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Geochemical characterisation of Fika Formation in the Chad (Bornu) Basin, northeastern Nigeria: Implications for depositional environment and tectonic setting

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ABSTRACT

Late Cretaceous shales of the Fika Formation in the Chad (Bornu) Basin, northeastern Nigeria, were analysed to define paleoenvironment and source of the organic matter, and their relation to tectonic setting. The organic carbon and sulphur contents of Fika shale samples are in the range of 0.51–2.13 and 0.31–1.65 wt.%, respectively, pointing that these shales were deposited in suboxic-anoxic marine conditions. The biomarker and chemical compositions provide evidence for a major contribution of aquatic algae and microorganisms with minor terrigenous organic matter input. Moderate salinity stratification and relatively anoxic-suboxic bottom water conditions are also likely in the Fika shales. Therefore, stratified water column with moderate salinity and relatively anoxic-suboxic bottom water conditions have contributed to organic matter (OM) preservation in the Fika shale layer. Fika shale samples are rich in SiO_2 (54.80 wt.%), followed by Al_2O_3 (23.75 wt.%) and Fe_2O_3 (10.19 wt.%). Compared with average shale, the analysed shale samples are obviously enriched in Al_2O_3 (23.75 wt.%), TiO_2 (1.34 wt.%), and P_2O_5 (0.30 wt.%), indicating that these sediments are rich in clay minerals and represent a good possibility for enhanced organic matter production and enrichment.

Plots of Fika shale on bivariate discriminant function diagram suggest an active continental margin setting for the provenance. The inferred tectonic setting for the late Cretaceous shales of the Fika Formation of the Chad (Bornu) Basin is in agreement with the tectonic evolutionary history of the west and central Africa during the Cretaceous period.

1. Introduction

The Chad Basin is an extensive structural depression, covering an area of about 2,335,000 km^2 in Chad Republic, Niger Republic and extending into Cameroon, Central Africa Republic, Sudan and northeast Nigeria (Fig. S1). Chad Basin, also known as Bornu Basin, is one of Nigeria's frontier inland sedimentary basins where exploration activities are currently being undertaken (Fig. 1). These inland basins constitute parts of a series of rift basins in central and west Africa whose origin is linked to the separation of the African crustal blocks in the Cretaceous as part of the West and Central African Rift System (Fairhead, 1986; Genik, 1993, 1992) (Fig. S1). Apart from the Chad (Bornu) Basin in Nigeria, commercial hydrocarbon deposits have been discovered in the other parts of the rift trend in neighbouring countries of Chad (Doba, Doseo and Bongor fields), Niger (Termit-Agadem Basin) and Sudan (Muglad Basin), which are genetically related and have the similar structural settings (Mohammed et al., 1999; Obaje et al., 2004; Alalade and Tyson, 2010). According to Mohammed et al. (1999) and Obaje et al. (2004), the major source rocks in the Muglad Basin discoveries are in the Aptian-Albian-Cenomanian continental deposits of the Abu Gabra Formation, which are similar and correlative to Bima and Fika Formations in the Nigerian sector of the Chad Basin. 23 Exploratory wells have been drilled in the Nigerian part of the Chad Basin by the Nigerian National Petroleum Corporation. Minor gas occurrence was encountered in only two wells.

The poor knowledge of the evolution of the subsurface rocks in the Chad (Bornu) Basin, especially with respect to the characteristics of the organic matter and the depositional conditions of the

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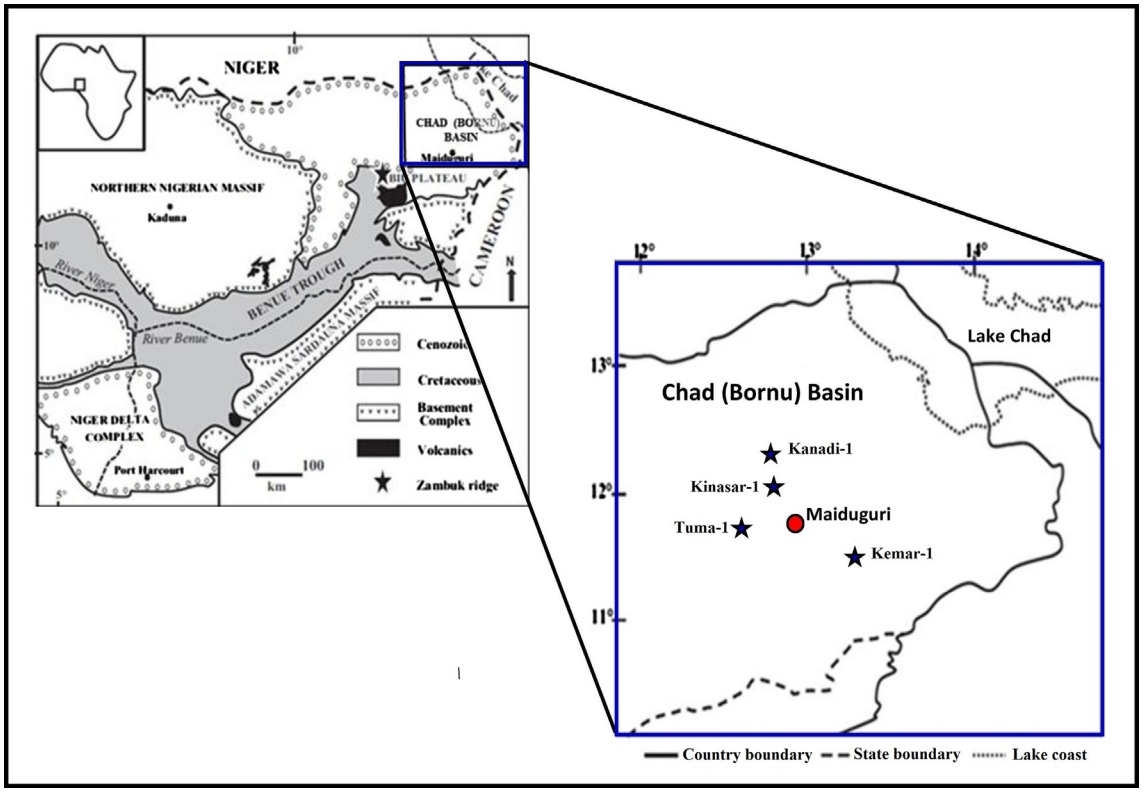

Fig. 1. Geological map of Nigeria, showing the Chad (Bornu) Basin and the location map of the studied exploratory wells: Kanadi-1; Kemar-1; Kinasar-1; Tuma-1 (after Whiteman, 1982).

potential source rocks may have been responsible for the unsuccessful exploration attempts within the basin. Although, several studies had been undertaken on the basin's source rock potential and organic matter (OM) maturity (Petters and Ekweozor, 1982; Olugbemiro et al., 1997; Obaje et al., 2004; Alalade and Tyson, 2010), detailed geochemical investigations of the origin and depositional environment of the organic matter are scarce or missing. Most of the previous studies of the basin have established the predominantly gas-prone nature of the potential source rocks in the study area, but without adequate examination of the source input and the depositional conditions of the organic matter. Moreover, most of these interpretations were based primarily on pyrolysis methods, without significant input from biomarkers and inorganic geochemistry.

Biomarker distributions have been used effectively in characterisation of the environmental conditions and source input of organic matter during the deposition (Peters and Moldowan, 1993; Peters et al., 2005). Likewise, elemental analysis of some major and trace elements can provide insight into the depositional environment conditions (Galarraga et al., 2008; Moosavirad et al., 2011; Mohialdeen and Raza, 2013; Shu et al., 2013; Jia et al., 2013). The integration of biomarkers and elements' distribution can give more detailed information needed to answer exploration questions on source input and conditions of deposition of the organic matter. This current study focuses on the detailed organic and inorganic geochemistry of the Fika "Shale" Formation, to provide an overview of the type, source input and depositional environment conditions of the organic matter in the Fika Shale sediments. This is aimed at re-appraising and validating the potentials of the formation as an effective source rock, and hence ultimately provides further insight into the geology of the basin, for future petroleum exploration programme and resource assessment in the region.

2. Geologic setting

The Nigeria sector of the basin (also known as Bornu Basin), which represents about one-tenth of the total area extent of the Chad Basin, is believed to be genetically linked with the Benue Trough, thus representing the northern border of a NE–SW trending aulacogen basin (Olade, 1975) (Fig. 1). The Chad Basin is genetically and physically related to the fault and rift systems termed the West and Central African Rift Systems (WCARS), whose origin is generally attributed to the Cretaceous breakup of Gondwana and the opening of the South Atlantic Ocean and the Indian Ocean (Fairhead, 1986). According to Fairhead (1986), the WCARS have two subsystems namely; the West African Rift Subsystem (to which the Chad Basin belongs) and the Central African Rift Subsystem. The Benue – Chad axial trough is believed to be the third and failed arm of a triple junction rift system that preceded the opening of the South Atlantic during the early Cretaceous and the subsequent separation of the African and South American continents (Carter et al., 1963; Burke et al., 1972; Olade, 1975; Avbovbo et al., 1986; Genik, 1992) (Fig. 1). However, Avbovbo et al. (1986) suggested three main phases as leading to the reconstruction of the structural events in the Bornu Basin, namely; Tensional (Pre-Albian-Albian), Sub-compressional (Maastrichtian-Danian) and Quiescent (Tertiary-Recent). Although, this model is without exact age delineation and more generalized, it fits in reasonably well into the model proposed for the West African Rift System (Genik, 1993).

The main stratigraphic succession of the Chad (Bornu) Basin is presented in Fig. 2. It was dominated by a thick Cretaceous succession that ranges in age from Albian to Pliocene (Fig. 2) (Okosun, 1995; Petters, 1981; Whiteman, 1982). The stratigraphic succession took place under varying conditions with each deposit representing one complete cycle of transgression and regression and has been