

DIPLOG ANALYSIS OF PALEOCURRENT AND DEPOSITIONAL ENERGY OF MIOCENE RESERVOIR SANDS IN THE NORTHWESTERN NIGER DELTA.

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ABSTRACT

Dipmeter log is an invaluable tool in the description of paleocurrent and depositional energy associated with subsurface sediments due to its high depth resolution and uniqueness as a method for studies of this kind. Interpretation of dip patterns and variations in dip amounts, in conjunction with composite log and biostratigraphic data, shows that the Lower to Middle Miocene sand reservoirs identified in two onshore wells in the Niger Delta were deposited under high to low energy conditions. The paleocurrent directions are mainly to the southwest, northwest, and southeast. Transporting water currents, waves, tides, and longshore currents dictated both paleocurrent directions and depositional energy. The interaction of these nearshore influences and the resulting pattern of sedimentation of the reservoir sands reinforce the conclusions drawn from studies conducted on Quaternary sediments along the Nigerian southwest coast and on Cretaceous sediments in the adjoining Anambra Basin. The levels of depositional energy deduced are indicative of the bathymetry of the reservoirs and their petrophysical properties. High-energy deposits occur in shallower water depths than the low energy deposits and are likely to be better sorted and more permeable. High variability in energy levels in some sand zones have been shown to correlate with depth intervals having repeated sequences of very thin reservoir sands often separated by minor shale beds.

KEY WORDS: Dips, paleocurrent, energy, deposition reservoir

INTRODUCTION

The high resolution dipmeter log (diplog) usually has lithologic dips and azimuths presented as dip arrow plots (or tadpoles) against their depth of occurrence. It has been found very useful in solving many subsurface problems, including well correlation, determination of paleogeomorphic features, determination of reservoir geometries, sediment transport and structural interpretation (Atlas, 1987). In spite of the relevance of the dipmeter data and the improvements being made in its acquisition, they are infrequently used by geologists and geophysicists due, possibly, to the mode of data presentation and, partly, to the labour involved in manual reconstruction of interpreted sections (Etchecopar and Bonnetain, 1992). However, the practical importance of the dipmeter as a subsurface technique has been demonstrated by a number of workers, including Berg and Avery (1995), who employed it to identify sheared zones. In the Niger Delta, Ojoh and Bedford (1993) used the Formation Microscanner (FMS) along with tadpole plots to determine paleocurrent directions and to confirm areas of expanded turbidite sand development, with a view to optimising exploration targets.

In the present study, dip arrow plots of high quality rating from two onshore wells are analysed in order to determine paleocurrent directions and the depositional energy for some Miocene reservoir sands in the Niger Delta. According to Okonkwo et al (1994), deltaic reservoirs usually exhibit lateral lithologic variations and diplog analysis, as shown in this study, can assist in establishing paleocurrent and energy contributions to such variations.

Location and Geology

Dipmeter data were obtained from onshore wells drilled in a field located between latitudes 5° and 6°N and longitudes 5° and 6°E in the northwestern part of the Niger Delta (Fig. 1). The Niger Delta is one of the major sedimentary basins of Nigeria and the most petroliferous. Its origin is attributed to the basement tectonics associated with crustal divergence and translation during the Late Jurassic to Early Cretaceous continental rifting, which led to the opening of the South Atlantic and the formation of the Benue-Abakiliki trough as a failed arm of the rift triple junction.

The present Niger Delta is derived from a major regression and sediment progradation into the Gulf of Guinea following the post-Paleocene regression. The major lithostratigraphic units comprise the basal Akata Formation overlain by the paralic Agbada Formation and the top, largely continental lithofacies unit, the Benin Formation. While the basal unit consists predominantly of prodelta, undercompacted shales, the transitional Agbada Formation is made up of an alternation of sands and shales. Poorly indurated sands and sandstones are the major constituents of the Benin Formation. Hydrocarbon reservoirs in the delta are mainly found in the Agbada Formation. Detailed review of the evolution and stratigraphy of the Niger Delta have been published by Murat (1972), Kogbe and Burollet (1990), Petters (1991), and Reijers et al (1997).

METHOD OF STUDY

Composite logs were used in conjunction with biostratigraphic data to define the upper boundary between the Benin and Agbada Formations. Such

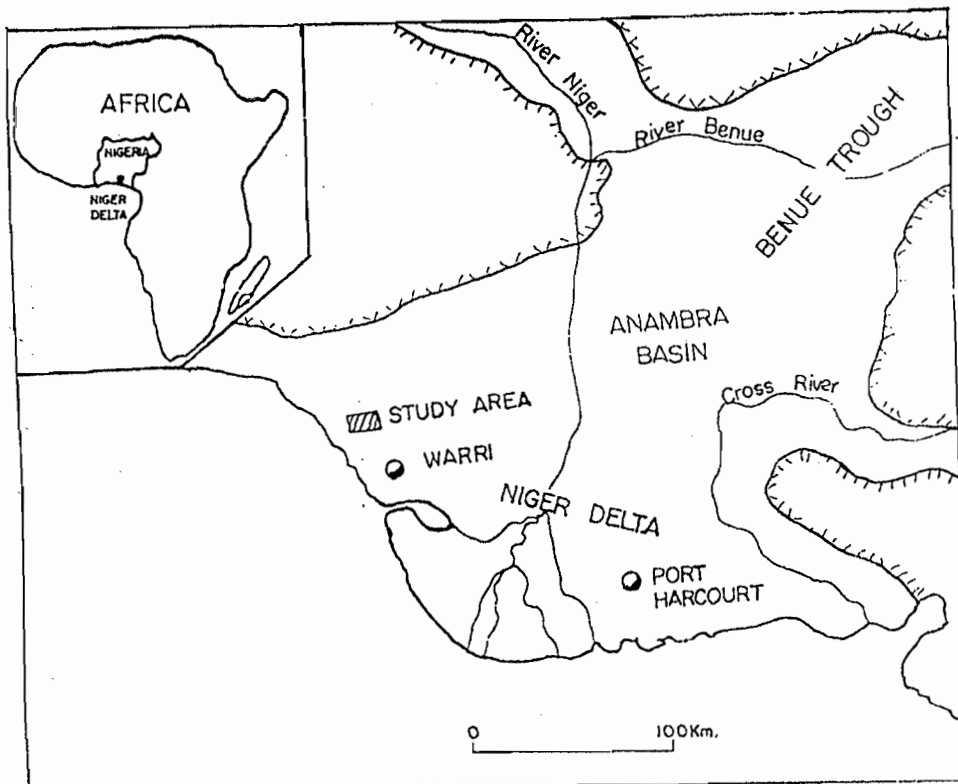


FIG. 1: Map of Niger Delta showing study area

boundary is usually characterized by self potential (SP) log reversal at the fresh water-salt water boundary and a corresponding lower resistivity and higher sand-shale intercalation within the deeper Agbada interval (Bustin, 1988; Kofron et al., 1996). Reservoir units within depth ranges for which dip measurements existed were identified and correlated using self potential (SP), gamma ray (GR), and resistivity logs. The reservoir sands were subsequently divided into five zones that were separated by significant thicknesses of correlatable shale beds.

Dip plots recorded for the corresponding reservoir interval (Fig. 2) in each well were grouped into their corresponding red, blue, green, or yellow patterns. The green patterns were useful in assessing overall structural dips as the effect of post depositional structural uplift or downwarping of beds usually have to be corrected for in the process of determining sedimentary dips. However, such corrections are only necessary if structural dips are up to or in excess of 5° and structural dips of 8° can still be accommodated when depositional dips and structural dips are known to have the same orientation (Atlas, 1987). The identified dip patterns corresponding to the different sand units and zones in each well were coloured appropriately. Blue patterns occurring within short vertical depth intervals (less than 50ft (15m) and usually between 20 (6m) and 30ft (9m)) and the applicable sand zones were identified and azimuth frequency diagram drawn to determine predominant paleocurrent direction(s) for the totality of the reservoir sands in each well. Blue patterns occurring within short depth intervals are often linked with paleocurrent cross-bedding while much longer

persistence is rather related to folds or faults (Schlumberger, 1985; Atlas, 1987). The use of other logs (SP and resistivity logs) helped in resolving this difference.

Variations in dip amounts for each sand zone in the respective wells also assisted in identifying energy levels applicable to each zone. Dips varying by less than 2 to 3° and having consistent direction (green dip patterns) are associated with low depositional energy while variation of between 20° and 40° are linked with high energy; intermediate ranges may signify medium energy (Atlas, 1987).

RESULTS AND DISCUSSION

Structural Dip Effect

Structural dip histograms plotted for the two wells (Figures 3 and 4) shows that structural dips vary between 0 and 5° , with 1° dip being most predominant in well 1 and 3° dip in well 2. These dip values are lower than should warrant structural dip corrections on determined paleocurrent dips. The corresponding azimuth frequency diagram (AFD) indicates that the dips are predominantly in the southwest direction (Fig. 5). This dip direction is in consonance with basin trend and the general axis of sediment progradation in the Miocene. Growth faulting which is a major structural feature in the Niger delta capable of causing stratal reorientation may not have had significant effect on the initial (depositional) disposition of the stratigraphic units within these wells, particularly at the depth under consideration. The structural dips obtained (1 to 3°) are

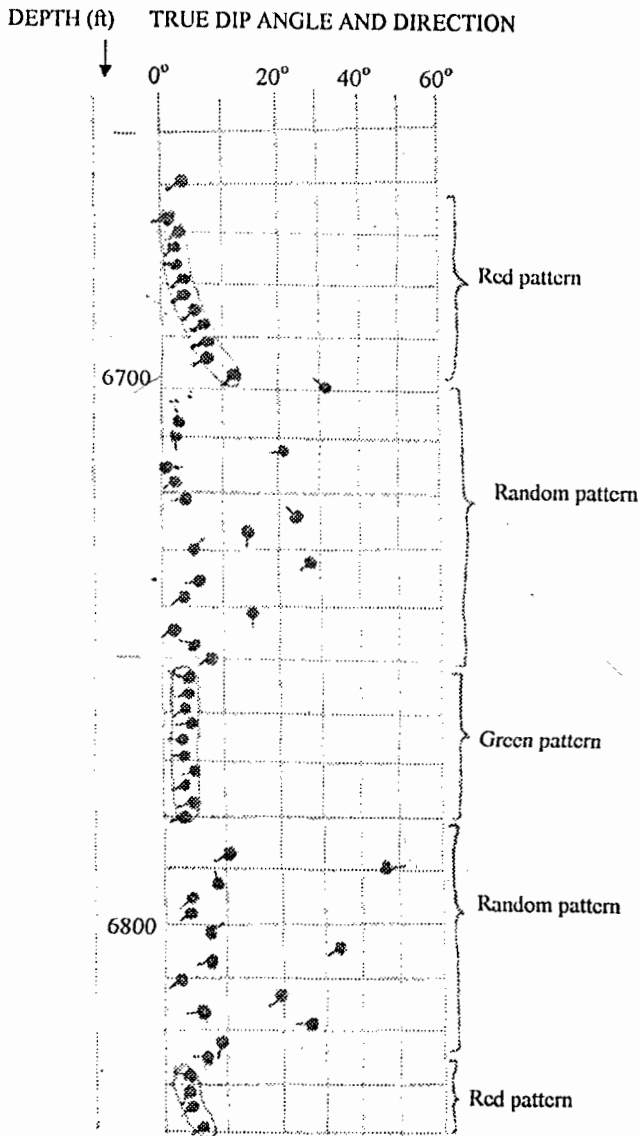


FIG. 2: Typical diplog (tadpole) for well 2 showing a variety of dip patterns

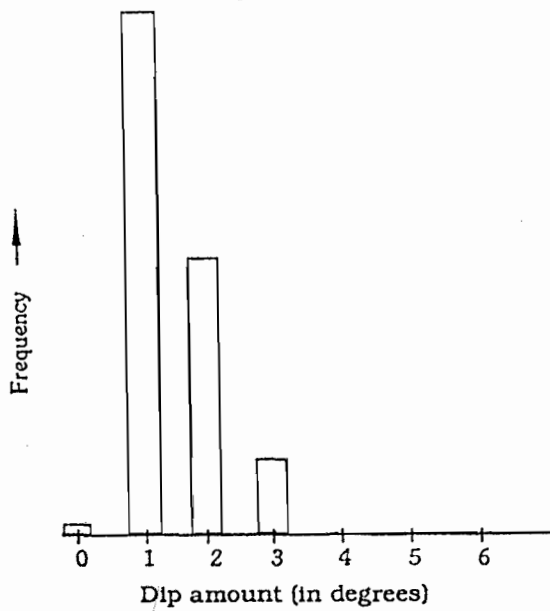


FIG. 3: Structural dip histogram for well 1

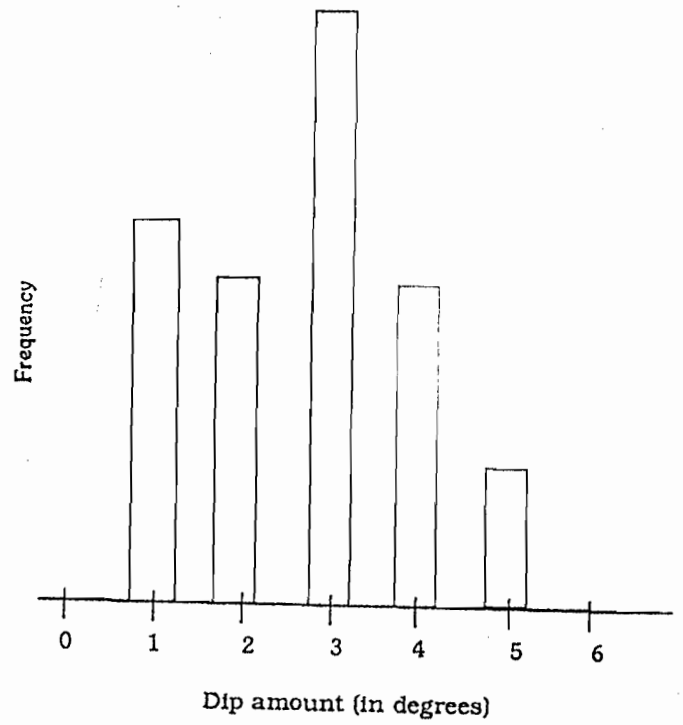


FIG. 4: Structural dip histogram for well 2

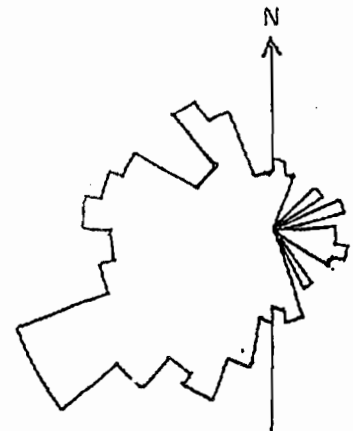


FIG. 5: Azimuth frequency diagram for structural dip orientation in field area

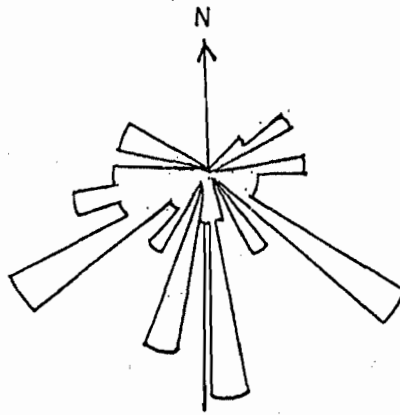


FIG. 6: Azimuth frequency diagram for paleocurrent with data from well 1

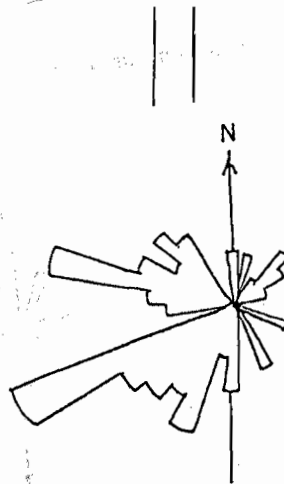


FIG. 7: Azimuth frequency diagram for paleocurrent with data from well 2

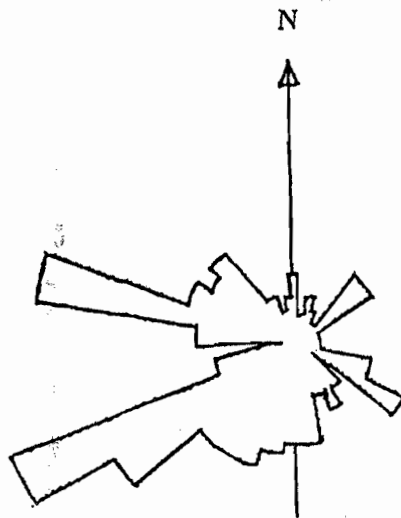


FIG. 8: Azimuth frequency diagram for paleocurrent with data from wells 1 and 2

less than the value of 4° in the southeast reported by Ojoh and Bedford (1993) in the offshore Niger Delta. The relative locations of the two study areas within the delta could probably explain these lower values in the onshore area.

Paleocurrent

Dip directions derived from the blue patterns within the different sand zones were analyzed for the two wells using the AFD. Polymodal paleocurrent dips are evident from the AFD for well 1, with major paleocurrent directions in the southwest, south, and southeast. Paleocurrent in the northeast and northwest directions are relatively insignificant (Fig. 6). Paleocurrent dips for sands in well 2 are basically bimodal and are predominant in the southwest and northwest (Fig. 7). The implication is that the bulk of reservoir sands in the two wells were deposited under common paleocurrent influence that seems to have prevailed mostly in the southwest and, depending on location, some other factors have equally contributed significantly to paleocurrent in the southeast and northwest. AFD based on data from the two wells (Fig. 8) confirms that paleocurrent directions are principally in the southwest and northwest. The dominant southwest paleocurrent direction can be attributed to a northeast clastic provenance during the uplift and subsequent erosion of the highlands of the northeast in the Miocene. Paleocurrent in other directions may be attributed to resedimentation influence which could have obliterated the initial depositional signature in most of the reservoirs, as also noted by Ojoh and Bedford (1993). The resedimentation may likely have been driven by coastal dynamics associated with wind action, littoral currents, tidal influences, and waves. Reijers et al (1997) in describing paleocurrent circulation pattern in the upper

extremity of the Niger Delta (the Anambra Basin) have explained how the converging flow of southwest to northeast-directed drift cell and a southeast to northwest-directed cell caused resedimentation dominated by storm and waves and tides, especially during periods when the paleocirculation was reinforced by transgressive tendencies. This influence is likely to have similarly prevailed during the formation of the Eocene Niger Delta.

In a study of contemporary (Quaternary) coastal sedimentation in the Victoria beach (Lagos) area of Nigeria, Ibe and Awosika (1988) reported the influence of southwesterly winds (confined to 215° - 266° azimuth) on sediments in the beach and described the three main sources of sediments to be hinterland, alongshore, and offshore. It is therefore apt to describe the Miocene reservoirs with southwest paleocurrent as primarily unworked sediments sourced from the hinterland and deposited by waning water currents flowing southwestward. Alongshore and offshore sediments or those sediments reworked by hydrodynamic forces are therefore likely to be those whose paleocurrent directions reflect northwest, southeast, or northeast. These deductions also imply that the reservoir sands are likely to have been nearshore or very shallow water

deposition. The absence of marine fauna (in the barren zone) as portrayed in the biostratigraphic data (Table 1) may be due to the non-preservation of tests, perhaps due to the reworking of sediments by the said coastal processes.

Depositional Energy

Table 2 gives a summary of depositional energy deduced for the various sand zones in the two wells and their corresponding dip patterns. It is obvious that the

Table 1 : BIOSTRATIGRAPHIC DATA FOR SAND ZONES

GR LOG		SAND ZONE	BIOSTRATIGRAPHIC DATA		
WELL 1	WELL 2		AGE	FORAMINIFERAL ZONATION	ECOZONE
		BENIN FM	MID MIOCENE	BARREN	CONTINENTAL TO SUBCONTINENTAL
		AGEBADA FM ↓			
		1			
		2			
		3			
		4	LOWER MIOCENE	FOSSILIFEROUS	TRANSITIONAL TO INNER NERITIC
		5			INNER NERITIC

Table 2: Dip patterns and inferred depositional energy for sand zones in wells 1 and 2

SAND ZONE	WELL	NET SAND THICKNESS		OBSERVED DIP PATTERNS	DEPOSITIONAL ENERGY
		(m)	(ft)		
1	1	66	218	*	
	2	71	234	Random	High
2	1	17	56	Green, red partly random	Variable (Medium to high)
	2	17	56	Mainly random; few red, green, and blue patterns also occur	High
3	1	76	250	Mainly random with green patterns present	Variable
	2	62	204	Partly random with red, green, and blue patterns present	Medium
4	1	39	127	Random	High
	2	35	116	Random	High
5	1	6	19	Mainly green with few random	Variable (Low to medium)
	2	4	13	Red, green	Medium

No dip data

random dip pattern, with its characteristic large variation in dip amounts and directions, were observed in virtually all the sand zones.

The random pattern can be more appropriately associated with high-energy conditions at the time of deposition. These conditions, according to Atlas (1987), apply to shallow water (< 50ft (15m)) along the coast where waves, tides, longshore currents, and the ambient mixtures of fluvial versus marine conditions cause a great deal of turbulence. This inference is based also on the fact that composite log information describes the sands within these zones as generally fine to medium grained and having traces of glauconite, pyrite, and dolomite. These minerals are diagnostic of shallow water deposition. Umoren (1998), in carrying out a stick plot analysis of the stratigraphic patterns of these sands, showed parts of the sand zones to be cross-bedded tidal channel deposits within a lagoonal subenvironment.

The presence of a variety of other patterns (red, blue, and green) within some sand zones also corroborates the possibility of different energy regimes being applicable to the reservoirs during deposition. The red and blue patterns are commonly measured in medium energy, subtidal conditions of 50 (15m) to 300ft (91m) bathymetry, where the possibility of paleocurrent deductions is enhanced (Atlas, 1987). The predominance of the green pattern in sand zone 5 (with only few random patterns) indicates the lower energy and deeper water depths which sands of this zone may have been deposited. Ecozone description from biostratigraphic data classifies sand zone 5 within the inner neritic and generally fossiliferous. These sands, going by the dip information, may not have been

reworked and were possibly deposited in quiet water conditions favouring the preservation of tests.

The energy conditions associated with the various sand zones and their corresponding paleocurrent attributes have significant petrophysical implications. The high-energy sand reservoirs are more likely to be well sorted, porous, and permeable, while the lower energy sands will tend to be finer in grain size, probably porous but low in permeability and might generally be shaly and dirty. Reservoir sands within zones 2 and 3 exhibit more variable energy conditions, alternating between high and low within its intervals. Petrophysical properties of these zones are equally likely to show significant variations with depth, with the probable existence of repeated thin reservoir beds in their respective intervals due to the cycles of energy that accounted for their deposition. The lithologic logs (SP and GR) have characteristic (serrated) shapes within the affected zones that buttress this description.

CONCLUSION

Dipmeter log interpretation has shown that Agbada reservoir sands exhibit a variety of dip patterns. Random patterns are observed to be the dominant pattern in the sand zones correlated across two onshore wells. Paleocurrent analysis using the azimuth frequency diagram indicates a predominance of southwest paleocurrent direction. Paleocurrent directions to the northwest, northeast, and southeast are less important. The result establishes the main source of the reservoir sands to be hinterland, with some of the sands reworked at some locations during deposition. It also

confirms that there is a strong correlation in the pattern of sedimentation and coastal dynamics between the time the reservoir sands were deposited (in the Miocene) and the present (Quaternary) observations. The reservoir sands were deposited nearshore under varying energy conditions. High energy conditions are likely to enhance the petrophysical attributes of the reservoir sands, while alternation between high and low energy in some sand zones may be responsible for the existence of thin reservoir intervals.

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