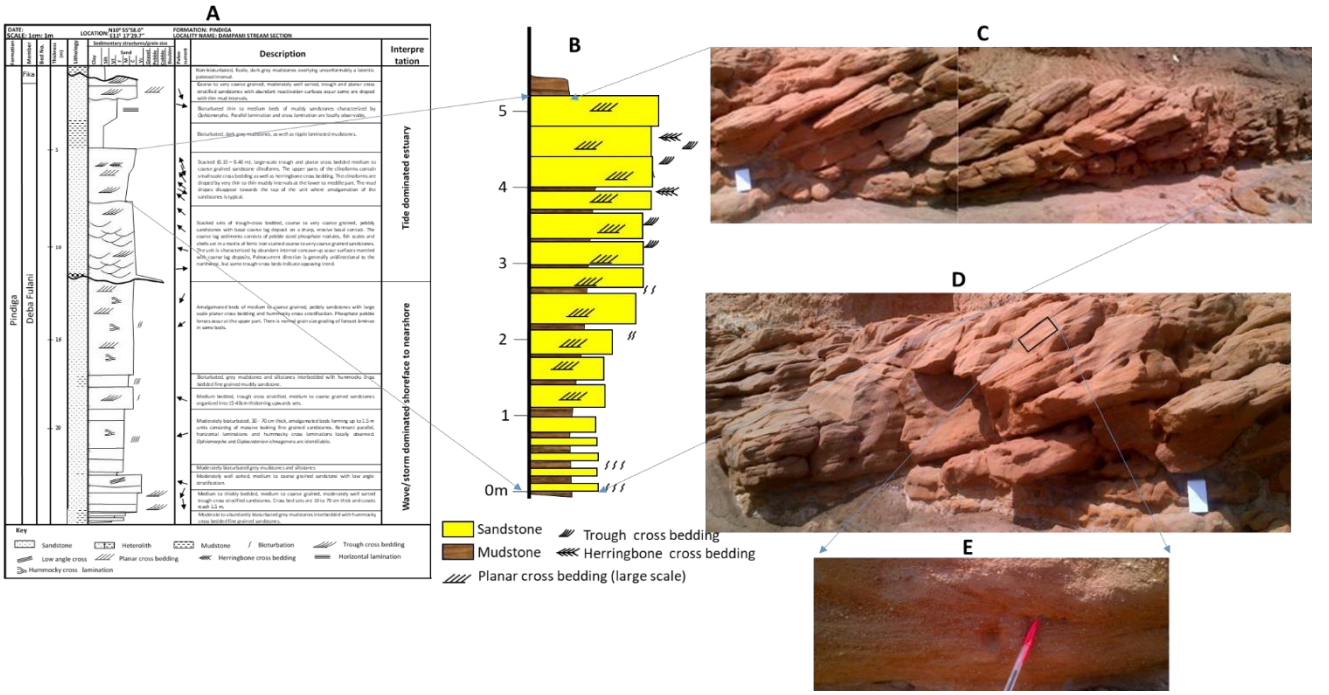
From the definition of compound dunes "large to very large dunes upon which are smaller simple dunes (Dalrymple and Rhodes, 1995; Dalrymple, 2010), the single often sigmoidal shaped sandstone beds described in the present study represent compound dunes. Their stacking into offlapping, coarsening and thickening-up, and amalgamation of upper parts suggests deposition by forward accretion (Miall, 2010; Olariu et al., 2008; Dalrymple 2010). Based on the characteristic, the interval of study is interpreted as a compound dune complex following the terminologies of Olariu et al., 2008. Sedimentological details of how compound dunes and compound dune complexes are generated were provided by Dalrymple (1984) as well as Dalrymple and Rhodes (1995).

Allen (1980) suggested sedimentological models to explain the range of possible structures in a compound dune complex (Fig. 4). Model A (Fig. 4) is characterized by the occurrence of high angle master surfaces (E2, Fig. 4) (i.e. surfaces separating compound dunes); large scale cross beds at their lower parts; small-scale cross beds and reactivation surfaces at their upper parts and muddraped intervals at their trough. Model B is however characterized by low angle master surfaces and medium to large sized dunes at the upper part of the complex so that compound cross beddings are produced. The compound dunes herein described are better explained by the Model A owing to the similarities in the contained sedimentary structures.

Based on detailed study of the tidalites of the Baronia Formation, Ager Basin, Spain; Mutti et al. (1985), distinguished bottom set, bar slope (foresets/dune lee face) and bar crest units on similar dune structures (Fig. 5) which were interpreted as tidal bars deposited at the mouth of a delta. More recently, Olariu et al. (2008) reinterpreted the units as compound dunes deposited in a tectonically generated embayment or tidal seaway. Distinction between tidal bars and compound dunes were also given in detail by Olariu et al. (2008) where it was pointed out that tidal bars consists of overall fining upward facies association, accumulate by lateral accretion processes and are commonly deposited at the mouth of tidal dominated deltas and estuaries (e.g. Dalrymple and Zeitlin 1994; Berne et al., 2002) while compound dunes are recognised by their overall coarsening and thickening upwards character and accumulate by forward migration (Allen 1980; Dalrymple, 2010). Dalrymple (2010) observed that the coarsening and thickening-up character of compound dunes is equivalent to the forward accretion architectural element of Miall (2010) with the heterolithic bottom set recording deposition at the trough where energies are low, allowing bioturbation to occur and the amalgamated sandstones of the crest recording strongest energy region.

Implications for reservoir studies

Accurate identification of compound dunes and compound dune complexes is vital for correct interpretation of environment of deposition and most importantly, reservoir characterization. Distinction between tidal bars and tidal compound dune complexes and their importance in hydrocarbon exploration has been highlighted by Olariu et al., 2008. With regards to reservoir characterization, the fining upwards within compound dunes may cause vertical heterogeneity at individual well level (macroscopic) while the mud intervals between them may create permeability barriers within the reservoir at this scale. The Upwards increase in grain size as well as up-section amalgamation of individual compound dune units within the compound dune complex may lead to increased porosity and permeability towards the top of individual complexes. This enhancing flow properties towards upperparts of compound dune complexes which is readily sort for especially reservoir geologists and engineers in the oil industry. Essentially, opposing trends are however expected in tidal bar complexes.



Figur3 [A] Sedimentological graphic log of part of the Sandy Members of Pindiga Formation modified from [B] sedimentological illustrating the internal character of a well exposed compound dune complex ; [C] lower to middle part (left to right), displaying interbedded thin sandstones and mudstones at the base and medium bedded sigmoidal shaped sandstones separated by thin mud drapes in the middle; [D] upper part showing amalgamation of sandstone bed sets; [E] herringbone cross bedding at upper parts of sandstone beds.

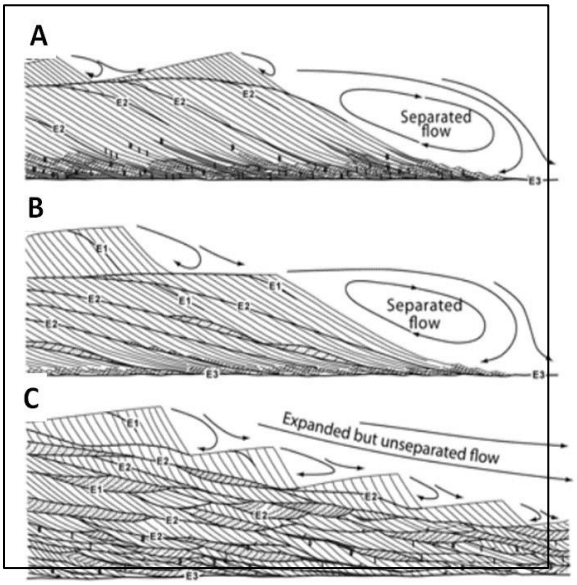


Figure 4. Schematic sections through compound dunes showing the range of possible sedimentary structures. [A] large-scale simple crossbedding bedding with randomly spaced reactivation surfaces each of which is formed by the trough of smaller superimposed dune passes over the brink of a larger dune; [B] compound crossbedding with low angle master bedding planes separating the individual simple dunes; [C] compound crossbedding with smaller superimposed dunes and lower angle master planes.

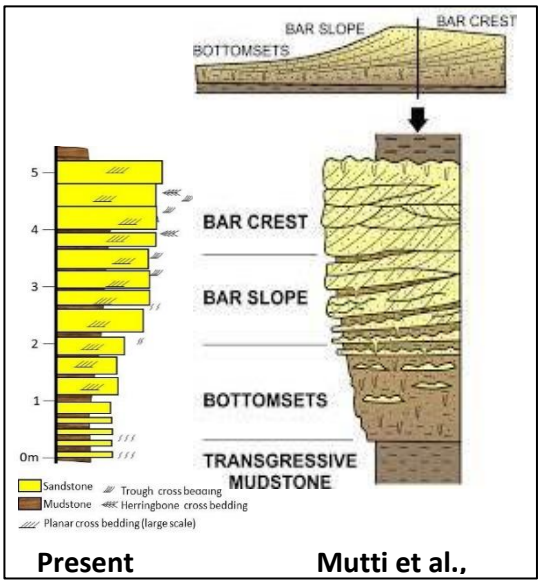


Figure 5. Schematic vertical succession of the deposit created by a compound dune complex.

CONCLUSION

The distinction between compound dunes and tidal bar/tidal channel is important as they differ in the way they affect reservoir performance. The presence of coarsening and thickening up grain size profile, and tidal indicators such as reactivation surfaces, herringbone cross bedding, mud drapes between cross beds characterize the well exposed compound dunes of the Deban Fulani Member of Pindiga Formation, Gongola sub-basin, Northern Benue Trough, NE Nigeria. Identification of this feature has essential implications in harnessing reservoir performance and their identification is a key element in reservoir characterization.

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