Coal Resource Evaluation And Models: A Case Study From Parts Of Okobo And Enjema In Kogi State Within The Lower Coal Measures Of Mamu Formation, Nigeria

Mamah Luke, Nwafor, C. Gideon, Omada, J, I, Akpa Fabian, Okogbue Cele

Abstract: In the wake of search for alternative energy resources amidst increasing oil prices, coal exploration with new technology and software interpretation cannot be underestimated. Subsurface delineation and evaluation of Okobo-Enjema coal resources within the Upper Coal Measures of Mamu Formation at Okobo Coal Field Nigeria was undertaken in this study. Topographic data obtained with global positioning system (GPSRS) and processed with Minex 6.05 software showed top soil thickness gradient dependence. Areas with steep slopes of less than 12 degrees were found to have top soil thickness of 0.5m whereas areas of 12 – 30 degrees slope had top soil thickness of 0.25m. Overburden or Waste above Coal seam has same conformity as the top soil but shows gradients that mimic past Mamu Sea and fluvial system drainage. Topography also enhanced geologic mapping as topographic gradient differentiated lithotypes which corroborated core logs. Coal spatial attributes and geometry derived from geologic models formed the input to Gemcom Minex software for reserve estimation. The resource evaluation estimated a total of 51m of waste thickness and in situ Coal as 20.5 Tonnes with a strip ratio of 18.1.

Index Terms: Keywords: Coal resources exploration, geologic models

1 INTRODUCTION
Coal resource evaluation and analysis within tropical environment posed difficult exploration challenges while working for Western Goldfields Ltd in Okobo-Enjema coal field. Coal is a naturally occurring sedimentary rock formed from vegetative matter through the process of coalification. This process is driven by the application of pressure and heat. Through the application of these agents, vegetative matter is converted to peat, then to lignite, and finally to coal. Increase of heat and pressure as a result of burial depth, change the rank of the coal from sub-bituminous to bituminous, and finally to anthracite. The higher the rank of the coal, the lower the moisture and volatile gas content. In this study, comprising the Anambra Basin in the Lower Benue Trough Nigeria, basin infilling was punctuated by incursions of marine sedimentation followed by continental sedimentation that provided conditions conducive to the deposition of coal. The primary coal deposits occur at the base of the Enugu Escarpment, within Mamu Formation and appear to extend under the Udi plateau in the east, cropping out again along the western margin of the basin near Dekina and Idah.

Stream drainages expose coal at the base on both sides of the escarpments at the basin edges. These coal outcroppings, along the eastern margin of the Anambra Basin, were first reported in the early 20th century. Subsequently, they were mapped and drilled during the 1940’s and 1950’s by the Geologic Survey of Nigeria (GSN). Commercial mining at two locations near Enugu and two other locations along the northeastern margin of the Igala Plateau at Orukpa and Okaba were undertaken then. With an exception of limited production from the mine at Okaba, none of these mines is currently operating. Coal exposed in stream drainages at the base of the Enugu Escarpment on the eastern edge of the basin near the contact between the False Bedded Sandstones of overlying Mamu Formation and the underlying Enugu Shale was mined at Okpara and Onyeama mines. The primary source of data for this study is the exploration program and core drilling conducted by Western Goldfields Ltd. Other information include The Coal Resources of Nigeria, published by the GSN in 1963. New tools in the form of software provide better analysis of the coal’s economic potential and this paper attempts to develop new geological models that can be used to improve mining plans, capital expenditures, production costs and identify potential problems or opportunities, with drillings and topographic mapping.

2 MATERIALS AND METHOD
The present study utilized the following pattern and tools to evaluate the coal resource of the area, the sedimentology and stratigraphic controls on the distribution and geometry of the coal seam and its characteristics.

- Topographical Survey and surface geological mapping of the study area

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Department of Geology University of Nigeria Nsukka, Email luke.mamah@gmail.com Tel: +2348039306212
University of Nigeria Nsukka
Kogi State University Anyigba Nigeria
- Production of a digital and terrain model for complete assessment of topographical pattern of the area
- Core drilling and geologic core logs
- Detailed geologic assessment and estimation
- Delineation of resource target areas to include the sub crop line to aid mining activities via establishing a wash-out elevation and zones with accurate topographic map model

Production of different geologic models and interpretation to include digital quantitative maps, surface hydrological pattern, cross section. (The software tools utilized include ArcGIS 9.2a, Rockwares 14, AutoCAD Map Development, IPI12Winv2.1, VES 1.30, Surfer, EXE8.12, Global Mapper 11, GENCOM MINEX 6.0.5 and Map Source 6.13.7)
2.1 Geology
The study area covers an area approximately 13.6 sq. km and lies within Okobo and Enjema in Enjema District of Ankpa Local Government Area in the south eastern part of Kogi State, Nigeria. It is bordered in the east by Benue State and in the South by Enugu State. The geographical location puts it in Sheet 249SW (Fig: 1) between 354729 and 358407 in the Easting’s and 829224 and 832923 in the Northings (32N UTM, WGS 84). The area of study lies within the Lower Coal Measures of Mamu Formation which is comprised of alternating sandstones, shales, sandy shales and mudstones, with coal seams or carbonaceous shales at various horizons. West of Enugu there is a characteristics pattern in the sequence of rock types, marked by units which are repeated at least five times, suggesting repeated uplifts and subsidence of the land and deposition of transgressive and regressive sequences. A typical sequence unit is as follows:

i. 5. Shale or sandy shale, etc.
ii. 4. Coal, sometimes shaley at top
iii. 3. Carbonaceous shale, passing downwards into shale
iv. 2. Sandstone, with a few shaley layers, or alternating sandstones and shales
v. 1. Shale or sandy Shale

The sandstone in each unit vary considerably in thickness, and sometimes rest directly on the coal. The coals and shales may thin out laterally in any direction and re-appear further on. This rhythmic pattern is typical of the formation north of Amaowele, but nowhere else are the units well developed and persistent as in the Enugu area. A more usual pattern appears to be an en echelon arrangement of in persistent thin coals and carbonaceous shales. In the Lower Coal Measures sandstone always predominate. Over at Okobo and Odokpono, shales make up a greater proportion of the succession than elsewhere and occur in thicker bands.

2.2 Topographic Mapping
A detailed topographical survey of the area that was carried out on land shows the minimum value of topography within the resource area to be 284.23m and maximum to be 447.27m with an average of 335.78m. Geodetic control network in the area was created using the GPRS-1 receiver. The average quadratic error of definition of coordinates is 5mm. The given observations had defined coordinates numbering up to 5021 points pegged in on the ground or on the stumps of trees or felled trees secured with nails. A topographical plot of elevation figure 4 was the result from Minex 6.0.5 software. It shows a warped basin with a southern plunge. High elevation in central portions are probably a result of differential tectonics. Sinusoidal yellow patch (fig 5) on the east of a shaded topography mimics a Mamu river valley at its mature stage. Its flood plains would be the green patches observed as relatively flat. At the western part of the field a basement fault may have contributed to a deep topography and contour intervals showing sharp changes in slope grades. Topography was a key tool to qualitative and quantitative analysis of the coal resource. The coal thickness for example decreases to the
northern basin margin as seen from coal seam isopach on the east escarpment. Washed out elevation was filtered out from the plots, leaving topographic plots that correspond to the coal outcrop line to the north, south and east to +/- 10m.

2.3 Core Drilling
Drilling and sampling programs were conducted to augment and probably narrow the uncertainty in the definition of the coal resources in the area. A total of 102 core holes were drilled within the study area, out of which 94 boreholes intercepted coal seam at various depth. All the core drilling were conducted by Zuma Coal Ltd using Boart Longyear 2008 rig with specifications as 9.4m mast length, 76mm bit diameter, 73mm core barrel diameter, 70mm diameter drill stem, 3m length drill stem, 1250rpm maximum head speed, 3500 psi maximum operation pressure, 47011Nm (3925lbft) maximum head torque, 85km/h maximum wind resistance and 4184N (9326lbft) feed thrust. The entire hole was cored at an angle of 900 to the desired depth where coal or open cast coal seam is believed to be won.

2.4 Seam Triangulation
A seam floor triangulation was carried to locate various holes and locations including the barren holes, the barren holes were conspicuously rejected from the triangulations to easily correlate the extent of seam floor in the study area.

3 Results and Discussions

3.1 Geologic Model
A geologic model is composed of a structural model delineating the physical and spatial attributes of the deposit as relevant to their economic exploitation. The Coal geological model provides the basis to estimate coal resources and calculate coal reserves in a manner consistent with established estimation standards. The geological model used in this evaluation presented herein is created using Gemcom Minex software. This is a three dimensional representation of the coal deposit's individual components usually defined by XYZ (Northing, Easting and elevation) grid points with information attached regarding coal quality revenues, costs and other relevant data. The geological model is characterized by one seam of commercial interest, referred to as Okobo seam. It is overlaid by complex of sandstones, shale and consolidated red and brown clays comprising the majority of the overburden. The topsoil layer was recognized but not reported in the drill logs because the drilling process washed away the loose material near the surface.
The top soil surface was constructed based on a number of test pits that showed about a half meter of topsoil in areas of relatively low gradients to being non-existent in the steeper areas. The steeper areas were interpreted as slope greater than 30 degrees. The topsoil was estimated from the depth of washed out material reported in the drill holes to within 0.25 meters at a gradient break from a 120 degree slope to a steeper sloping topography. A topsoil model was created to reflect these observations. The coal is underlain by carbonaceous shale. In several drill holes, it is over a half meter thick but averages 0.08 meter thick over the entire study area bounded by the outcrop line. The following sections, A-A through G-G as located on the plan view in figure 7 and breakdown of the sections demonstrate the structural model's internal consistency.

### 3.2 Top soil and seam interpretation

Figures: 8 through Figure 12 demonstrate model interpretation of topsoil, overburden /waste thickness, to the base of coal and underlying carbonaceous shale. Top soil undulates with elevation while the gradient of the seam is gentle and conforms to regional slopes and dips.

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**Fig 13** shows top soil map
Fig 14 shows Waste thickness contour map at 5m interval

Top soil map fig. 13 is only an approximation because it is based on very limited information as the drilling water washed away the unconsolidated coring data. The depth of the topsoil is estimated to be approximately 0.5 meters deep, as obtained from pit sampling in areas with less than 12 degrees slope at the top. In areas with gradients between 12 degrees and 30 degrees, the depth of the topsoil was estimated to be 0.25 meters. Steeper areas are estimated to have no topsoil. The interpretation from this map (fig 13) is the semblance of Mamu sinusoidal rivers draining into a North-northeast coastline. The waste thickness grid (figure 14) not only shows the outline of the Mamu Rivers as demarcated by high gradient areas, and adjoining sea but also indicates broad areas to the north and east that served as flood plains.

Fig 15 shows 3D topographic model superimposed on the local geology

The winding trends nature of the Mamu River indicates that it may not have been consistent with the present river system as seen from the 3D topographic model fig 15 where rivers closely follow fault zones and underlying geology.

Fig 16a, b shows Coal thickness map at .5m contour interval and lower carbonaceous shale at .25m contour intervals

The coal thickness isopach figures 16a, b shows coal as thickest at the south west where it reaches 3m whereas it is only 2m towards the east and thins to the north. The underlying carbonaceous shale is thin with low variability in thickness over the field. Lower carbonaceous shale thickness contours show the limited area of thickening where special attention will be required to segregate the lower shale from the coal to avoid excessive dilution during mining.

3.3 Resources Estimation

There are a number of accepted ways to develop estimates of in-place resources. Commonly used methods include polygonal estimates such as were used in Bulletin No. 28 NGS and number of gridding algorithms that The drill data, subcrop line definition and JORC standards were used to develop the resource statement.

- Generally, the following assumptions are used to develop the restrictions applied to the coal seam considered for classification as shown in the figure 17
  The boundary of the northeast area within the segment enclose by the subcrop line
- The coal thickness is considered to be greater than 0.5m (mineable resource)

This Study uses the Australasian Joint Ore Reserves Committee Code (JORC Code) Standards to report Coal Resources, and Coal Reserves. This methodology of reporting has been adopted as a general world standard of “best practices” and the principles are clearly stated in the “Australian Guidelines for Estimating and Reporting of Inventory Coal, Coal Resources, and Coal Reserves, Prepared and Issued by the Coal Fields Geology Council of New South Wales and the Queensland Mining Council – March 2003.” Several concepts used in this report are considered key to reporting Coal Resources and Reserves on an international basis.
Figure 17: Assessment of JORC Resource Classification of the Area: (All resources within the subcrop line were classified to JORC standards.)

The strength of using grids to model deposits is that the grids can be used to develop maps, provide a means of mathematically comparing various attributes, such as depth of cover and tonnage to develop derivative grids, in this case strip ratio.

Table 3: JORC Resource Statement of the Okobo Coal Field

<table>
<thead>
<tr>
<th>JORC Classification</th>
<th>Seam Name</th>
<th>Waste (M Bcm)</th>
<th>Waste Thickness (Meters)</th>
<th>In Situ Coal (M Tonne)</th>
<th>Vertical Strip Ratio</th>
<th>Seam Thickness (Meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured</td>
<td>Okobo</td>
<td>174.2</td>
<td>36.4</td>
<td>12.62</td>
<td>13.8</td>
<td>2.05</td>
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<tr>
<td></td>
<td>Lower Carbonaceous Shale</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Indicated</td>
<td>Okobo</td>
<td>198.0</td>
<td>63.8</td>
<td>7.92</td>
<td>25.0</td>
<td>2.06</td>
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<tr>
<td></td>
<td>Lower Carbonaceous Shale</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Demonstrated</td>
<td></td>
<td>372.2</td>
<td>51.0</td>
<td>20.5</td>
<td>18.1</td>
<td>2.05</td>
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<tr>
<td>Inferred</td>
<td>Okobo</td>
<td>180.7</td>
<td>65.8</td>
<td>3.17</td>
<td>57.0</td>
<td>1.27</td>
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<td></td>
<td>Lower Carbonaceous Shale</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Remaining Model</td>
<td>Okobo</td>
<td>0.2</td>
<td>149.6</td>
<td>0.00</td>
<td>57.5</td>
<td>2.75</td>
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<td>Lower Carbonaceous Shale</td>
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</table>
CONCLUSION
From the results of all the investigations, evaluations and geological models carried out within the concession area, a general assessment and careful interpretations were made. The following conclusions were made:

- The outcrop line were delineated to the eastern part of the study area
- The average geometry of the topography contributes to qualitative and quantitative analysis of coal resources
- The coal thickness decreases to the north and to the west as the outcrop line is approached
- The lithological sequence in the area include clay, sandstone, siltstone, shale, carbonaceous shale and coal
- The base of coal elevation model demonstrate that the seam floor is relatively sloping towards the west at about 1.2 degrees
- The overburden waste over the area of evaluation shows about 372m BCM, the total insitu coal resources is 20.5m tonnes on an overall vertical stripping ratio of 18m. The seam thickness is 2m on average.

The general evaluations of the resource has shown that the deposit can be mined at profit; though a general mine schedule will show the best stripping ratio at initial production for a quick break even margin

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REFERENCES

