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Evaluation of Coalbed Methane Potentials of Eha-Alumona and Ehiandiagu coals, Anambra Basin, Nigeria.

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ABSTRACT
The present research deals with the proximate analysis of the Eha-Alumona and Ehandiagu coal seams. Coal samples from these seam was evaluated for coal rank and quality, gas content, gas composition and origin. Based on the result,Eha-Alumona and Ehandiagu coals revealed alow moisture content, medium volatile matter yield, and high ash content and low-medium fixed carbon. Further evaluation for rank, gas content, gas composition show the a sub-bituminous to bituminous rank (0.83%-0.96% R_o), gas potential (1.79-18.62m^3/t) and a methane dominated thermogenic gas (92% average) at its early stage of thermal maturation

KEYWORDS: CBM, Eha-Alumona, Ehandiagu,Proximate analysis, Gas content, Vitrinite reflectance.

I. INTRODUCTION

Coalbed methane (CBM), an unconventional natural gas in coal seams has emerged as an important energy resource which can be used to fulfil energy demand (Wilson et al., 1995; Narasimhan et al., 1998; White et al., 2005;). Coalbed methane or methane gas which are either of thermogenic or biogenic origin is formed during coalification, where large quantities of methane rich gas are generated and stored within the coal on internal surfaces; because coal has such a large internal surface area.It can store surprisingly large volume of methane rich gas, six or seven times as much as a conventional natural gas reservoir equal rock volume can hold. Considering the advocacy to reduce global methane emissions in order to enhance economic growth, strengthen energy security, improve air quality, improve industrial safety, and reduce emissions of greenhouse gases, there is need to harness the potentials of methane in these coal. Coalbed methane can be found almost anywhere there is coal.

Nigeria's proven reserve of coal are about 639Mt (million tonnes), whereas the inferred reserves are about 2.75Gt (Adedosu et al., 2007; Ohimain, 2014; Chukwu et al., 2016). The bituminous and sub-bituminous coal seams of the vast coal reserves are ideal reservoirs for the generation and accumulation of CBM. Despite the ample coal reserves, Nigeria has been facing an extreme electricity shortage. The development of coalbed methane will offer an opportunity to boost the economy of Nigeria.Gas content of a coal is a critical component in determining whether a coal bed is an economically viable gas resource (Kuuskraa and Boyer, 1993). According to Gale and Freund (2001), around 200m^3 of methane may have been generated for each tons of coal formed. Jüntgen, 1966; Meissner, 1984, empirically estimated the theoretical amounts of methane expected from coals during the entire coalification process and suggested that the methane yield is influenced by coal rank and composition. The maximum volume of methane obtained from coalbeds is formed by thermogenic process, where interns are controlled by burial history, maceral composition and basin hydrodynamics (Berbesi et al., 2009, Scott and Kaiser, 1996). Generally, higher amount of methane is associated with higher rank coals, as they have been exposed to severe temperature and pressure during formation. Several researchers have proposed several models of gas generation in coals using numerical methods and

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laboratory simulations (Jüntgen and Karweil, 1966; Karweil, 1969; Kim, 1977; Meisner, 1984). Originally, coal rank was used to diagnose the origins of associated coalbed gases. The chemical gas composition and the ratio of the abundance of CH_4 relative to higher hydrocarbons (i.e., "gas dryness") became indispensable proxies for evaluating the origin of coalbed gas (Stahl, 1973; Bernard, 1978; Schoell, 1980; 1983; Whiticar, 1996).Successful exploitation of coal bed methane needs the complete knowledge of the coal and its behaviour at varying condition hence characterization of coal is important. Therefore, the presentstudywas aimed at examining the chemical properties from Eha-Alumona (EHA) and Ehandiagu (EHN) coal deposits in the Anambra Basins of Nigeria, with a view to predict their rank, gas content and gas product composition during thermal maturation.

II. STUDY AREA

The studied areais boundedby latitudes 7^0 32'51.72"N and 7^0 26'42.29" N and longitudes $6^0$51'22.71"E and 6^0 45' 34.26"E. These areas are within Eha-Alumona in Nsukka LGA and Ehandiagu in Ezeagu LGA, all situated in Enugu State, Nigeria (Figure 1). The area is accessible by roads and footpaths. The main access routes are the Ama-Ngwo-Ezeagu, Enugu-Makurdi roads.

The study area lies within the Anambra basin in the southeastern part of Nigeria, one of the Cretaceous sedimentary and intracratonic basins in Nigeria. It represents one of the sub-basins of the Benue rift structure which is flanked by the Basement Complex rocks and the Bida basin on the western side, while the eastern portion is bounded by Abakaliki/Benue Basin. The Anambra Basin contains about 6km thickCretaceous / Tertiary sediments and is the structural link between the Cretaceous Benue Trough and the Tertiary Niger Delta (Mebradu, 1990). The northern and southern side is bound by the middle Benue Trough while the northern part is bound by the Niger Delta basin.

The morphology of Anambra basin is roughlytriangularand covers about 40,000 km^2(Figure2).The geological evolution of the southern sedimentary basins in the country began during the early Cretaceous period (Albian) following basement subsidence along the Benue and Niger troughs (Nwachukwu, 1972; Olade, 1975). Folding and uplift occurred during the Santonian along a northeast-southwest in the Abakaliki folded belts, subsided to form the Anambra basin (Reyment, 1965; Murat, 1972). Sedimentation in the Anambra Basin commenced with the Campanian- Maastrichtian (Figure 3) marine and paralic shales of the Nkporo Formation, overlain by the Early – Late Maastrichtian coal measures of the Mamu Formation, comprising paralic sandstones, mudstones and coals. The Middle - Late Maastrichtian fluviodeltaic sandstones of the Ajali Formation lie on the Mamu formation and constitute its lateral equivalents in most places. In the Paleocene, the marine shales and paralic coaly sequence of the Nsukka Formation were deposited to complete the succession in the Anambra Basin (Umeji, 2005).

III. MATERIALS AND METHODS

Sampling/Sample Preparations

Eight coal samples, four each from each coal seam of Eha-Alumona (EHA) and Ehandiagu (EHN) coal fields were collected for this study at different depth. A bulk sample of approximately 300g of coal was collected from each sample and sealed in polythene bags for transport to the laboratory for analysis. Collected representative coal samples were named as EHA1, EHA2, EHA3, EHA4 (for Eha-Alumona), EHN1, EHN2, EHN3, and EHN4 (for Ehandiagu).

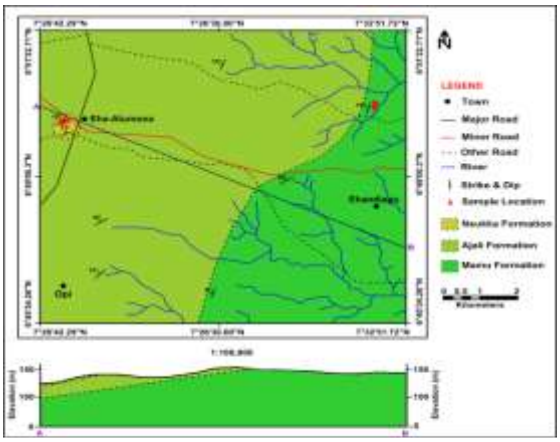

Fig.1 Geologic map of the study area

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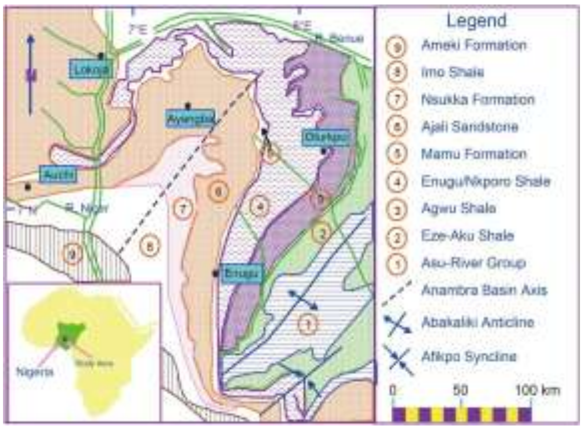

Fig.2Regional stratigraphy of southeastern Nigeria withthe sample points (after Tijani et al., 2010).

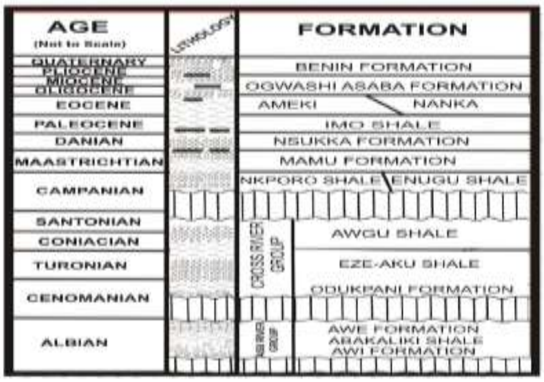

Fig.3 Stratigraphic and lithologic section of southern Benue trough and Anambra basin (Akaegbobi et al., 2000)

Proximate Analysis

Samples from each bulk sample were crushed in a rotary mortar to pass a 200-mesh sieve. An automatic sieve shaker was used for sieving the samples to the desired size distribution required for each test, while a hand rifle was used to split the samples into representative subsamples of 100g each. The proximate analysis was done with precision under the instrumental test standard Test Methods for proximate analysis of coal by Method ASTM D 2013/ D 346 at theNational Geosciences Research Laboratory of Nigeria (NGRL) a subsidiary of Nigerian Geological Survey Agency (NGSA), Kaduna.Proximate analysis of coal consists of moisture content (MC), ash content (AC), volatile matter (VM), fixed carbon (FC). The fixed carbon (FC) was determined by the difference between 100% and the sum of the M, VM, and AC. Proximate analysis can be used to establish the grade and rank, gas content, sorption potential of coals. It was also used for classifying the coal seams in terms of their gassiness.

Estimation of Vitrinite Reflectance

Vitrinite Reflectance is the amount of incidental light reflected by the vitrinite maceral. The value of vitrinite reflectance (R_o%) gives idea about the coal rank and grade. The vitrinite reflectance (R_o%) is calculated by using the formula given by Rice (1993), which is as follows:

$R_o\% = -2.712 \times \log(VM) + 5.092$

The applicability of this formula is restricted to the particular range of VM, i.e., 15% <VM <40%.

Estimation of Gas Content

Coalbed gas content was also estimated by an indirect method using empirical equations of Meisner (1984). He observed that the amount of gas is related to volatile matter on dry ash basis, by the following equation:

$V_{CH4} = -325.6 \times \log(VM_{daf}/37.8)$

Estimation of Gas compositionand origin

Coalbed Methane is mainly composed of methane (CH_4) with variable additions of carbon dioxide (CO_2), elemental nitrogen (N_2), and heavier hydrocarbons such as ethane (C_2H_6), and traces of propane (C_3H_8), and butanes (C_4H_{10}). Several studies empirically estimated the theoretical amounts of methane expectedfrom coals during the entire coalification process (Jüntgen and Karwiel, 1966; Meissner et al., 1984)based on the empirical relationshipbetween vitrinite reflectance R_o and the expected relative abundances of thermogenic gas components. In order to determine chemical composition of coal gas, equations quantifying the generation of methane, ethane, and propane during coalification was used (Berner and Faber, 1988).

$CH_4 = 9.1 \ln R_o + 93.1$

$C_2H_4 = - 6:3 \ln R_o + 4.8$

$C_3H_8 =-2.9 \ln R_o +1.9$

In order tocharacterize the origin of coalbed methane,coal rank was originally was used to diagnose the origins of associated coalbed gases.Coals of low rank with vitrinite reflectance values R_o<0.3% were considered to hostbiogenic gas whereas higher-rank coals were assumed to contain thermogenic gases (Claypool, 1974).Also, the chemical gas composition and the ratio of the abundance of CH4 relative to higher hydrocarbons (i.e., "gas dryness") an indispensable proxies for evaluating the origin of coalbed gas was implored as shown in Table 1.

Table 1 Proxies for thermogenic and biogenic coalbed gases distinction (Bernand et al., 1978; Rice, 1993; Scott et al., 1994; Strapoć et al., 2008).

Parameters	Origin of gas	
	Thermogenic Gases	**Biogenic Gases**
Vitrinite reflect-ance(R_o in %)	0.6% -3.0%	0.3% -0.8%
Hydrocarbon index $CH_4/(C_2H_6 + C_3H_8)]$	< 20	>1000

IV. RESULTS AND DISCUSSION

Coal quality

Proximate analysis showed the coal samples contain the following range of properties: Moisture content (MC), 3.39 – 4.13 wt%; Ash content (AC), 12.95–14.10 wt%;volatile matter (VM), 28.6-30.50 wt%; and fixed carbon (FC),40.85–45.25wt%.Eha-Alumona and Ehandiagu coals samples shows a low moisture content, medium volatile matter yield, high ash content and low-medium fixed carbon. Moisture and ash content within the coal reduces the adsorption capacity of methane. Adsorption capacity of methane decreases with increasing ash and moisture percentage within the coal, as little as 1% moisture may reduce the adsorption capacity by 25%, and 5% moisture results in a loss of adsorption capacity of 65% (Lama and Bodziony, 1996).The amount of gas adsorbed depends enormously on the quality of coal (Widera, 2014).

Coal rank

From the proximate analysis, the vitrinite reflectance (R_o%) was determined forEha-Alumona and Ehandiagu coals (Table 3). It is observed that the values are in between 0.82% to 0.96%. The coal samples are inferred to bemedium sub-bituminous to bituminous rank (Diessel, 1992). Medium volatile bituminous to low volatile bituminous coals are important for prospect of CBM than anthracite or lower rank coals because of amount of methane retention.Based on vitrinite reflectance value, Chen and Jia (2008) classified coalbed methane reservoirs into three - low rank CBM reservoirs (Ro < 0.7%), medium rank CBM reservoirs (0.7% <R_o<2.0%), high rank CBM reservoirs (R_o >2.0%). The CBM reservoir is of medium rank. Coal rank is an important parameter that influences the generation of thermogenic gas from coal. However, the coal rank equivalent to vitrinite reflectance range of 0.82% to 0.96%, asobserved in the Eha-Alumona and Ehiandiagu coal, has generated thermogenic gas. It is commonly accepted that generation of thermogenic gas takes place at vitrinite reflectance levels above 0.6% (Rice, 1993), and R_o needs to be between 0.8% and 1.00% before large volumes of thermogenic gas are generated (Scott, 2002).

Table 2 Proximate Analysis result

Coal Sample	**MC**	**AC**	**VM (ad)**	**FC**
	(%)			
EHA1	3.39	13.20	31.00	45.16
EHA2	3.44	13.25	29.00	45.19
EHA3	3.46	13.33	28.72	45.20
EHA4	3.71	13.40	29.20	45.25
Average	3.50	13.30	29.48	45.20

EHN1	3.42	12.95	32.20	40.85
EHN2	3.61	13.19	32.40	40.94
EHN3	3.64	13.36	31.80	40.95
EHN4	4.13	14.10	31.40	41.00
Average	3.70	13.40	31.95	40.94
MC – Moisture Content; AC – Ash Content; VM_{ad} – Volatile matter (air dried basis); FC – Fixed Carbon.				

Gas content

The values of the amount of gas generated for Eha-Alumona and Ehandiagu coal samples are given in Table 4. The gas content variation as determined by the Meisner (1984) equation was in the range from 1.79m^3/t to 4.74m^3/t for Ehiandiagu while 8.03m^3/t to 18.62m^3/t for Eha-Alumona. The Eha-Alumona coal seam indicates good potentiality of methane gas of economic viability. The depth of this seam (41-52m and 30-35m) for Eha-Alumona and Ehandiagu respectively) corroborates these observations of CBM.Studies of the major coal-bearing basins in the world suggest that more than 50% of the estimated in situ coal bedded methane CBM resources is found in coals at depths below 1500m (Thomas, 2013). We can draw a strong suggestion that coals beneath less than 10m overburden mined as open cast may not constitute fire hazards.

Gas Origin and Composition

The results for the theoretical amounts of methane and other associated thermogenic gases during the entire coalification process are presented in Table 4. The results show that methane (91.29%-91.94%) is the dominating compound in the gas content with relatively lesser variation of ethane (4.99%-5.97%) and propane (1.98%-2.44%) for the coal samples. Also, in distinguishing the coal as biogenic or thermogenic gas, the vitrinite reflectance and hydrocarbon index (Table 1) revealed the studied coal samples can be inferred to be of thermogenic gases origin as the Ro% and hydrocarbon index proxies are within the limits of 0.6%-3.0% and less than 20 respectively (Bernand et al., 1978; Rice, 1993; Scott et al., 1994; Strapoć et al., 2008). The thermogenic gas is at early stages which are characterized by breakdown of functional groups.

Table 3 Estimated Vitrinite Reflectance and gas content (m^3/t) for the coal samples

Coal Sample	**VM (daf)**	**R_o %**	V_{CH4} (m^3/t)
EHA1	35.71	0.88	8.03
EHA2	33.43	0.96	17.38
EHA3	33.13	0.97	18.62
EHA4	33.72	0.95	16.16
EHN1	36.99	0.84	3.06
EHN2	37.32	0.83	1.79
EHN3	36.70	0.86	4.16
EHN4	36.55	0.85	4.74
$VM_{daf} = 100xV_d/100-A_{ad}$			

Table 4Results of estimated gas compositionfor the coal samples.

Coal Sample	**CH_4** (%)	**C_2H_6** (%)	**C_3H_8** (%)	**HI**
EHA1	91.94	5.60	2.27	12.02
EHA2	92.73	5.06	2.05	13.04
EHA3	92.82	4.99	1.98	13.31
EHA4	92.63	5.12	2.05	12.91
Average	92.53	5.19	2.09	12.82
EHN1	91.40	5.89	2.41	11.01
EHN2	91.29	5.97	2.44	10.85
EHN3	91.62	5.82	2.37	11.19
EHN4	91.62	5.82	2.37	11.19

Average	91.48	5.88	2.39	11.06
CH_4 –methane; C_2H_6 – ethane; C_3H_8 – propane; HI – hydrocarbon index				

V. CONCLUSION

The proximate analysis reveals that the Eha-Alumona and Ehandiagu coals are alow moisture content, medium volatile matter yield, and high ash content and low-medium fixed carbon. Further evaluation for the rank, gas content, composition and origin revealed a medium sub-bituminous to bituminous rank, medium rank reservoirs with potentiality of gas especially for the Eha-Alumona. The coal seams have dominantly methane with small associated gases which are of thermogenic origin and at its early stage of thermal maturation.

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