

Organic Matter Characterization and Palynological Evidence of Mid-Ordovician to Pennsylvanian Age of the Tabenken Coal, Northwest Cameroon

Abimnui Norine Wendi¹, Njilah Isaac Konfor¹, Yongue Fouateu Rose¹ and Bruno Ndicho Nfor²

1. Department of Earth Sciences, Faculty of Science, The University of Yaounde 1, Yaounde 812, Cameroon

2. Department of Geology, Chukwuemeka Odumegwu Ojukwu University, Anambra State 234, Nigeria

Abstract: In this work, we intend to investigate the kerogen composition of the Tabenken coal hence, its palaeo-depositional environment and age. Tabenken is one of the three areas in the continental sectors of the CVL (Cameroon Volcanic Line) where coal occurs in between a granitic basement and volcanic outpours. Samples of coal from this seam were studied to determine the organic matter richness, maturity, depositional environment and its age through organic geochemical techniques such as Rock-Eval pyrolysis and palynological studies. HI (Hydrogen Index) obtained is less than 200 mgHC/gTOC for most of the samples indicating Type III kerogen for these samples (gas prone) and terrestrial source of the original peat-forming organic matter. One sample presents a HI of 462 mgHC/gTOC indicating organic matter type II, prone to producing oil. Palynological studies reveal the presence of hydrogen-rich AOM (Amorphous Organic Matter) indicating preservation under dysoxic-anoxic conditions. High values of TOC ranging from 0.29 to 1.98 are suggestive of AOM of terrestrial origin. The remarkable absence of pollen suggestive of deposition before the Pennsylvanian during which the earliest forms of flowering plants first appeared displays a relative abundance of spores in the organic residue suggestive of deposition from the mid-Ordovician. Careful interpretation of palynological data suggests the coal was laid down from the mid-Ordovician to the Pennsylvanian age.

Key words: Kerogen, dysoxic-anoxic, Ordovician, palynology, Pennsylvanian.

1. Introduction

The assessment of organic matter constituents of coal is prerequisite in the interpretation of palaeo-depositional environment of a coal forming locality, palaeo-climate, dating and hydrocarbon potential of the deposit etc. However, previous works on this seam did not consider the organic matter content of the coal [1, 2]. This work is intended to investigate the kerogen composition of the Tabenken coal hence, its palaeo-depositional environment and age. Due to the limitations of Rock eval pyrolysis in deducing kerogen assemblages, we found a need to employ other organic geochemical techniques in achieving the objective of this research. Hence, the type and maturity of the organic matter constituents of

the coal deposit as well as the age of this black sediment investigated were based on palynological studies and Rock-Eval pyrolysis.

2. Location of Study Area

Tabenken is situated about 155 km from Bamenda Northwest Region of Cameroon and belongs to the Nkambe plateau of the Oku volcanic massif. It is found between longitudes 010°42'00" E and 010°46'48" E and latitudes 06°30'00" N to 06°36'00" N. It is bordered to the East by Binka and to the North East by Binshua, to the West by Njap and Nsuni, to the south by Warr and Mbot and to the east by Bwanmbe villages (Fig. 1).

3. Geological Setting

The CVL is geographically divided into the oceanic sector and the continental sector. The oceanic sector is

Corresponding author: Abimnui Norine Wendi, M.Sc., research fields: earth sciences and metallogeny.

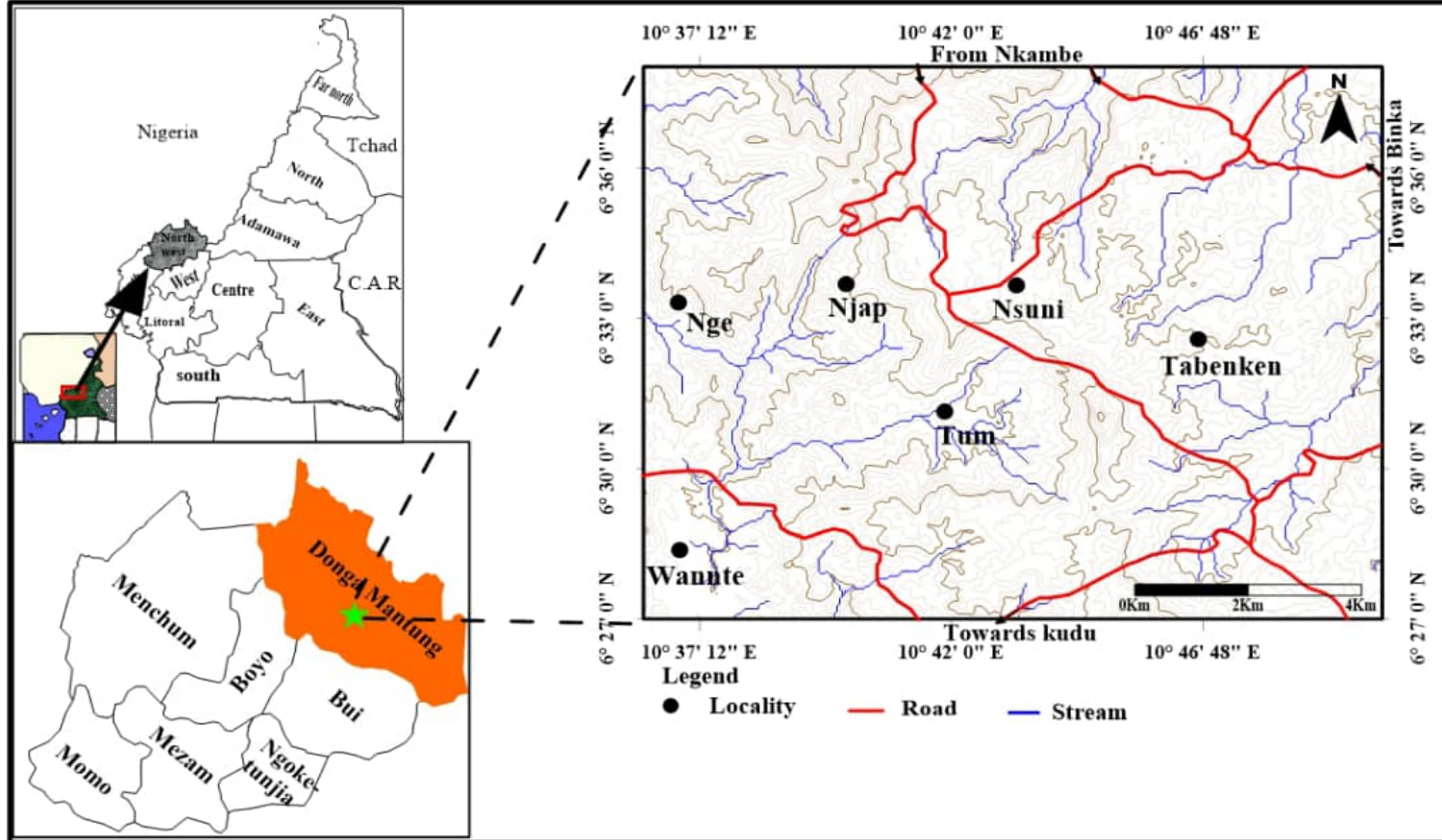


Fig. 1 Location map of Tabenken in the north west region of Cameroon.

made up of the Atlantic islands of Pagalu, Sao Tome, Principe and Bioko while the continental sector is made up of Mt. Etinde, Mt. Cameroon, Mt. Manengouba, Mt. Bambouto, the Bamenda mountains, the Oku Massif (where the Tabenken coal seam is situated), the Adamawa and Biu plateau. Tabenken is a volcano-sedimentary terrain situated in the southern part of the Nkambe stratovolcano found on the midway in the continental segment of the CVL group of volcanoes based on a swell in the CVL, located in the Oku area of the western high plateau of Cameroon [3]. The Mt. Oku stratovolcano rises 3,011 m above sea level. It has a diameter of almost one hundred kilometers and contains four major stratovolcanoes; Mt. Oku, Mt. Babanki, Nyos and Nkambe [3]. Volcanic activity of the massif started 31 Ma ago and continued intermittently to recent [4] with the outpour of rhyolites, trachytes, basalts and recent maars and craters of basaltic cinder cones [3].

4. Methodology

Samples used for rock-eval pyrolysis and palynology were obtained from surface outcrops and pits dug about 10 m apart.

Rock-Eval pyrolysis was performed at the University of Lausanne in Switzerland. A total of 100 mg of the rock is heated at a temperature programmed at an increase rate of 25 °C/min under inert atmosphere (in the presence of helium) and the type of

organic matter was determined by the method described by Espitalié et al. [5] i.e. plotting different parameters S_1 (free hydrocarbons), S_2 (hydrocarbons yield from cracking of kerogen), S_3 (the trapped CO_2 released during pyrolysis), T_{max} (Rock-Eval pyrolysis oven temperature in °C at maximum S_2 generation), the total petroleum potential (S_1+S_2), hydrogen index ($HI = (S_2/TOC) \times 100$, mg HC/g TOC) and oxygen index ($OI = (S_3/TOC) \times 100$, mg CO_2 /g TOC), the production index ($PI = (S_1/(S_1+S_2))$) and the S_2/S_3 together with the HI are proportional to the amount of hydrogen in the kerogen and can indicate the potential of the rock to generate oil, and the pyrolysable carbon index PCI ($PCI = 0.83 \times (S_1+S_2)$) [6]. Data for Rock-Eval parameters of the analysed samples are given in Table 1.

For palynological analysis, samples are washed to remove contaminants and dried in an oven at 1,500 °C for 3 h, then crushed. Analysis was done in the palynological laboratory at Geotechniques Research Ltd. Sunbury in Thames, UK, using standard palynological techniques, including digestion of carbonates and silicates with concentrated HCl (32%) and HF (40%), sieving of residue and oxidation. Slides were produced from unoxidized and oxidized residues. Photomicrographs of palynological assessments are presented on Fig. 2.

5. Results

5.1 Rock-Eval Pyrolysis

Table 1 Data obtained from Rock-Eval pyrolysis of some samples of coal from Tabenken.

Sample	PC (%)	RC (%)	TOC (%)	MINC (%)	HI (mg CO_2 /g)	OI (mg CO_2 /g)	T_{max} (°C)	S_1 (mgHC/g)	S_{2a} (mgHC/g)	S_3	Petroleum potential
IFP 160000	1.07	2.21	3.28	3.26	378	24	416	0.22	12.43	0.79	12.65
TAB2A	0.08	1.9	1.98	0.03	46	4	545	0.01	0.9	0.09	0.91
TAB3	0.01	0.29	0.29	0.01	18	0	508	0.01	0.05	0	0.06
TABG	0.58	0.7	1.28	0.07	462	53	431	0.85	5.92	0.68	6.77
ANTHRA	0.06	26	2.65	0.01	24	3	559	0	0.65	0.08	0.65

5.2 Palynological Analysis

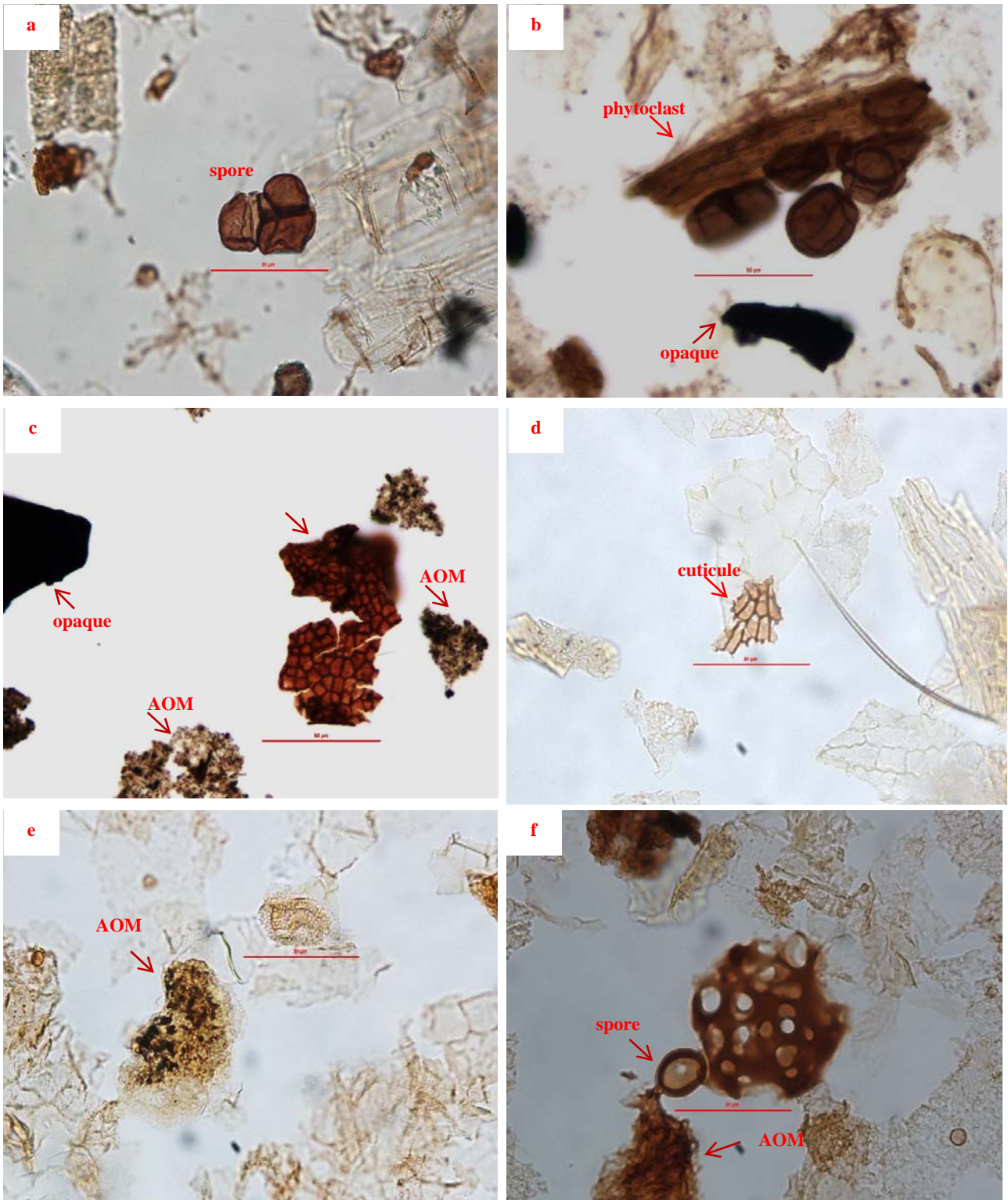


Fig. 2 Photomicrographs of palynological assemblages of the Tabenken Coal.

(a) spores, dispersed cuticles and some opaque material, (b) large phytoclasts and opaque materials, (c) opaque material and amorphous organic matter, (d) mostly cuticles, (e) mostly amorphous organic matter, (f) spores and cuticles.

6. Interpretation and Discussion of Results

6.1 Organic Matter Content

The TOC (Total Organic Matter) content of the analysed samples ranges between 0.29 and 2.6 wt% (Table 1). The minimum TOC value defining a good source rock is 0.5 wt% for shale, 0.3 wt% for carbonate rocks and 1 wt% for clastic rocks [7]. The range of 1.5-2 wt% has been generally accepted for good source rock [7, 8]. Therefore, the TOC for Tabenken coal which ranges from 0.9-2.6 wt%, exceeds the acceptable minimum value required for a potential source rock hence indicating a good source material.

6.2 Kerogen Quality

The values of the T_{max} range from 432 °C to 545 °C (Table1) indicative of a super mature sediment. S_1 peaks (quantity of free hydrocarbons) range from 0.01 to 0.85 mg HC/g whereas S_2 (quantity of fixed hydrocarbons) peaks vary between 0.05 and 5.92 mg HC/g. The S_{2a} peaks detect hydrocarbon compounds

between 180 °C and 325 °C [9]. The values of S_3 recorded range from zero to 0.79 mg CO₂/g. All other parameters such as HI and OI show variations corresponding to the values of S_1 , S_2 and S_3 peaks. HI peaks range from 18 to 462 mg HC/g while OI peaks range from 0.00 to 53 mg HC/g.

S_1 and S_2 peaks show that in the Tabenken coal, fixed hydrocarbons (S_2) are more abundant than free hydrocarbons (S_1) with a very small concentration of carbondioxide (S_3) ranging from 0.00 to 0.68 mg. The Rock-Eval data reveal HI (ranging from 18 to 462 mg HC/g) which is far higher than the OI values (ranging from 0 to 53 mg HC/g) indicating that the Tabenken coal is hydrogen rich and oxygen poor.

The coal rank on basis of T_{max} is anthracite. Plotting Espitalie's graph of T_{max} versus HI (mg HC/g TOC) (Fig. 3), Tabenken coal developed from kerogen type II and III which is generally composed of terrestrial plants and vitrinite, a maceral formed from wood. This is ideal for coal formation, less oil and gas, comparatively higher proportion.

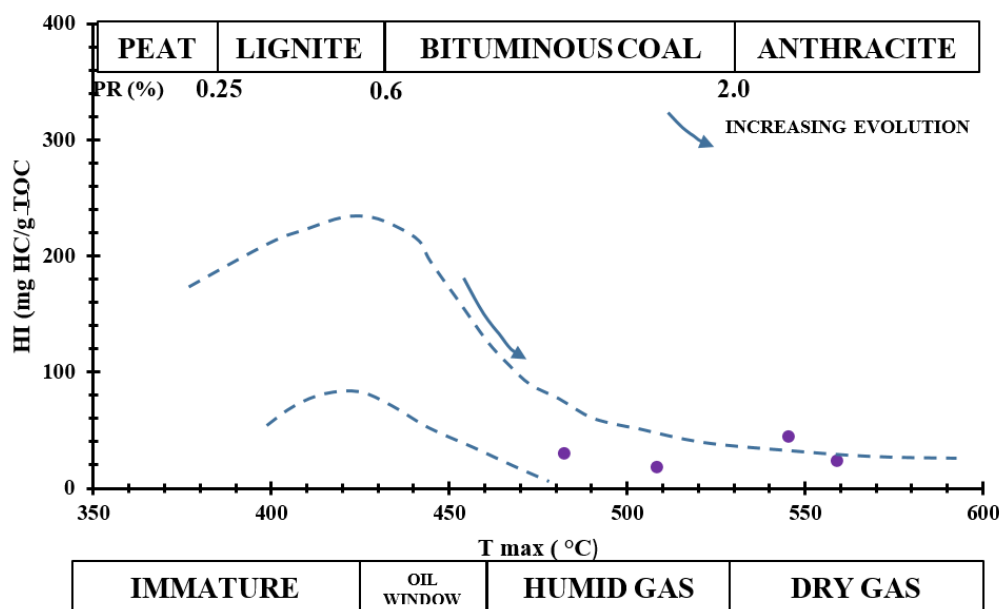


Fig. 3 Espitalie's Graph of HI (mg HC/g TOC) VS T_{max} illustrating maturity of coal and hydrocarbon potential.

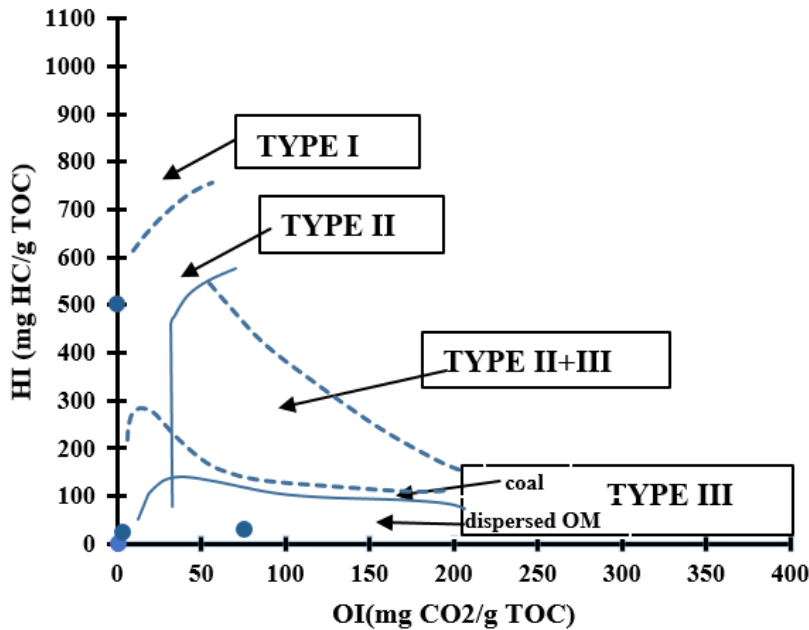


Fig. 4 Espitalie's Graph of HI (mgHC/g TOC) versus OI (mgCO₂/g TOC) showing kerogen composition of the Tabenken coal.

HI (mgHC/g TOC) versus OI (mgCO₂/g TOC) ratio allows for the classification of organic matter (into type I, II or III) and its pathway through maturation. Types I and II are organic material rich in hydrogen, derived from phytoplankton, pollen and spore, fluorescing AOM while type III is made of organic matter rich in oxygen, derived from humic components (phytoclasts). The plot of OI vs. HI shows most of the samples fall within the organic matter type III area while one falls within the area of organic matter type II (Fig. 4). Considering the measured parameters T_{max} and HI, sample TABG has T_{max} of 432 °C and HI of 462 °C and therefore is prone to producing oil. The kerogen type susceptible to producing oil is type II. However, rock eval data alone according to Refs. [10-12], are insufficient to determine what kerogen is present and what kind of hydrocarbon they can generate.

7. Palynological Composition

7.1 AOM

There is a strong predominance of AOM on most of the photos. The AOM identified is opaque to dark

brown in colour and is present in large quantities in these samples. The possible origin of such organic matter is terrestrial plant matter (Fig. 2).

High percentage of AOM reflects enhanced preservation under reducing conditions and to a lesser extent, sedimentation removed from active sources of terrestrial organic matter [13]. AOM consists of easily degradable material that survives only where the duration and extent of aerobic degradation is limited [13]. The hydrogen-rich components of the AOM are preserved by dysoxic-anoxic conditions.

AOM is composed of higher plant decomposition products corresponding to vitrinite or huminite maceral and can be derived from several sources including the degradation of phytoplankton or bacteria and bacterial reworking of organic matter [14]. They equally went ahead to suggest another group of AOM which is terrestrially derived and has been reworking to different extents exhibiting high contents of carbohydrate with AOM associated with high TOC. The total organic carbon content of the Tabenken coal is generally high, ranging from 0.29 to 1.98. These high values are suggestive that the AOM in Tabenken is of terrestrial origin and corresponds to the maceral

group vitrinite and type III kerogen, prone to producing gas.

7.2 Phytoclasts

Phytoclasts are present in the form of woody tissue and cuticles. Woody tissues are observed as opaque and semi-transparent dark brown particles with sharp and angular outlines, poorly to moderately preserved. Cuticle on the other hand is observed as transparent filter-like light fragments. Their possible origin is terrestrial plant tissue. Cuticle is most typical of proximal i.e. fluvio-deltaic, prodeltaic or estuarine mangrove facies especially rich in microscopic plant debris. The nature of the phytoclasts in the samples can be used to deduce the environment of formation of the original peat and the conditions under which they were preserved. The phytoclasts of high particle sizes as seen on the thin sections is indicative of deposition close to a fluvio-deltaic source of terrestrial organic matter. The woody tissue belongs to the vitrinite or huminite maceral group and is made up of type III kerogen, prone to producing gas. Phytoclasts in the form of cuticle belong to the exinite group of macerals, made up of kerogen type II and prone to producing oil.

Cuticles are only present in rocks in small quantities and are found only in sediments near deltas and estuaries. This environment of formation of cuticles and its occurrence in the samples can serve as a palaeo-environmental indicator of the Tabenken area. With this, it is possible to conclude that the coal was deposited in an estuarine/deltaic environment i.e. a partially enclosed body of water into which one or more rivers flow.

7.3 Palynomorphs

Sporomorphs are the only observed palynomorph on the analysed samples. They are observed as transparent to yellow granular particles on some of the microphotographs and are possibly terrestrial plant spores. The sporomorphs observed here belong to the liptinite or exinite group of macerals consisting of

kerogen type II, prone to producing oil. There are no fungal remains, angiosperm pollen or dinoflagellate cysts recorded.

The type of spores (not precise in this research) and its relative abundance is used for paleoclimate interpretation. Spores are commonly produced by bryophytes, pteridophytes and their primitive ancestors. The Bryophyte and pteridophyte life cycles are strongly dependent on moisture for fertilization hence spores are generally common in wet/humid climates. Hence, the vegetation was developed during a period of wetness.

The earliest fossil evidence for land plants comes from microscopic dispersed spores. These microfossils are abundant and widely distributed in sediments and the earliest generally accepted reports are from rocks of the mid-Ordovician, 475 Ma [15]. Meanwhile, drilling cores from Switzerland have revealed the oldest known fossils of the direct ancestors of flowering plants dated Early Triassic, between 252-247 Ma [16]. The Tabenken coal harbors no record of fossil pollen indicating that it was formed before the Triassic. This suggests that the original peat-forming material might have been developed during mid-Ordovician and Devonian. This period was followed by the carboniferous rainforest collapse which saw the destruction of life and mass extinctions leading to the deposition of the original peat from which the Tabenken coal developed. The CRC (Carboniferous Rainforest Collapse) which occurred in the carboniferous period was an extinction event during which climate change devastated the tropical rainforests causing mass extinctions of plant and animal species. Several hypotheses have attempted to explain the CRC, some of which include climate change [17-19]. Particularly, at this time climate became cooler and drier, reflected in the rock record as the earth entered a short intense ice age. The cooler drier climatic conditions were unfavourable for the growth of rainforests and most of the biodiversity within them. Then the succeeding period of global

warming reversed the climatic trend; the remaining rainforests, unable to survive the rapidly changing conditions were finally wiped out and replaced by seasonally dry biomes [20]. This is most likely to have been the mode of formation of the Tabenken coal.

7.4 Opaque Material

This is dark material observed on some of the thin sections considered to always be the result of terrestrial post depositional alteration, reflecting seasonal fluctuations in water column allowing exposure to sub-areal oxidation and also due to oxidation during transport [13, 21]. The presence of opaque phytoclasts in Tabenken coal suggests that the region had experienced cycles of rising and dropping of the water column which enhanced the oxidation of the woody tissue present therein. Such phytoclasts are usually produced under subaerial conditions or by charcoalfication (natural pyrolysis, not burning) where there is effect of high temperature in the absence of oxygen that can occur in the middle of large natural fires [22]. This is also a terrestrial process. Opaque or black woody material is partly (but not precisely) equivalent to the inertinite maceral group and has a high carbon and low hydrogen content with no hydrocarbon potential and corresponds to kerogen type I/II. Also, opaque material is formed from charcolification of spores. Pteridophyte spores are known to thrive in warm humid lowlands e.g. river sides and coastal areas [23, 24] suggesting that Tabenken had been marked probably by marine incursion indicated by the presence of Kerogen type II. Progressive increase in temperature and burial pressure probably led to the formation of coal. This deposit was disturbed by intense volcanic activity which produced the volcano-sedimentary assemblage and high grade coal in Tabenken.

8. Conclusion

The Tabenken coal seam is made up of anthracites and consists of kerogen type II and III and to a very

minimal extent, kerogen type I. The organic matter is more susceptible to producing dry gas and less oil. The coal was deposited in an estuarine/deltaic environment. High percentage of AOM reflects enhanced preservation under reducing conditions and to a lesser extent, sedimentation removed from active sources of terrestrial organic matter. Easily degradable material in AOM survives only where the duration and extent of aerobic degradation is limited. The hydrogen-rich components of the AOM are preserved by dysoxic-anoxic conditions. Phytoclasts, AOM and palynomorphs are abundant although there is a remarkable absence of pollen suggestive of deposition before the Pennsylvanian during which the earliest forms of flowering plants first appeared; but displays a relative abundance of spores in the organic residue suggestive of deposition from the mid-Ordovician being the era during which the earliest forms of spore producing plants first appeared. Careful interpretation of this data suggests the coal was laid down from the mid-Ordovician to the Pennsylvanian.

Acknowledgement

Appreciation goes to the Director and staff of IRGM in Yaounde, Cameroon for their technical and material input in the realization of this work. The technical assistance of the lecturers of the Department of Earth Sciences of the University of Yaounde I is also well appreciated.

References

- [1] Kenfack, P. L. 2002. "Données Sédimentologiques Préliminaires sur les Sédiments Intercalés entre les Niveaux Pyroclastiques de Ngwa." In *Mém. Maît. Sci. Terre. Univ. Dschang*. p. 44. (in French)
- [2] Wendi, A. N., Konfor, N. I., Rose, Y. F., Nanje, M. F., and Ndicho, N. B. 2022. "Geology, Palaeodeposition and the Involvement of Rhyolite Melts in the Petrogenesis of the Tabenken Coal Seam in the North West Region of Cameroon." *Journal of Geoscience and Environment Protection* 10: 111-26.
- [3] Burke, K. 2001. "Origin of the Cameroon Line of Volcano-Capped Swells." *The journal of Geology* 109: 349-62.

- [4] Njilah, I. K. 1991. "Geochemistry and Petrogenesis of Tertiary-Quaternary Volcanic Rocks from Mt. Oku Volcano, N.W. Cameroon." Ph.D. thesis, University of Leeds.
- [5] Espitalié, J., Deroo, G., and Marquis, F. 1986. "La pyrolyse Rock-Eval et ses applications." *Revue de l'Institut Français du Pétrole* 41: 73-89. (in French)
- [6] Shaaban, F., Lutz, R., Littke, R., Bueker, C., and Odisho, K. 2006. "Source-Rock Evaluation and Basin Modelling in Ne Egypt (Ne Nile Delta and Northern Sinai)." *Journal of Petroleum Geology* 29 (2): 103-24.
- [7] Killips, S. D., and Killips, V. J. 1993. *An Introduction to Organic Geochemistry*. Harlow: Longman.
- [8] Hunt, J. H. 1996. *Petroleum Geochemistry and Geology* (2nd ed.). New York: Freeman, p. 743.
- [9] Trabelsi, K., Espitalié, J., and Huc, A. Y. 1994. "Characterization of Extra Heavy Oils and Tar Deposits by Modified Pyrolysis Methods." In *Proceedings of the "Heavy Oil Technologies in a Wider Europe" Thermie EC Symposium*, Berlin, pp. 30-40.
- [10] Larter, S. R., and Douglas, A. G. 1980. "A Pyrolysis Gas Chromatographic Method for Kerogen Typing." *Physics and Chemistry of Earth* 12: 579-83.
- [11] Dembicki, Jr. H. 2009. "Three Common Source Rock Evaluation Errors Made by Geologists during Prospect or Play Appraisals." *American Association of Petroleum Geologists Bulletin* 93: 341-57.
- [12] Dembicki, Jr. H., Horsefield, B., and Ho, T. T. Y. 1983. "Source Rock Evaluation by Pyrolysis-Gas Chromatography." *International Journal of Coal Geology* 32: 55-67.
- [13] Tyson, R. V. 1993. "Chapter 5; Palynofacies Analysis." In *Applied Micropalaeontology*, edited by Jenkins, D. G. Amsterdam, the Netherlands: Kluwer Academic Publishers, pp. 153-91.
- [14] Mendonca Filho, J. G., Chagas, R. B. A., Menezes, T. R., Mendonca, J. O., da Silva, F. S., and Sabadini-Santos, F. 2010. "Organic Facies of the Oligocene Lacustrine System in the Cenozoic Taubate Basin, Southern Brazil." *International Journal for Coal Geology* 84 (3-4): 166-78.
- [15] Wellman, C. H., Osterloff, P. L., and Mohiuddin, U. 2003. "Fragments of Earliest Land Plants." *Nature* 425 (6955): 282-5.
- [16] Peter, A. H., and Feist-Burkhardt, S. 2013. "Angiosperm-Like Pollen and Afropollis from Middle Triassic (Anisian) of the Germanic Basin (Northern Switzerland)." *Frontiers in Plant Science* 4: 344.
- [17] Herkel, P. H. 1991. "Lost Branch Formation and Revision of Upper Desmoinesian Stratigraphy along Midcontinent Pennsylvanian Outcrop Belt." *Geological Survey, Geology Series*.
- [18] Fielding, C. R., Frank, T. D., Begeheier, L. P., Rygel, M. C., Jones, A. T., and Roberts, J. 2000. "Stratigraphic Imprint of the Late Palaeozoic Ice Age in Eastern Australia. A Record of the Alternating Glacial and Non-glacial Regimes." *Geological Society of London Journal* 150: 129-40.
- [19] Dimichele, W. A., Cecil, B., Montanez, I. P., and Falcon Lang, H. J. 2010. "Cyclic Changes in Pennsylvanian Palaeoclimate and Its Effects on Floristic Dynamics in Tropical Pangea." *International Journal of Coalgeology* 83 (2-3): 329-44.
- [20] Torsvik, T. H., Smethurst, M. A., Burke, K., and Steinberger. 2008. "Long Term Stability in Deep Mantle Structure: Evidence from 300Ma Skagerrak-Centered Large Igneous Province (the SCLIP)." *Earth and Planetary Science Letters* 267: 444-52.
- [21] Tyson, R. V. 1995. *Sedimentary Organic Matter. Organic Facies and Palynofacies*. Londres: Chapman and Hall, p. 615.
- [22] Cope, M. J. 1981. "Products of Natural Burning as a Component of the Dispersed Organic Matter of Sedimentary Rocks." In *Organic Maturation Studies in Fossil Fuel Exploration*, edited by Brooks, J. London and New York: Academic Press, pp. 89-109.
- [23] Pelzer, G., Riegel, W., and Wilde, V. 1992. "Depositional Control on the Lower Cretaceous Wealdon Coals of Northwest Germany." *Geol. Soc. Am. Spec. Pap.* 267: 227.
- [24] Abbink, O. A., Van Konijnenburg-Van Cittert, J. H. A., and Visscher, H. 2004. "A Sporomorphs Ecogroup Model for Northwest European Jurassic-Cretaceous: Concepts and Framework." *Neth. J. Geosci.-Geologie En. Mijnbouw* 83: 17-38.