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# The Role of Rhyolites Melts in the Petrogenesis of Tabenken Coal Seam, Northwest Region, Cameroon

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***Abstract***

*In Cameroon, coal has been identified in Bali, Dschang, Fundong, Mamfe and Tabenken. Though its occurrence has been identified, detailed geologic studies in the areas of geochemistry and petrographic have not been done to qualify these coal seams, which knowledge will afford geologists to have a holistic view of coal. The objective of this research thus was carry petrographic and geochemical analyses of the coal samples in other to have an insight about its quality and afford Government and potential investors take informed decisions when considering exploitation and use of the resource. In other to achieve these ten coal samples collected during field studies were subjected to petrographic studies and two samples for geochemical analyses following standard procedures. Results from field description and petrography show that, coal ranks within the seams range from peat to anthracite, some occurring singly, while most were mixed with shale, sandstone and rhyolites. Thin sections show that the coal intercalated with rhyolites has high quartz content The presence of high quartz percentage may suggest two origins; coal formed from detrital origin and intrusion of silica from rhyolitic tuffs, since rhyolites contain high percentages of silica (>70 %). The presence of hydrocarbon veins observed in the thin sections are interpreted as resulting from the presence of the rhyolitc fluids, whose outpours were caused by diapiric movement, of the coal into the viscous rhyolite. These temperatures thus were sufficiently high to melt the coal into liquids. Results obtained for major elements geochemistry reveal that the percentage composition of the elements SiO2, Al2O3 and Fe2O3 are dominant constituents and account for over 57.46 % average weight composition. Other major elements such as K2O, TiO2, MgO, Na2O and MnO are present in low concentrations (average of 3.97 wt %). The high concentration of SiO2 and Al2O3 indicate high detrital quartz and clay mineral content in the coal measures. This is in general agreement with results obtained with work done in the nearby Anambra basin, Nigeria. The high concentrations of SiO2 (57.46 average wt %), (as observed in thin sections as well) for the samples TBN04, TBN08 and Al2O3 content (19.58 average wt %) compared with the concentrations of other major elements in the analyzed samples, suggest a high detrital input from the surrounding of the basin during peat formation. The presence of TiO2 and P2O5 is indicative of basaltic rocks of oceanic environment. These elements also reveal that Si, Al, Ti and K originate mostly from a mixed clay assemblage, which is a constituent of kaolinite and illite. The XRD analytical results show that the TCS is mainly composed of siliceous mineral such as quartz (SiO2), kaolinite [Al2 (SiO2O5)(OH)4)]. The mineral suites in the TCS coal samples used are similar with the South African coals. Kaolinite is uniformly distributed in the coal samples.*

**Keywords:** Autonomous Shipping, Autonomous Ship Control System, Formalization of Navigation Operations.

## Introduction

Coal has been used worldwide as a source of fuel for household and more especially during the industrial revolution as fuel for the running of engines. At that time several coal mines were opened in England and most of Europe. Moreover, fluctuations in crude oil prices have pushed importing countries into searching for other sources of energy. The use of coal could be an appropriate choice. Although coal can be converted into several products, its conversion into transportation fuels (liquids) in which 47.5 % of crude is also in use and is of prime importance [1].

In Cameroon, coal is a very rare natural resource as research has only found peat in Bali in the North West Region, lignite in Dschang, in Foundong East of Bamenda, Mamfe in the South West Region and unquantified coal seams in Tabenken [2]. Tabenken is situated South of Nkambe town around longitudes (10°47’00’’E and 10°47’00E) and latitudes (06°30’00’’N and 06°35’00’’N) in the Donga Mantung Division of the North West Region. Tabenken is underlain by a granitic basement, upon which Tertiary-Quaternary volcanoes uncomfortably lie. The volcanic deposits range from basalt to trachyte and rhyolites [3].

## General Geology of Tabenken

Tabenken (Figure 1) is dominantly underlain by granitic rocks as well overlain by volcanic outpours composed of basalts, trachyte, rhyolite and hyaloclastite. . While the granites are of the Pan African age, K-Ar age determination show that the volcanoes are Tertiary-Quaternary laid down 31-28 Ma [3].

Tabenken lies in the Nkambe massif of the Oku volcanic field situated North West of the continental segment of the Cameroon volcanic line. The Cameroon volcanic line CVL (Figure 6) is a major volcano-tectonic feature of West Central Africa. It is a Cenozoic volcanic event characterized by a 1600 km long Y-shaped chain of Tertiary to Recent, generally alkaline volcanoes that follows a trend of crustal weakness and stretches from the Atlantic Island of Pagalu, through the Gulf of Guinea, to the interior of the African continent [3]. It is one of two unique volcanic trends in the world that straddles the continental margin characterized by both oceanic and continental volcanisms. The continental sector enters into mainland of Cameroon from South West to North East of Mount Etinde, Mount Cameroon (that erupted seven times in the last century the most recent being in 2000), Mount Bamboutos, the Oku massif, the Adamawa plateau and the Mandara mountains [4, 5]. Tabenken lies on the Nkambe plateau which is one of the strato volcanoes of the Oku massif.

The coal seam of Tabenken outcrops at full lengths along the Mammie and Kummie stream channels with arkosic sandstones overlain by rhyolite. The rhyolite appears to have cut through or overlain the coal and boiled it to produce hydrocarbons, which subsequently flowed into the fractures of this rhyolite constituting micro veins.

The first research carried out on the Tabenken coal seam was done in 2013 [6]. This work involved ultimate analysis which enabled us to determine the percentage of fixed carbon, hydrogen, nitrogen, sulphur, oxygen and ash content in coal. However, this coal seam was first identified and documented by Ntep et al, 2000. The main objective of this work therefore is to evaluate the geochemistry and petrography of the coal so as to ascertain its proper mineralogical composition considering its close association with igneous rocks.

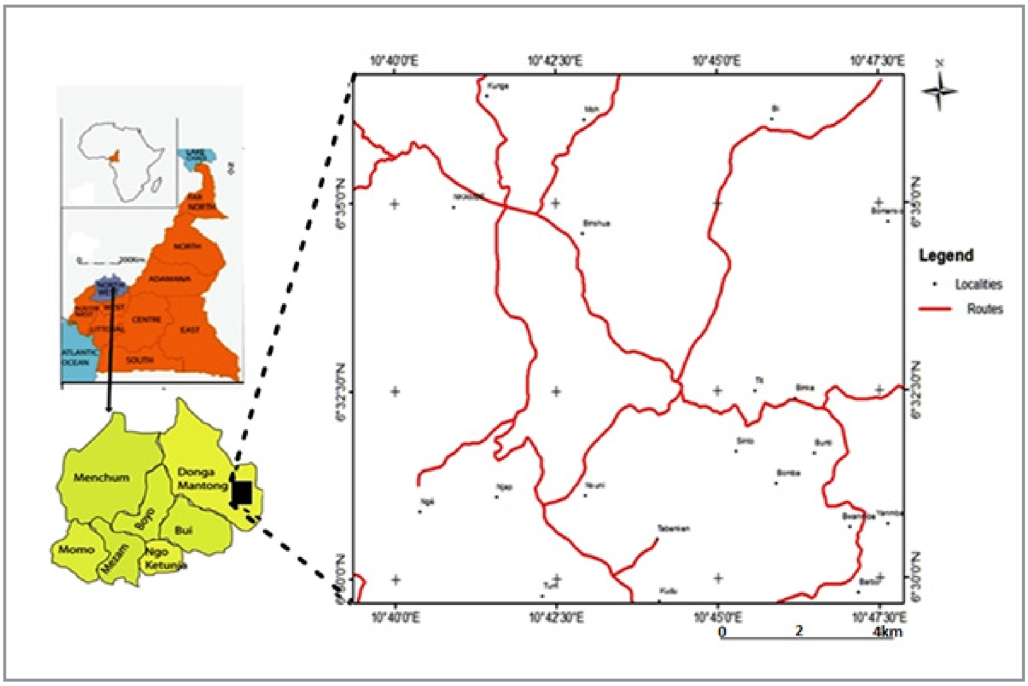



**Figure 1:** Location map of the study area (We need to increase the font size in the map.)

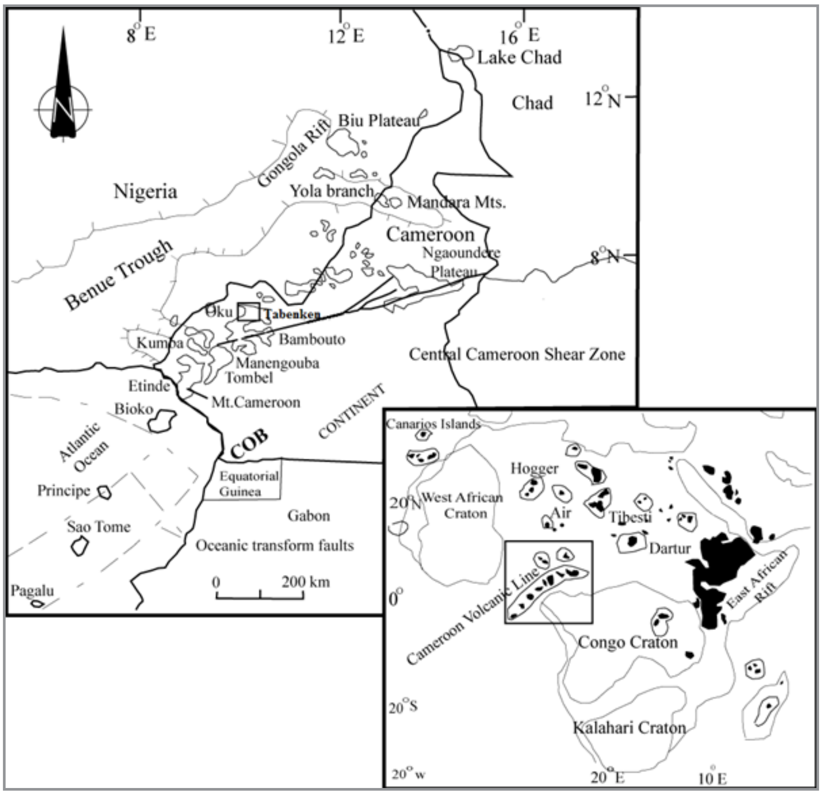



**Figure 2:** The Cameroon Volcanic Line showing main volcanic centers from Fitton and Dunlop, (1985).

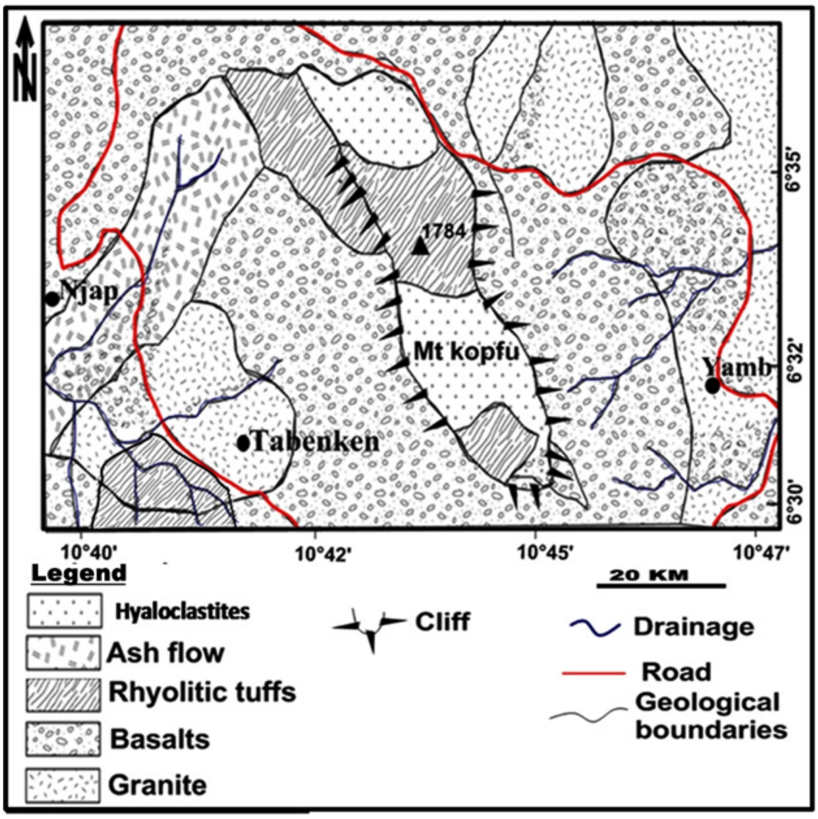



**Figure 3:** General geology of Tabenken (modified from Njilah, 1991) I suggest we get a section of the map by Tepsogang. This was poorly modified

**Identification and Description of the Outcrops**

The general outcrop of this area consists of two main formations; igneous formations (granites and volcanics) and sedimentary units as minor outcrops of (clay, conglomerates, arkosic sandstone and coal).

The Tabenken coal is found along the Kummie and Mammie River valley in Tuku, at longitudes 06”29’32.5”N and latitudes

10’41”16.6E. The exposed basal sequence here consists of conglomerates and arkosic sandstones.  These sedimentary formations consist of particles of older rocks which have been transported and deposited. Floats and boulders contain particles of varied sizes and shapes which range from angular to sub angular, rounded to sub rounded and poorly or unsorted pebbles. Downstream, the basal unit consists of shales spread out throughout, with colors ranging from grey reddish brown to pink. Where the rhyolites intrude the coal, the shales grade into units of easily fragmented peat. This unit is overlain by ash beds and patches of mud mixed with sandstone. Further downstream, the basal unit consists of patches of vegetation alongside weathered rhyolites. The rhyolitic tuffs appear with colors ranging from cream white to pale yellow. They are in direct contact with coal. The rhyolites appear in bands of fragments and are not compacted.

Along the streams, coal is mixed with clay, arkosic sandstone and intercalated with volcanic material. The rounded nature of some of the boulders suggests long distance transportation. There is massive transportation and deposition of material throughout the river bed (Figure 9d) at geographical coordinates N06°29’06.0” and E010°41’21.2”, petrified wood can be seen lying along the river bank beneath rhyolites (Figure 9c). This shows a cross section of plant stem with aspects of collenchyma and sclerenchyma clearly displayed.


**Figure 4a:** Surrounding wall of the upper section of stream bed showing water leakage.

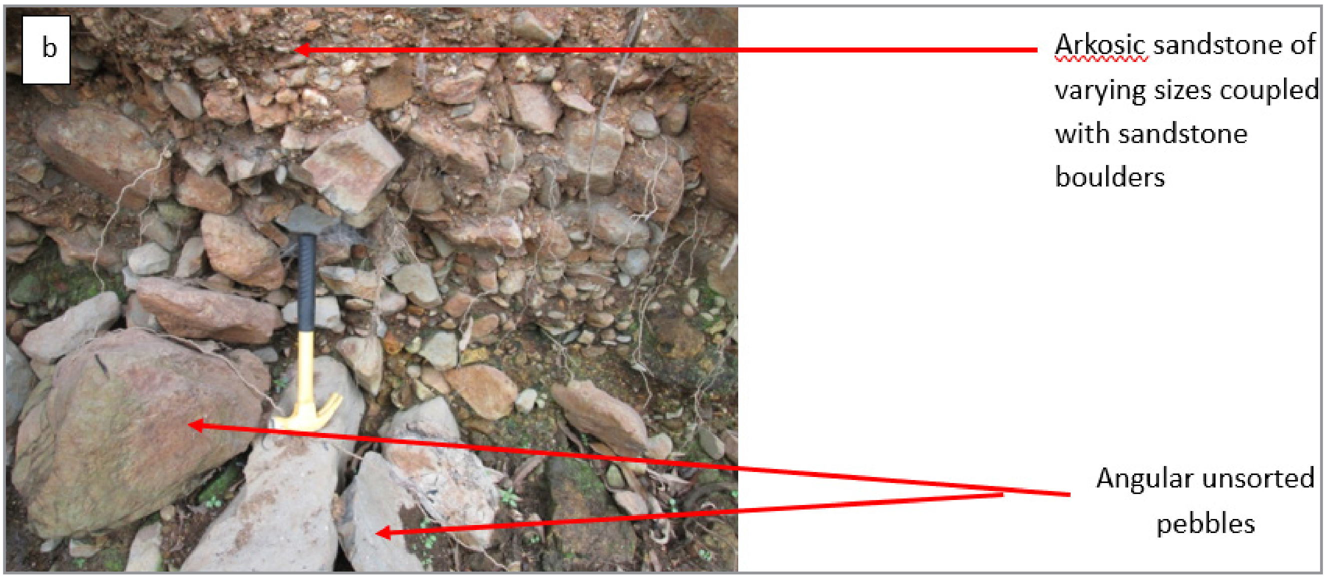



**Figure 4b:** Conglomerate outlining full length of the mammie river channel.

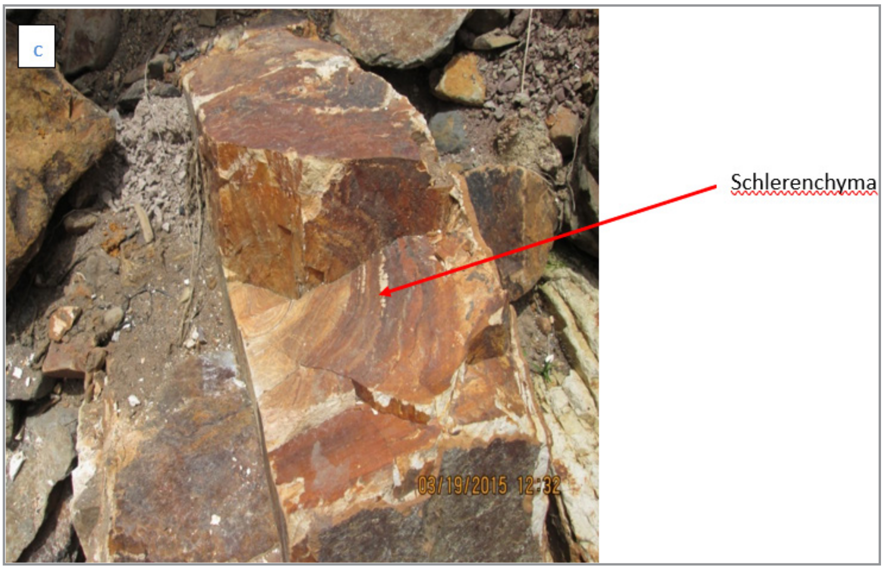



**Figure 4c:** Petrified wood

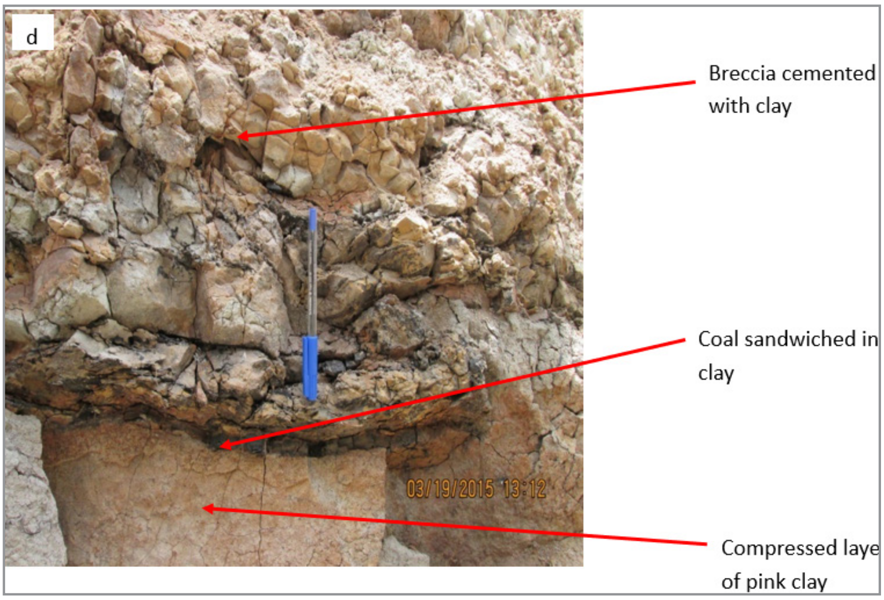



**Figure 4d:** Coal embedded in clay material

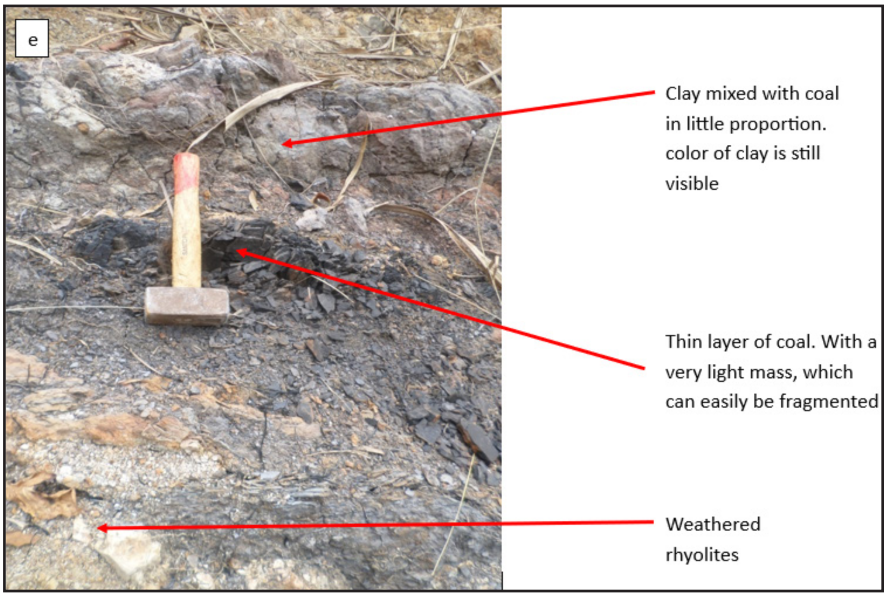



**Figure 4e:** Coal in its earliest stage of formation (peat).

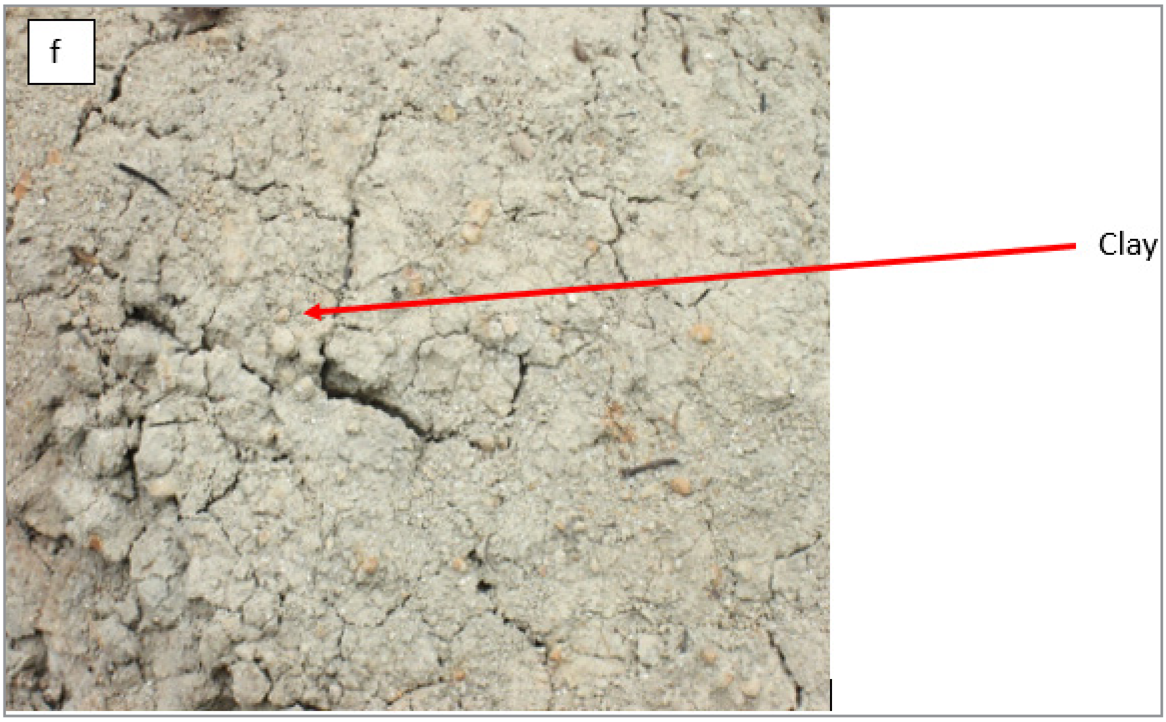



**Figure 4f:** Clay a typical mineral that spreads throughout the Mammie River channel.

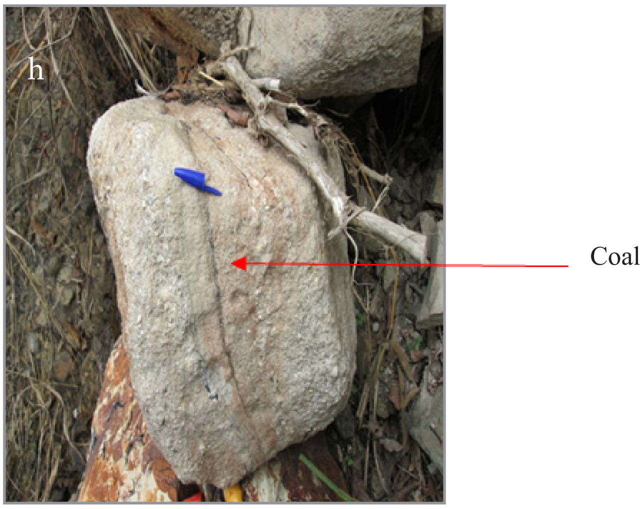




**Figure 4:** General outcrop covering the Tabenken coal seam:
g) Coal found within a 6-meter pit dug on the southern portion of the river where cultivation is taking place.
h) Coal completely cemented and covered with clay and rhyolites.

**Field Sampling**
A total of 9 samples were collected for geochemical, petrographic and mineralogical analysis. These were labeled with a labeling maker TBN01-TBN09.

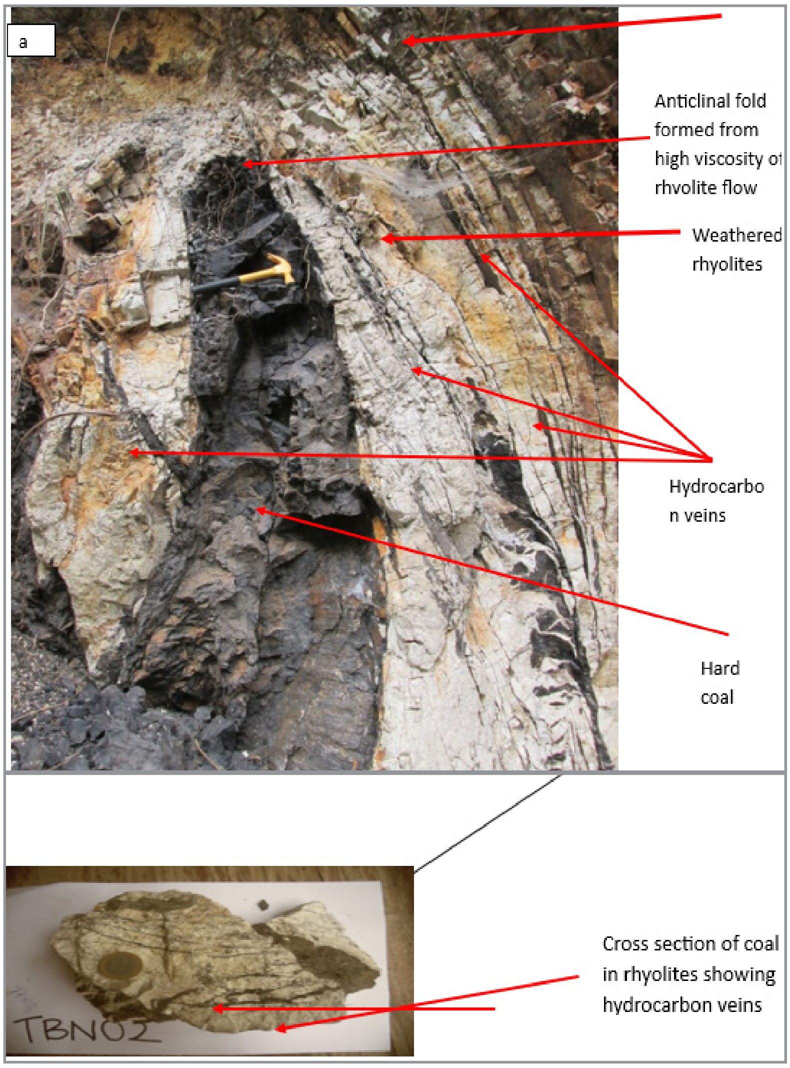
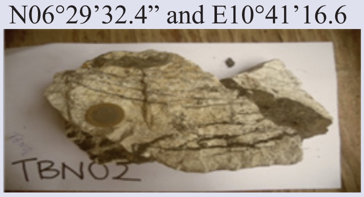



**Figure 5:** Outcrop showing a coal seam interbedded with sedimentary rocks.

**Table 1:** Field description of coal and associated rock samples collected from different locations within the study area

| Sample name | Location | Description |
|---|---|---|
| TBN01 | N6°35' and E10°40' | This sample consisted of the different clay types (based on colors observed) that were found around the study area. |
| TBN02 | N06°29'32.4" and E10°41'16.6  | This was the main area of focus for the study. Grey white rhyolite was seen extending a large surface with coal appearing in form of veins. Outcrop was about 6m wide and the coal intercalations appearing in a centimetric direction. Coal layer of about 50 cm thick was seen extending right below the basement and almost extending into the flowing stream. The surface of this formation was covered by vegetation. At this same point we could find thick fine black layer of coal. Coal was folded in an asymmetric direction with the intrusion of yellowish rhyolitic dyke. |

| | | |
|---|---|---|
| TBN03 | N06°29’36.6”and E010°29’36.6”    | Within the river valley at this point coal appeared completely mixed with fine grains, loose and coarse grain sandstone forming a coherent mass. Rock mass was heavy. Grains of quartz could be observed with the eyes. At some points, coal occurred as an interruption in the deposition of sandstone forming a thin continuous layer of coal within the sandstone layer. Sample was cracked with the aid of a geologic hammer. The interior shows a continuous uniform mixture of sandstone and coal with an overall black colour. |
| TBN04 | N06°29’32.4” and E010°41’16.6  | Coal was hard with shiny black color and glassy texture. |
| TBN05 | This was the rhyolite sample I can’t lay hand on the picture of this sample | |
| TBN06 | N06°29’00.1”and E010°41’16.6” | Coal was quite friable, occurring in thin layers which are very fragile and crumble easily into dust. Some where they are coated with reddish brown material. At the base was found black dust and highly fragmented coal of different sizes and variable shapes. |
| TBN07 | N06°29’30.8” and E010°41’16.6”  | It is fragile woody and fibrous and covered with ground mass. The wood was in its early stage of coal formation and demonstrates characteristics of peat. |
| TBN08 |   | This was a piece of coal in sandstone matrix with partially decomposed plant leaves. The color was brownish black. The proportion estimated as 40 % coal and 60 % sandstone. |
| TBN09 | N06°00’54.41” and E010°41’17.8  | It was a light weighted coal covered with ash. |

**Laboratory Analysis**
**Petrography**
A total of eight thin sections were prepared at the Institute of Mining and Geological Research Nkolbisson-Yaoundé from selected samples. The observations of the thin sections were done at the laboratory of Magmatism and Natural hazards, Depart-

ment of Earth Sciences, University of Yaoundé I and photomicrographs were taken using a digital camera.

**Geochemistry**

Geochemical analysis of major elements of coal and coal bearing rhyolite was carried out on two samples, TBN04 and TBN08, using the ICP-AES and ICP-MS at MIPROMALO.

**X-Ray Diffraction Analysis**

The X-ray diffraction (XRD) patterns were obtained with a Bruker D8-Avance Eco 1Kw diffractometer (Copper Kα radiance, λ=1.5418 Å, V=40 125 KV, I=25 mA) with Lynxeye Xe energy dispersive detector in the Laboratoire d"Argiles, Géochimie et Environnements Sedimentaires (AGEs)" at the University of Liège, Belgium, using standard procedures. The analyses were carried out on the bulk material (non-oriented powder with grinded particles <50 µm). The XRD patterns were recorded over the 2-70°2θ angular range for the bulk material. The step sizes considered for this analysis was 0.02°2θ, whereas the time per step chosen were 0.25 seconds. The primary optic is motorized in order to illuminate a fixed sample length whatever the angular position (16 mm for bulk). The identification of mineral phases was carried out using Eva software.

## Data Analysis and Results

**Petrographic Description**

Macroscopic and microscopic descriptions and the estimation of the modal composition of the minerals were done by observing the various proportions in the thin sections.

The yellowish to greyish white rhyolitic rock TBN02 was found to be fully compacted and partially weathered, with coal appearing in between in form of veins fragments. Observation under the microscope reveals rock texture to be clastic ranging from fine to coarse grains clayey silty to sand. It contains polycrystalline quartz of about 3 mm max and 20 % modal proportion of the whole matrix. It has orthoclase and clay mineral content of 1-2 % modal proportion. The rock matrix is essentially argillaceous coal; (clayey coal) 80-85 % modal proportion.

Coal intercalated in rhyolite( TBN020) in thin section reveals that rock fragment consist of quartz  (10-15 %). Their sizes range from semi angular to angular. The rock matrix consists essentially of argillaceous (80-85 %). Rock has a fine clastic to averagely heterogranular texture. It is sandy to clayey.

**Sample: TBNO2” (Coal Intercalated in Rhyolite)**

Microscopic observation reveals that the rock consists of angular quartz of 2 mm max occupying (10-15 %) matrix is clayey mixed with coal (90-95 %). The texture ranges from fine clastic to larger grains. Plagioclase has a proportion of <1 % and the ground mass is sandy-clayey. Figure 17G, H.

**Sample: TBN08 (Coal Mixed with Sandstone Showing Leafy Portions).**

The thin section reveals a clastic texture. The matrix has a modal proportion of (40-45 %) of ferruginous clay. It has micro fractures filled with clay, organic matter and liquids. It has opaque minerals (oxides) which appear angular to sub angular occupying (2-5 %) of the sample. It is dominated with quartz of length (1-0.9 mm) which are angular and sub rounded with a proportion of (50-55 %). Figure 17C, D

**Sample: TBN04 (Coal Mixed with Sandstone)**

Rock consists mostly of Quartz of modal length 2 mm max under microscopic observation. It has clayey texture with a clay composition of (70-80 %) of the whole rock sample. Microcline 300 mm max makes up (5-10 %). Matrix is clayey coaly contributing (10-15 %) of rock sample. It is clastic with coarse heterogranular grains.

**Sample: TBNO5 (Rhyolite)**

The rock is made up of phenocrystals, with modal lengths varying between 3- 0.2 mm and modal proportions of (15-20 %) of quartz, feldspath (sanidine), rock fragments (quartzite, granite). Microcline  makes up (80-85 %) and has minerals quartz and feldspars (plagioclase, sanidine). It has a microlitic porphyritic texture. Figure 17I, J

A: TBNO2 (coal intercalated in rhyolite observed in plain polarized light),
B:  TBN02’ (coal intercalated in rhyolite),
C: TBNO8 (coal mixed with sandstonesandstone observed in polarized light),
D: TBNO8 (coal mixed with rhyolite observed in natural light),
E: TBN04 (coal in advanced stage of formation observed in plain polarized light),
F: TBN04 (coal in advanced stage of formation observed in natural light),
G: TBNO2” (other portions of the same sample of coal intercalated in rhyolite observed in polarized light),
H: TBN02” (other portions of sample TBN02 observed in natural light),
I: TBN05 (rhyolite observed in plain polarized light),
J: TBN05 (rhyolites observed in natural light).

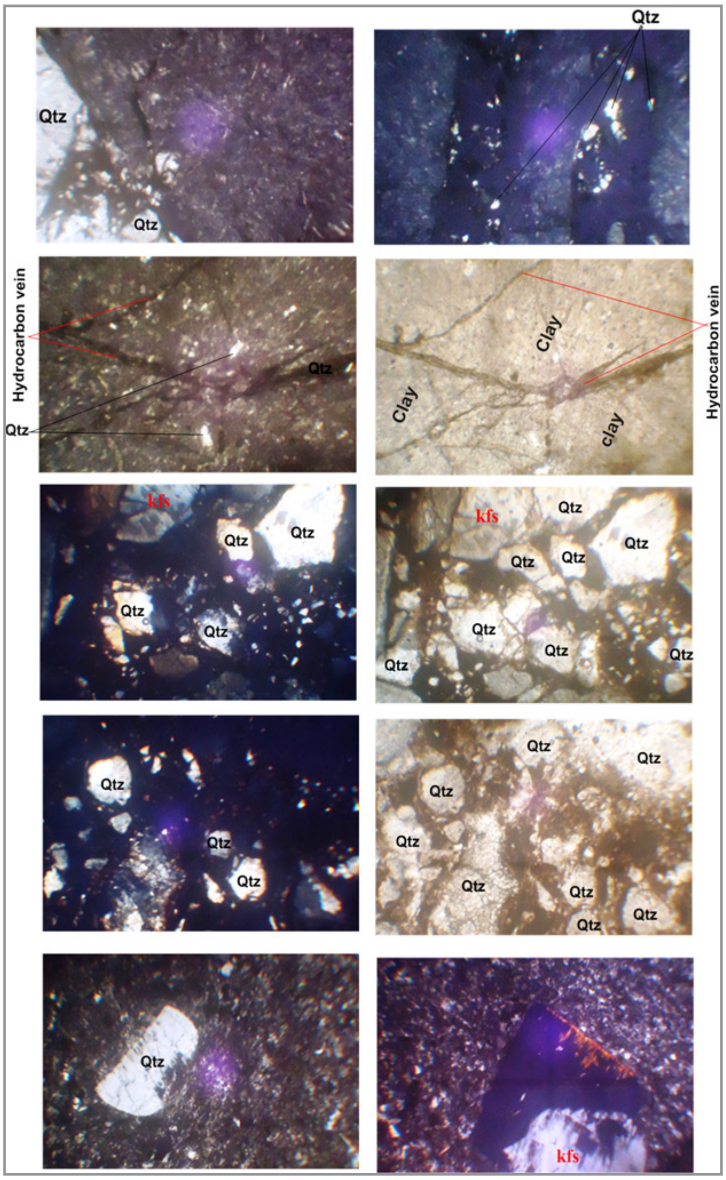



**Figure 6:** Microscopic features of samples

**Major and Trace Element Geochemistry**
**Major Elements Variation**

Major Element's variation in coal: SiO2 exhibits a wide range within the suite ranging from 49.06 to 65.91 % weight in coal in advanced stage of formation (TBN04) and coal mixed with sandstone (TBN08) respectively. Al2O3 decreases sharply in the sample TBN08 17.87 wt% with respect to 21.29in sample TBN04. Total iron decreases slightly in TBN04-TBNO8 2.892-1.816 wt% within the suite, with respect to SiO2 wt%. CaO ranges from 0.0584-1.266 wt% in the samples TBN08, TBN04 respectively. There is an increase from in K2O (0.815-1.276) wt% for TBN04 and TBN08 respectively. MnO is completely absent in sample TBN04, and present in very small amounts 0.0425 % in TBN08. There is a decrease in the percentage of P2O5, 0.177 %- 0.297 wt% in TBN08 and TBN04 respectively. MgO is found in coal bearing samples in trace amounts. It increases within the suit from 0.061 %- 0.0943 wt% concentration. Further major element plot following the work (After Suttner and Dutta, 1986) in Yandoka, 2015 of major elements in coal, SiO2 versus (Al2O3 + K2O + Na2O) for coal samples TBN04 and TBN08 was done to get a provenance study for the tectonic.

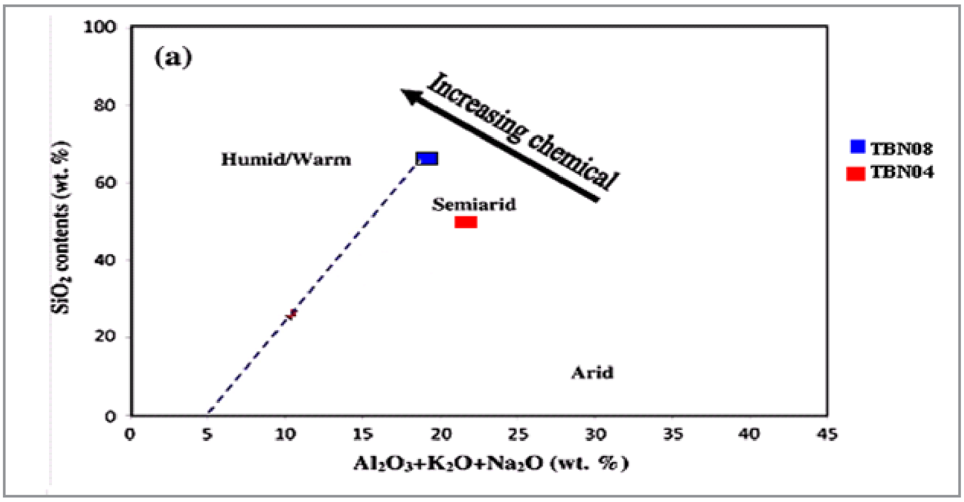



**Figure 7:** Bivariate plots of SiO2 versus (Al2O3 + K2O + Na2O) contents for paleoclimate discrimination (After Suttner and Dutta, 1986).

**Table 2:** Major element geochemistry of coal bearing samples collected from the field TBN08- coal mixed with sandstonesandstone. TBN04- coal in advanced stage of formation

| TBN08 | | TBNO4 | |
|---|---|---|---|
| FORMULA | CONCENTRATION % | FORMULA | CONCENTRATION% |
| $SiO_2$ | 65.91 | $SiO_2$ | 49.06 |
| $Al_2O_3$ | 17.87 | $Al_2O_3$ | 21.29 |
| $Fe_2O_3$ | 2.982 | $TiO_2$ | 2.987 |
| $K_2O$ | 1.276 | $Fe_2O_3$ | 1.916 |
| $TiO_2$ | 1.08 | CaO | 1.266 |
| CaO | 0.584 | $K_2O$ | 0.815 |
| MgO | 0.51 | MgO | 0.519 |
| $P_2O_5$ | 0.177 | $P_2O_5$ | 0.297 |
| $SO_3$ | 0.0672 | $SO_3$ | 0.175 |
| $Na_2O$ | 0.061 | $Na_2O$ | 0.0943 |
| $ZrO_2$ | 0.04277 | $ZrO_2$ | 0.06604 |
| Mno | 0.0425 | ZnO | 0.0557 |
| SrO | 0.0294 | $Cr_2O_3$ | 0.0434 |
| ZnO | 0.0284 | $CeO_2$ | 0.041 |
| $Cr_2O_3$ | 0.013 | $V_2O5$ | 0.0379 |
| CuO | 0.005 | SrO | 0.0214 |
| LOI (actual) | 9.31 | CuO | 0.0136 |
| SUM | 99.99 | $Y_2O_3$ | 0.0124 |
| | | NiO | 0.0107 |
| | | $Nb_2O_5$ | 0.0083 |
| | | $Ga_2O_3$ | 0.005 |
| | | $Rb_2O$ | 0.0036 |
| | | LOI (actual) | 21.25 |
| | | SUM | 99.99 |

**Rare Earth Elements (REE) Geochemistry**

REE elements are a group of elements with atomic number between 57 (La) and 72 (Lu). They are generally characterized by relatively large ionic radii and valences of either +2 or +3. Ionic radius for these elements decreases slightly but steadily as atomic number of REE's increases. REE are generally classified into two groups, LREE, HREE and MREE.

**X-Ray Diffraction Analysis**

The XRD analytical results (Figure 25) show that the Tabenken coal is composed of siliceous mineral such as quartz (SiO2), kaolinite [Al2 (SiO2O5) (OH)4)] and other minerals such as microcline, NH4-illite, calcite, muscovite and biotite. The mineral suites in the coal sample used in the present study are consistent with the previous studies in South African coals [7]. In both samples quartz and kaolinite are the dominant mineral phases

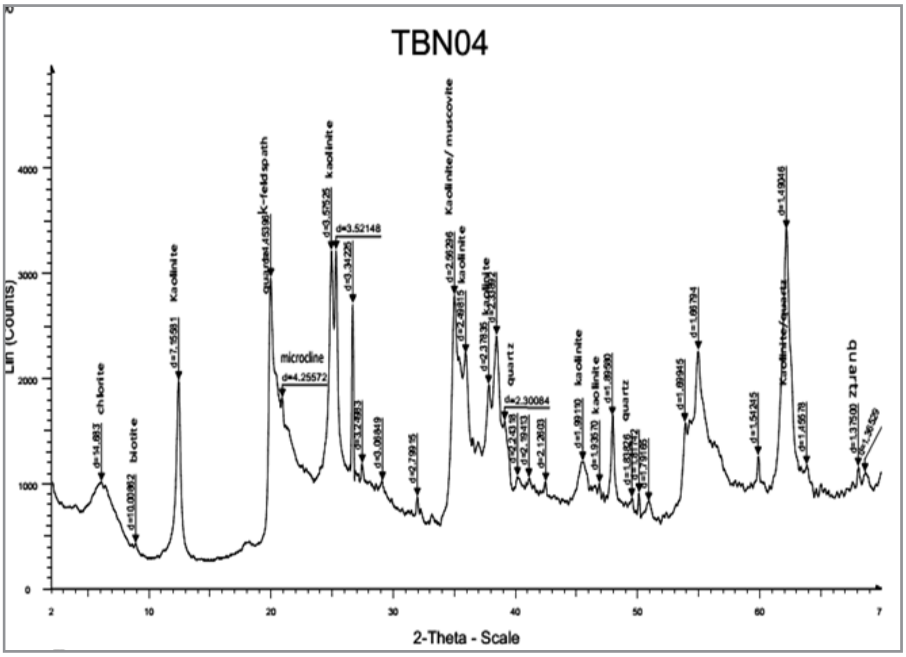



**Figure 8:** Characteristic Spectral lines of sample TBN04

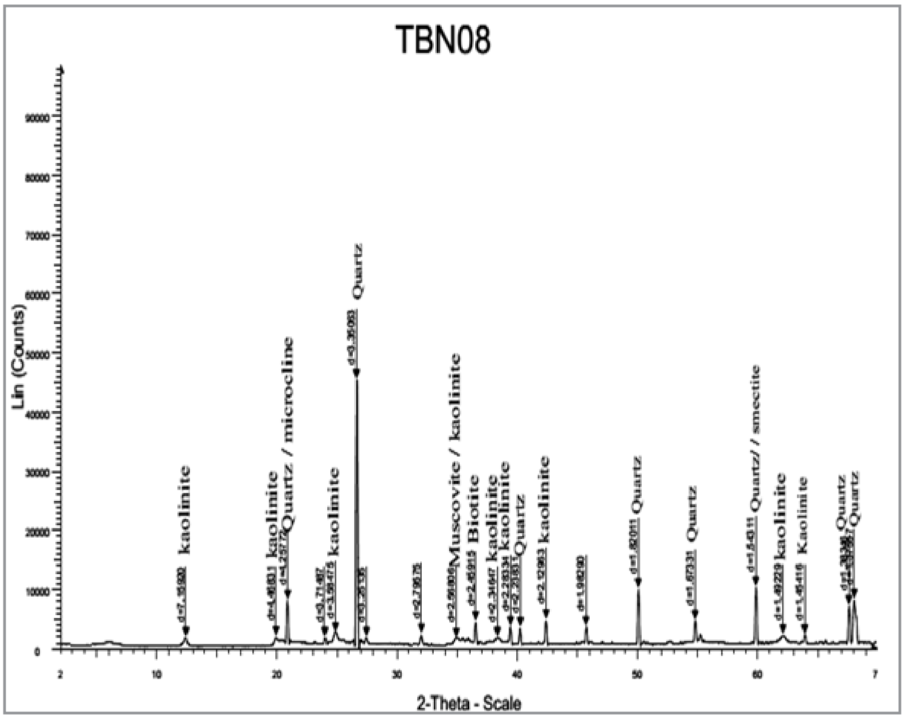



**Figure 9:** Characteristic Spectral lines of sample TBN08

## Interpretation and Discussions

### Interpretation of Field Occurrence

Field investigation of Tabenken coal seam reveals a sedimentary environment, which has been modified by volcanic events. The textural relationship of the coal reveals that the areas where there was a direct contact of coal and rhyolites, it had graded to anthracite, whereas in other areas where the coal is further from the rhyolites, it is lighter, easily breaks of and some have patches of ash. In other cases the coal appears in forms of veins or as inclusion inside the rhyolites. This could be explained by the fact that the rhyolites probably erupted at very high temperatures which were sufficient to cook the buried vegetation and cause the coal to form.

## Interpretation of Laboratory Results

### Results from Petrography

Coal petrographic composition is very important from the point of view of coal utilization. Coal petrographic studies are conducted on coal to measure its thermal maturity by vitrinite and huminite reflectances and marceral composition analysis to reconstruct the peat forming conditions. Coal composition is dependent on its origin, degree of carbonization and place of coal basin. From the observations of thin sections, it is seen that, coal intercalated with rhyolites had numerous quartz content. The presence of high quartz percentage may suggest two origins. Firstly, it may suggest coal formed from detrital origin and secondly the intrusion of silica from rhyolitic tuffs since rhyolites contain high percentages of silica above 70 % [8, 9].

The presence of hydrocarbon veins observed in the thin sections are interpreted as resulting from the presence of the rhyolitc fluids, whose outpours were caused by diapiric movement, of the coal into the viscous rhyolite. These temperatures thus were sufficiently high to melt the coal into liquids [10].

**Interpretation from Coal Geochemistry**

Results obtained for major elements geochemistry reveal that the percentage composition of the elements SiO2, Al2O3 and Fe2O3 are dominant constituents and account for over 57.46 % average weight composition. Other major elements such as K2O, TiO2, MgO, Na2O and MnO are present in low concentrations (average of 3.97 wt %). The high concentration of SiO2 and Al2O3 indicate high detrital quartz and clay mineral content in the coal measures. This is in general agreement with results obtained with work done in the Anambra basin, Nigeria [12]. The high concentrations of SiO2 (57.46 average wt %), for the samples TBN04, TBN08 and Al2O3 content (19.58 average wt %) compared with the concentrations of other major elements in the analyzed samples, suggest a high detrital input from the surrounding of the basin during peat formation [13].

The presence of TiO2 and P2O5 are indicative of basaltic rocks of oceanic environment. Minerals such as Si, Al, Ti and K are mostly associated with quartz, clay minerals and feldspar. These elements also reveal that Si, Al, Ti and K originate mostly from a mixed clay assemblage, which is a constituent of kaolinite and illite.

SiO2 is the dominant major element in both samples. SiO2 is higher in sample TBN08 (coal mixed with sandstone). Constituent of SiO2 may be probably caused by the inter-bedded sandstone or mudstone [14].

The high percentage of Al in coal is related to the presence of clay minerals. High Al2O3 values are explained by the presence of kaolinite and illite minerals observed in the sample. Al is generally enriched in kaolinite [15]. The K/Al ratios in the TCS is relatively low 1.27/17.87 and 0.815/21.29 suggesting the occurrence of kaolinite higher than illite. Such enrichment of kaolinite has been reported in much of the world's coals for example in [16].

Ti originates mostly from clay assemblages constituents with the occurrence of kaolinite and illite. The higher Titanium Ti/Al ratios are as a result of clay mineral input [17]. Ti/ Al ratio for the TCS is 1.08/17.87 and 2.987/21.29 respectively for the two samples analyzed. This is relatively high suggesting occurrence of Ti within clay lattice [18, 19].

Ca concentration in TCS sample TBN04 is considerably higher than that of the world average of 1 % weight. This suggests that peat was deposited in mire supplied with calcium rich water [17]. The high Ca concentration is explained by carbonate minerals observed in thin section and mineralogy studies [20].

MgO in coal is related to clay minerals, particularly smectite and chlorite as well as carbonates. Mg concentration in TCS is 0.042 % weight is higher than the world average of 0.02 %. The higher Mg concentration is due to the enrichment of carbonates in TCS [21].

The concentration of K in the oxides of the TCS average weight is (0.01 and 0.009) respectively. This is substantially higher than that of the world's coal average (0.01 weight %), [19]. Higher concentration is mainly attributed to the presence of illite clays in the analyzed coals [22].

Fe in coal occurs in a number of forms such as Fe sulfides (pyrite and marcasite, Fe carbonates, siderite and ankerite) Fe-bearing clay- iron sulphates ferrous sulphate and Jarosite are organically bound Fe [20]. High Fe contents were recorded in the TCS. The iron availability may have been associated with the transport of organic colloids or clay into the basin. (Figure20) Plotting SiO2 content against Al2O+NaO+K2O reveals that coal formed during semi-arid environmental conditions [23].

**Results from x-ray Diffractogram Analysis**

Most of the inorganic matter in coal is present as minerals dispersed throughout the coal macerals [24]. The dominant minerals in coals are usually composed of sulfides, clay, carbonates and quartz [25]. Sulfides are composed of pyrite and marcasite but pyrite is dominant by and usually found associated with other sulfides or oxides in coal bed and as a replacement mineral in fossils [26].

The XRD analytical results show that the TCS is mainly composed of siliceous mineral such as quartz (SiO2), kaolinite [Al2 (SiO2O5) (OH)4)]. The mineral suites in the TCS coal samples used are similar with the South African coals [27]. Kaolinite is uniformly distributed in the coal samples. According to Akinyemi, (2012), kaolinite is commonly present in coal as two species with different crystallinity, namely a low crystallinity detrital kaolinite and a high crystallinity neomorphic kaolinite. Kaolinite contains water bound within their lattices [28].

The heat from the rhyolitic intrusions which could have to 1000o C at the time of the injection may have caused changes in the organic matter of the coal. According to Benedict et al., (1968), Teichmuller et al., (1998) this can be changed to natural coke characterized by the presence of a mosaic structure and pores [29]. Anthracites may soften a little if at all, during intrusion and tend to become meta-anthracites, in which case the texture of anthracite is retained, although in chemical composition, optical and other properties, the altered coal approaches graphite, a phenomenon largely observed in Tabenken. The higher rank of some of the samples in Tabenken may be attributed to metamorphism as a result of excessive heat from volcanic activity which then transformed the coal into a higher grade [30]. Such a phenomenon has been observed in coals of Tanjung Enim in the South Sumatra basin in Indonesia [31-81].

## Conclusion

The main objectives of this research was carry petrographic and geochemical analyses of the coal samples in other to have an insight about its quality and afford Government and potential investors take informed decisions when considering exploitation and use of the resource. Analyses of field and laboratory data indicated the presence of coal of all grades, ranging from peat to anthracite; coal/sandstone and coal -rhyolite mixtures and as well liquefied coal. The influence of the environment of formation was evident in the geochemistry of the coal with high concentrations of SiO2 and Al2O3 compared to the other elements indicates that the coal is of detrital origin formed during semi-arid conditions.

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