Journal of African Earth Sciences 104 (2015) 56–70

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Geochemistry of the Cretaceous coals from Lamja Formation, Yola Sub-basin, Northern Benue Trough, NE Nigeria: Implications for paleoenvironment, paleoclimate and tectonic setting

Babangida M. Sarki Yandoka [a,b,*], Wan Hasiah Abdullah [a], M.B. Abubakar [b], Mohammed Hail Hakimi [c], Adebanji Kayode Adegoke [a,d]

[a] Department of Geology, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] National Centre for Petroleum Research and Development, A.T.B.U, P.M.B 0248, Bauchi, Nigeria
[c] Geology Department, Faculty of Applied Science, Taiz University, 6803 Taiz, Yemen
[d] Department of Geology, Ekiti State University, P.M.B. 5363, Ado-Ekiti, Nigeria

ARTICLE INFO

Article history:
Received 12 June 2014
Received in revised form 13 January 2015
Accepted 14 January 2015
Available online 28 January 2015

Keywords:
Cretaceous coals
Lamja Formation
Paleoclimate
Paleoenvironment
Tectonic setting
Yola Sub-basin

ABSTRACT

The Cretaceous coals of Lamja Formation located in Yola Sub-basin of the Northern Benue Trough, northeastern Nigeria, were analyzed based on a combined investigation of organic and inorganic geochemistry to define the paleodepositional environment condition, organic matter source inputs and their relation to paleoclimate and tectonic setting. The total organic carbon and sulfur contents of Lamja Formation coals ranges from 48.2%–67.8% wt.% and 0.42%–0.76% wt.%, respectively, pointing their deposition in freshwater environment with inferred marine influence during burial. Biomarkers and chemical compositions provide evidence for a major contribution of land-derived organic matter, with minor aquatic organic matter input. Minerals such as quartz, pyrite, kaolinite, illite, montmorillonite and calcite were present in the coals, suggesting that these minerals were sourced from terrigenous origin with slightly marine influence, considered as post-depositional. This is consistent with a significant amount of the oxides of major elements such as SiO_2, Fe_2O_3, Al_2O_3, TiO_2, CaO, and MgO. The investigated biomarkers are characterized by dominant odd carbon numbered *n*-alkanes (*n*-C_{23} to *n*-C_{33}), moderately high Pr/Ph ratios (1.72–3.75), very high Tm/Ts ratios (18–29), and high concentrations of regular sterane C_{29}, indicating oxic to relatively suboxic conditions, delta plain marine environment of deposition with prevalent contribution of land plants and minor aquatic organic matter input. Concentrations of trace elements such as Ba, Sr, Cr, Ni, V, Co and their standard ratios also suggested that the organic matter was deposited under oxic to relatively suboxic conditions, which is in parts deposited under marine influenced. Some standard binary plots of SiO_2 versus ($Al_2O_3 + K_2O + Na_2O$) indicate a semi-arid paleoclimatic condition whereas log SiO_2 versus (K_2O/Na_2O) also revealed passive continental margin setting. The inferred tectonic setting is in agreement with the tectonic events witnessed in the West and Central Africa during the Cretaceous period.

1. Introduction

Coal is a multi-component of organic and inorganic materials. Organic matter is a major constituent in coal which determines the combustible energy and sources of hydrocarbons while, inorganic or mineral matter is a minor component, consisting of elements and minerals of environmental concerns that are hazardous during coal combustion in coal-fired power plants (Romeo, 2014). The constituent of coal depends on the properties of country rocks, diagenesis, coalification process, depositional environments and mineralization as well as hydrological conditions (Sia and Abdullah, 2011; Arbuzov et al., 2011; Gürdal, 2011).

Nigeria has the largest coal reserves in Africa with over 2 billion metric tons of which 650 million tons are proven (Adedosu, 2009; Obaje et al., 1999). Due to the importance of coal reserves in Benue Trough, the coals have been the subject of a large number of studies (e.g. Obaje et al., 1999; Akande et al., 2007; Jauro et al., 2007; Adedosu, 2009). Detailed organic and inorganic geochemical characterization of the Cretaceous coals from Lamja Formation in the Yola Sub-basin, are lacking. The integration of organic and

* Corresponding author at: Department of Geology, University of Malaya, 50603 Kuala Lumpur, Malaysia. Tel.: +60 166737410.
E-mail address: bmsydgombe@yahoo.com (B.M. Sarki Yandoka).

http://dx.doi.org/10.1016/j.jafrearsci.2015.01.002

inorganic geochemical approach was used to assess the paleodepositional environment and source of organic matter inputs in relation to paleoclimatic condition and tectonic setting.

2. Geological setting

The Benue Trough is a major rifted basin in Nigeria (Fig. 1). It was formed from the tension generated, due to the separation of African and South American plates during the Early Cretaceous. Several authors have presented different tectonic models for the genesis of the Benue Trough (Abubakar, 2014; Sarki Yandoka et al., 2014). King (1950) proposed tensional movement resulting in a rift, while Stoneley (1966) proposed a graben-like structure. The RRF triple junction model leading to plate dilation and opening of the Gulf of Guinea was proposed by Grant (1971). Olade (1975) considered the Benue Trough as the third failed arm or aulacogen of a three armed rift system related to the development of hot spots. Benkhelil (1982, 1989), Guiraud and Maurin (1990, 1992) considered the wrench faulting as the dominant tectonic process during the Benue Trough evolution.

The Benue Trough is geographically sub-divided into Southern, Central and Northern portions (Abubakar, 2014). The Northern Benue Trough is made up of N–W trending Gongola Sub-basin and the E–W trending Yola Sub-basin (Fig. 1). The stratigraphic succession of the Yola Sub-basin comprises the continental Early Cretaceous Bima Formation, the Cenomanian transitional marine Yolde Formation and the marine late Cenomanian–Santonian Dukul, Jessu, Sekuliye, Numanha Shales and Lamja Formations (Fig. 2). The Lamja Formation was described as "Carbonaceous Beds" by Carter et al. (1963). It consists of crystalline and shelly limestone, siltstone and yellowish to whitish fine-grained well bedded sandstone, dark grey shale and dark coals (Fig. 2) deposited in marine environment (e.g. Nwajide, 2013; Abubakar, 2006; Abubakar, 2014; Sarki Yandoka et al., 2015a).

3. Sampling and methods

Fourteen coal samples were collected from Lamja Formation (Fig. 2). The samples were collected using channel sampling after removing the weathering surfaces by digging to about 0.5 m. All samples were crushed to less than 200 meshes. About 0.50 g of each sample was used for the analysis of total sulfur (TS) and total organic carbon (TOC) contents using multi EA 2000 CS equipment. About 12 g of each sample was subjected to bitumen extraction with Soxhlet apparatus for 72 h using an azeotropic mixture of dichloromethane (DCM) and methanol (CH_3OH) (93:7). The extracts were separated into saturates, aromatics and NSO (nitrogen, sulfur and oxygen) compounds by liquid column chromatography. The saturated hydrocarbon fractions were dissolved in hexane and analyzed by gas chromatography–mass spectrometry (GC–MS) on HP 5975B MSD mass spectrometer with gas chromatograph attached directly to the ion source (70 eV ionization voltage, 100 milliamps filament emission current, 230 °C interface temperature).

X-ray Powder Diffraction (XRD) analysis was performed on the powdered sample using SIEMENS D5000 X-ray diffractometer with Cu Kα radiation, run from 5° to 60° 2θ, with a step increment of 0.02° and a counting time of 2 s per step. The minerals were identified from the diffractograms by referencing to the ICDD Powder Diffraction File. About 0.50 g of each sample was prepared for non-destructive wavelength dispersive X-ray fluorescence spectrometer (PANalyticalAxiosmAX 4KW sequential XRF spectrometer). The XRF analysis was used to determine the concentration of oxides of major elements. About 0.50 g of each sample was weighed in a Teflon beaker and dried at 105 °C overnight. The dried samples were moistened with a few ml of deionized water. 5 ml of Nitric acid (HNO_3) was slowly added and placed on hotplate at 150 °C, followed by 10 ml and 4 ml of hydrofluoric

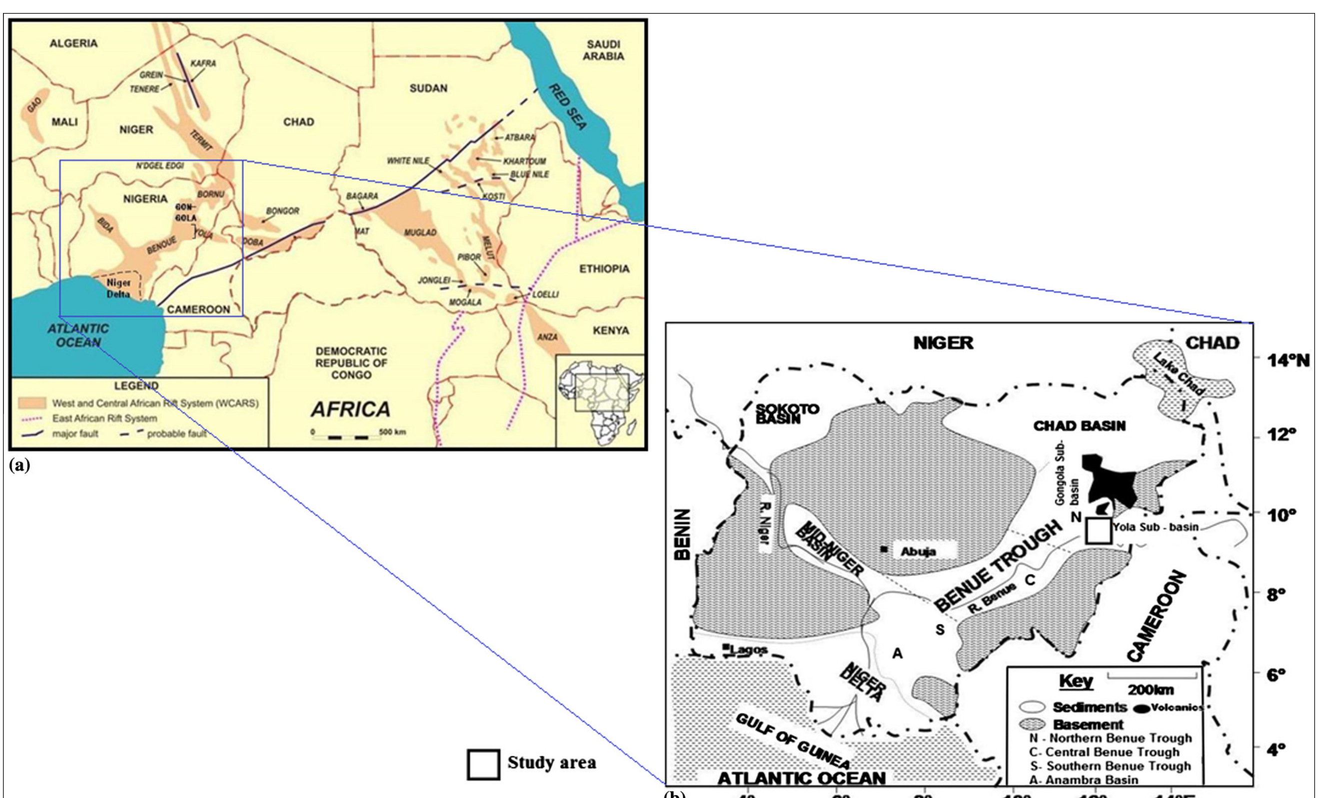

Fig. 1. Regional tectonic map of western and central African rifted basins showing the Nigerian Benue Trough and study area (Adapted from United Reef Limited Report, 2004 and Abubakar, 2014).