Aspects of Hydrocarbon Potential and Clay Mineralogy of the Patti Formation, Southern Bida Basin, Nigeria

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ABSTRACT

Among the major lithostratigraphic units making up the southern Bida basin are the Lokoja and Patti Formations, overlain by the Agbaja Ironstone. Outcrop samples from the associated shales and claystones units of the Patti Formation were examined and characterised to deduce the hydrocarbon potential of the associated shales as well as determine the clay mineralogy in other to deduce the provenance and the palaeoclimatic setting of the basin. Altogether, a total of sixteen samples, made up of ten (10) shale and six (6) claystones were analyzed for this study. Field relationships show that the sediments are cyclical. The shales are dark to greyish while the claystones are milky to whitish. Within the sequences are associated ironstone, sandstones and mudstone.

The result of Total Organic Carbon (TOC) ranges from 1.73 to 3.45 wt%, which is greater than 0.5 wt% threshold for clastic rocks to be considered as good source rocks. The Hydrogen Index (HI) ranges from 28 to 79 mgHC/gTOC. This value reveals terrestrial type IV organic matter. Cross plots of Hydrogen Index (HI) versus Oxygen Index (OI), S2 vs TOC indicate types III and type IV organic matter. In addition, cross plot of HI vs Tmax shows immature sediments and mainly type IV organic matter. Tmax values range from 418 to 428 °C while the Production Index (PI) ranges from 0.04 to 0.13, which further indicate immature sediments. The clay mineralogy reveals kaolinite as the major clay mineral type, comprising 21.28 to 60.48 %, dickite (6.00%) whiles the non-clay minerals are mainly quartz, hematite and feldspar.

It can be deduced that the shales are immature with terrestrial organic matter having potential to generate gas at appropriate maturation. The prevalence of kaolinite is attributable to weathering of feldspar-rich rocks from the adjoining basement rocks under warm, humid climatic setting.

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INTRODUCTION

The Bida basin is located between Latitudes 70 30' and 100 30' North and Longitudes 40 31' and 70 15' East (Fig. 1). It is one of Nigeria's inland sedimentary basin oriented in the northwestern-southeastern direction, perpendicular to the main axis of the Benue Trough and the Niger Delta basin of Nigeria. It is frequently regarded as the northwestern extension of the Anambra Basin to the southeast, both of which were major depocentres during the third major transgressive cycle of southern Nigeria in the Upper Cretaceous times.

The lithology comprises mainly sandstones, subsidiary breccia, siltstones, shale, ironstones and claystones, which are cyclically arranged in a vertical profile and range from Campanian to Maastrichtian in age. The total sediments thickness in the basin is about 4700 meters, estimated from magnetic data (Udensi and Osazuwa, 2004). Previous geological investigations in the Bida basin include among others (Falconer, 1911; Jones, Jones 1953; 1955, 1958; Ojo and Ajakaiye 1974 ;Jan du Chene et al, 1978 Ladipo et. al. 1994), however the work of Braide (1990) shifted attention to the hydrocarbon prospect of the basin, as a result of increased awareness in Nigeria for new oil and gas discoveries.

Akande and Ojo, (2002) and Akande et al; (2005) focused on the determination of source rock, palaeodepositional environment as well as age determination using organic geochemical and paleontological techniques. This work further examines the mineralogical characteristics of the associated claystones, its provenance and aspects of hydrocarbon potential of the shales associated with the Patti Formation.

LOCATION AND GEOLOGY OF AREA OF STUDY

In this study, the outcrop exposures on Lokoja – Abaji road between Ahoko and Acheni were sampled. The area is accessible through the newly reconstructed Lokoja – Abuja highway (Fig.1). The generalised stratigraphic description of sediments in the basin is shown in Fig. 2. The Bida basin is divided into the Northern and Southern Bida Basins, each varying in lithostratigraphic succession (Adeleye 1971).

The Northern Bida Basin extends from Bida to Kotangora and the stratigraphic succession is made up of Bida Sandstone, Sakpe Ironstone, Enagi Siltstone and Batati Ironstone. The Bida Sandstone is the oldest stratigraphic sequence in the Northern Bida basin and has been divided into two members namely; the Doko and Jima members (Adeleye,1973). The Doko member

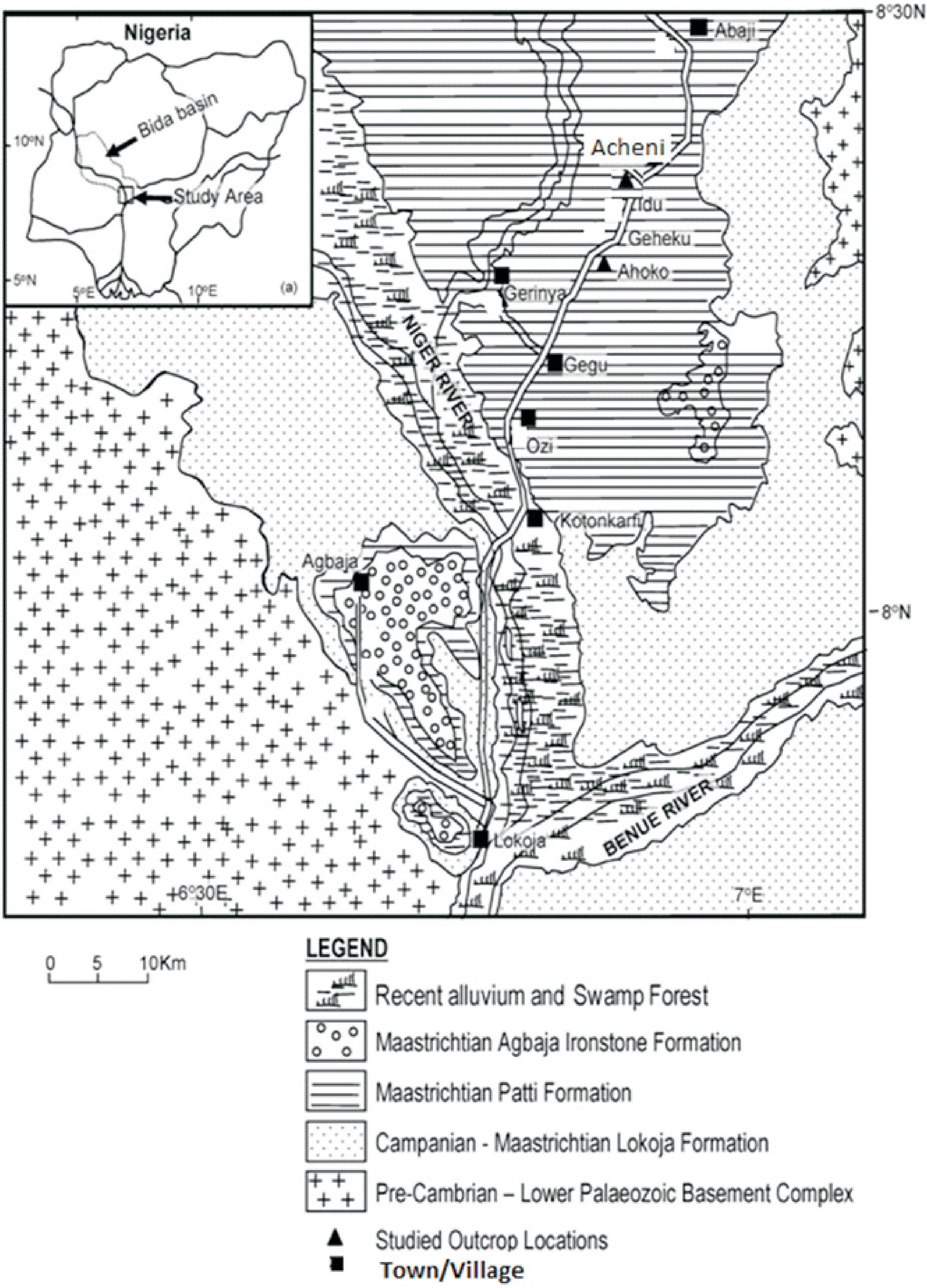

Fig. 1.: Geological map of Nigeria showing the location of Bida Basin (modified after Agyingi, 1991)

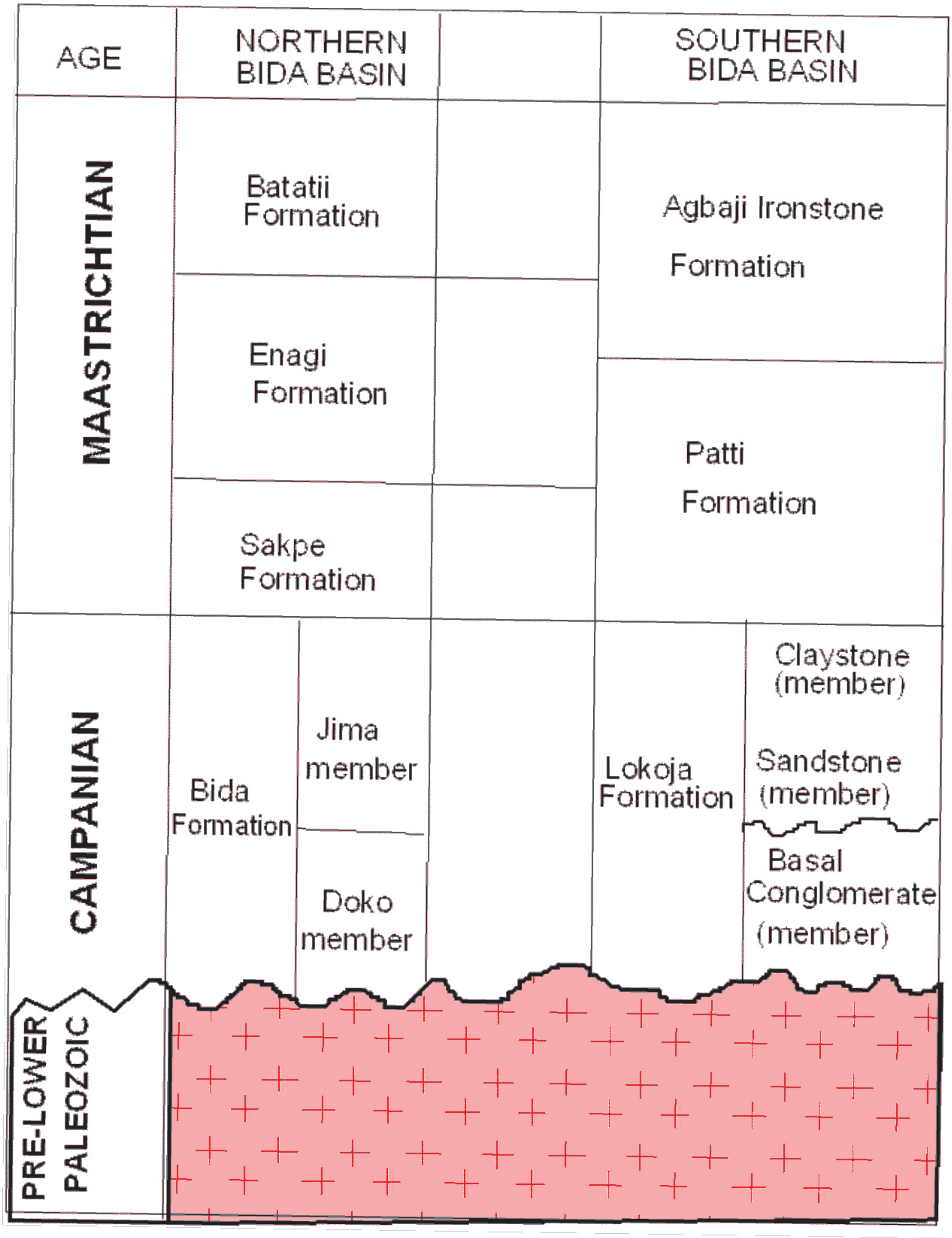

Fig. 2. : Generalised stratigraphic subdivisions in the northern and southern Bida basin (after Akande et al, 2005)

directly overlies the Precambrian Basement Complex and is succeeded by the Jima Member. The Sakpe Ironstone Formation overlies the Bida Sandstone and as reported by Adeleye (1973), it is divided into two members namely; Wuya Ironstone and Baro Ironstone Members , each about 5m thick . Overlying the Sakpe Ironstone is the Enagi Siltstone Formation which consists of argillaceous sediments. The youngest unit in the Northern Bida basin is the Batati Ironstone.

In the Southern Bida Basin, where the focus of this study lies, three lithostratigraphic units have been reported. They are from oldest to youngest; Lokoja Formation, Patti Formation, Agbaja Ironstone Formations which are lateral equivalents of the Bida Sandstone , Sakpe Ironstone, Enagi Siltstone and Batati Ironstone respectively (Akande et al, 2005). The Lokoja Formation is the oldest stratigraphic sequence in the Southern Bida Basin, and unconformably overlies the Precambrian Basement Complex. The basal unit consist of conglomerates, subrounded to well-rounded quartz, feldspars, pebbles and cobbles, especially at the basement-sediment contact. The pebbles are embedded in whitish clayey matrix. The basal conglomerate is overlain by fine to very coarse-grained conglomeratic sandstone. The predominant sandstone facies vary in colour from milky to purple. (Adeleye, 1989; Braide, 1992).

The Patti Formation conformably overlies the Lokoja Formation and comprised upto 100m thick sequences of sandstone, claystone, shale and coaly units exposed between Korton-karfi through to Abaji (Ladipo et al. 2011). The Ahoko section exposes about 26m sequence of claystone,shales and siltstone which are rhythmically interbedded with conventional to massive bio-turbated ironstones (Fig.3a, 3b and 3c). The shales are dark grey, carbonaceous, silty and fissile while the claystones are greyish, partly mottled and fractured in most parts. Four bands of ironstone interbeds occur within this profile. The overall sequence is capped by lateritic overburden . The Acheni section exposes about 18.5 m sequence of claystone, shale, siltstone and sandstone cyclically arranged. The sandstones and siltstones are cross bedded and burrowed .The shales are dark to grey, fissile and weathered in some parts while the claystones range in colour from purple, through dark grey to brownish. The lower claystone, shale and sandstone contain ironstone concretions (Fig. 4). The silty basal shales contain woody fragments and plant remains and this is interpreted as channel lag deposit (Akande and Ojo, 2002). In the upper part of the section, silty shales, siltstones are more pronounced and are interbedded with conventional ironstone. The massive ironstones contain vertical and horizontal burrows. Agyingi (1991) assigned a Maastrichitian age to this succession based on floral assemblages. Around Abaji (reported elsewhere), the section consists predominantly of the sandstone facies of the Patti Formation. The basal part consists of massive poorly sorted sandstone and sandy claystone, which are overlain by massive conglomeratic sandstone. Akande and Ojo (2002) interpreted the argillaceous rocks (siltstone, shales, claystone) as deposit of quiet, low energy environment.

The Agbaja Ironstone Formation is the youngest rock sequence in this area and overlies the Patti Formation. This forms the protective lateritic capping, consisting of oolithic to pisolitic, concretional and massive ironstone facies. It is about 20m thick (Abimbola, 1994).

METHODS OF SAMPLING AND ANALYSES

A total of sixteen (16) samples made up of ten shale and six claystone were collected from two outcrop locations at Ahoko and Acheni on Lokoja –Abaji expressway. The different outcrops locations were described and lithologs sketched (see Figs 3a-c and 4).The samples were taken in well labelled sampled bags to the laboratory for detailed examination and preparation for analyses.

Organic Geochemical Analysis

Rock Eval pyrolysis

Each of the ten (10) shale samples was pulverised and sieved through 63 micron. The samples were later treated by standard procedures and analysed using LECO 600 analyzer which has a TOC module. Based on the total organic carbon (TOC) adequacy, the selected samples were further characterized for Rock Eval . The pulverised samples were heated in an inert environment to measure the yield, (S1, S2, and S3), as three peaks on a pyrogram. Detailed analytical procedures and operating conditions can be consulted in Okunade, (2012). This analysis was carried out at the Weatherford Laboratories, Texas, USA.

XRD Analysis

A total of six (6) claystone samples were selected for mineralogical analysis. 10g of each pulverised sample was mixed with acetone to produce thin slurry. The mixture was smeared onto a glass slide and scanned using Siemens D500 Diffractometer (with MDI Data Scan and JADE 8 softwares) instrument for determination of the clay mineral composition. This analysis was carried out at the Acme Analytical Laboratories, Vancouver, Canada.

The diffractograms were compared with established standards and interpreted with reference to Brown (1972), JCPDS (1974) and Pei-Yaun Chen (1977) tables of X-ray diffraction patterns. Quantitative estimation of the different minerals was undertaken by computing their peak areas based on Gibbs (1967).

Detailed analytical procedures are reported in Okunade (2012).

RESULTS AND DISCUSSIONS

Organic Geochemical Evaluation

Organic Matter Richness:

The results of Rock-eval pyrolysis is shown on Table 1. It is known that adequate organic content, expressed as percentage TOC is a pre-requisite for generation of

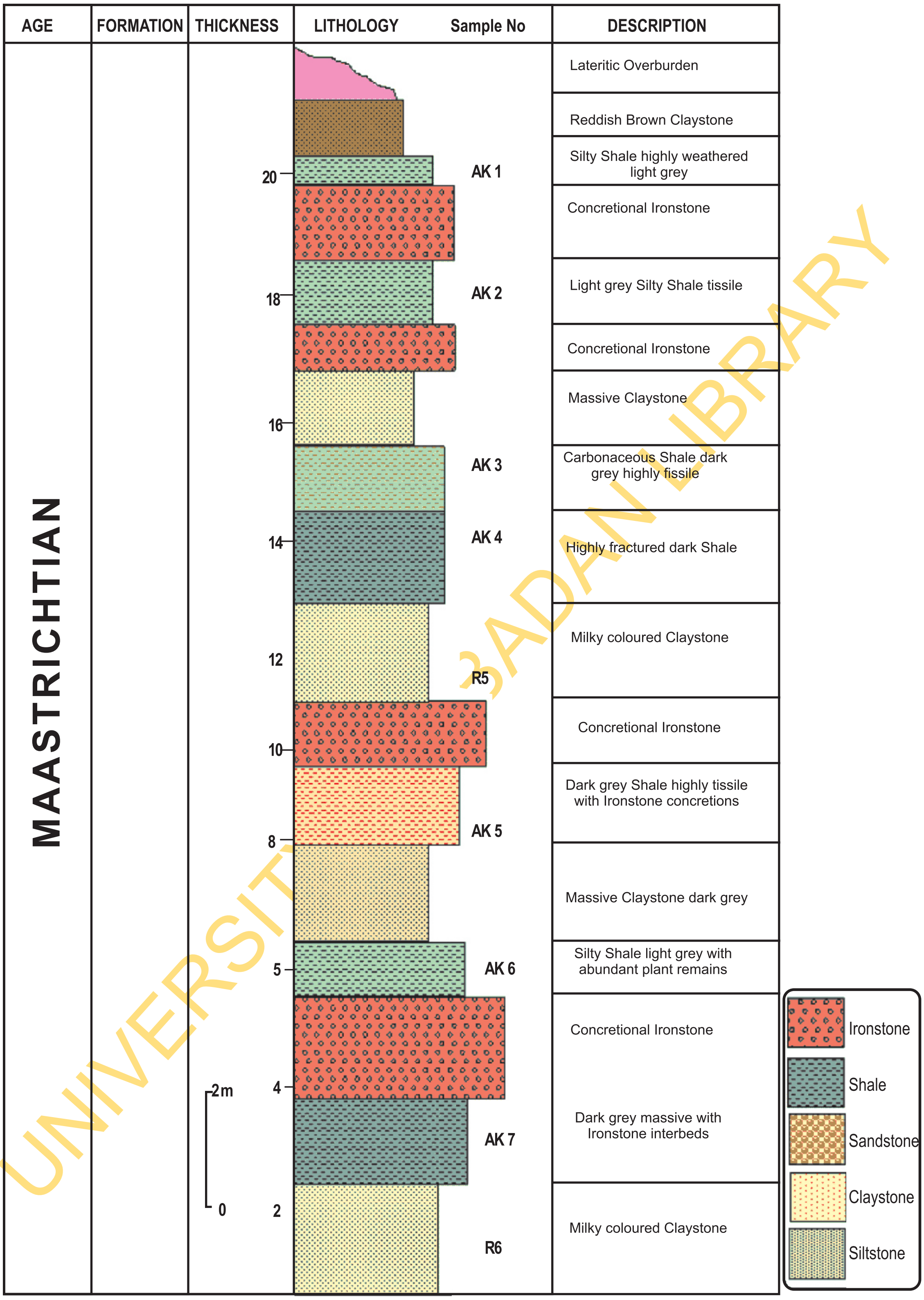

Fig. 3a: Lithological section of the Patti Formation exposed at Ahoko showing sample points investigated

Fig3b. Field photograph of interbedded claystone, shale and ironstone at Ahoko-Latitude 8^0 19.N and Longitude 6^0 53' E Elevation of 82m

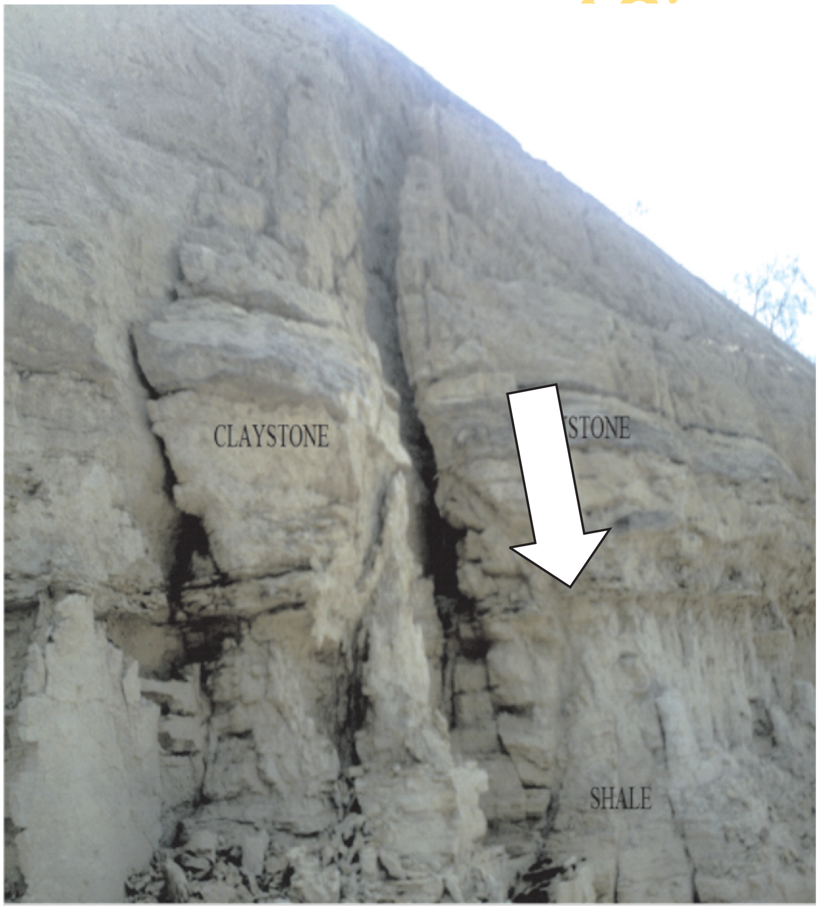

Fig. 3c: Field photograph of vertically fractured alternating claystone, ironstone and shale at Ahoko -Latitude 8^0 11' N and Longitude 6^0 48'E Elevation of 116m

hydrocarbon (Cornford, 1986). The results of the total organic content ranges from 1.73 to 3.45wt% (av 2.16 wt%, Table 1) which indicate all the shales have moderate source rock potential since their TOC values are generally above the minimum threshold value of 0.5 wt.% expected for clastic sedimentary rocks (Hunt, 1995; Tissot and Welte, 1978).

Organic Matter Type:

The quality of organic matter content of a source rock determines the type of hydrocarbon generated (Tissot et al; 1984). The HI values range from 28 to 79 mgHC/gTOC (av. 53.15 mgS2/TOC) and lie in the gas proned type. Cross plots of HI against OI (Fig. 5) indicate Type IV kerogen . Cross plot of HI vs Tmax indicates also type IV kerogen while plot of S2 vs TOC (Figs 6 and 7) indicate the predominance of gas rather than oil in the basin. The Genetic Potential (GP) (S1+S2 mg HC/g) is a measure of hydrocarbon- generating potential and depends on organic matter amount, type and thermal maturity (Espitalie et al, 1977). Arising from this study, the genetic potential (GP) ranges from 0.64-1.85 kgHC/ton (mean 1.21 kgHC/ton). This is lower than the 2 kgHC/ton expected for good source rock (Dymann et al., 1996). Based on the concept of Tissot and Welte (1984), as applied in Dymann et al. (1996) and also reported by Akande and Ojo (2002), the shales of the Patti Formation have lower than 2kgHC/ton of rock and suggest little or no oil source rock potential but some potential for gas. This supports the findings of Obaje et al, (2011).However, the low GP and HI values for the shales could have resulted from mineral matrix effect or weathering (Espitalie et al., 1980). This may not be completely ruled out in this study.

Organic Matter Maturity

Thermal maturity describes the extent of heat-driven reactions which convert sedimentary organic matter into petroleum (Peters and Moldowan, 1993). In general, the extent of maturity depends on the relation of organic matter to the oil generative window. The Tmax is a thermal stress parameter, dependant primarily on time/temperature conditions and can only be approximately related to the stage of petroleum generation for the rock type. The Tmax values for the samples range between 418 and 428°C (av. 421°C; Table 1). These indicate that the shales of the Patti Formation are immature.

Cross plots of Tmax versus hydrogen index (HI) (Fig. 6) further supports the shales as immature with mainly types III and IV kerogen having terrestrial organic matter input. The production index (PI), defined as the ratio S1/(S1+S2), can used to estimate thermal maturity. It is related to how much petroleum has actually been generated from the organic matter present in the source rock. According to Peters and Moldowan (1993), Tmax and PI values < 435°C and 0.1% respectively, indicate immature organic matter. In this study, PI values obtained range from 0.04 to 0.13 (av. 0.07; Table 1) and indicate immature status for the sediments. Arising from this study and as corroborated by Ladipo et at. (2011), the potential to yield gas however may exist if sufficiently buried under high enough temperatures to attain maturity.

Hydrocarbon Resource Evaluation

From the above discussions and as reported by earlier workers based on integration of standard organic geochemical parameters, sedimentological characteristics and field relationships (Akande et al., 2005; Obaje et al., 2011), the shales of the Patti Formation constitute the major source rock with prospect to generate more of gas than oil at maturation. The stratified nature of the shales and sandstones may provide likely favourable pathways for migration of fluids into potential reservoir rocks made up mainly of fluvial, shelf and flood plain sandstones in the Lokoja and the Patti Formations (Ladipo et al., 2011). As rightly reported by Obaje (2011), the relatively well sorted sandstone units of the tidally influenced facies of the Patti Formation have better characterized reservoir rock compared to the fluvial Lokoja Sandstone with prevalence of alluvial fans containing poorly sorted massive conglomeritic sandstone proximal to the basement.

The trapping mechanisms in the basin may be enhanced by regional seals provided by the shales , siltstones and claystones of the Patti Formation and the overlying Agbaja Formation (Obaje et. al. (2011)

Clay Mineralogy

The result of the clay mineral content is shown in Table 2. The non clay minerals include quartz, feldspar and haematite. In this study, attention is focussed on the clay minerals suites which include kaolinite (21.28-60.48%) and dickite (6.00%). A typical diffractogram for one of the samples is shown in Fig. 8. Clay mineralogy strongly reflects the characteristics of their source materials. They are alteration products of rock forming silicates minerals, and therefore reflect the kind of rocks weathered as well as the climatic conditions that existed at the time of weathering (Friedman and Sanders, 1978). In this study, conspicuous intensities of kaolinite are reflected at 2 θ values of 3.56, 4.45 and 7.16; for quartz, conspicuous intensities are reflected at 2 θ values 3.33, 4.25; hematite at 2 θ values of 2.69 and 3.67. Feldspar is reflected at 2 θ values of 3.76 and 6.58 while dickite is at 3.84 and 4.16.

The relatively high proportion of kaolinite is attributable to the weathering of feldspar-rich rocks in humid climatic setting (Nton, 1999). This agrees with the findings of Pollard (1973) that kaolinite formed as primary products from granite and gneissic sources. The presence of kaolinite also indicates that the sediments were deposited in a continental or near-shore environment, this view is supported by the observation of David and Roger (1977). Hematite occurs as secondary mineral formed by weathering and is an alteration product of iron bearing mineral precipitated by chemical or inorganic processes attributed but not limited to normal and oxidizing environment (Blake et al., 1966). Ladipo et al.

Table 1: Toc And Rock Eval Data Of Selected Samples

Sample NO.	Location	TOC	S1	S2	S3	Tmax	HI	OI	S1/	PI	Cal. Ro %	GP
		Wt. %	mg/g	mg/g	Mg/g				TOC*100			
Ak1	Ahoko	1.88	0.06	0.70	0.49	420	37	26	3.16	0.08	0.40	0.76
Ak2	Ahoko	2.02	0.09	1.49	0.89	421	74	44	4.41	0.06	0.42	1.58
Ak3	Ahoko	3.45	0.04	0.98	0.99	419	28	29	1.20	0.04	0.38	1.02
Ak4	Ahoko	1.75	0.06	1.39	0.84	419	79	48	3.61	0.04	0.38	1.45
Ak5	Ahoko	2.21	0.08	1.67	1.04	428	76	47	3.72	0.05	0.54	1.75
Ak6	Ahoko	2.08	0.07	1.09	0.79	423	52	38	3.37	0.06	0.45	1.16
Ak7	Acheni	2.83	0.13	1.72	0.84	422	61	30	4.44	0.07	0.44	1.85
Ak8	Acheni	1.85	0.16	1.13	0.44	425	61	24	8.86	0.13	0.49	1.29
Ak9	Acheni	1.73	0.07	0.53	0.56	418	31	32	4.25	0.12	0.36	1.60
Ak10	Acheni	1.83	0.05	0.59	0.51	428	32	28	2.83	0.08	0.47	0.64
AVERAGE		2.16	0.08	1.13	0.74	421	53.15	34.56	3.99	0.07	0.43	1.21

Notes:

TOC=weight percent organic carbon in rock
S1, S2=mg hydrocarbons per gram of rock
S3= mg carbon dioxide per gram of rock
S1/TOC=normalised oil content=S1 X 100/TOC
PI= production index= S1/ (S1+ S2)

HI=hydrogen index= S2 X 100/TOC
OI=oxygen index= S3 X 100/TOC
Tmax=^{0}C
GP= (S1+S2)
Measured % Ro =measured vitrinite reflectance

Table 2: Data of Clay mineral composition

Sample No. / MINERAL	R1	R2	R3	R4	R5	R6
Kaolinite	27.85	21.28	60.48	56.51	26.59	57.67
Quartz	70.15	78.49	39.52	47.49	36.61	42.33
Hematite					36.80	
Feldspar	2.00	0.23	-		-	-
Dickite	-			6.00		

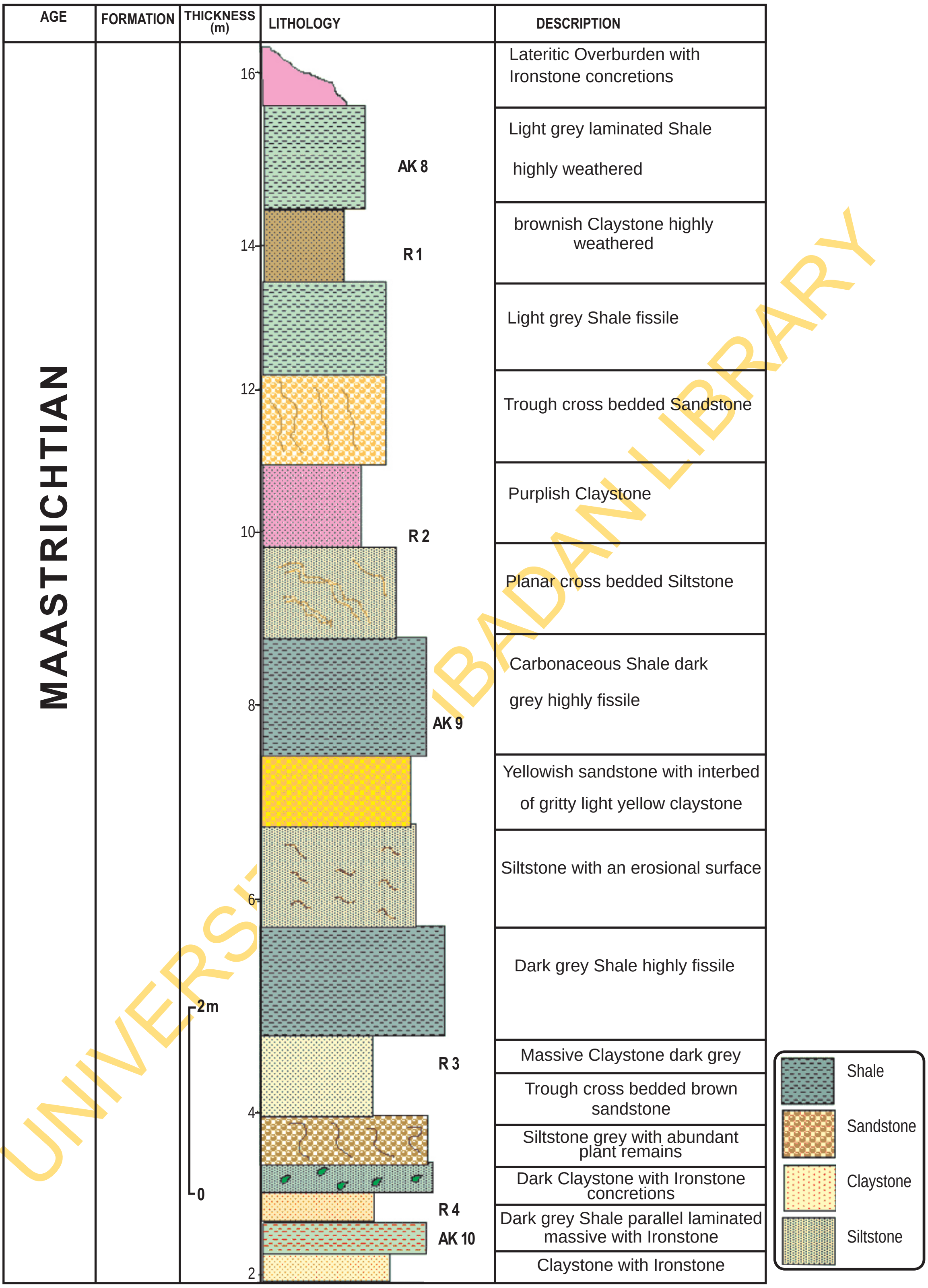

Fig.4:Lithological section of the Patti Formation exposed at Acheni showing the sample points investigated

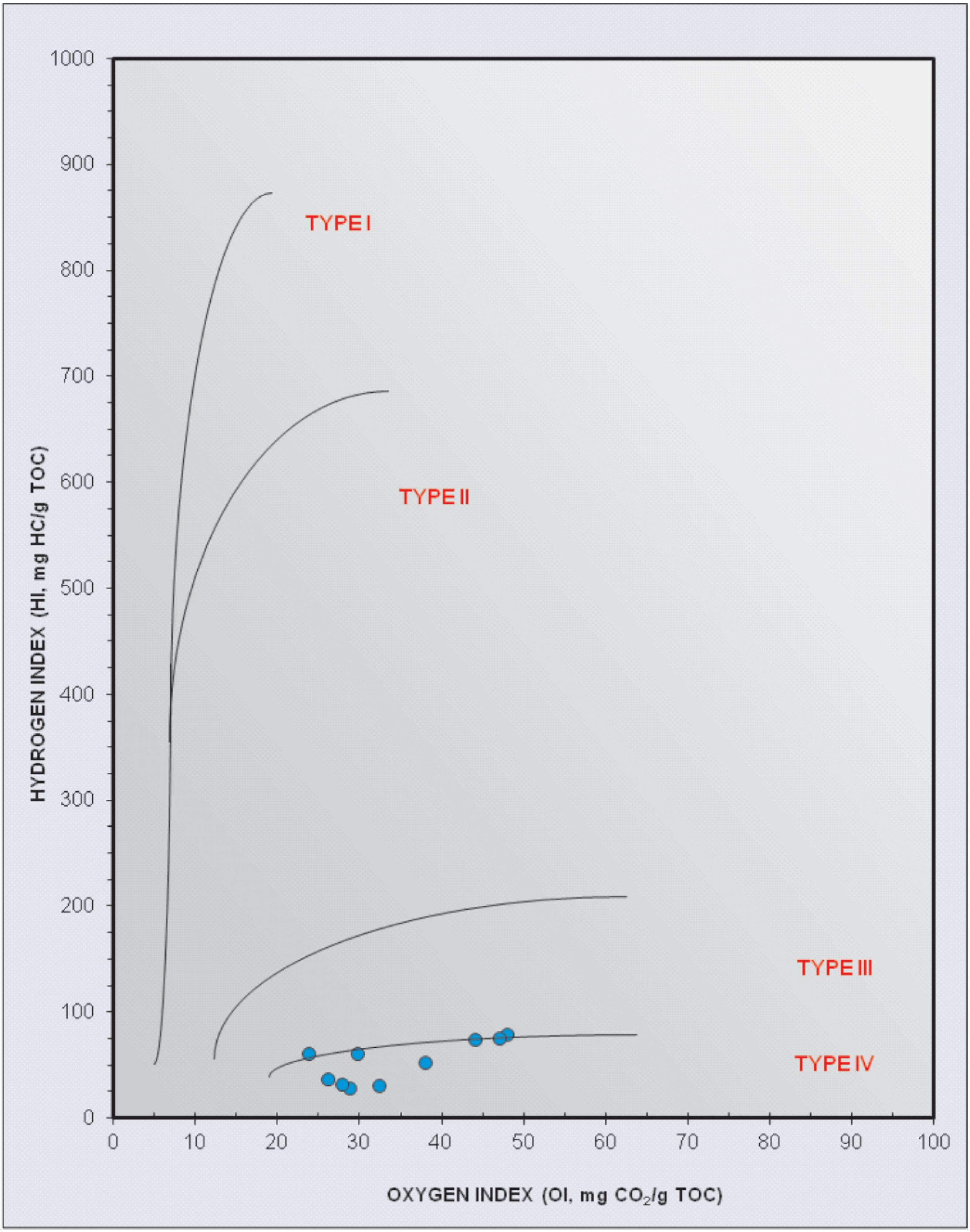

Fig. 5: Plot of HI Vs OI, showing the kerogen type (After Espitalie et al: 1977)

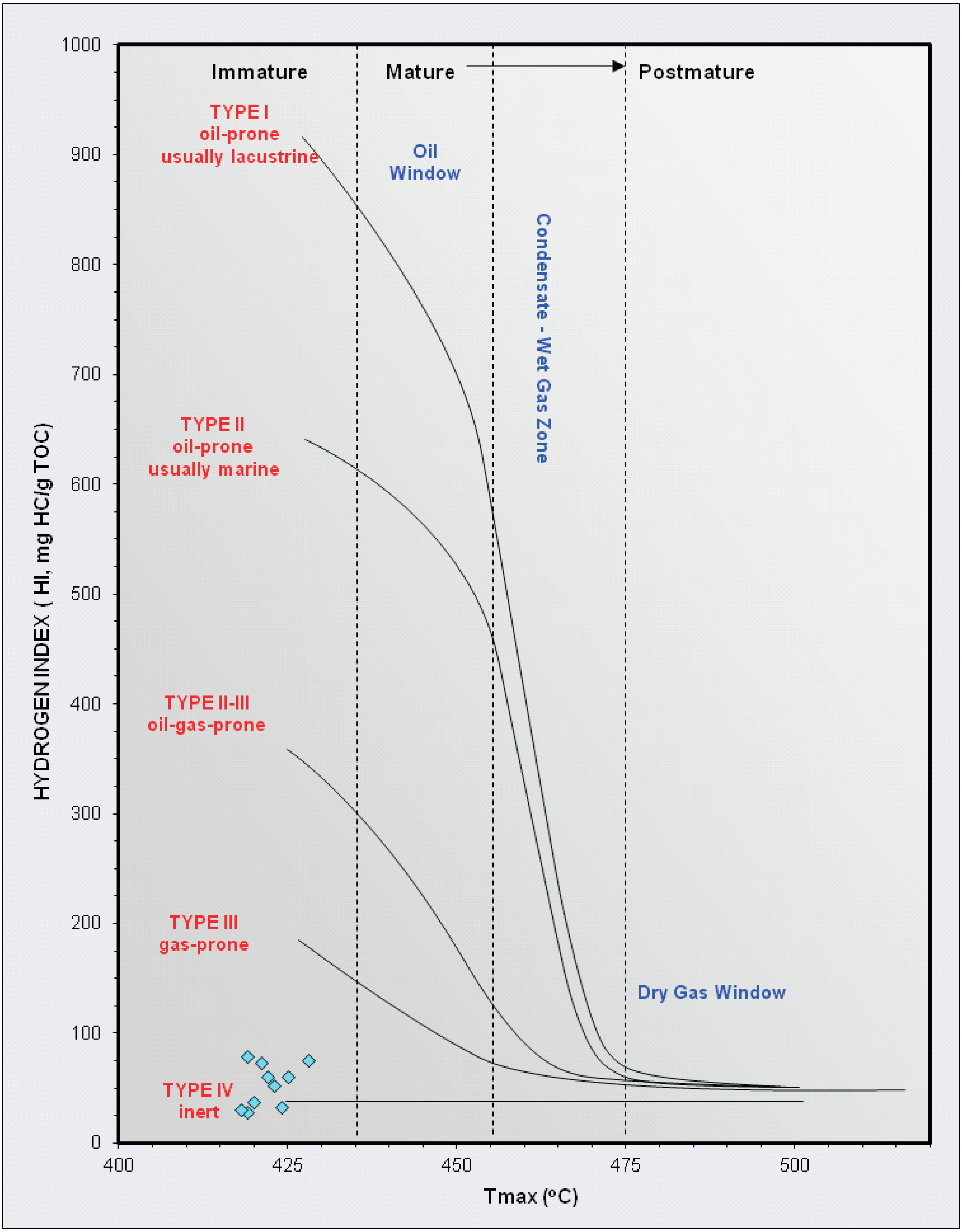

Fig. 6 Plot of Hydrogen index vs Tmax

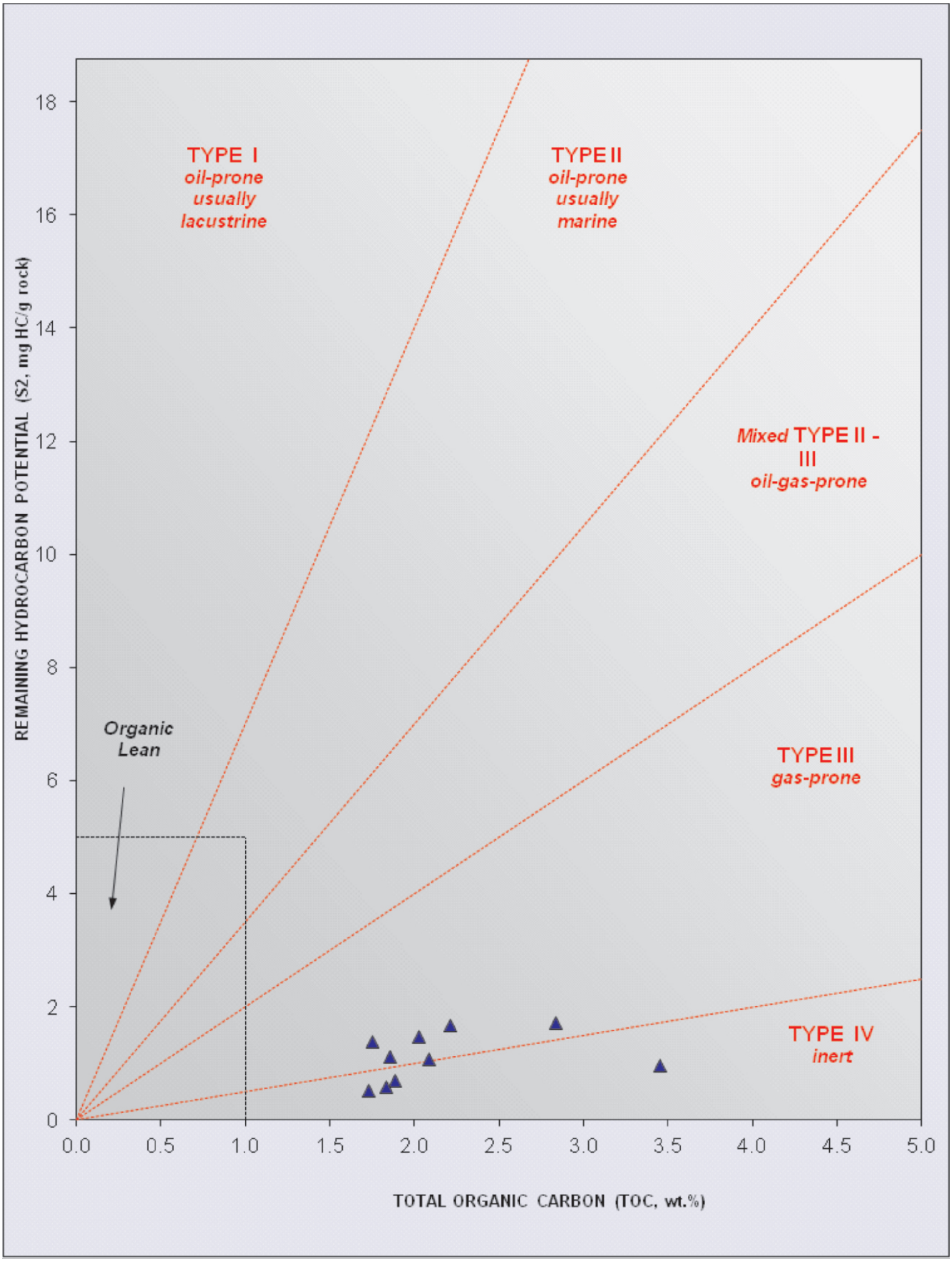

Fig. 7: Cross plot of Hydrocarbon potential vs Total organic Carbon

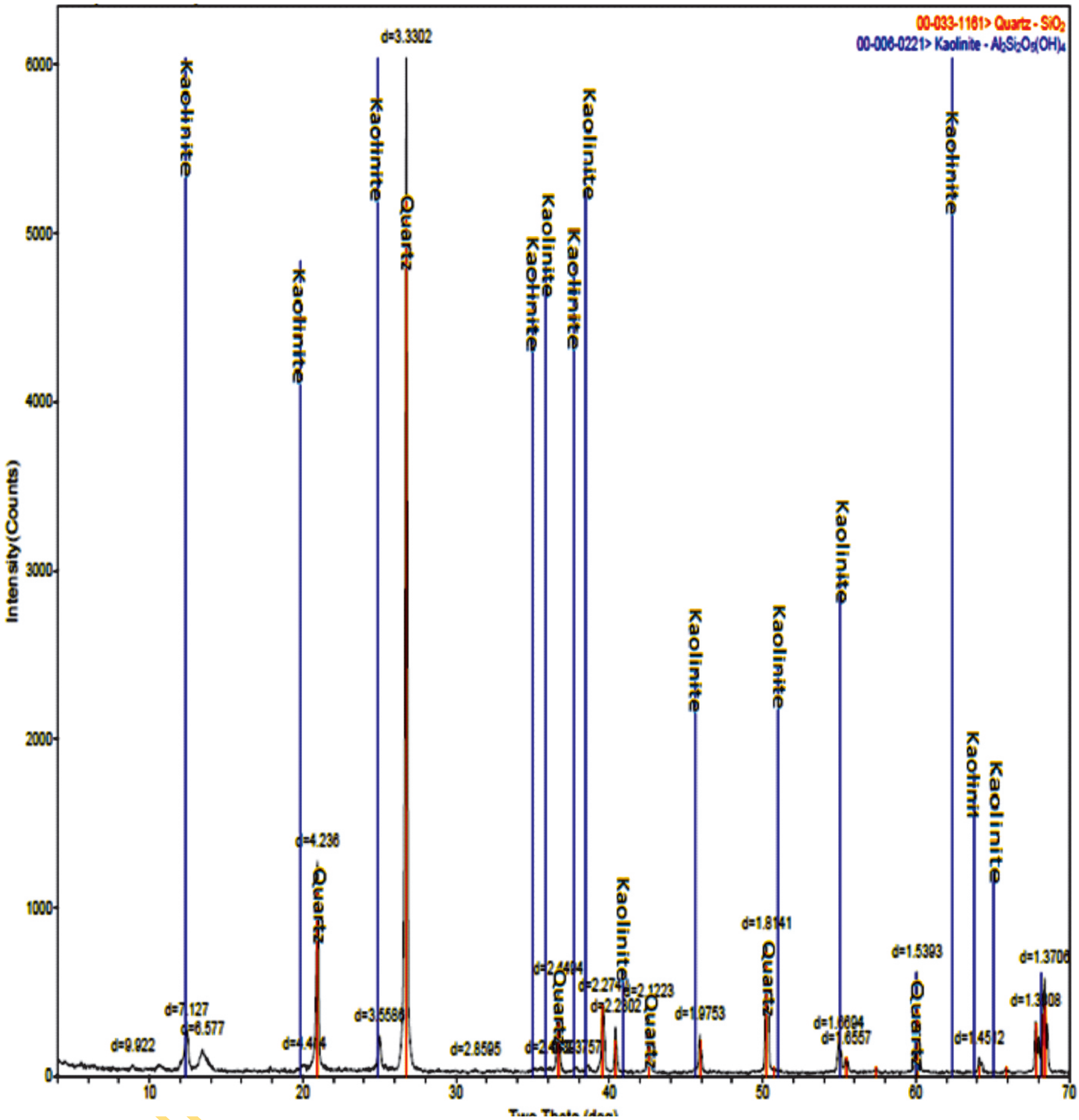

Fig. 8: Typical X-Ray Diffractogram for sample R2

(1994) have reported that marine reworking of the claystones could result in the formation of oolitic and concretional ironstones associated with this formation. Findings of Abimbola et al. (1999) indicate that the ironstone of the overlying Agbaja Ironstone Formation is principally a kaolinite precursor, formed through the supergene enrichment of iron to goethite kaolinite ooids and subsequent hematite ooids. The presence of hematite (36.80%) in sample R5 is however expected and could undoubtedly be associated with similar processes and setting.

SUMMARY AND CONCLUSIONS

Outcrop samples belonging to the Patti Formation of the Bida basin were studied for hydrocarbon potential as well as characterized the mineralogical content of the associated claystone. The organic richness points to good source rock potential. Rock-Eval data for the shales (TOC, Tmax, HI, Yield Potential) suggest the prevalence of a humic Type III and type IV kerogen of immature status and of terrestrial precursor. Such organic matter is gas proned, with prospect of generation at appropriate maturity. The predominance of kaolinite indicates weathering of feldspathic rocks under humid climatic setting while that of hematite can be attributable to kaolinite precursor. The shale facies are the potential source rocks while the tidal channels and shore face sands facies within the Patti Formation may serve as reservoir rocks. The maturity status, trapping system and retention could be re-examined if deeper well data are available.

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