CONTRIBUTION OF PETROGRAPHIC AND GEOCHEMICAL ANALYSES OF THE KIPALA SHALE (CENTRAL BASIN, DRC) TO THE ASSESSMENT OF ITS POTENTIAL AS A HYDROCARBON SOURCE ROCK

DJONIVE MUNENE ASIDI[*1], FLEURY SIMBUNGU ANGBOKO[2], THOMAS KANIKA MAYENA[3], RUTH ILUNGA MULAJI[1], ANGE THIJENIRA LOKETO[3], FREDERIC MAKOKA MWANZA[3], LEVESQUE MAKUKU MBO[1], RACHIDI OPULUKU[1], JEAN IYOLO LUNGEMBO[1]

[1]*Faculty of Oil, Gas and New Energies, University of Kinshasa, Democratic Republic of Congo*

[2] *Center for Geological and Mining Research, Kinshasa, Democratic Republic of Congo*

[3]*Faculty of Science and Technology, University of Kinshasa, Democratic Republic of Congo*

Abstract: A geological study of the Kipala region, in the "Cuvette Centrale" of the Democratic Republic of Congo, has identified two groups of shales: the dark greasy facies, interbedded with the brownish-gray facies. Their high Total Organic Carbon (TOC) content (11 % TOC on average for the dark greasy shales, compared with 8 % for the second group) classifies them as very good hydrocarbon source rocks, according to the criteria of Epistalie et al. Field and laboratory data suggest that the rocks studied were deposited in a lagoon connected to the sea by an intermittently closing channel.

Keywords: shale, evaluation, hydrocarbon source, Cuvette Centrale, lagoon, total organic carbone, depositional paleo-environment

1. INTRODUCTION

The "Cuvette Centrale" of the Democratic Republic of Congo (DRC), a large intercontinental sedimentary basin of which the Kipala area under study is a part, is located in central DRC, between Longitude 16°.30 E, Latitude 0°.30 S and Longitude 25°.15 E, Latitude 4°.30 S (Figure 1). It has long been the focus of the following scientific research: geology [1-3], geophysics [4-6], stratigraphy [7-8], paleontology [9-11] and hydrocarbons [12-14]. The data resulting from this work constitute an argument in favor of promoting oil exploration in this basin.

The study area, Kipala region, located in the Kwilu province (Figure 1), has been little studied; the few works are those carried out by [2, 11] who reported the presence of fossiliferous sedimentary rocks named "Kipala Fossiliferous Formation", and subsequently identified as a fossiliferous sandstone. Both authors specify that the fossils consist of fish remains of mixed origin (marine + freshwater) for [11], and freshwater (continental) for [2], due to the absence of large species among these fish fossils. Moreover, the alternation of marine and freshwater fish fossils led [11] to suggest that the host rocks were deposited in a lagoon connected to the sea by an intermittently closed channel.

[*] Corresponding author, email: munenedjonive@gmail.com
https://doi.org/10.29081/jesr.v29i4.003

A few years later (2005), during an itinerant geological survey undertaken by [15], rock samples were collected in the study area, and identified by the author as organic-rich shales (TOC: 6.7 - 8.7 %). These results motivated our conviction to undertake in-depth investigations of these formations.

The aim of this study is to determine the depositional paleo-environment of the Kipala shales, their spatial extension, as well as their petrographic and geochemical compositions; all the results lead us to assess the potential of the rocks studied as hydrocarbon source rock. In this way, the data generated by this work contribute to the promotion of oil exploration in the “Cuvette Centrale“ of the DRC.

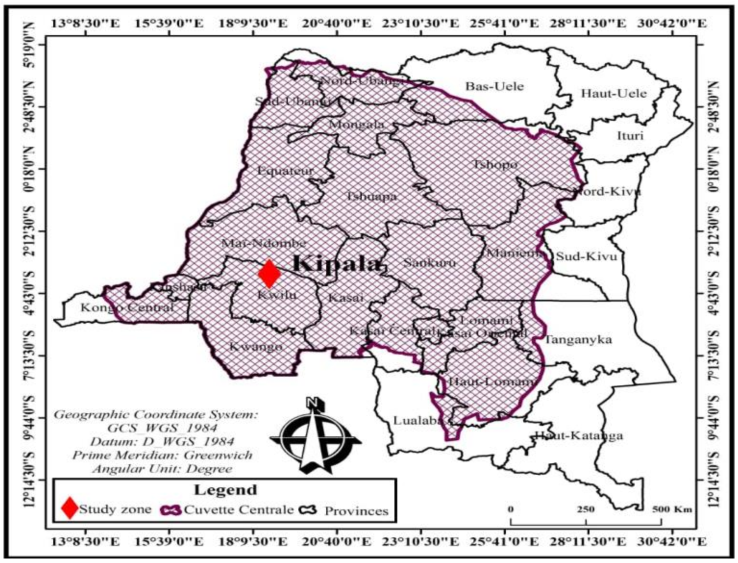

Fig. 1. Location map of the study area in the "Cuvette Centrale" of the DRC.

2. ANALYSIS METHODS, TECHNIQUES AND MATERIALS

2.1. Analysis methods and techniques

Apart from the documentation stage, this investigation goes through the main stages of geological research below.

2.1.1. Fieldwork stage

To gain a general idea of the geological environment of the shales in the study area, we spent three weeks in the field, carrying out an exhaustive geological survey and rock sampling. The following basic geological equipment was used: a hammer, a compass with built-in clinometer (for structural measurements), a GPS (Grawin brand) (for geographical location), a marker, a notebook and pen, bags (for packing samples) and a 1/125,000 topographical map of the study area.

2.1.2. Laboratory stage

This consisted of:

- Preparation of thin sections of rock samples at the Geosciences Department of the University of Kinshasa, for determination of rock constituents using a polarizing transmitted-light microscope (Optical brand).
- Chemical analysis of rock samples for oil exploration at the Centre de Recherches Géologiques et Minières (CRGM). In the hydrocarbon sector, the evaluation of source rock is an essential operation which aims to determine the following parameters: (1) the Total Organic Carbon (TOC) content, (2) the type of organic matter conditioning the evolutionary path it has taken and, consequently, the rate of transformation of the kerogen, and (3) the degree of thermal maturation of the organic matter. It should be noted in passing that the means at our disposal did not allow us to determine the last two parameters, which can only be obtained using the Pyrolysis Rock Eval method. Only the first parameter (TOC) could therefore be determined using the Walkey-Black method. This method uses potassium dichromate ($K_2Cr_2O_7$) in an acid medium (H_2SO_4) to dissolve the sample, followed by titration with Mohr's salt in the presence of diphenylamine.

3. RESULTS AND DISCUSSION

Geological field studies were carried out mainly along the main rivers (Siel Mbwa, Mfunu, Lwam, Lining,) and on the lower hillsides; the study area having a thick sand cover. This stage of the work enabled us to draw up a map showing the location of observation and sampling stations (Figure 2). Two shale sub-facies were macroscopically identified in the study area: fat dark shales and brownish grey shales. Clayey sandstones and soft micro-sandstones are the other lithofacies accompanying the two shale groups. But these other lithofacies are not covered in this article. It should also be noted that all the geological formations in the study area have an azimuthal direction varying from N170° to N178°, and a dip varying from 5° to 10° towards the west.

3.1. Petrographic analysis of the shales

3.1.1. Dark greasy shales (samples KP1b, KP4b, KP5, KP6, KP7, KP8, KP9, KP10 and KP11)
Macroscopically, this is a dark, fine-grained rock, oily to the touch. It has millimetric to centimetric bedding and is cut into sheets. Its constituents are invisible to the naked eye, except for pyrite, whose crystals reach centimetric size. Occasionally, the rock is crossed by black laminae (organic matter) (Figures 3A and 3B). Microscopically, the rock has a pasty texture and fine to medium grains. It is composed of abundant clay minerals, rounded to sub-rounded quartz silts and rare small biotite flakes; these elements are poorly sorted and bound together by a clay-silica cement (Figure 4A). In places, the rock is invaded by bands that remain black, in both Unanalyzed Polarized Light (LPNA) and Analyzed Polarized Light (LPA), which could be identified as bitumen (Figure 4).

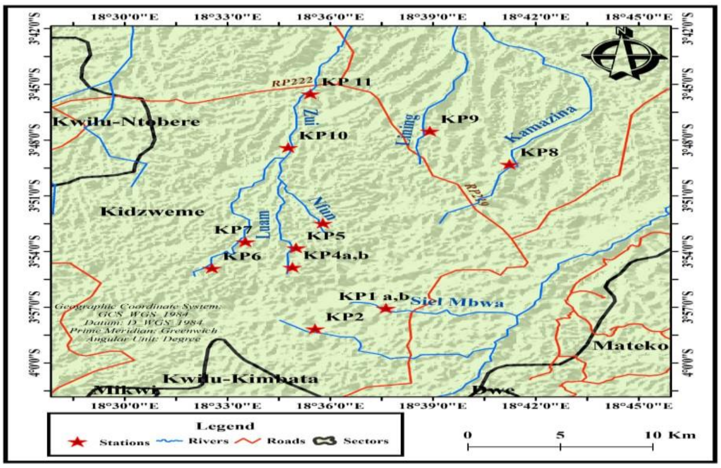

Fig. 2. Location map of observation and sampling stations.

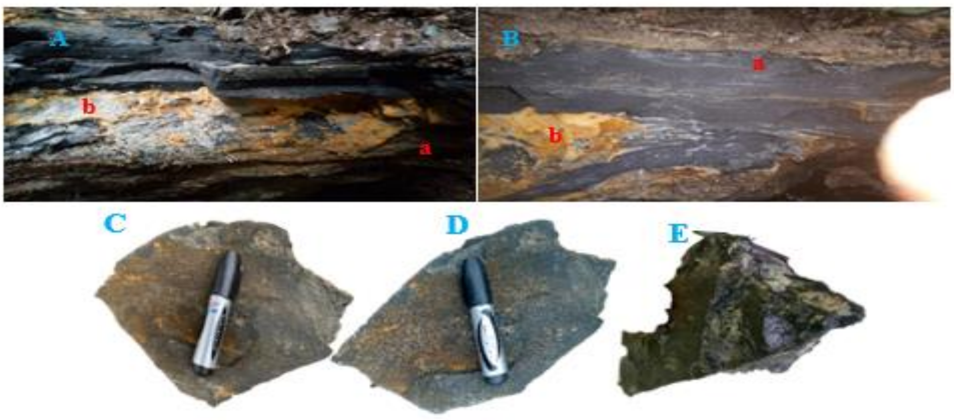

Fig. 3. Views of outcrops (A, B) and samples (C, D, E) of the Kipala dark and greasy shales.
Note, in Figures 3A and 3B, the intercalated position of the brownish-grey shale (b) in the dark greasy Kipala shale (a).

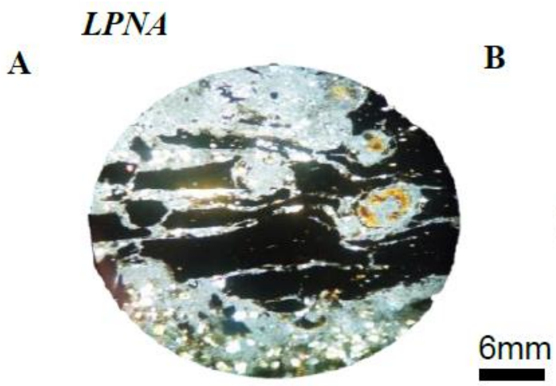

Fig. 4. Microscopic views of dark greasy shale (KP1b); A: in LPNA; B: in LPA. Note the invasion of the rock by dark matter (bitumen).

3.1.2. Brownish-gray shales (samples KP1a, KP2, KP3 and KP4a)
The rock is gray to brownish-gray, uniformly bedded in millimeters to centimeters, friable and cut into sheets. Its constituents are invisible to the naked eye (Figure 3A and Figure 5).

Microscopically, the rock has a jointed texture and medium grain size, with the following components: rounded to sub-rounded quartz accompanied by opaque oxides; these elements are bound by clay cement (Figure 6).

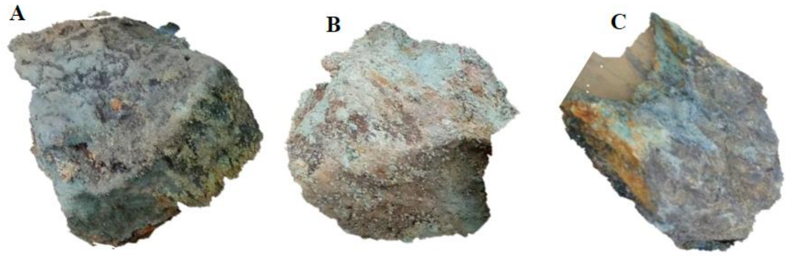

Fig. 5. A, B, C: Views of brownish gray shale samples.

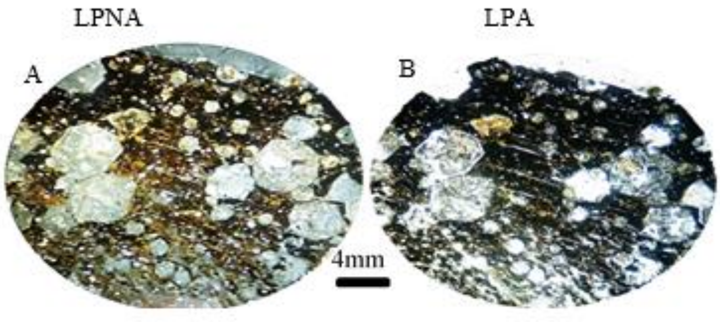

Fig. 6. Microscopic views of brownish-grey shale (KP1a); A: in LPNA; B: in LPA.

3.2. Geochemical analyses
The results of the chemical analyses of the Kipala shales are given in Table 1 and illustrated in Figure 7. They give rise to the following comments:
- A significant difference in SiO_2 and Al_2O_3 contents must be noted between the two subfacies of the Kipala shales (SiO_2-S0-6I % n SiO_2:30-39 %, Al_2O_3:02-0.7 %vs Al_2O_3:24-52 % respectively for the dark greasy shale and brownish-grey). The high Al_2O_3 contents of the brownish-grey shales are probably linked to the clayey nature of the matrix of these shales [16]; while the richness in SiO_2 of the dark greasy shales could be attributed either to the siliceous nature of their matrix, or to a possible silicification process of the rocks, or again the presence into them of the siliceous layers [17].
- Total organic carbon contents are relatively higher in the dark greasy shales (TOC: 9.3-15.8 %) than in the brownish grey shales (TOC: 6.7-8.7 %).

- The TOC content of the shales studied appears to be too high, particularly for the dark greasy sub-facies, where this parameter reaches a value of 15 %. At first sight, such high TOC values might suggest a supergene origin of the organic matter (i.e. superficial enrichment in organic matter). However, the solubility of the organic matter contained in the rocks studied in the presence of organic solvents (CS_2) indicates that the organic carbon richness of the shales studied (whose proportions of soluble matter rise to 24 %: see Table 1) is of deep origin (i.e. reductive environment) [18].
- Based on the criteria for hydrocarbon source rock established by [16], the Kipala shales, with an average TOC of 11 % for the dark greasy sub-facies, and 8% for the brown-grey sub-facies, rank among the very good hydrocarbon source rocks.
- Note the presence, in both groups of rocks, of volatile matter (represented here by non-hydrocarbon gases: hydrogen sulfide (H_2S), nitrogen (N_2) and carbon dioxide (CO_2)). The presence of these non-hydrocarbon gases suggests the thermal degradation of organic matter during burial in the diagenesis zone, respectively, and the oxidation-reduction reactions, at high temperature, of organic matter; the reduction reactions of sulfate ions to H2S, and the decomposition of proteins attached to clays during diagenesis [19].

Table 1. Chemical analyses of Kipala shale (for data source, see below the table).

Parameters	Brownish-gray schists				Dark, greasy schists						
	KP1a	KP2	KP3	KP4a	KP1b	KP4b	KP5	KP6	KP7	KP8	KP19
COT	8.7	7.6	7.3	6.7	10.3	9.3	15.8	12.9	12.9	11. 3	9.5
SiO_2	39.0	37.0	30.0	39.0	59.6	55.6	61.7	59.6	61.7	57.8	50.7
Al_2O_3	24.0	46.7	52.4	44.2	0.2	0.2	0.5	0.7	0.5	0.7	0.4
Fe_2O_3	-	-	-	-	0.4	0.4	1.1	0.8	1.1	0.8	0.5
TiO_2	0.1	0.2	0.5	0.4	0.02	0.02	0.03	0.01	0.03	0.01	0.03
CaO	0.7	0.7	1.5	1.7	2.2	2.2	0.8	1.2	0.7	1.2	2.1
MgO	0.2	0.4	0.5	0.5	1.0	1.0	0.3	0.4	0.2	0.4	0.3
Na_2O	0.5	0.5	1.0	1.0	0.8	0.8	0.4	0.3	0.4	0.2	0.8
K_2O	0.8	0.5	0.5	0.8	0.9	0.3	0.2	0.2	0.2	0.2	0.2
CuO	-	-	-	-	0.01	0.02	0.03	0.04	0.03	0.04	0.05
Humidity at 110°C	3.0	6.4	6.0	5.8	15.0	14.0	13.7	20.2	12.7	19.2	15.0
N_2	0.3	-	-	-	0.4	0.4	0.2	0.2	0.2	0.2	0.2
S_2	0.4	-	-	-	9.4	8.4	5.2	3.2	5.2	2.2	4.1
CO_2	8.8	-	-	-	2.0	2.0	1.5	1.4	1.4	1.4	2.0
Soluble matter in CS_2	23.0	-	-	-	23.0	24.0	17.0	11.0	16.0	10.0	23.0

KP1a, KP2, KP3 and KP4a: Brownish-grey shale samples [15].
KP1b, KP4b, KP5, KP6, KP7, KP8 and KP9: Dark greasy shale samples.

The sulfur present in the rocks studied (S_2: 0-0.4 % in brownish-gray shales vs. 2.2-9.4 % in dark greasy shales) attests to their deposition in an anaerobic (and therefore reducing) environment rich in organic matter, whose reduction led to the formation of the pyrite crystals identified in these rocks. This would be a marine environment rich in sulfates [19].

The latter hypothesis is in line with that of [11], according to which the depositional environment of the Kipala formations was a lagoon linked to the sea by a channel that closed intermittently, which, according to this author, would explain the alternation of marine and freshwater fish fossils at the Kipala site.

This study reveals the existence, in the field, of two shale sub-facies in the Kipala region (one dark-coloured and greasy to the touch, containing in intercalations ,the other brownish-grey color), as well as significant differences in their chemical compositions (high % TOC versus relatively low % TOC; $Si0_2$ > 50 % versus $Si0_2$< 40 %; Al_20_3 <1 % versus Al_20_3> 20 %), both of which are further arguments in favor of the deposition of the rocks studied in a confined environment (lagoon-type) receiving, among other things, flows of organic matter accompanied by mineral particles (i.e. clay mineral, SiO_2.).The preservation of this organic matter would be promoted, as recommended by [20], by the development of anoxia in a weak water column, and by the presence of clayey environments offering better preservation conditions than siliceous environments [21]. Thus, the high SiO_2 content in the sub-facies of dark greasy shales although richer in TOC than the brownish-gray sub-facies, would support the hypothesis of the secondary origin, or the presence of the siliceous layers for this silica enrichment. We believe that the silicification process in these rocks, or the presence into them of the siliceous layers are responsible for this silica enrichment.

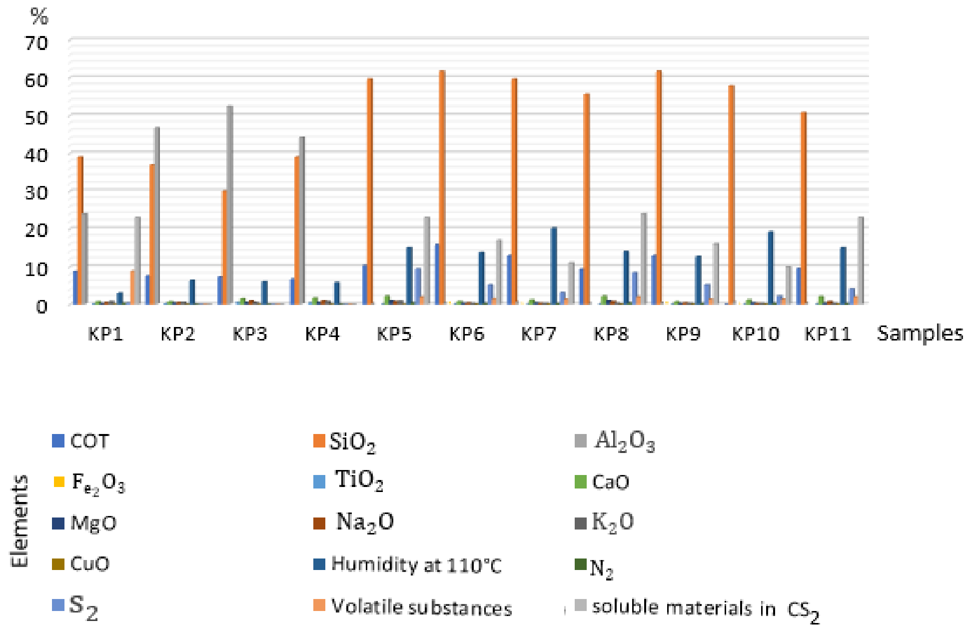

Fig. 7. Histogram of chemical analyses of the Kipala shale: KP1a - KP4a: brownish-grey shale samples [15]; KP1b- KP9: dark greasy shale samples.

4. CONCLUSIONS

The geological study of the Kipala region in the "Cuvette Centrale" of the DRC has revealed two shale subface's, one black and greasy to the touch (bituminous), containing in intercalation, the other brownish-grey.

The presence of pyrite crystals in these rocks suggests that they were deposited in a reductive environment, favorable to the preservation of organic matter, which would explain the high TOC content of these rocks, as revealed by the chemical analyses. In accordance with the criteria established for the evaluation of hydrocarbon source rocks, the TOC content of the rocks studied ranks them among the best source rocks.

However, the two groups of rocks show significant differences in TOC content (11% on average for the dark shales versus 8% for the brownish-grey sub-facies). These differences, coupled with the alternating nature of the two shale sub-facies in the field, support the hypothesis that these rocks were deposited in a lagoon connected to the sea by an intermittently closing channel, implying variations in the flow of organic sediment into the sedimentary basin.

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