PRELIMINARY ASSESSMENT OF SOURCE ROCK POTENTIAL AND PALYNOFACIES ANALYSIS OF MAASTRICHTIAN DARK SHALE, SW ANAMBRA BASIN

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ABSTRACT

The source rock potential of Maastrichtian Dark Shale in the South Eastern flank of the Anambra Basin has been extensively studied, with very little or no research carried out in the South Western flank (Benin flank). To this end, outcrop samples of the Maastrichtian Dark Shale obtained from Auchi, Uzebba, Sobe, Agbanikaka and Ikabigbo, SW flank, were assessed using Rock-Eval Pyrolysis and Palynofacies analysis techniques. Results of this preliminary assessment show that organic richness ranges from good to excellent; plot of HI against Tmax shows that its source quality is predominantly of Type III (gas prone Kerogen). Kerogen analysis reveals Phytoclast palynofacies (vitrinite) as the most abundant palynofacies (over 75%), about 20% miospore and less than 5% dinocysts recorded. This also depicts dominant Type III (gas prone) kerogen and a Terrestrial – Transitional depositional environment for the shales. Thermal maturity based on Tmax and Spore colour index suggests largely immature to early mature kerogens. Although a low thermal maturity exists at the surface, this study reveals that the Maastrichtian Dark Shale in the SW Anambra Basin/Benin flank has good source potential (sufficient organic richness, mainly of gas prone type III kerogen) and compares favourably with published data from the SE. Furthermore, it is anticipated that the right thermal maturity required for hydrocarbon generation may be attained at depths or close to regional fractures, which is the case in the SE Anambra Basin.

Keywords: Palynofacies, Pyrolysis, Black-shale, Kerogen, Anambra Basin, Maturity

INTRODUCTION

The Maastrichtian Mamu Formation has been described as a cyclotherm comprising Dark Shale, sandstones and sandy shales (with coal beds at various stratigraphic levels) deposited in a marginal marine environment (tidal flat - estuarine setting; Ladipo, 1988).This Formation exhibits variable sediment thickness and facies throughout the basin. Its thickness is greatest at the basin center (about 300m) and thins out towards the North and South, 80 and 90m respectively (Ladipo, 1988). The source rock potential of the Dark Shale and coals of the Mamu Formation in the SE has been extensively studied (Akande *et al.*, 2007; Aganbi, 2010; Nton and Awarun, 2011; Ogala 2011; Chiaghanam *et al.*, 2013) with very little or no research carried out in the SW flank of the basin. Their findings suggest that the Maastrichtian Dark Shale has good to very good organic richness (> 2% TOC), type II/III kerogen and is thermally immature to early mature.

Furthermore, subsurface data from Alade-1, Alo-1, Anambra River-1,Nzam-1,Igbariam-1 and Atu - 1 wells indicate that the Dark Shale of the Mamu Formation has good to very good organic richness, possesses type II/III kerogen and thermally immature to peak mature (Total,1984).

This study aims at characterizing and assessing the source rock potential of the Maastrichtian Dark Shale in the SW part of the Anambra Basin, using Rock-Eval Pyrolysis and Palynofacies analysis.

Geologic Setting

The Anambra Basin is one of the sub-basins in the Benue Trough (Reijers *et al.*, 1997). It is a multicycle basin whose initiation began in the Late Jurassic to Early Cretaceous associated with the opening of the Gulf of Guinea and South Atlantic Ocean consequent upon the separation of the African and South American plates (Benkhelil, 1989).

The Anambra Basin is about 40,000 km^2 in size (Ogala, 2011) and is bounded to the west by the Okitipupa Ridge, in the east by Abakaliki Basin, and in the south by the Niger Delta Basin (Fig. 1) The present day Anambra Basin evolved after the Santonian tectonism that affected the Benue Trough, characterized by uplift of the Abakaliki structure and subsequent downwarping of the Anambra Platform and Afikpo Syncline which are respectively SW and SE of the Abakaliki structure (Reijers *et al.*, 1997). Its basin fill is estimated to be about 5000-7000 m (Agagu and Adhijie, 1983) and contains mainly Cretaceous to Tertiary continental - marine sediments (Fig. 2). The sediments display a wedge shaped outline and exhibit soft sediment deformation structures (Obi and Okogbue, 2004) which suggests that sedimentation was tectonically controlled.

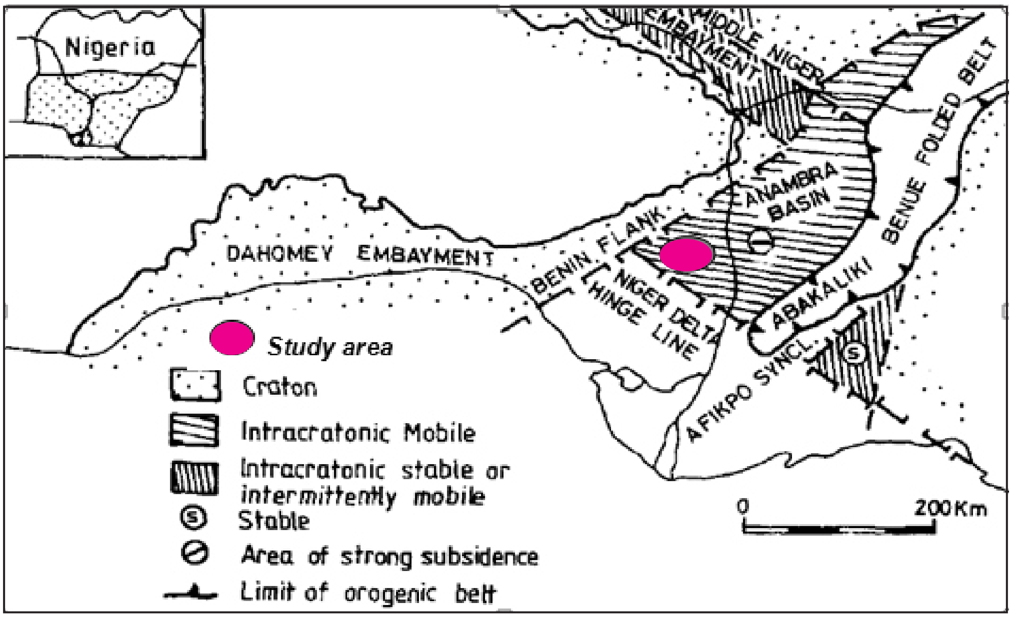

Fig 1: Anambra Basin Showing the Study Area and its Tectonic Elements (modified from Murat, 1972)

Tectonic and Sedimentation History

The Anambra Basin suffered two main tectonic episodes: the Late Jurassic to Early Cretaceous rifting episode associated with the evolution of the Benue Trough and the Santonian tectonism that brought about the uplift of the Abakaliki structure and fault controlled subsidence of the Anambra Basin to its west. This tectonic episode determined its present geometry.

Sedimentation in the present day Anambra Basin began after the Santonian episode via two depositional cycles. The first cycle: Late Campanian-Early Maastrichtian Nkporo depositional cycle (Reijers *et al*, 1997) brought about the deposition of the deltaic complexes which Agagu *et al.* (1985) subdivided into three (3) lithostratigraphic units: the Coniacian Agbani lithofacies group, the Campanian Owelli lithofacies, and the Maastrichtian Mamu-Ajali lithofacies group (Reijers et al., 1997). Reijers *et al* (1997) recognized that each deltaic package within this depositional cycle comprises prodelta (represented by the Nkporo Shale and Enugu Shale), delta plain and fluvial lithofacies.

The second depositional cycle corresponds with the Late Paleocene Sokoto depositional cycle (Petters, 1979) which resulted in the deposition of the Imo Shale. This was succeeded by the Late Eocene regressive cycle (which saw the deposition of the Ameki Formation.) signifying the beginning of the Niger Delta progradation. Altogether, according to Reijers *et al.* (1997), the basin has experienced two short pulses of transgression in the Late Campanian and Paleocene. However, Ladipo (1988) and Adeniran (1991) share a different opinion; they believe that one continuous transgressive event was experienced by the basin between Late Campanian and Paleocene.

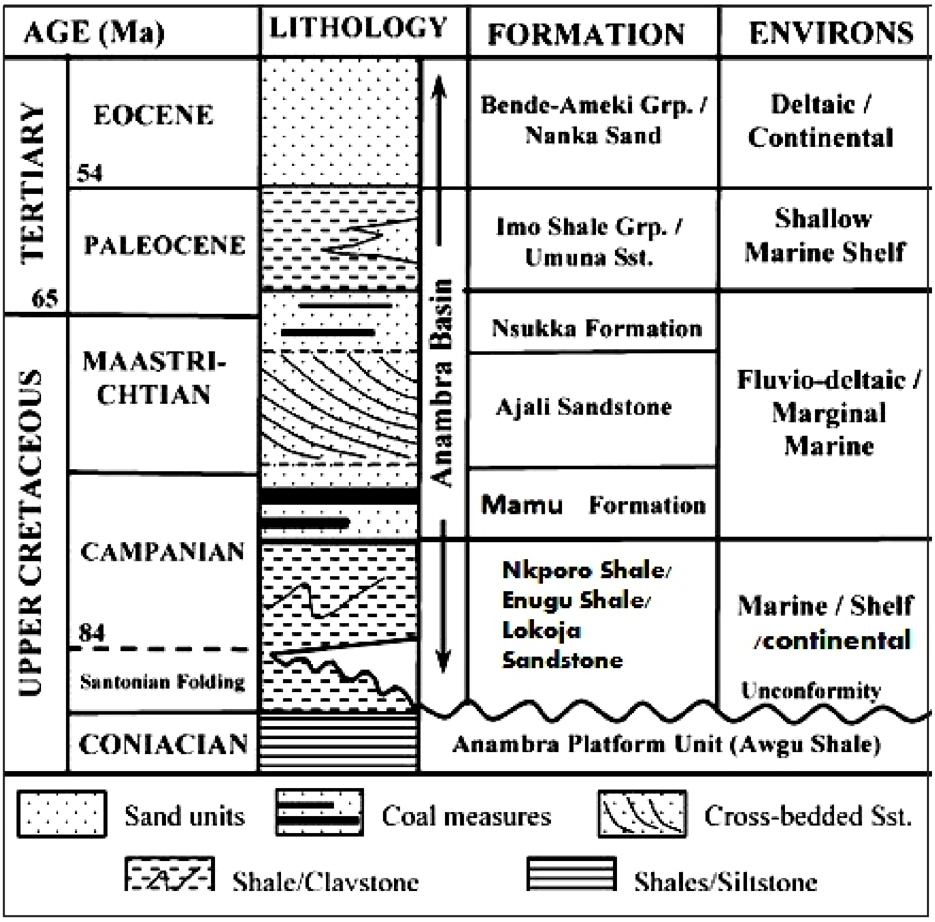

Fig. 2: Anambra Basin Stratigraphy and Gross Depositional Environment (modified from Tijani *et al.*, 2010)

METHODOLOGY

Figure 3 shows the workflow adopted in this study. Five (5) outcrop samples of the Maastrichtian Dark Shale collected from Auchi, Uzebba, Sobe, Agbanikaka and Ikabigbo areas were evaluated for their source rock characteristics (Fig.4).

Palynological slides were prepared after Tyson (1995) and evaluated by transmitted light microscopy at magnifications of X10, X20 and X40 in the Department of Geology, University of Benin Sedimentology laboratory. Point-counting technique (Tyson, 1984) was used to quantitatively estimate the organic matter types which were grouped into three (3) classes: Phytoclast, Miospore,Dinocyst and amorphous, corresponding to Vitrinite, Exinite and alginite kerogen/maceral types.

Furthermore, the samples were crushed and analysed (in lighthouse laboratory, Warri) using Rock-Eval Pyrolysis method (Espitalie *et al.*, 1977). Thermal maturity of the samples was estimated using spore colour index technique [which employs a ten point spore colour scale comprising pale yellow colours (immature) through golden yellow to brown or black (overmature)] and Tmax data (from Rock-Eval Pyrolysis).

Table 2: Nucleotide S n in Bilge Water

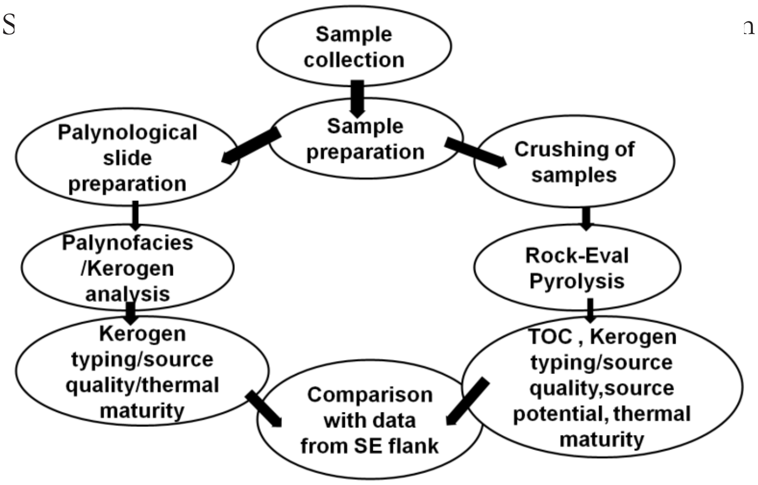

Fig. 3: Research Methodology

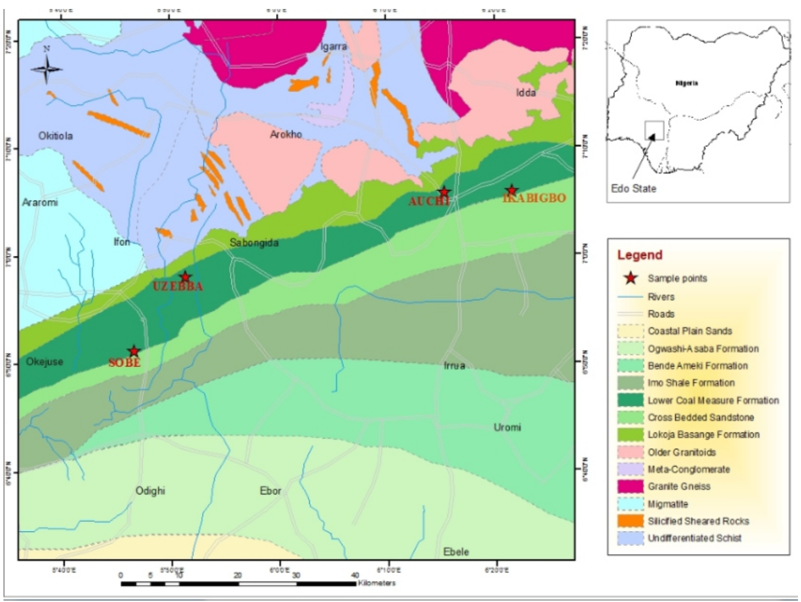

Fig 4: Geological Map Showing Sample Locations

RESULTS AND DISCUSSION

The results of the Palynofacies study and Rock-Eval pyrolysis will be discussed under the following sub-headings below:

Organic richness

The Total organic carbon (TOC) of the Maastrichtian Dark Shale ranges from 2.58 to 8.34 wt. % (Table 1). This is very good to excellent when compared with the organic richness guideline in Table 2.

Table 1: Rock Eval Pyrolysis Data

location	TOC (wt.%)	S1(mgHC/g)	S2(mgHC/g)	S3(mgHC/g)	Tmax (^{0}C)	HI(mgHC/g)	OI(mgHC/g)
Auchi	2.58	1.64	2.97	3.68	328	115	143
Ikabigbo	2.42	0.06	1.47	1	421	61	41
Uzebba	8.34	0.34	10.76	0.42	440	129	5

Table 2: Guideline for Organic Richness Assessment (Law, 1999)

Generation Potential	wt.% TOC, Shales	wt.% TOC, Carbonates
Poor	0.0-0.5	0.0-0.2
Fair	0.5-1.0	0.2-0.5
Good	1.0-2.0	0.5-1.0
Very good	2.0-5.0	1.0-2.0
Excellent	>5.0	>2.0

Source Quality

Point Counting Of Macerals Reveals 574 Macerals In Dark Shale From Ikabigbo, 521 Macerals From Agbanikaka, 481 From Sobe And 97 From Auchi. Phytoclast (Vitrinite) Is The Dominant Palynofacies (Plate 1), Followed Closely By Miospore (Exinite) (Figs. 5&6). Very Few Dinocysts And Amorphous Kerogen Were Identified In The Slides. Plot Of HI Against Tmax Is Consistent With Palynofacies Analysis. It Reveals That The Maastrichtian Dark Shale Is Dominantly Type III Kerogen (Fig. 7).

Thermal Maturity

Tmax Data Obtained From Rock-Eval Pyrolysis Reveal An Immature To Early Mature Thermal Maturity. Thermal Maturity As Estimated From Identified Miospore Shows Spore Colour Index (Spore Colour Index Chart Shown In *Plate 2*) Of Between 2 To 5.5 (*Plates 3-6*).This Suggests That At The Surface, The Maastrichtian Dark Shale Is Thermally Immature (*Table 3*).

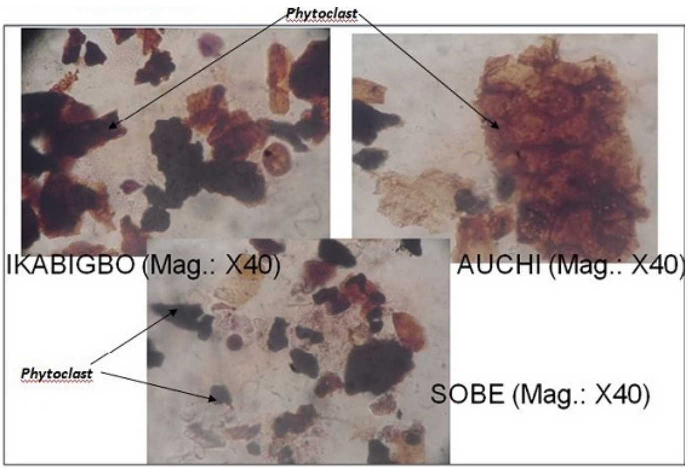

Plate1:Palynofacies Atlas from Ikabigbo, Auchi and Sobe

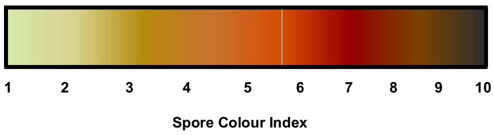

Plate 2: Spore Colour Index Chart (modified from Pearson, 1984)

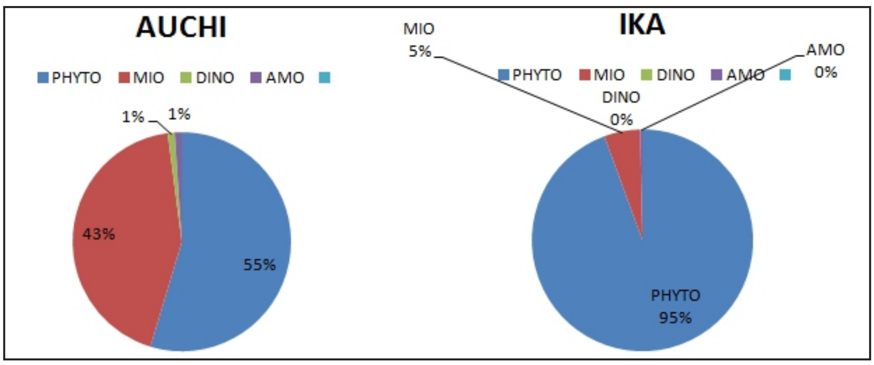

Fig. 5: Quantitative Palynofacies Analysis from Auchi, Ikabigbo

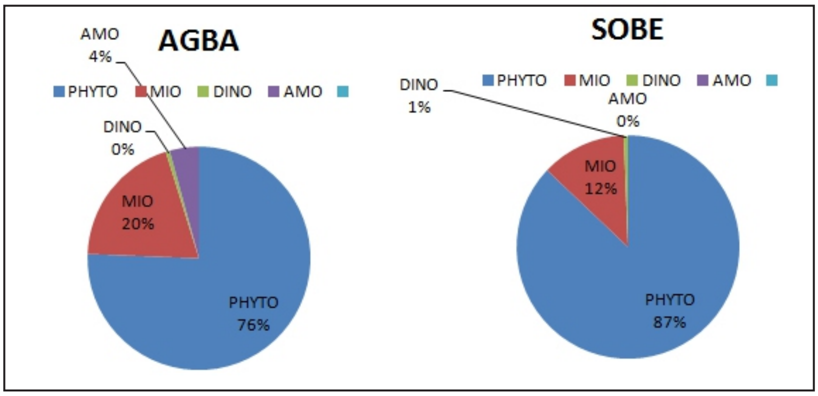

Fig. 6: Quantitative Palynofacies Analysis from Agbanikaka and Sobe

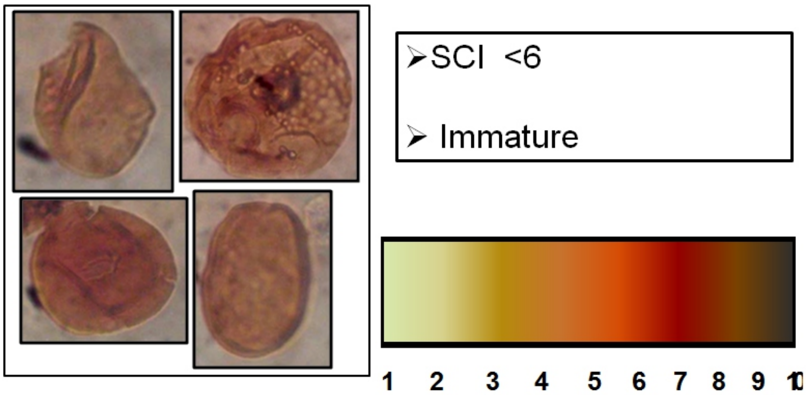

Plate 3:Miospore Identified in Auchi Sample (Magnification: X40)

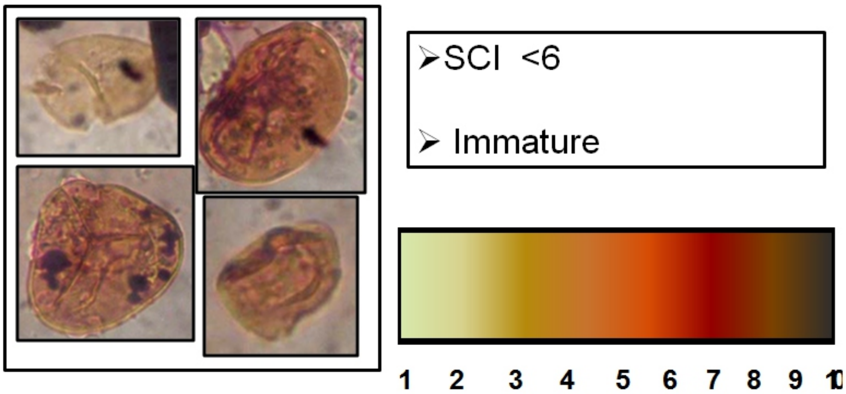

Plate 4: Miospores Identified in Sobe Sample (Magnification: X40)

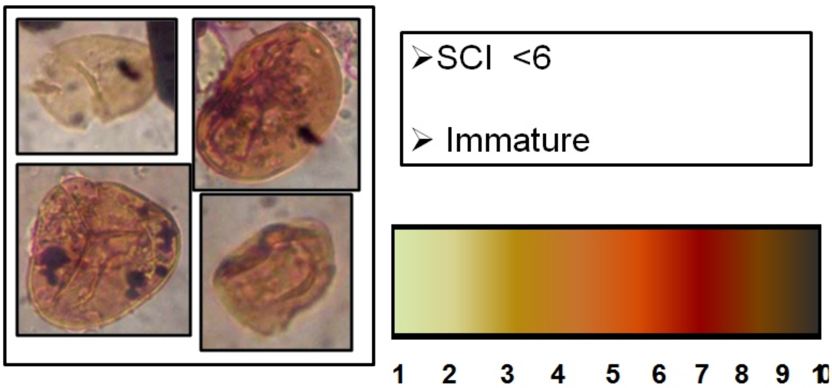

Plate 5: Miospore Identified in Agbanikaka Sample (Magnification: X40)

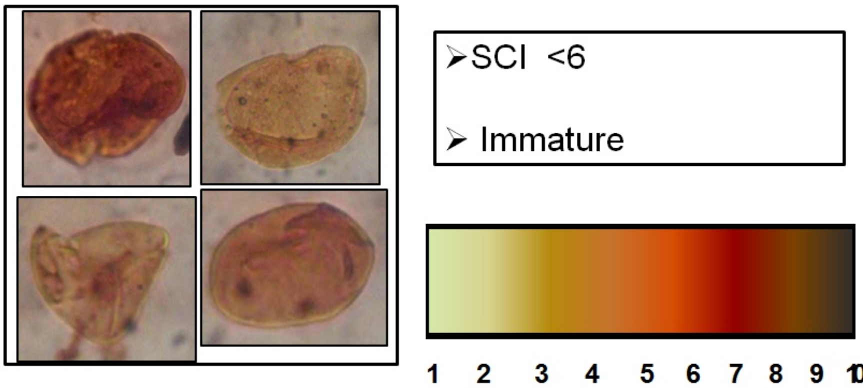

Plate 6:Miospore Identified in Ikabibgo Sample (Magnification: X40)

Table 3: Generalized Correlation of Different Maturity Indices (Waples, 1985)

Vitrinite Reflectance (%R_o)	Spore Coloration Index (SCI)	Thermal Alteration Index (TAI)	Pyrolysis T_{max} (°C)	Generalized Hydrocarbon Zone
0.40	4.0	2.0	420	Immature
0.50	5.0	2.3	430	Immature
0.60	6.0	2.6	440	Oil
0.80	7.4	2.8	450	Oil
1.00	8.1	3.0	460	Oil
1.20	8.3	3.2	465	Oil & wet gas
1.35	8.5	3.4	470	Wet gas
1.50	8.7	3.5	480	Wet gas
2.00	9.2	3.8	500	Methane
3.00	10	4.0	500+	Methane
4.00	10+	4.0	500+	Overmature

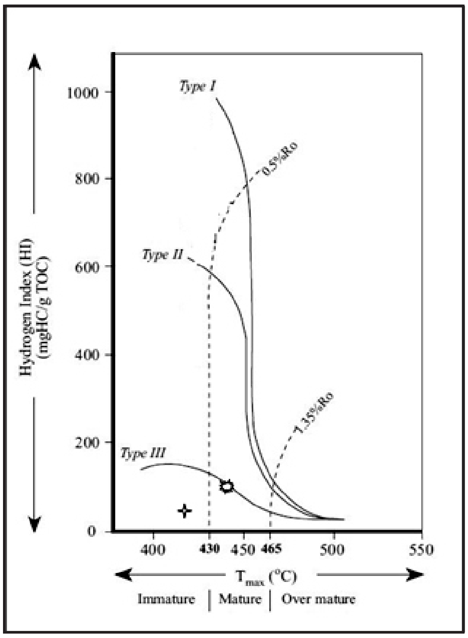

Fig. 7: Plot of HI against Tmax

Comparison of Source Character in SE and SW Anambra Basin

From the foregoing, it has been shown that the source character of the Maastrichtian Dark Shale in the SW compares favorably with what obtains in the SE of the basin. Table 4 gives a summary comparison.

Table 4: Summary Comparison of Source Character in SE and SW Anambra Basin

Source rock characteristics	Aganbi (2010)	Akande et al. (2007); Coals	Ogala (2011)	Nton and Awarun (2011)	Chiaghanam et al. (2013)	Total (1984)	Akaegbobi et al. (2000) (subsurface data)	SW (This Study)
Av.TOC	>2%	>2%	>2%	>2%	>2%	>2%	>2%	>2%
Maturity	Immature /Early mature	Immature /Early mature	Immature /Early mature	Immature	-	Immature/peak mature	Early mature/ mature	Immature/ early mature
Source quality/kerogen type	II/III	III	III	III	III	II/III	III	III

CONCLUSION

This preliminary study has shown that:

- the Maastrichtian Dark Shale in the SW has very good to excellent organic richness;
- the plot of HI against Tmax (Fig. 7) and Palynofacies analysis (*Figs.*5&6) indicate that Maastrichtian Dark Shale in the SW is dominantly of type III kerogen;
- from the Tmax data (Table 1) and spore colour index of miospore identified during kerogen analysis (Plates 3-6) the Maastrichtian Dark Shale SW Anambra Basin is immature to early mature; and
- in general, the source character of the Maastrichtian Dark Shale in the SW is very similar with that in the SE (Table 4).

However, since this is a preliminary study, more detailed sampling should be carried out and many samples (cuttings, core and outcrop) should be analysed by Rock-Eval Pyrolysis and Palynofacies analysis. Also, other analytical techniques like biomarker analysis and Vitrinite reflectance measurements are encouraged to complement the findings of this study. Furthermore, 1D Basin modeling should be carried out to understand the burial history of the Maastrichtian Dark Shale and other potential source rocks within the Anambra Basin.

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