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Integrated well log and 2-D seismic data interpretation to image the subsurface stratigraphy and structure in north-eastern Bornu (Chad) basin

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ABSTRACT

Structural and stratigraphic mapping within the Bornu Basin in north east Nigeria was commonly carried out using traditional field geological methods. However, such traditional approaches remain inadequate in the semi-arid region characterised by topographically flat areas and lack of continuous bedrock outcrops that are mostly concealed beneath sand cover. Previous studies in the north-eastern part of the basin carried out using ditch cuttings from few wells and disconnected seismic data were largely inadequate and the resulting stratigraphic analyses were more often generalised. This paper presents an integrated structural and stratigraphic study of the basin using combined subsurface geophysical datasets. A Combined Log Pattern (CLP) method is a well log analysis, which utilises various well log data including gamma ray, resistivity, bulk density and sonic logs to identify lithology and stratigraphic boundaries of subsurface formations. This method is applied to constrain the subsurface stratigraphy of the north-eastern part of the Bornu Basin bordering the Lake Chad. In addition to qualitative combined well log analysis, the time-depth relationship of the sonic log and seismic data was quantitatively determined by tying a well with an intersecting seismic section to validate the stratigraphic facies horizons identified. Four well log facies and their environments of deposition were characterised from the combined well log analysis of the different log types. It is discovered that the Cretaceous basement structural features controlled the deposition of overlying formations in the basin. Without intact core data, the shallower wells were discovered to have bottomed over subsurface horst features while deeper wells penetrated into the basal facies contained mainly within the grabens. Main subsurface structural lineaments in the area include NW-SE, NE-SW and NNW-SSE trending faults, which mainly formed the horst and graben features. Some stratigraphic formations described in previous generalised stratigraphic schemes for the Bornu Basin were herein not found in the north-eastern part of the basin.

1. Introduction

Bornu Basin is one of the most explored inland basins in Nigeria and its hydrocarbon potentials have been well identified (Petters and Ekweozor, 1982; Avbovbo et al., 1986; Genik, 1992, 1993; Olugbemiro, 1997; Moumouni et al., 2007; Obaje, 2009; Anakwuba and Chinwuko, 2012; Hamza and Hamidu, 2012; Adepelumi et al., 2012). Several discrepancies exist in the literature for the litho-stratigraphic classification of the Bornu Basin. The subsurface stratigraphy in the north-eastern part of the basin towards the south western shores of the Lake Chad remain unclear since specific data were routinely used and not a combination of different datasets, which allow for correlation and validation. The stratigraphy of the Bornu Basin was thus commonly associated with the stratigraphy of its south adjoining Gongola Basin in the Upper Benue Trough. Bornu Basin is an inland sub-basin within the south-western boundary of the Lake Chad Basin and forms part of the regional Cretaceous West and Central African Rift System (WCARS) basins (Binks and Fairhead, 1992; Genik, 1992). The Lake Chad Basin is a large intracontinental basin which covers areas in Nigeria, Republic of Chad, Republic of Niger, Libya, Cameroon and Central African Republic. Thus, Bornu Basin is the Nigerian sector of the Lake Chad Basin located in north-eastern Nigeria and characterised with semi-arid climatic conditions typical of the Sudan and the

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Northern and Central Africa (Miller et al., 1968; Isiorho and Matisoff, 1990; Isiorho, and Nkereuwem, 1996) (Fig. 1).

Generally, bedrock outcrops in the basin are scarce, mainly covered by thick Quaternary sediments forming broad flat terrain in the north towards the south-western boundary of Republic of Chad and the Lake Chad (Isiorho, and Nkereuwem, 1996). However, few rock outcrops were found in the southern part of the basin towards its boundary with the Upper Benue Trough (Obaje, 2009; Boboye and Akaegbobi, 2012; Chinwuko et al., 2012; Hamza and Hamidu, 2012). The limited outcrops mapped using traditional field methods were used to generalise the stratigraphy of the entire basin. The stratigraphic investigations carried out in localised parts of the basin using the geological field mapping were therefore inadequate since the greater part of the basin in the northern part remained constrained by flat topography and inadequate bedrock outcrops. Previous subsurface stratigraphic studies in the north-eastern part of the basin which involved few core samples or segregated ditch cuttings were obtained from few wells (e.g., Moumouni et al., 2007; Boboye and Abimbola, 2009; Alalade and Tyson, 2010; Hamza and Hamidu, 2012; Boboye and Akaegbobi, 2012; Adeigbe and Abimbola, 2013; Adegoke et al., 2014). Similar previous studies including gamma ray log analysis; Adepelumi et al. (2012) and 2D seismic data analysis; Avbovbo et al. (1986); Okpikoro and Oluronniwo (2010) were insufficient in identifying detail subsurface stratigraphy of the north-eastern part of the basin. Consequently, in the absence of bedrock outcrops and intact core samples, this study presents an alternative effective subsurface stratigraphic study using multi-well log data including gamma ray, resistivity, bulk density and sonic logs obtained from the complete twenty three (23) wells drilled in the basin and intersecting 2D seismic data.

The primary objective of this study is to constrain the subsurface stratigraphy in the north-eastern Bornu Basin bordering the Lake Chad using combined seismic and well log data. Specifically, the study aim at (1) correlating the multiple well log datasets, (2) tying well log data to seismic data for validation of the stratigraphy, (3) detailed seismic facies interpretation, (4) detailed well log facies interpretation, (5) identifying the sedimentary formations and delineating their thicknesses and lateral variations, (6) deducing the environments of deposition of the formations, (7) characterising the subsurface seismic lineaments and (8) identifying the synergy between combined application of the different data types. The main advantage of the integrated data analysis is to provide more detail subsurface analysis which would enhance reliability of geological interpretations than using any single data only.

2. Geological and tectonic background

Bornu Basin is an intra-cratonic basin which evolved from the Cretaceous extensional rifting that followed the separation of the African and South American plates at a Rift-Rift-Fail (RRF) triple junction earlier linked from Niger Delta (Grant, 1971; Olade, 1975; Burke, 1976). Bornu Basin, earlier known as "Maiduguri sub-basin" (Avbovbo et al., 1986) is an east–west elongated inland sub-basin in the south-western boundary of the Lake Chad Basin in north-eastern Nigeria covering Latitude 11°.00′N – 13°. 45′. 38″N and Longitude 8°. 21′. 49″E – 14°. 40′. 22″E (Olugbemiro et al., 1997). Bornu Basin referred to as the Nigerian sector of the Lake Chad Basin makes up approximately ten percent of the 230, 000 km^2 extent of the entire Lake Chad Basin (Fig. 1). The southern flank of the Chad Basin which constitutes the Bornu Basin is bounded by Upper Benue Trough (Alalade and Tyson, 2010) (Fig. 1). The study area is in the north-eastern sector of the Bornu Basin covering Latitudes 12° 00′ N – 13° 30′ N and Longitudes 12° 30′ E – 14° 00′ E.

Bornu Basin is part of a regional active tectonic setting with

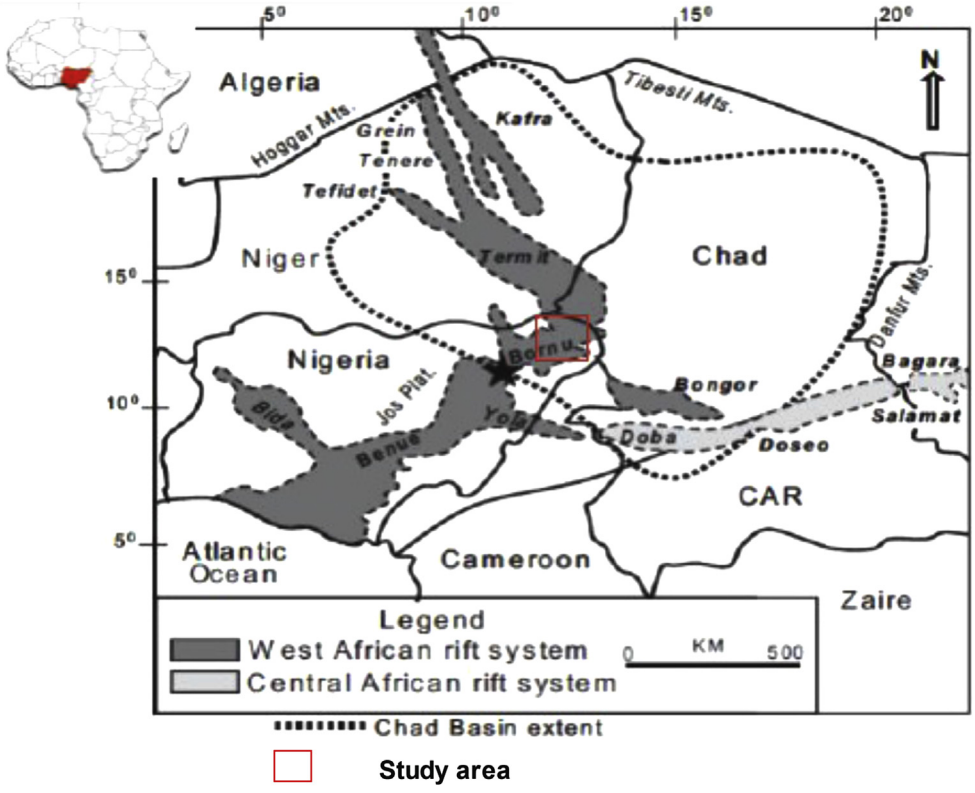

Fig. 1. Map showing location and extent of Lake Chad Basin including the north-eastern Bornu Basin in north east Nigeria (modified from Alalade and Tyson, 2010).