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Influence of igneous intrusions on thermal maturity of Late Cretaceous shales in the Tuma well, Chad Basin, NE Nigeria

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ABSTRACT

This study evaluates the influence of igneous intrusions on the thermal maturity of Late Cretaceous (Turonian–Santonian) potential source rock shales within the Gongila and Fika formations penetrated by the Tuma well. Twenty representative shale samples of the two formations between 1000 m and 3195 m were analyzed by bulk organic geochemical and palynofacies methods.

A positive excursion in Rock-Eval T_{max} values and an increase in the percent of non-fluorescent amorphous organic matter (AOM) were observed between 1500 m and 2900 m. These anomalies are moderately correlated with the abundance of igneous intrusive fragments. At depths greater than 2900 m where igneous intrusive fragments are absent, Rock-Eval T_{max} values return to the same trend as observed above 1500 m and the percentage of fluorescent AOM also increases. These observations suggest that the thermal maturity of the shales between 1500 m and 2900 m was elevated by the heating due to the emplacement of the intrusives.

Further studies should be undertaken to differentiate reliably the effects of regional burial and those of more localized contact metamorphism, and to determine the effects of each on the maturation of the Late Cretaceous potential source rocks.

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1. Introduction

The Chad Basin is a broad structural depression within the West and Central African Rift System that straddles five countries (the Central African Republic, Cameroon, Chad, Niger and Nigeria) and covers an area of about 230,000 km^2 (Avbovbo et al., 1986; Okosun, 1995). Commercial oil and gas discoveries have been reported in the eastern and western parts of the basin in Niger and Chad Republics while minor gas shows were encountered in two of the 23 exploratory wells drilled in the south western part of the basin in NE Nigeria.

Hydrocarbon accumulations discovered in the neighbouring Chad and Niger Republics are reported to have been sourced from Early Cretaceous and Eocene lacustrine shales and Late Cretaceous marine shales (Genik, 1993). Although the presence of lacustrine shales has not been reported in the Nigerian sector of the basin, about 2 km of Late Cretaceous marine (potential source rock) shales have been penetrated by exploratory wells drilled in this sector (Okosun, 1995; Olugbemiro et al., 1997; Alalade and Tyson, 2010). Several publications have addressed the source rock richness, quality and maturity of these potential source rocks (Olugbemiro et al., 1997; Olugbemiro and Ligoius, 1999; Obaje et al., 2004a,b; Moumoni et al., 2007; Alalade and Tyson, 2010), and have mostly concluded that they are predominantly gas-prone. Apart from Olugbemiro and Ligoius (1999), who, relative to other wells they studied, associated the higher thermal maturity gradient recorded in the Kanadi well with local intrusive activity, none of the previous studies evaluated the potential effect of igneous intrusions on the thermal maturation history of the shales. This is despite the literature reporting a long history of intrusive activity in the basin (Avbovbo et al., 1986; Genik, 1992). Raymond and Murchison (1988) have noted that basins with such a history must be carefully assessed in order to correctly apportion the effects of contact metamorphism and regional burial maturity.

The aim of this study is to report the influence of igneous intrusions on thermal maturity of Late Cretaceous marine shales penetrated by the Tuma exploratory well in the Chad Basin of NE Nigeria (Fig. 1). We will also attempt to distinguish regional burial maturation from local contact metamorphic effects.

2. Previous studies of the influence of igneous intrusion on source rocks

Contact metamorphism of source rock shales by igneous intrusions has been studied by many authors using techniques such as

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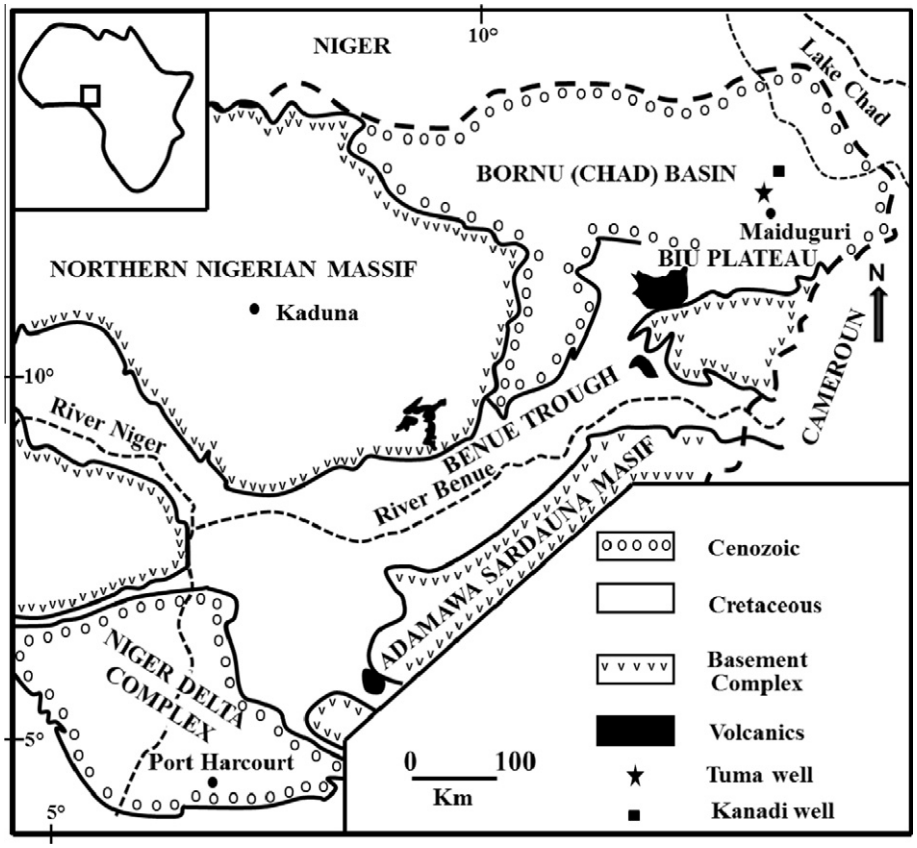

Fig. 1. Geological map of Nigeria showing the Chad Basin (after Whiteman (1982)) and location of the Tuma well.

vitrinite reflectance measurement (Simoneit et al., 1978; Perregaard and Schiener, 1979; Clayton and Bostick, 1986; Ujiié, 1986; Wang et al., 1989; Bishop and Abbott, 1995), Rock-Eval T_{max} and Hydrogen Index, H/C ratio (Simoneit et al., 1978; Clayton and Bostick, 1986; Ujiié, 1986; Gilbert et al., 1985; Bishop and Abbott, 1995), biomarkers (Simoneit et al., 1978; Perregaard and Schiener, 1979; Clayton and Bostick, 1986; Gilbert et al., 1985; Bishop and Abbott, 1993), blue and UV fluorescence microscopy (Clayton and Bostick, 1986). These studies show that the widths of the thermally metamorphosed zones vary from one example to another.

Dow (1977) has suggested that contact metamorphism affects the maturity of the intruded rocks to a maximum of about twice the thickness of the intrusive body. Simoneit et al. (1978) assessed the effects of a basaltic intrusion on the measured parameters of the organic matter in Albian–Turonian black shales from the Eastern Atlantic Ocean. They observed a drop in vitrinite reflectance values to 1.55% in a sample closest to the intrusion from values greater than 2.0% in the samples adjacent to it. According to Perregaard and Schiener (1979), the heating effect of a basaltic dyke altered the saturated and aromatic hydrocarbons compositions of the Kimmeridgian shales of East Greenland up to about half the thickness of the dyke. A maximum vitrinite reflectance of 4.71% was observed in the sample closest to the dyke.

Peters et al. (1983) used Rock-Eval pyrolysis data and kerogen colour to assess the effects of igneous intrusion on shales. They reported geochemical and optical changes in organic-rich Cretaceous black shales from the Cape Verde Rise in the eastern Atlantic that were penetrated by hot diabase sills during the Miocene. With decreasing distance from the sill, the colour of kerogen in the shales darkened (from yellow through shades of brown to black when viewed in transmitted light). The increase in Rock-Eval T_{max} was non-linear, becoming more rapid within about half the thickness of the sill. In this case, the effect of the intrusive was restricted to a distance equivalent to 70% of the thickness of the sill.

Gilbert et al. (1985) noted that steric configuration of the hopanes in the Rundle oil shale around a dolerite intrusion changed from one dominated by the thermally less stable at some distance from the intrusion to one dominated by the thermally more stable configuration in the immediate vicinity (about 2 m) of the intrusion.

Clayton and Bostick (1986) used vitrinite reflectance, Rock-Eval pyrolysis, and H/C ratios to assess the temperature effect of a 130 cm wide igneous dyke on the kerogen, molecular and isotopic composition of organic matter in a suite of siltstone samples from the Upper Cretaceous Pierre Shale, near Wolcott, Colorado, USA. The vitrinite reflectance values were observed to increase from 0.4% at about 75% of dyke thickness to 3.3% at about 5% of dyke thickness. The H/C ratio of the kerogen and the Hydrogen Index decrease most rapidly in the 0.6–1.7% Ro range. Autofluorescence from blue and UV excitation of whole rock polished samples also showed corresponding changes.

Raymond and Murchison (1988) have discussed organic maturation in the thermal aureoles of sills in the Carboniferous of the eastern and central Midlands Valley of Scotland. They noted striking contrast of virtual absence of any aureole above or below alkaline intrusion compared to aureoles of many tens of metres associated with the quartz dolerite sills. They attributed this to differing levels of consolidation and water saturation of the organic material and sediment, both of which probably strongly influenced the rank level of the organic matter prior to invasion by the magma.

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