Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 5 (4): 689-695, 2005
ISSN 1812-5654

Hydrocarbon Potential and Thermal Maturity of Nkporo Shale from Lower Benue Trough, Nigeria

[1]O.A. Ehinola, [2]O.O. Sonibare, [3]O.A. Falode and [1]B.O. Awofala
[1]Department of Geology, University of Ibadan, Ibadan, Nigeria
[2]Department of Chemistry, University of Ibadan, Ibadan, Nigeria
[3]Department of Petroleum Engineering, University of Ibadan, Ibadan, Nigeria

Abstract: Campano-Maastrichtian Nkporo Shales from the Lower Benue Trough, Nigeria were analyzed to assess their petroleum potential by sedimentological analysis and Rock-Eval pyrolysis. The Nkporo Shale consists of dark grey and highly fissile shale with interbeds of sandy shale, siltstone and mudstone. The Total Organic Carbon (TOC) ranges from 0.54 to 3.01 wt.%. These values exceed the minimum value of 0.5 wt.% usually required for potential petroleum source rocks. Hydrogen indices are relatively low, fluctuating within a small range of 20 and 153 mg HC/g TOC revealing kerogen of type III and mixed III/II organic matter (OM), which is predominantly gas prone. Tmax and Production Index (PI) ranged from 426 to 439°C (av. 432°C) and 0.02 to 0.08 (av. 0.03), respectively. These values indicated that the shales are presently thermally immature. Analytical parameters determined from the peak shape analysis of S_2 pyrolysis curves such as asymmetry (B/A), asymmetry-1 (D/C) and Full Width at Half Height (FWHH) are between 0.64 to 1.18, 0.44 to 0.77 and 60 to 80°C, respectively. The broad width of FWHH indicated broad range of activation energy and further confirmed the classification of organic matter contained in Nkporo Shale as Type III. The present study showed that the Nkporo Shale has prospects to generate gas rather than oil at appropriate thermal maturity.

Key words: Nkporo Shale, peak shape, organic matter, kerogen type, thermal maturity

INTRODUCTION

The geology of Santonian to Maastrichtian sediments in the lower Benue Trough of Nigeria has been studied by notable workers[1-5]. They reported that the Agwu and Nkporo Shales constituted the main source and seal rock and that the percentage of the organic carbon of the Santonian shales was quite comparable to those of the nearby Niger delta. Unomah and Ekweozor[6] have assessed the petroleum source rock potential of the Nkporo Shale and concluded that the organofacies are provincial with the Calabar flank having the highest oil potential due to the presence of abundant oil prone marine derived Organic Matter (OM). Nkporo Shale in the Anambra basin and Afikpo syncline was reported to contain mainly terrestrially derived organic matter that is essentially gas prone. The organic facies, hydrocarbon source potential and reconstruction of the depositional environment of the Campano-Maastrichtian Nkporo Shale have been studied by Akaegbobi and Schmitt[7]. Their results showed that the source rock composed of type III/II kerogen with dominance of terrestrially derived OM and low contributions from marine OM.

The compositional differences between various types of organic facies such as mixed kerogen, oil stained kerogen and kerogen with reworked organic matter are not discernible when parameters obtained from Rock Eval pyrolysis of oil shale are plotted on a conventional modified Van Krevlen plot, where Hydrogen Index (HI) is plotted against Oxygen Index (OI). The normalized hydrocarbon yield (HI) has been reported to be the discriminating parameter in such a plot. However, the differences become obvious when the overall peak shapes of their S_2 curves are assessed using peak shape and asymmetry parameter as described by Javie[8]. These developments compel us to review the petroleum potential of Nkporo shale using peak shape analysis of the S_2 pyrolysis curve to complement the conventional modified Van Krevelen plot. The lithostratigraphy of the outcrop sections was also described.

Geological setting: The Nkporo Shale is spread across the Lower Benue Trough (Fig. 1) and consists of dark grey, fissile shale, brown silty and sandy shale, mudstone and fine-grained sandstone. In the Calabar flank, lateral persistent black shales facies can be identified in both

Corresponding Author: Dr. O.A. Ehinola, Department of Geology, University of Ibadan, Ibadan, Nigeria
Tel: 234 8033819066 Fax: 234 02 8103043 E-mail: oa.ehinola@mail.ui.edu.ng

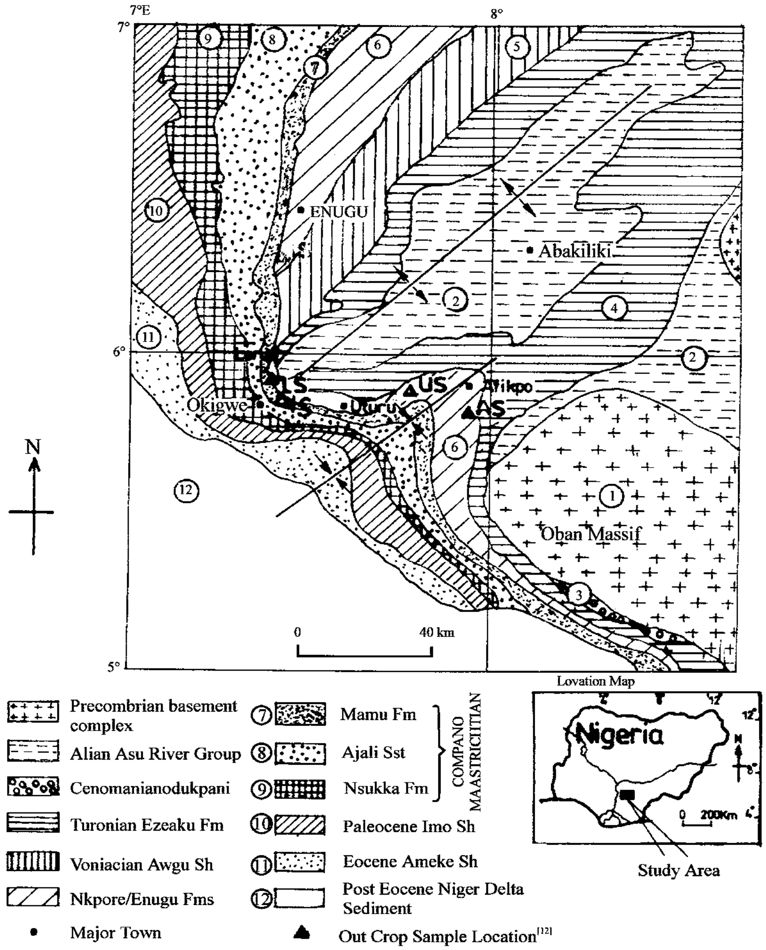

Fig. 1: Geological map of Lower Benue Trough, Nigeria showing sampling positions[12]

outcrops and subcrops[6]. However along the Enugu–Port-Hacourt expressway, the pervasive facies of the formation is usually associated with mudstones which resulted in blocky fissility[6]. The Nkporo Shale is well exposed at the Leru (LS) near Okigwe and become substantially sandy northwards with sand content of up to 70%[9]. The Lower Benue Trough comprises the tectonically inverted Abakaliki Anticlinorium and the flanking Anambra basin and Afikpo synclines to the west and east, respectively[6]. The main factors responsible for sedimentation within the Benue trough during the Cretaceous are the progressive sea level rise from Albian-Maastrichtian leading to world-wide transgression, regression and local tectonics[10]. As a result of this, four major cycles of deposition; Albian–Cenomanian, Turonian-Coniacian, Campanian-Maastrichtian and Palaeogene Sequences have been recognized in the lower Benue Trough.

Albian–cenomanian: Asu River Group represents the first and oldest cycle of shallow marine to brackish water sediments deposited on the basement complex consisting roughly of 2000 m of poorly bedded shales (Abakaliki Shale), siltstone and limestone[11] and mudstone[1]. There has been reported presence of Cenomanian sediments[12] and Santonian intrustives of dykes and sills extrusive and important Pb-Zn mineralization zones along the gently folded axis of the Abakaliki anticline[13].

Turonian-coniacian: Eze-Aku Formation overlies the Asu River Group and it consists of black calcareous shales, shelly limestone siltstone and sandstone, which were deposited as a result of renewed transgression in the second depositional cycle of the Benue Trough[10]. This Formation attained a thickness of 1000 m in some places, representing shallow water deposit[14]. The Awgu Formation consists of mainly shales and limestone depicting a marine influence[12]. Further lithostratigraphic synthesis has shown a lower shale unit of Awgu Shale and an upper sandstone unit of Agbani Sandstone[1]. This rapid sandstone was interpreted as being the first indication of the onset of active tectonic phase of faulting, folding and uplift of the Abakaliki anticlinorium which later led to the termination of this depositional cycle[15]. The Agbani Sandstone are white, medium to coarse grained, poor to moderately sorted, cross laminated depicting a fluviatile environment as a result of regression during Coniacian to lower Santonian[1].

Campanian-maastrichtian: This marks the beginning of deposition within the Anambra Basin and the third cycle of marine incursion in the Benue Trough. Ogugu Shale is deposited conformably on the Agbani Sandstone. This is dark grey shales with shelly calcareous nodules marl bands and occasional coaly remains. The lateral equivalents are: the Enugu Shales with maximum thickness of l6m and of Santonian to Campanian age, the Owelli Sandstone which are coarse grained to pebbly, poorly sorted, planar and trough cross bedding with interdigitations of siltstone, clays and mudstone and Nkporo Shale which consists of dark grey, highly fissile, soft shales with interbeds of sandy shale, fine sand and marl with prominent coating of sulphur[16].

Mamu Formation (Lower coal measures) overlies the Nkporo shale. This consists of fine grained sand, carbonaceous shales and coal with the thickest seam of 1 km typifying a transitional environment. The Ajali Sandstone (Middle coal measures) overlies the Mamu Formation conformably. It is coarse grained, poorly sorted, friable and cross-stratified sandstone. Red earthy sands due to weathering and ferruginization cap this formation. The Nsukka Formation (Upper coal measures). This is youngest formation from this cycle consisting of interdigitations of very fine-grained sandstones, dark shales and coal indicating a paralic environment of Maastrichtian to Palaeogene age.

Palaeogene sequences: These are deposited as a result of the Palaeogene transgression and Eocene regression, which led to the deposition of Imo Shale and Ameki Formation respectively, grading to the proximal Niger Delta[1]. Imo Shales consists of clayey shale, with clay ironstones and sandstone bands. It rests conformably on the Nsukka Formation and forms a down dip continuation of the Akata Shales in the Niger Delta[17]. Ameki Formation overlies the Imo shales and consists of highly fossiliferous greyish–green, sandy clay with calcareous concretions and white clayey sandstones. It displays a rapid lateral facies change, with local shale development or inclusions of sandstones; carbonaceous plant remains may be present. The Nanka Sand is a lateral equivalent and consists of a succession of interbedded friable sandstone and mudrocks with ironstone horizons depicting a tidal-to-fluvial environment[18].

MATERIALS AND METHODS

Location of outcrop sections and estimation of the distance from the nearest village or landmark were carried out using THURAYA HUGHES HNS-7100 Global positioning system equipment. Thickness of the formations and their corresponding depths from ground surface are estimated in the field for each outcrop section.

The Rock–Eval pyrolysis of the shales was carried out at Humble Geochemical Services Division, Texas, USA and Geolabnor, Norway. The samples were heated in an inert atmosphere to 550°C using a special temperature program. During the assay, three characteristics peaks are given. The first peak (S_1) represents hydrocarbons already present in the sample, which are mainly striped at temperatures of about 300°C. The second peak (S_2) represents the hydrocarbon generated by the thermal cracking of the kerogen at temperature of 300-550°C, while the third peak (S_3) represents the CO_2, which is generated from the kerogen during the thermal cracking of the kerogen. The instrument also gives the temperature at maximum S_2 peak (Tmax) and the Total Organic Content (TOC) of the oil shale. Parameters such as Hydrogen Index (HI), Oxygen Index (OI) and Production Index (PI) were calculated from the pyrolysis data and recorded by the instrument.

The peak shape parameters used for analysis of the S_2 curve in the present work are asymmetry (B/A), asymmetry-1 (D/C) and Full Width at Half Height (FWHH) (Fig. 2). Asymmetry is the parameter of S_2 curves at 10% peak height and is defined as the ratio (B/A) of right width (B) and left width (A) in °C at 10% peak height. The initial and final °C at 10% peak heights is the measured temperature on the rising and falling sides of the pyrolysis curve. The total width at 10% height is the sum A+B[8, 19] Asymmetry-1 is the asymmetry parameter of the S_2 curve at 50% peak height and this is defined as the ratio (D/C) of the right width (D) and the left width (C) in °C at 50%

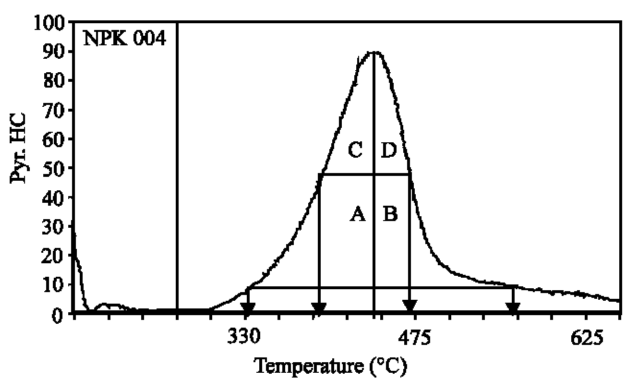

Fig. 2: Pyrolysis curve showing different peak shape parameters

peak height. The initial and final temperatures are the measured temperature on the rising and falling side of the curve at half (50%) height[19]. Full Width at Half Height (FWHH) is the full width (C+D) temperature at 50% peak height[19].

RESULTS AND DISCUSSION

Lithofacies: The stratigraphic profiles for the four outcrop sections range in age from Campanian to Maastrichtian. The Uturu Section (US) is located along the Uturu-Afikpo road with thickness of about 4.8m and consists of alternating fissile shale and mudstones with lateritic topsoil (Fig. 3a). The Leru Section (LS) is over 15m in thickness and consists of shales and sandstone. The basal part of the LS is thinly laminated black shale that is interlaminated by thin lenses of fine quartz sand[18]. The sandstone beds thicken up the section (Fig. 3b). The overlying part of the section consists of several tens of meters thick of black shales with interbedding of sharply bounded, burrowed, partly with ferruginous mudrocks. The topmost part of the LS consists of black shales overlain by siltstone and sandstone considered to be Mamu Formation[18]. The Amuzo Section (AS) is located in Afikpo Syncline with thickness of about 3 m. It consists of black shale with lateritic topsoil (Fig. 4a). The Ihube Section (IS) is located along the Enugu-Port-Harcourt Expressway (about 1km to the tollgate). The IS is 6m in thickness and consists of dark grey shale alternating with whitish sandstone (Fig. 4b).

Organic richness and kerogen type: The Total Organic Carbon (TOC) content of the shale samples from the four sections ranges from 0.54 and 3.01 wt.% (Table 1). These amounts of organic carbon content exceed the minimal 0.5 wt.% threshold for a potential source rock[20], indicating that the shale can generate oil and gas. The highest TOC value of 3.01wt.% is observed in the Leru section.

The kerogen content of the shales classified mostly as Type III on the plot of HI against OI (Fig. 5). This is suggestive of organic matter derived from terrestrial source which can generate mainly gas. However, some samples from LS plotted within the Type II and III zone (Fig. 5). The Hydrogen Indices (HI) is relatively low, fluctuating within a small range of 20 and 153 mg HC/g TOC (Table 1). These values suggest an organic matter that will generate gas with little or no oil[20]. This result supports the earlier findings of Akaegbobi and Schmitt[7], Unomah and Ekweozor[6].

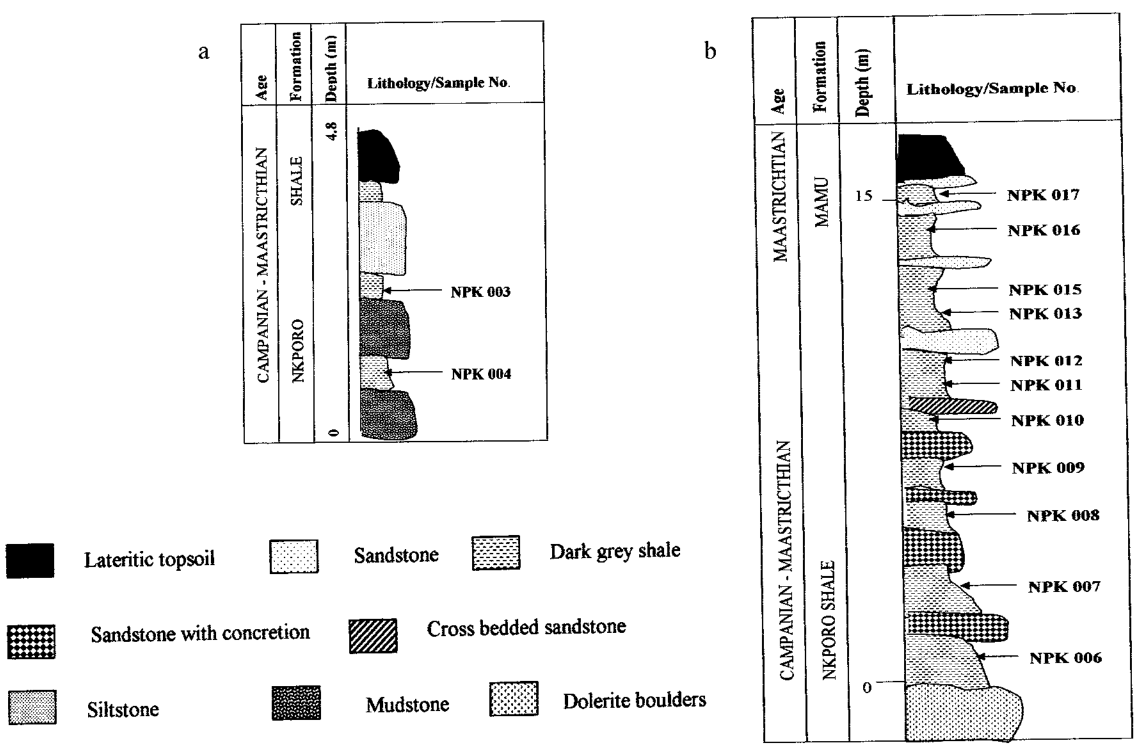

Fig. 3a and b: Lithofacies and sampling intervals in a-Uturu (US) and b-Leru (LS) outcrop sections

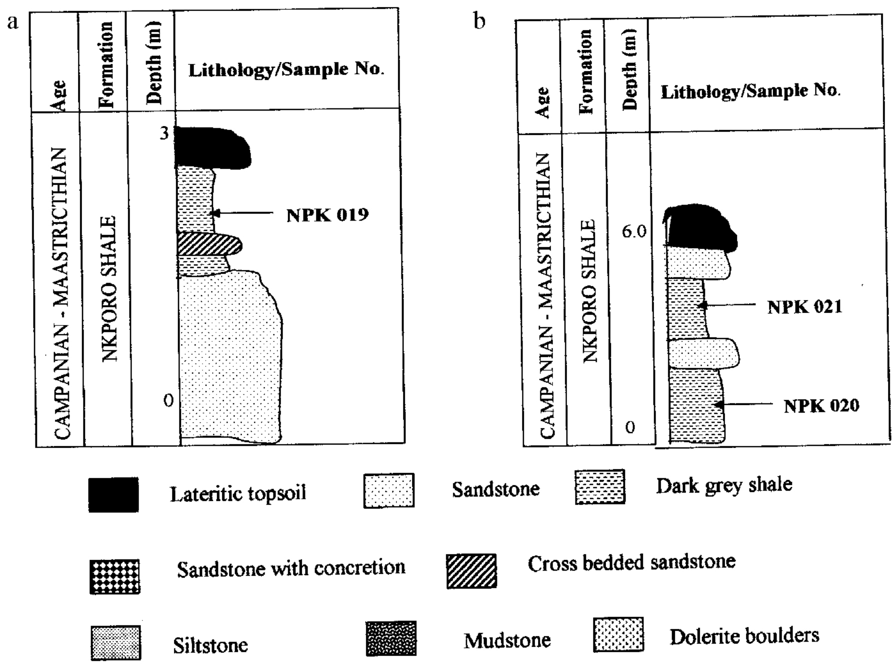

Fig. 4 a and b: Lithofacies and sampling intervals in a-Anuzo (AS) and b-Ihube (IS) outcrop sections

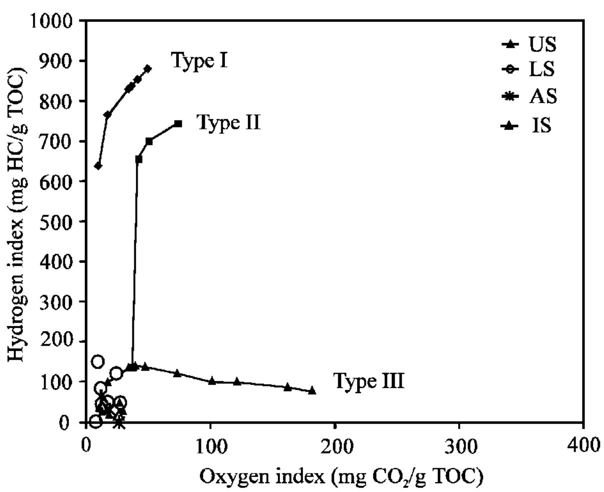

Fig. 5: Quantity and characterization of organic matter from outcrop sections of Nkporo Shale in HI-OI diagrams

Thermal maturity: The Tmax values of the shale samples range between 426 and 443°C (av. 433°C) (Table 1). Most of the samples have Tmax values lower the 435°C required for a mature source rock. Other maturity parameters considered in this investigation is the Production Index (PI) with most values less than 0.1 for the Nkporo shale samples. These observations indicate that the oil shale is thermally immature and could not have generated any hydrocarbon.

Rock-eval S_2 pyrolysis curves: The asymmetry and asymmetry-1 parameters of the studies samples range from 0.64 to 1.18 (av. 0.88) and 0.44 to 0.77 (av. 0.63), respectively (Table 2). The pyrolysis curves are comparatively more symmetrical at 10% height than at 50% height. The higher asymmetry at 10% peak height results from the pyrolysis of the lignin fraction in Type III OM, which normally cracks at high temperatures of around 500°C[8,19]. This further supports that Nkporo Shale is of type III kerogen. The FWHH of the studied samples ranges from 60 to 80°C with average values of 70°C (Table 2). The broader widths are due to a broad range of activation energies, which are recommended for Type III OM[8,19].

The average value of initial temperature at 10% height for the data is 357°C while the final time at the same height is 534°C. The average value of initial temperature at 50% height is 408°C while the final temperature is 479°C. The initial temperature at 10% height and 50% height are less than those reported for Type I and II kerogen[8,19] while the corresponding final temperature are higher. The lower values of initial temperatures and higher values for final temperature are indicative of wider distribution of activation energies, typical of Type III OM. A lower initial temperature at 10 and 50% heights also indicates that the onset of hydrocarbon generation will be earlier for the Type III OM[8,19].

Table 1: Total organic carbon and Rock-Eval pyrolysis results for the Nkporo Shale, Lower Benue Trough, Nigeria

Sample No.	Section	TOC (wt.%)	T. max. (°C)	Hydrogen index (mg HC/g TOC)	Oxygen index (mg CO_2/g TOC)	S_1 (mg HC/g rock)	S_2 (mg HC/grock)	S_3 (mg CO_2/grock)	Production index
NKP 003	Uturu	0.79	428	38	28	0.01	0.30	0.18	0.03
NKP 004	Uturu	1.92	431	30	17	0.03	0.58	0.33	0.05
NKP 006	Leru	2.36	429	7	7	0.00	0.17	0.16	0.06
NKP 007	Leru	1.02	434	123	23	0.04	1.25	0.23	0.03
NKP 008	Leru	2.33	436	52	15	0.01	1.20	0.34	0.01
NKP 009	Leru	1.88	431	49	11	0.02	0.92	0.21	0.02
NKP 010	Leru	1.53	429	27	14	0.01	0.42	0.21	0.02
NKP 011	Leru	1.71	432	41	15	0.01	0.70	0.26	0.01
NKP 012	Leru	1.25	430	31	19	0.03	0.39	0.24	0.07
NKP 013	Leru	1.93	438	78	10	0.03	1.51	0.19	0.02
NKP 015	Leru	3.01	435	84	10	0.06	2.25	0.31	0.02
NKP 016	Leru	2.72	443	51	26	0.01	1.38	0.71	0.01
NKP 017	Leru	2.83	439	153	8	0.08	4.34	0.24	0.02
NKP 019	Amuzo	1.61	428	32	19	0.03	0.52	0.3	0.05
NKP 020	Ihube	0.54	426	20	26	0.01	0.11	0.14	0.08
NKP 021	Ihube	1.37	432	35	13	0.01	0.48	0.18	0.02

Table 2: Initial and final temperature at 10 and 50% peak heights Asymmetry, Asymmetry-1 and FWHH of Rock-Eval S_2 Curves of Nkporo Shale from Lower Benue Trough, Nigeria

	Temperature at 10% peak height (°C)		Temperature at 50% peak height (°C)		Width at 10% peak height (°C)		Asymmetry	Width at 50% peak height (°C)		Asymmetry-1	Full Width at Half Height (FWHH) (°C)
Sample No.	Initial	Final	Initial	Final	B	A	B/A	D	C	D/C	D+C
NKP 003	345	543	398	475	95	103	0.92	22	50	0.44	72
NKP 004	350	568	405	485	118	100	1.18	35	45	0.77	80
NKP 006	370	510	410	476	60	80	0.75	25	40	0.63	65
NKP 007	360	537	400	480	87	90	0.97	30	50	0.60	80
NKP 008	361	539	420	490	79	99	0.80	30	40	0.75	70
NKP 009	352	535	408	474	85	98	0.87	24	42	0.57	66
NKP 010	359	508	411	475	58	91	0.64	25	39	0.64	64
NKP 011	358	530	415	475	80	92	0.87	25	35	0.71	60

Asymmetry = S_2 curve at 10% peak height, Asymmetry-1 = S_2 curve at 50% peak height, FWHH = Full width of S_2 curve at 50% peak height.

CONCLUSIONS

Rock–Eval pyrolysis of the Nkporo shale reveal that the shale can serve as a good source rock having attained the threshold of 0.5%wt required for petroleum source rocks. Low values of Hydrogen Indices (av. <100 mg HC/g TOC) and plots of HI against OI reveals that the shale contained mostly Type III organic matter which can generate mainly gas with little or no oil. The shales are barely matured based on the Tmax and Transformation values.

Rock Eval. S_2Peak analysis supports the Type III OM of Nkporo shales already inferred from the conventional van Krevelen diagram.

ACKNOWLEDGMENTS

The authors are very grateful to Dr. D. Jarvie of Humble Geochemical Services, Texas, USA and Geolabnor, Norway for the Rock-Eval and S_2 peak shape analysis.

REFERENCES

1. Agagu, O.K., 1978. Geology and petroleum potentials of the santonian to maastrichitian sediments in the Anambra Basin, Eastern Nigeria. Unpublished. Ph.D Thesis, University of Ibadan, Nigeria, pp: 214.
2. Agagu, O.K. and C.M. Ekweozor, 1982. Petroleum geology of the Senonian sediments in the Anambra Syncline Southeastern Nigeria. Nig. J. Min. Geol., 19: 52-61.
3. Ekweozor, C.M and J.R. Gormly, 1983. Petroleum geochemisty of the early Tertiary shales penetrated by the Akwkwa–2 well in the Anambra, Southern Nigeria. J. Petroleum Geol., 6: 207-216.
4. Nwachukwu, J.I., 1985. Petroleum prospects of Benue Trough, Nigeria. AAPG Bulletin, 69: 601-609.
5. Agagu, O.K., E.A. Fayose and S.W. Petter, 1985. Stratigraphy and sedimentation in the Senonian Anambra Basin of the Eastern Nigeria. J. Mineral. Geol., 22: 25-36.
6. Unomah, G.I. and C.M. Ekweozor, 1993. Petroleum source rock assessment of the Campanian Nkporo shale, Lower Benue Trough, Nigeria. NAPE Bulletin, 8: 172-186.
7. Akaegbobi, I.M. and M. Schmitt, 1998. Organic facies, hydrocarbon source potential and the reconstruction of the deposition environment of the Campano-Maastrichtian Nkporo shale in the Cretaceous Anambra Basin. NAPE Bulletin, 13: 1-19.
8. Jarvie, D.M., 1991. Factors affecting Rock-Eval derived kinetic parameters. Chem. Geol., 93: 79-99.
9. Avbovbo, A.A. and O. Ayoola, 1981. Petroleum prospects of the Southern Nigeria's Anambra Basin. Oil and Gas, J., 79: 334-347.

10. Petters, S.W., 1978. Stratigraphic evolution of the Benue Trough and its implications for the upper cretaceous paleogeography of the West Africa. J. Geol., 86: 311-322.
11. Reyment, R. A., 1965. Aspects of the Geology of Nigeria. University of Ibadan Press, Ibadan.
12. Ojoh, K.A., 1990. The Southern part of the Benue Trough, Nigeria Cretaceous Stratigraphy, Basin Analysis, Paleo-oceanography and the aerodynamic evolution of the Equatorial domain of the South Atlantic. Elf Bulletin, l.7, 2: 67-74.
13. Benkhelil, J., 1989. The origin and evolution of the Cretaceous Benue Trough. Nigeria J. African Earth Sci., 8: 251-282.
14. Kogbe, 1976. Paleogeographic History of Nigeria from Albian Time. In: Kogbe, C.A. (Ed.), Geology of Nigeria, University of Ife, pp: 237-252.
15. Burke, K., T. F. J. Dessauvagie and A. J. Whiteman, 1972. Geological History of the Benue Valley and Adjacent Areas. In: African Geology (Eds.) Whiteman, A.J. and T.F.J. Dessauvagie), Ibadan, pp: 187-206.
16. Akaegbobi, I.M. and Boboye, 1999. Textural, structural features and microfossil assemblage relationship as a delineating criteria for the stratigraphic boundary between Mamu Formation and the Nkporo shale within the Anambra Basin, Nigeria NAPE Bulletin, 14: 176-193.
17. Short, K.C. and A.J. Stauble, 1967. Outline of geology of Niger Delta. Am. Assoc. Pet. Geol. Bull., 62: 761-779.
18. Nwajide, C.S. and T.J.A. Reijers, 1997. Sequence Architecture of the Campanian Nkporo and the Eocene Nanka formations of the Anambra basin, Nigeria. NAPE Bulletin, 12: 75-87.
19. Mangotra, S.R., M. Kakoti, P.K. Bhatnagar, B.N. Prabhu and B.K. Sharma, 2000. Peak shape analysis of Rock-Eval curves: A case study of Rudrasagar field, Upper Assam Basin India. Petroleum Geochemistry and Exploration in the Afro-Asian Region, 5th Intl. Conf. Extn. New Delhi, pp: 425-431.
20. Tissot, B.P. and D.H. Welte, 1978. Petroleum Formation and Occurrence, Springer Verlag, Berlin, pp: 81-91.