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Potential shale resource plays in southeastern Nigeria: Petroleum system modelling and microfabric perspectives

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ABSTRACT

Nigeria is witnessing significant increase in energy demand as a result of rising population and economic growth; as more focus on clean energy take hold. These challenges have triggered the search for shale gas and shale oil in the inland basins of Nigeria. The aim of the study is to carry out an integrated study that incorporates petroleum systems modelling, field studies and advanced analytical programs in order to define the hydrocarbon prospectivity of Upper Cenomanian-Lower Turonian Eze-Aku Shale and Ekenkpon Shale as potential shale gas/oil plays in southeastern Nigeria. Available subsurface information which includes exploration wells and proprietary Oil Company archive data were used to calibrate and simulate 1-D basin models. Amount of silica content, major clay mineral group and microfabric of the potential shale resource plays were determined using Energy Dispersive X-ray Fluorescence analysis, Fourier Transform Infrared Spectroscopy and Scanning Electron Microscopy respectively. The simulated models showed that deeply buried Eze-Aku Shale and Ekenkpon Shale have undergone episodic generation of hydrocarbon. Significant amount of silica content (>30%) in Eze-Aku and Ekenkpon Shale samples suggested a brittle nature of the samples and the possibilities of the samples to capture portion of expelled hydrocarbon. Identification of non-swelling clay mineral group in the analyzed shale samples indicated that the samples have the potential for shale gas/oil. The SEM images of analyzed samples showed differences in cementation. This study recommends that deeply buried Eze-Aku Shale and Ekenkpon Shale are potential exploration targets for shale gas/oil in Abakaliki Fold Belt and Calabar Flank of the southeastern Nigeria.

1. Introduction

Abakaliki Fold Belt and Calabar Flank (Fig. 1) have been the focus of oil and gas exploration activities between late 50's and early 70's. This is based on the occurrence of surface hydrocarbon indications and sub-commercial discoveries of oil and gas in the basins. Prospectivity in Abakaliki Fold Belt and Calabar Flank are however, severely downgraded by poor reservoir development, Santonian uplift and associated magmatic activity; although source charge and traps have been proven (Ajayi, 1995). The understanding of shale resource plays is in its infancy in Nigeria; hence few information/data are available to sufficiently evaluate basins and formations for its shale resource potentials. The retention of generated natural gas and oil in organic (marine) matter has not been perceived to commercial level in Nigeria. Type II (oil-prone) and Type II/III (mixed oil and gas) organic matter have the capacity to generate and expel hydrocarbons. They also have retentive and self-centered storage capacities to hold oil and gas. Shale resource plays have been considered as world-class source rocks in conventional wells (Kolonic, 2004).

Recent studies by Beka et al. (2008), Ekweozor (2012), Ehinola and Oluwajana (2014), Aminu and Oluwajana (2014), Onuoha (2014), Amadi and Unomah (2014), Olawuyi (2015), Oluwajana and Ehinola (2016) and Onuoha and Dim (2016) have established that Eze-Aku Shale in the Abakaliki Fold Belt and Ekenkpon Shale in the Calabar Flank are organically rich, thermally mature shale with Total Organic Carbon (TOC) value reaching 10 wt%; and this is characteristic of Type II and Type II/III kerogen type. Eze-Aku and

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Ekenkpon marine shale units have been considered to possess huge potentials for unconventional shale resource systems (Ekweozor, 2012; Amadi and Unomah, 2014).

This study attempts an integrated regional geological framework that focused on Eze-Aku Shale in the Abakaliki Fold Belt and Ekenkpon Shale in the Calabar Flank as a potential shale plays by utilizing available stratigraphic (well) data, Oil Company archive data and outcrop samples. It is expected that this study would provide more insights into the potentials of Eze-Aku Shale and Ekenkpon Shale in southeastern Nigeria. The identification of shale resource plays in Nigeria would present a source of carbon-based energy with the lowest carbon dioxide emissions (Jarvie, 2012; Ejedavwe, 2016).

2. Geological setting

The Calabar Flank and the Abakaliki Fold Belt consist of Cretaceous to Neogene sediments (Fig. 2). Before the Santonian, the Abakaliki region was one of the most important depocentres in the lower Benue Trough with marine sediments, ranging in age from Albian to Coniacian. The Asu River Group in the Calabar flank consists of Barremian-Aptian Awi Formation, which comprises basal syn-rift fluvial calcareous arkosic sandstones resting on the basement surface (Adeleye and Fayose, 1978), and the Albian Mfamosing Limestone Formation (Ehinola et al., 2008). The Asu River Group in the Abakaliki Fold Belt is represented by the 500 m thick seam of Abakaliki Shale (Ehinola, 2002). The second sedimentary phase occurred between the Upper Cenomanian and Middle Turonian and was associated with the deposition of Eze-Aku Shale and its lateral equivalents; the Amasiri and Makurdi Sandstones (Ehinola, 2002). The Eze-Aku Shale in Abakaliki Fold Belt is represented by the Ekenkpon Shale in Calabar Flank and the underlying Awgu Shale which is also represented by New Netim Marl in the Calabar Flank; both represent the Nkalagu Formation (Petters and Ekweozor, 1982).

The Asu River Group, Eze-Aku Shale, Ekenkpon, Awgu Group and New Netim Marl Formations were deposited before the Santonian compressional tectonic phase, which is reflected by basic volcanism and a disconformity (Ehinola et al., 2008). The Campanian-Maastrichtian Nkporo Group overlies the New Netim Marl (Calabar Flank) and Awgu Shale (Abakaliki Fold Belt) unconformably above which are Paleogene-Neogene marine shales and regressive sandstones (Ehinola et al., 2008). The Imo Shale, Ameki Formation and Benin Formation are Paleogene to Recent sediments overlying the Nkporo Shale (Odumodu, 2012).

3. Materials and methods

3.1. Data set and field studies

This present study utilized outcrop samples, Oil Company archive data and available stratigraphic (well) data of two (2) exploration wells drilled in Abakaliki Fold Belt and Calabar Flank. The field studies involved the determination of sampled locations (Figs. 3 and 4) using Global Positioning System (GPS) (Table 1) and description of lithologic profiles (Figs. 5 and 6). The outcrop samples were collected using geological hammer and chisel and stored in labeled sample bags. A total of ten (10) shale samples were collected from different locations in Abakaliki Fold Belt and Calabar Flank. Eze-Aku Shale samples obtained from Abakaliki Fold Belt are generally grey to dark grey, platy and hard while Ekenkpon Shale sampled at Okonyong Usang Abasi section and New Odukpani-Mfamosing road section are characterized by light to dark grey, hard and fissile with occurrence of invertebrate fossils (pelecypods and gastropods).

3.2. 1-D model construction using PetroMod 2011.1

1-D basin modelling was carried out using Schlumberger PetroMod 2011 to basically infer the hydrocarbon generation phases of the deeply buried Eze-Aku Shale and Ekenkpon Shale in the southeastern Nigeria. The input data for the stratigraphic modelling included lithology of different layers, duration of deposition and

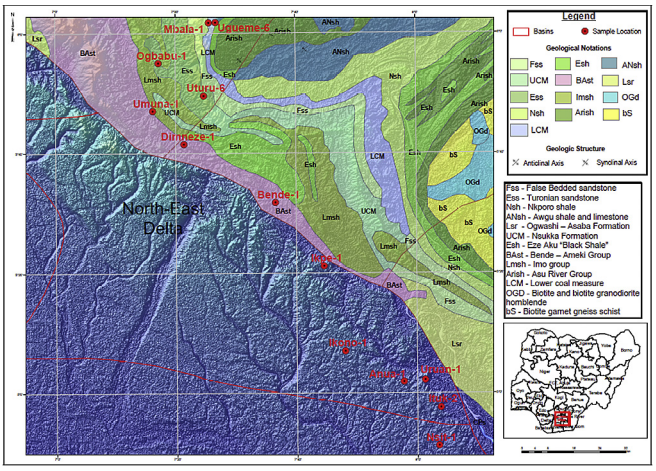

Fig. 1. Geological map of Abakaliki Fold Belt and Calabar Flank, showing some exploration wells used in this study (modified from Murat, 1969; Offiong and Edet, 1998; Ehinola et al., 2008; Ekpo et al., 2013; Oluwajana, 2017).

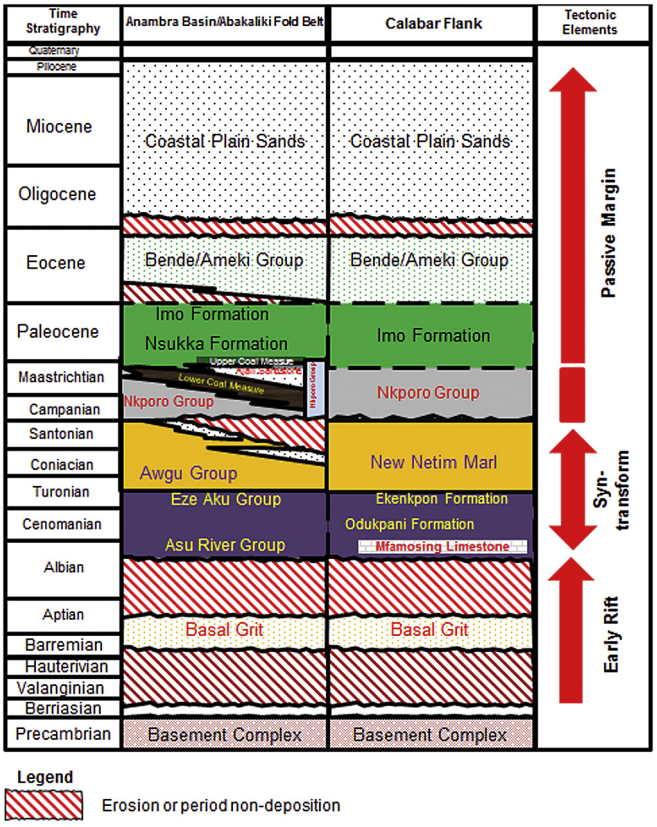

Fig. 2. Regional simplified Cretaceous and Neogene stratigraphy of Anambra Basin, Abakaliki Fold Belt and Calabar Flank (compiled after Murat, 1969; Petters and Ekweozor, 1982; Dim et al., 2016).