Geochemical and Palynological Studies of Some Maastrichtian Source Rock Intervals (Patti and Gombe Formations) in Nigeria: Implications for Hydrocarbon Prospectivity*

Olusola J. Ojo[1], Ayoola Y. Jimoh[2], and Juliet C. Umelo[3]

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[1]Department of Geology, Federal University Oye-Ekiti, Oye-Ekiti, Nigeria (olusola.ojo@fuoye.edu.ng)
[2]Department of Geology and Mineral Sciences, Kwara State University, Malete, Nigeria
[3]Department of Geology and Mineral Sciences, University of Ilorin, Ilorin, Nigeria

Abstract

The Maastrichtian Patti and Gombe Formations are located in Bida and Gongola Basins respectively. These two inland basins form part of the targets currently being tested for hydrocarbon prospectivity in Nigeria. Road cuttings and core samples of coal, coaly shale, and shale from the formations were analyzed using standard organic geochemical and palynological techniques to unravel their organic matter quantity, quality, palynofacies, expulsion efficiency, and thermal history. The age of the sediments were also constrained from the palynological data. Palynological data suggest a Maastrichtian age and influence of freshwater swamps for the sediments based on the microfloral assemblage like *Retidiporites magdalenensis*, *Echitriporites trianguliformis*, *Buttinia andreevi*, and *Botrycoccus braunii*. The organic geochemical results show relatively high TOC for the Patti shales (0.79-12.9 wt.%) and Gombe coals (38.8-61.2 wt.%) implying moderate to high concentrations of organic matter. Hydrocarbon source potential range from 0.19-0.70 mgHC/g rock except for a certain interval with high yield (30.23 mgHC/g rock) in the Patti shales. The Gombe coals have source potential ranging from 32.77-69.38 mgHC/g rock. Generally, the samples show low HI except one of the Patti shale samples with HI of 230 mgHC/g TOC (thought to be formed under reducing condition) and one of the Gombe coal samples with HI of 170 mgHC/g TOC. In spite of the favorable organic parameters, the thermal maturity is low with vitrinite reflectance and Tmax ranging between 0.41-0.52 % and 413-431 °C respectively. Biomarker analysis of the hydrocarbon extracts show abundance of odd number alkanes C27-C33, low sterane/hopane ratio (0.06-0.25). Pr/Ph in the samples are greater than 2. We conclude from the study that the Maastrichtian source rocks were sourced terrestrially under a prevailing oxic condition and dominated by Type III organic matter. Type II organic matter with oil and gas potential may be possible in the Patti Formation in the Agbaja area of Bida Basin. Thermal maturity and conversion ratio were low and not much hydrocarbon could have been generated from the source rocks.

Introduction

The present study is focused on the Maastrichtian source intervals (Patti and Gombe formations) in the hinterland Bida and Gongola basins of Nigeria respectively (Figure 1). Both basins are of rift origin and filled with Cretaceous sediments in Nigeria and they are relatively under explored in respect of petroleum prospectivity. The coal, coaly shale, and shale appear to be the most prospective source rock facies in the formations and were evaluated with respect to their hydrocarbon source rock potential. The paleodepositional environments, source, type, and maturity of the organic matters were investigated in this study. A total of 29 samples (26 surface and 3 core samples) of Gombe Formation, Gongola Basin were analyzed while five samples (4 surface and a core sample) from the Patti Formation, Bida Basin were selected for analysis. The samples were processed using standard palynological processing and also subjected to geochemical screening (TOC and Rock-eval Pyrolysis) to determine the organic source richness and hydrocarbon potential. Organic petrology (visual kerogen and maceral analysis) for determination of kerogen quality, maturity, and hydrocarbon potential was also carried out on a Leitz MPV-2 photomicroscope. Gas Chromatography, Medium Performance Liquid Chromatography, and Gas Chromatography - Mass spectroscopy were used to assess some of the selected source rocks for biomarker fingerprints.

Results and Discussion

Palynological Characteristics

Samples from Bida and Gongola basins yielded well preserved palynomorphs that are useful for biostratigraphic and paleoecologic deductions. The palynomorph assemblage from the study areas include *Retidiporites magdalenensis*, *Echitriporites trianguliformis*, *Buttinia andreevi*, and *Foveolotriltes magaritae*. Others include D. complex, C. ornatus (Figure 2). These are known Maastrichtian forms. The occurrence of *Botryococcus braunii* in the Patti shale at the Agbaja borehole section, Bida Basin was recorded. This is a typical freshwater algae that possibly indicates lacustrine source rock. At Ahoko, Bida Basin, marine dinocysts such as Dinogymnium, at the lower part of the section were recovered and this interval we considered to mark the maximum deepening in the basin. It is important to note that samples from Gombe Formation, Gongola Basin did not yield any marine form but rather exclusively terrestrial.

Palynofacies analysis suggests predominance of structured organic matter in the source rock intervals and minor amorphous organic matter suggesting gaseous prone Type III organic matter. The amorphous organic matter in the shales from Bida Basin amounts to about 16% which indicates probably type II-III organic matter (oil and gas prone). The APP plot according to Tyson (1995) suggests dysoxic to oxic conditions and transition from shelf to basin for the source rock intervals (Figure 3a and Figure 3b).

Organic Richness and Kerogen Quality

The average TOC of the source rocks in the two formations exceeds 0.5wt.% indicating excellent source rock for hydrocarbon generation. The quality of the organic matter contained in the samples was evaluated from their Hydrogen Index (HI). HI ranged from 22 mgHC/g TOC – 200 mgHC/g TOC for most of the samples in the two formations. However, a shale sample from the Patti Formation has HI of 230 mgHC/g TOC indicating Type II-III kerogen which is capable of generating oil and gas (Figure 4) (Hunt, 1996). The organic matters are largely Type III

indicating plant contributions from terrestrial sources with gaseous hydrocarbon potential (Langford and Blanc-Valleron, 1990). This is supported by the PI (< 0.1). The average Tmax for the coal and shaly facies is less than 435ºC, and the vitrinite reflectance less than 0.55Ro. The carbon preference index (CPI) is greater than unity and in conjunction with other saturate and aromatic maturity indices indicates that the samples are immature to low maturity status. The study therefore shows that even though the organic matter concentration is relatively high, the conversion condition is low for hydrocarbon generation and expulsion in the basins.

Depositional Environments and Source of Organic Matter

The coals and the shales are characterized by high molecular weight *n*-alkanes which range from C_{10}-C_{41} for the coal facies and C_9-C_{41} in the shaly facies. The *n*-alkanes are the dominant component of the aliphatic hydrocarbon fraction. The extracts are characterized by predominance of polar compounds indicating low maturity level of kerogen cracking. Saturated fractions are comprised of tricyclic and pentacyclic terpanes, steranes, diasteranes, and tetracyclic polyprenoids while aromatic fractions comprises mono, triaromatic steroids, and triaromatic methylsteroids.

The *n*-alkanes distribution in the coaly source rocks maximizes at C_{29}. This pattern indicates organic matter derived mainly from terrestrial organic matter while the shaly facies maximizes at C_{16} and C_{29} indicating mixed source (Figure 5a and Figure 5b). Pr/Ph ratio for the coaly facies ranges from 2.15-3.51 (average 2.79) while the shaly facies ranges between 0.95-2.37 (average 1.82) indicating fluvio-deltaic depositional environment in sub-oxic to oxic setting. The predominance of Pristane (n-C_{17}) over Phytane (n-C_{18}) suggests humic origin for the organic matter for the coaly source rocks in a mixed/transitional depositional environment. Obaje et al. (2004) reported mixed environments for most of the Nigerian coals.

The coals are rich in C_{29} steranes (> 50%) and (~40%) each for ratios calculated from isosterane αββS and αααR configuration. This is an indication of significant land plant contribution as evidenced from the very low C_{27} steranes. The shales also have high C_{29} steranes but with appreciable quantity of C_{27} and C_{28} αββS sterane (26% and 29%) and (34% and 24%) in C_{27}, C_{28}ααR sterane suggesting possible marine contribution for the organic matters. The sterane/hopane ratio values range from 0.06-0.35 (<0.6) suggesting incorporation of high level of bacterial inputs commonly associated with terrigenous organic matter in coals. The dibenzothiophene/phenanthrene (DBT/PH) ratio range from 0.03 to 0.19 for the coal and 0.08-0.14 for the shaly source rocks respectively indicating appreciable quantity of terrestrial organic matter.

Conclusions

The shale and coal facies of the Patti and Gombe formations (Bida and Gongola basins respectively) are dated Maastrichtian. The coal and shale of the Gombe Formation, Gongola Basin and the shales from the Patti Formation, Bida Basin constitute good to excellent source rocks with potential to generate mainly gas. Type II-III kerogen capable of generating gas and oil is documented in the Patti Shale from Bida Basin and may probably generate oil if higher thermal maturity level is attained.

At the present level, pyrolytic yield is high in the source rock facies, but conversion is low and source beds are barely within the oil window. The predominance of Pristane (n-C_{17}) over Phytane (n-C_{18}) suggests humic origin of the organic matter for the coaly source rocks in a

mixed/transitional depositional environment. The organic matters were derived from mainly terrestrial/terrigenous organic matter under oxidizing condition. Reducing lacustrine environments is however probable in the Bida Basin.

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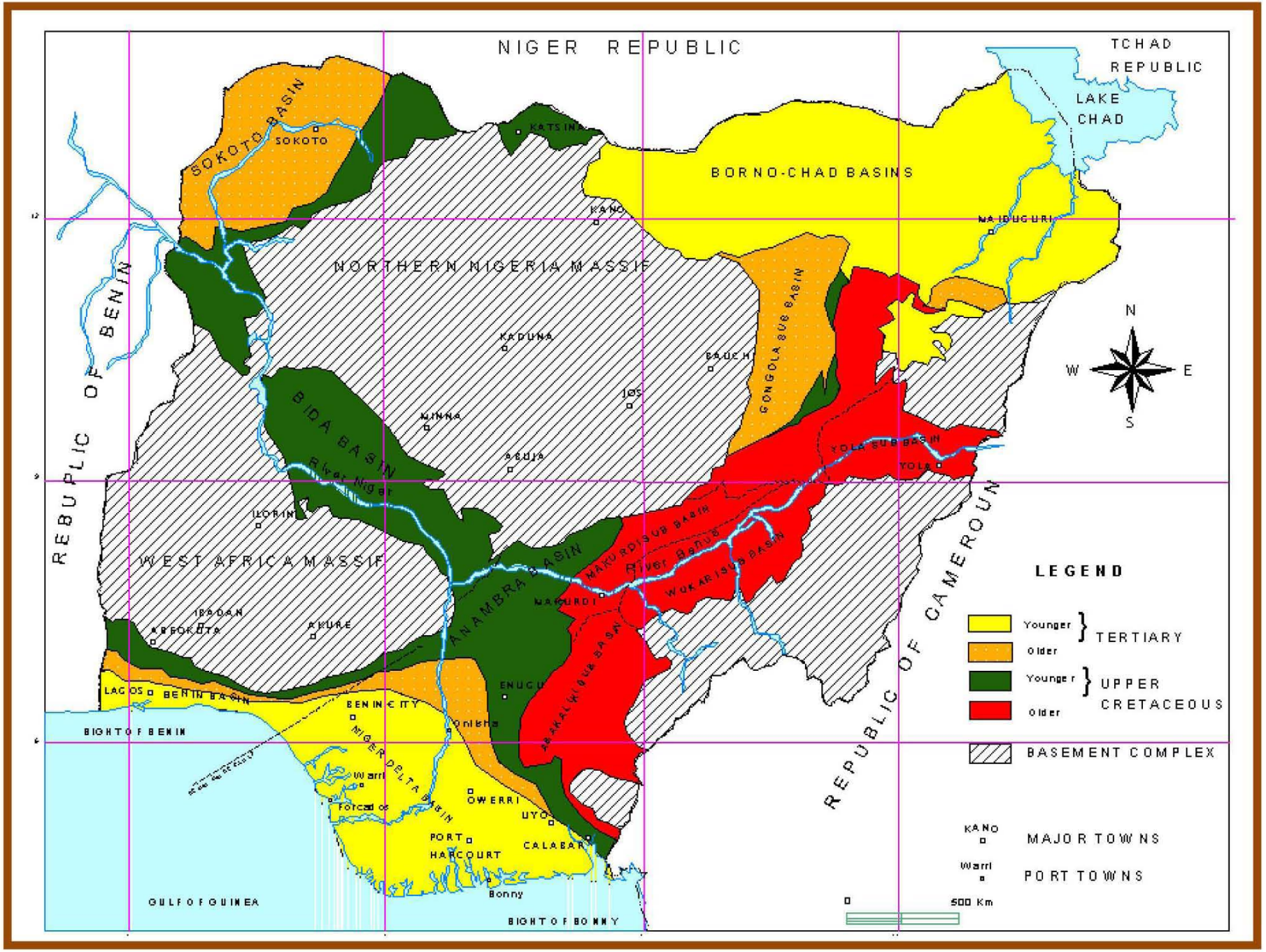

Figure 1. Geological map of Nigeria. Note the position of the investigated Bida and Gongola basins.

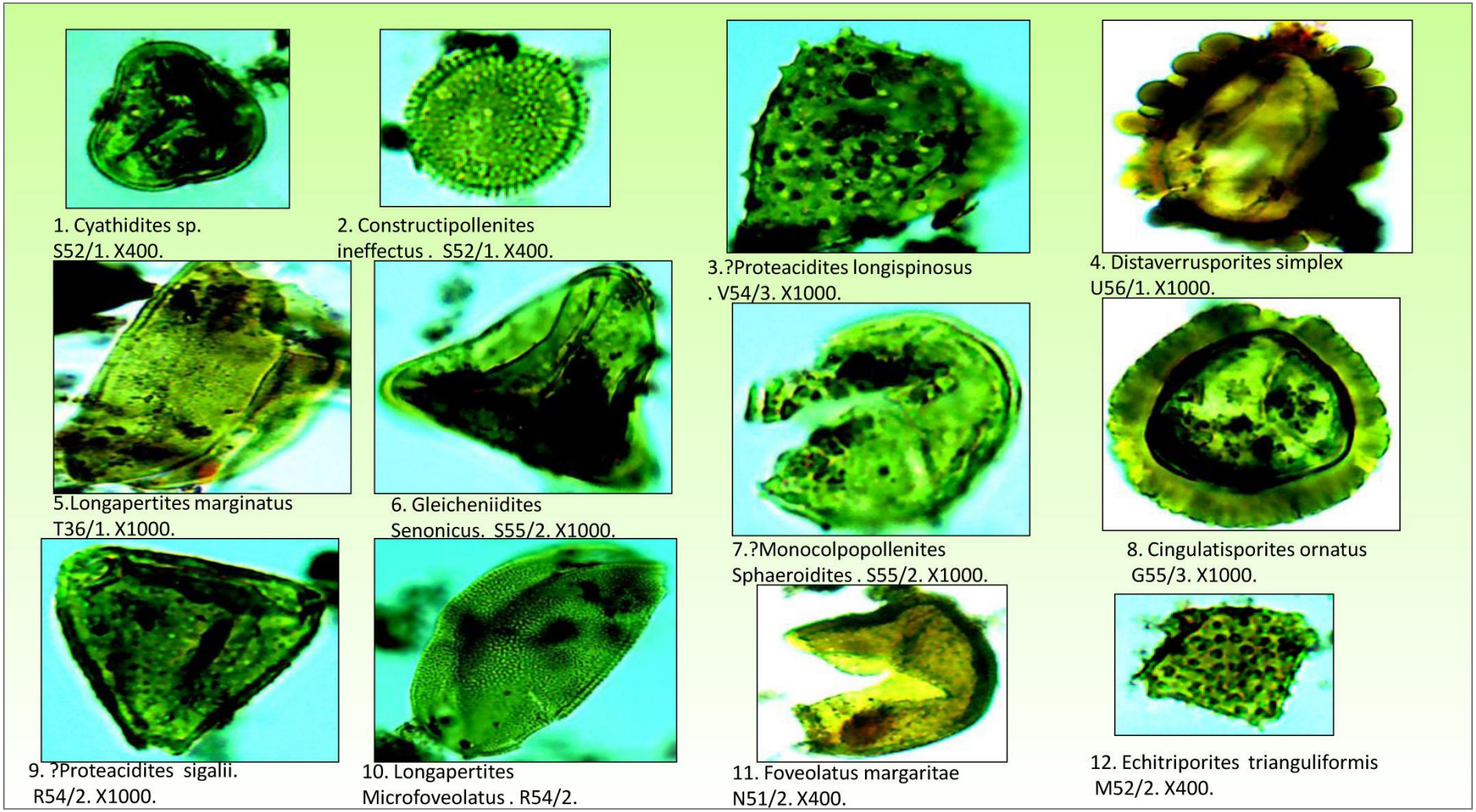

Figure 2. Some Maastrichtian marker palynomorphs from the source rock intervals.

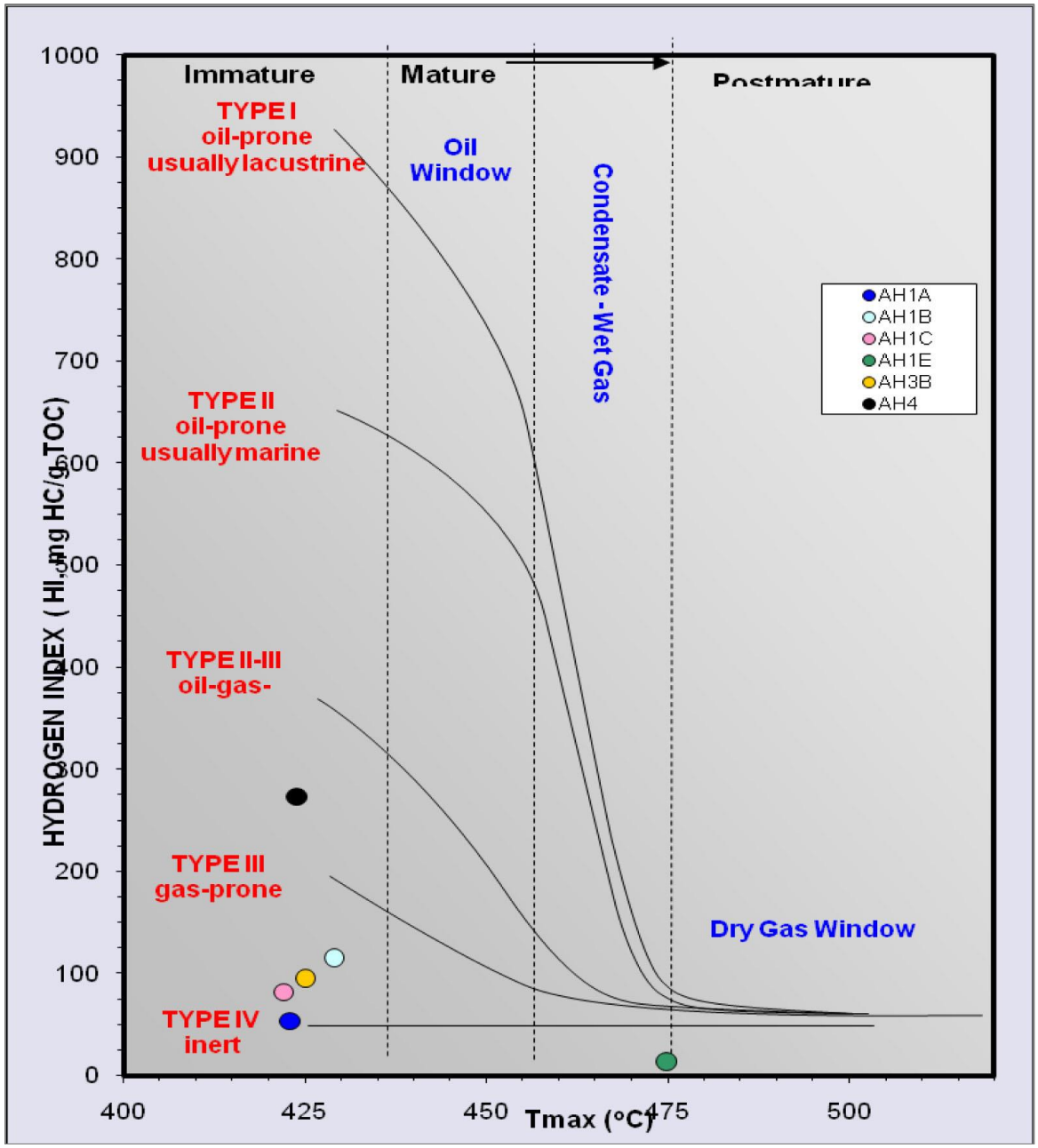

Figure 3a. Plot of HI versus Tmax for shale samples from Patti Formation, Bida Basin.

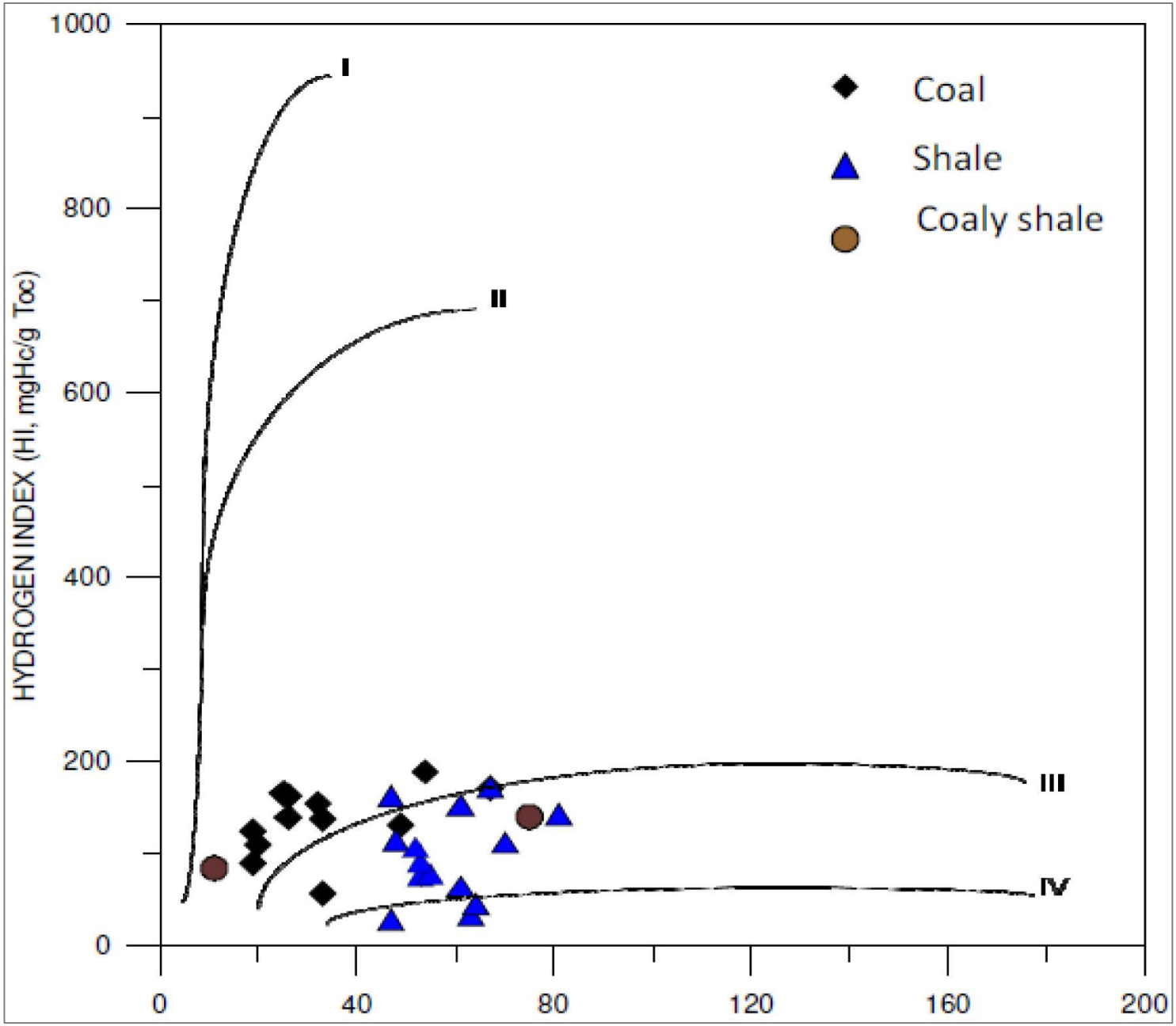

Figure 3b. Plot of HI versus OI for the Gombe Formation samples, Gongola Basin.

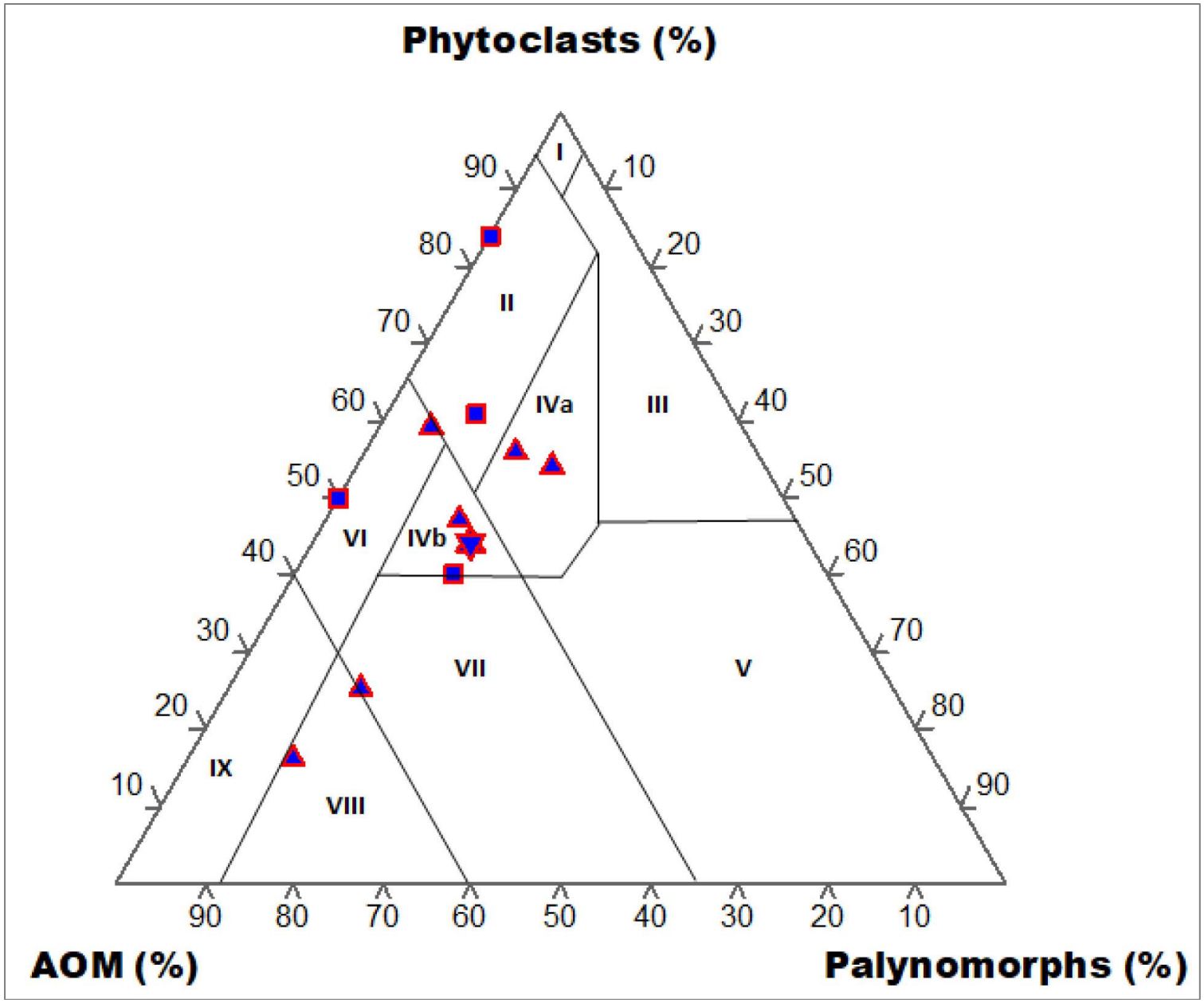

Figure 4. APP Palynofacies Ternary diagram for the investigated samples from Bida and Gongola basins. I Highly proximal shelf or basin, II Marginal dysoxic-anoxic basin, III Heterolithicoxic shelf (proximal shelf), IV Shelf to basin transition, V Mud-dominated oxic shelf (distal shelf), VI Proximal suboxic-anoxic shelf, VII Distal dysoxic-anoxic 'shelf', VIII Distal dysoxic-oxic shelf, IX Distal suboxic-anoxic basin.

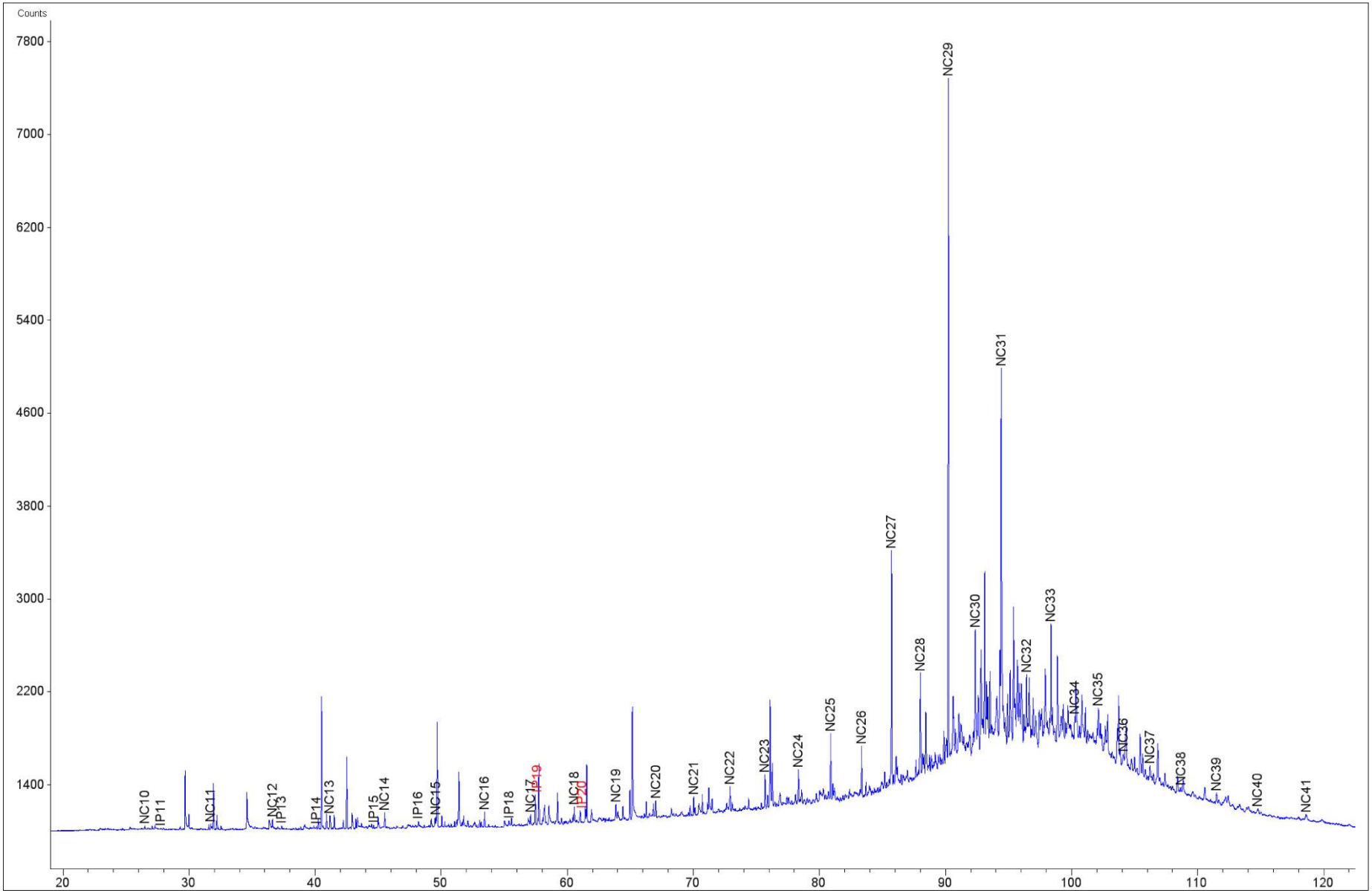

Figure 5a. Gas chromatography and biomarker diffractogram for Patti Formation shale, Bida Basin

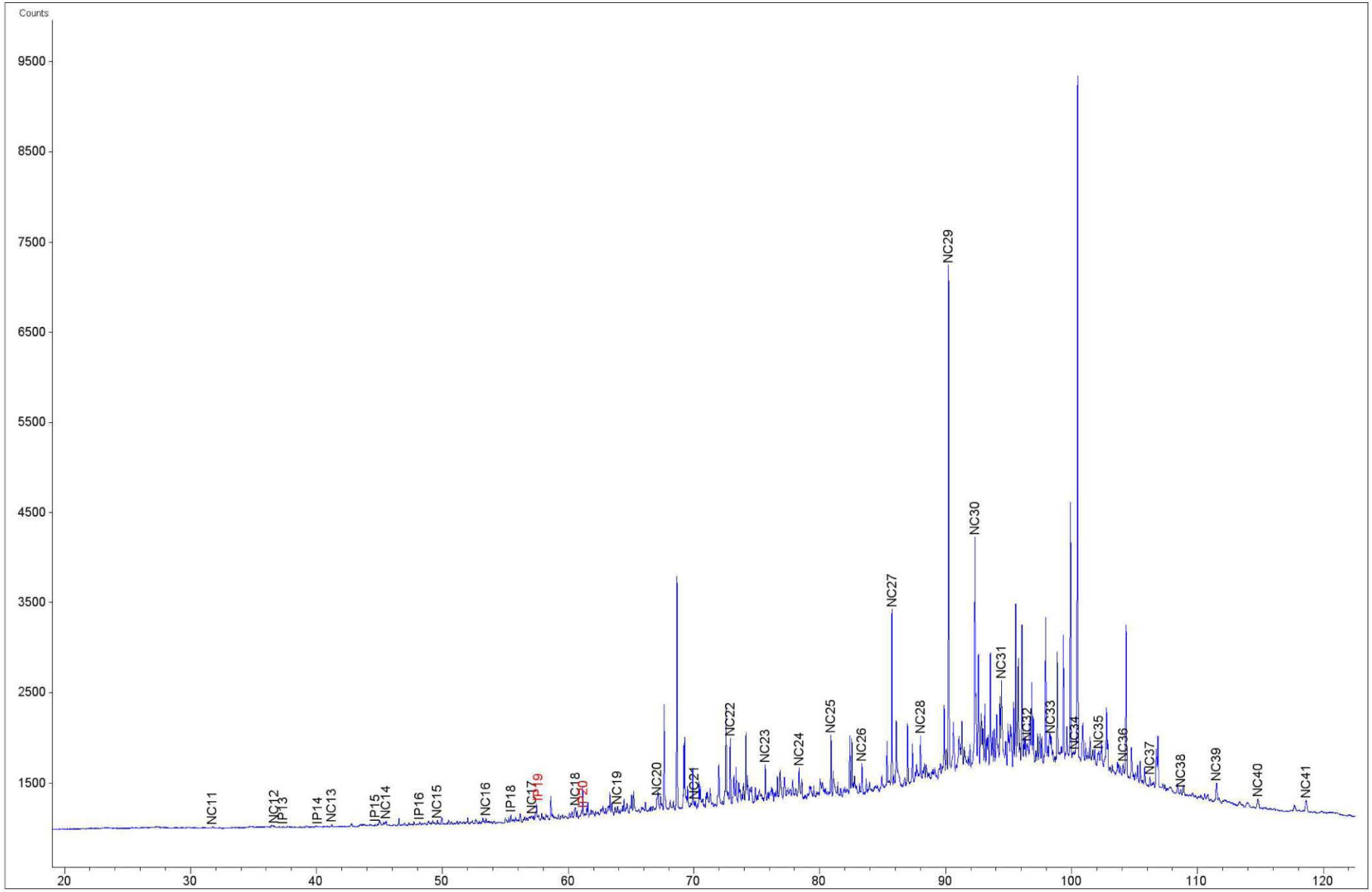

Figure 5b. Gas chromatography and biomarker diffractogram for Gombe (Gongola Basin). Note the single peak denoting single source from higher plants and prevalence of heavy fractions.