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Petrographic and geochemical characterization of the Upper Cretaceous coal and mudstones of Gombe Formation, Gongola sub-basin, northern Benue trough Nigeria: Implication for organic matter preservation, paleodepositional environment and tectonic settings

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ABSTRACT

Under-exploration of the Upper Cretaceous petroleum systems in the Northern Benue Trough Nigeria has been attributed largely to lack of subsurface samples and non-integration of organic and inorganic geochemical methods. Recent access to surface sampling from Maiganga coalfield revealed a need for detailed evaluation of the sedimentary facies types for better understanding of the hydrocarbon potential of the area. Detailed maceral point count, Py-GC, CHNSO as well as major oxides and trace element (ICP-MS) analysis were used to characterize the Gombe Formation coals and the mudstones for determination of the organic matter origin, preservation, paleodepositional environment, tectonic setting and paleoclimatic condition during sedimentation. Evaluation based on the maceral composition, TPI, GI values, plot of trace elements V versus Ni and sedimentary succession suggest deposition of predominantly terrigenous organic matter (45 to 73% huminite maceral) in an upper deltaic setting for the Maiganga facies. The maceral analysis associated with Py-GC studies indicates that the sedimentary facies of Gombe Formation have potential to generate liquid hydrocarbon. This can be estimated from an average of 21.50% liptinite content and the ternary plot of the Py-GC pyrolysate m(+p) xylene, *n*-octene and phenol suggesting presence of Type II and Type II/III kerogen within the basin. Assessment of the paleodepositional environment based on the trace elements composition indicates a moderate stratified water column and salinity within a relatively sub-oxic to oxic conditions during sedimentation. The major oxide composition as well as the binary plots of SiO_2 versus (Al_2O_3 + K_2O + Na_2O) and log SiO_2 versus (K_2O/Na_2O) for the shales and mudstones revealed a predominance of semi-arid to slightly humid-warm paleoclimatic conditions and a passive continental margin setting. This is in accordance with the Cretaceous tectonic events of the West and Central Africa which affected the petroleum system in the entire Benue Trough.

1. Introduction

Coal, mudstones and shale have distinguishing physical and chemical properties which are associated with their organic and inorganic components (Wilkins and George, 2002; Sia and Abdullah, 2012). The organic components of these sedimentary rocks can give useful information about the kerogen type/origin, hydrocarbon potential and paleodepositional environments (Peters and Cassa, 1994). On the other hand, inorganic constituents such as major and trace element composition are good indicators of redox conditions during sedimentation, water salinity, paleoclimate and tectonic settings (Makeen et al., 2015). The coal seams are usually interbedded with shale and mudstones and occur in large quantity in many places in Nigeria (> 2 billion metric tons) such as Anambra, Enugu, Gombe (Northern Benue Trough), Kogi, Nasarawa, Benue and Cross Rivers (Adedosu, 2009; Obaje et al., 1999). Even before the discovery of coal in Maiganga, Gombe Formation in 2007, Nigeria has been a major coal producer in Africa (Obaje et al., 1999; Ayinla et al., 2017).

The Gombe Formation (Fig. 2) belongs to the Gongola sub-basin, an important hydrocarbon system of the Upper Cretaceous Northern Benue

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Trough, which has been under-explored due to limited access to subsurface samples (Obaje, 2009; Abubakar, 2014). The Formation is characterized by coal as well as associated mudstones and shales containing terrigenous organic matter which are deposited in deltaic setting especially within Maiganga and Yaya-Ngari areas. Following the reports of significant occurrence of oil-prone macerals in the Maiganga coal (Ayinla et al., 2017), it becomes important to determine the origin of the organic matter, preservation conditions, paleodepositional setting, climatic conditions as well as the tectonic settings of the Gongola sub-basin. More so, when the hydrocarbon potentials of non-marine coal, even at a commercial quantity, has been established around the world (Bertrand, 1989; Hunt, 1991; Abdullah, 2003).

Although previous researchers have reported the geochemical and petrographic studies of Maiganga (Onoduku et al., 2013; Jimoh and Ojo, 2016; Ayinla et al., 2017), detail maceral analysis and inorganic studies are still missing. Thus, there is a need to integrate detailed organic and inorganic methods in evaluating the organic matter preservation, paleodepositional environment, paleoclimatic conditions and tectonic setting of the Gombe Formation. Towards achieving this goal, maceral point count, Pyrolysis-gas chromatography (Py-GC), CHNS(O) and ICP-MS analyses were carried-out on the Upper Cretaceous coal and mudstones from the Gombe Formation.

2. Geologic setting

The Benue Trough is one of the main sedimentary basins in Nigeria which is characterized by many episodes of tectonic events extending to Central West Africa (Benkhelil, 1989; Obaje, 2009; Abubakar, 2014). Geographically, it is located between the NE Chad (Bornu) basin and the prolific Southern Niger-Delta (Fig. 1). Generally, the Benue Trough trends NNE–SSW and is divided into Northern, Central and Southern basins (Nwajide, 2013). Following the Maastrichtian tectonic (compression) episodes, the pre-Palaeogene sediments of the Northern Benue Trough became folded and faulted in several localities. This leads to the formation of the Cretaceous Gongola and Yola sub-basins trending N-S and E-W respectively in the Northern Benue Trough (Abubakar et al., 2006; Sarki Yandoka et al., 2015; Ayinla et al., 2017). Within the Gongola Sub-basin, Aptian-Albian Bima Formation was deposited unconformably on the Precambrian Basement rocks. During the Cenomanian, the Yolde Formation was deposited conformably on the Bima Formation (Fig. 2). From Cenomanian to Santonian, there has been a deposition of the Pindiga Formation with a conformable succession in the Gongola Basin. The Pindiga Formation consists of the marine shales and intercalated limestones of Kanawa Member, the fluvial and littoral sandy facies of the Gulani, the sandy beds of Deba-Fulani, the Dumbulwa and the open marine Fika shale caps this sequence (Abubakar, 2014). Unconformity overlying the Campano-Maastrictian Fika shale is the Gombe Formation. The deposition of the Tertiary continental Kerri-Kerri Formation caps the succession (Fig. 2). (Ojo and Akande, 2004; Obaje, 2009).

The study area (Maiganga) is located in the N-S Gongola sub-basin (Fig. 1). It is characterized by faults and intrusive igneous body. This is probably associated with the several tectonic events before the Mid Santonian. Therefore, due to this tectonic activity experienced in the area, the coalfield is dipping Southwest direction.

3. Sampling and methods

Twenty-five representative samples of the Maiganga coals and interbedded mudstones from the Gombe Formation were used for the study. During the sampling, lateral and vertical lithologic changes within the Maiganga coalfield were considered. Contaminated and weathered surfaces were avoided to get true representation of the coal facies in the Formation. In this study, the geochemical methods employed are ultimate analyses, Total organic carbon (TOC), Total sulfur (TS), organic petrography (point count), Py-GC and Inductively-coupled plasma mass spectrometer (ICP-MS) analysis. The studies were conducted at the Geochemical laboratory in the Department of Geology,

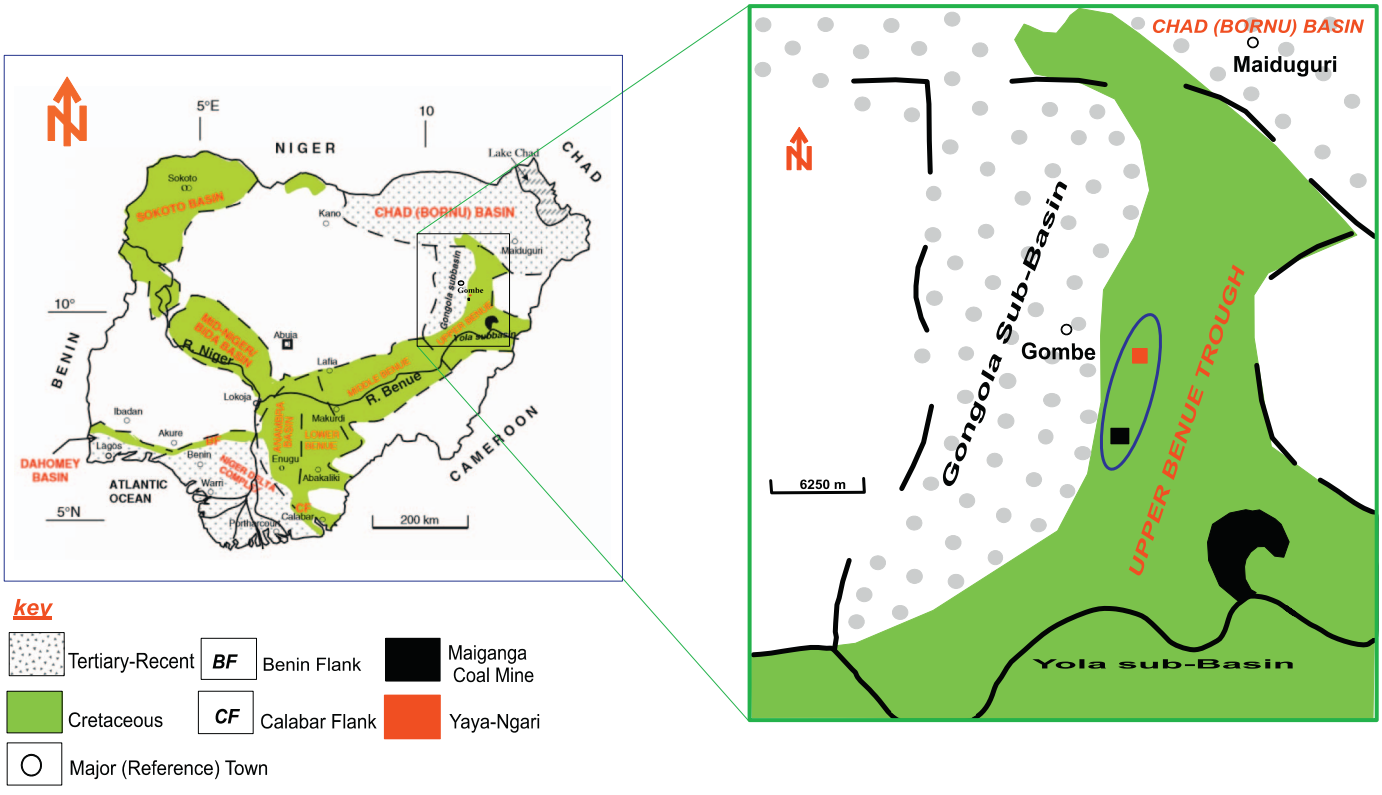

Fig. 1. Map of Nigeria showing the sedimentary basins and study area in Maiganga coalfield. (Modified after Obaje, 2009).