Implementation of statistical methods to the comparative study of heavy minerals of the Cover Formation and its bedrock in the Pointe-Noire and Brazzaville sectors (Republic of Congo)

Miyouna T.[1,]*, Essouli. O. F.[1], Malanda Nimy E. N[1],Boudzoumou F.[1,3],Kendé M.[1],Mokono-Mboko C.[1], Sow E. H.[2]

[1]Marien Ngouabi University, Facultyof Sciences and Technology, Department of Master, Laboratoryof Geosciences, P.O. Box: 69, Brazzaville, Republic of Congo

[2]Cheikh Anta DiopUniversity of Dakar, Faculty of Sciences and Technology, Department of Geology, Laboratory of sedimentologyand Biostratigraphy, P.O Box: 5005, Dakar-Fann, Republic of Senegal

[3]Research Institute in Exact and Natural Sciences, Department of Geosciences, P.O. Box: 2400, Brazzaville, Republic of Congo

ABSTRACT

The comparative study of the heavy minerals of the Cover Formation and its bedrock by statistical methods was carried out in Pointe-Noire and Brazzaville in order to understand its nature, origin, and relationship with its bedrock. The study shows that the Cover Formation contains a constant and homogeneous paragenesis of heavy minerals, which distinguishes it qualitatively and quantitatively from its bedrock. These heavy minerals come from the same distant source, containing mainly metamorphic rocks of green shale and amphibolite grades, secondarily magmatic and sedimentary or metasedimentary rocks. These heavy minerals have been transported by the wind after sometimesseveral sedimentary recycles. The Cover Formation hasan aeolian, it is not the product of *in-situ*weathering of its bedrock. So that, it must be stratigraphically separated from its bedrock as proposed by Thiéblemont et *al.* (2009) in Gabon.

Keywords: Heavy minerals, stone line, aeolian, CoverFormation, bedrock, Congo

I. Introduction

The Cover Formation is the yellow ochre sand that overlies all ancient formations in Congo, of Archean, Proterozoic, Neoproterozoic, Paleozoic, Mesozoic and Cenozoic age through a gully unconformity materialized by a polygenic or monogenic, simple or complex, autochthonous or allochthonous stone line, either by a palaeosolof Lousséké or ferralsol type **[1]; [2];[3]**. It stretches from Cameroon to Namibia through Gabon, the Republic of Congo, the Democratic Republic of Congo and Angola **[2]; [3]; [4]; [5]; [6]; [7]; [8];[9]; [10]; [11]; [12]; [13]; [14], [15]**. This yellow ochre sand is subject to several controversies. It is considered to be either the product of *in-situ*weathering of its bedrock, homogenized by termites **[8];[9]; [13]** or an allochthonous deposit of aeolian origin **[1]; [2]; [3]; [14]; [15]**. In the Congolese Atlantic coastal basin, for example, this yellow sand of the Cover Formation was associated withthe upper unit of the "Série des Cirques **[4]; [6]; [8];[9]** of Lower Miocene age **[16]**. On other and, in the Series of "Plateaux Téké" it forms the upper unit (Ba2)**[17]**. Since the work carried out by Thiéblemont **[14];[15]** in Gabon, this yellow ochre sand is considered as a stratigraphicalFormation, called "Cover Formation" or "Cover Horizon", belonging to the Stone line Complex **[1]**. The age of the Cover Formation obtained by radiometric dating (^{14}C) ranges from 3000 years B.P. to 2000 years B.P. **[1]; [14]; [15]**. These ages are however rejected by Schwartz **[18]**.In Republic of Congo, the Cover Formation is less studied.Most of the studies are old, although recent geological map work has studied a few sites containing this Formation **[1]**. This work studies and compares the heavy minerals contained in the Cover Formation and its bedrock, in order to determine the origin of its sediments and to conclude on its allochthony or autochthony. The samples used come from three fairly distant profiles in which the Cover Formation and his bedrock are well individualized. These are the Diosso profile located in the Kouilou department, the profiles of the "Pont du Djoué" cliff and "Main Bleue" both located in southern Brazzaville. The Figure 1 situates and locates them on the geological map of Dadet**[6]**. Due to field difficulties, the Cover Formation was not sampled in the Diosso profile, but it was sampled at Malélé where it is more accessible and thicker.

II. Material and Methodology

2.1. Situation and geological context of the studied profiles

The profile of Diosso is located in the Congolese Atlantic coastal basin of Mezo-Cenozoic age **[16]; [19]**. The cliff of the "Pont du Djoué" is located in the Palaeozoic Inkisi basin **[20]; [21]** and the profile of "Main bleue" is located in the Meso-Cenozoic basin of Congo**[1]; [22]** (**Figure 1**).

The Congolese Atlantic coastal basin located in the western Mayombemountain, originated in the Jurassic (Neocomian) period following the break-up of Gondwana and its separation into South America and the West Africa-Arabia to the east.

The evolution of the Congolese coastal sedimentary basin comprises three phases of sedimentary construction which correspond to three phases of tectono-dynamic evolution**[23]** described as follows: the ante-salt phase (which begins at the end of the Jurassic, but developed mainly from the Barremian to the Lower Aptian); the salt phase (which reflects the beginning of the marine transgression and ends the rifting stage); and the post-salt phase (which is the terminal sedimentary unit of the coastal basin). At the Lower Miocene, the fluvio-deltaic "Series des Cirques" covers the marine formations. The "Série des Cirques" is mainly composed of silico-clastic sediments **[24]**, structured in finning-up elementary sequences. The yellow ochre sands of the "Cover Formation essentially are essentially composed of thin quartz. They are underlain by a laterite and a stone line in the "Série des Cirques" of Diosso.

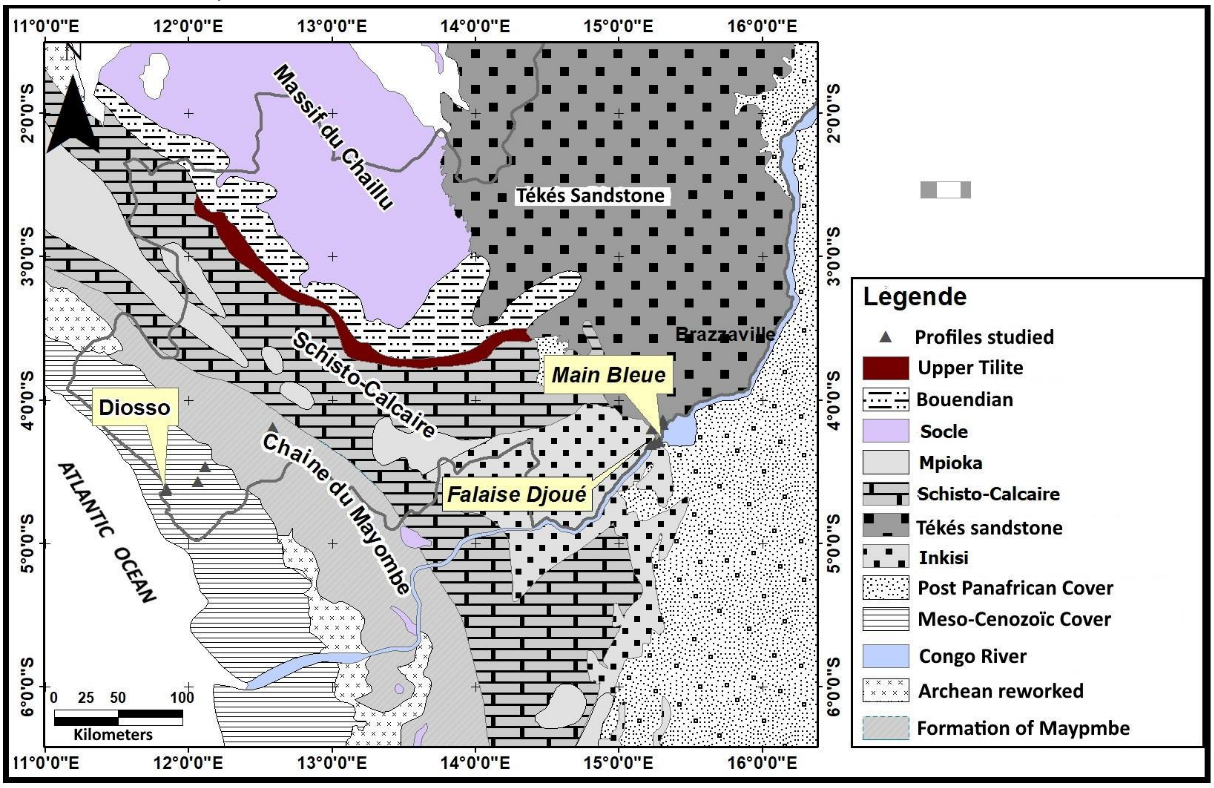

Figure 1*. Situation and location of the different studied profiles on the geological map of the Republic of Congo* **[6]**

The Profile of "Pont du Djoué" cliff is essentially made of red ochre sandstones of Inkisi Group which is part of the Lindian Supergroup of Combro-Ordovician age **[1]**. The age of the Inkisi Formation, obtained from the youngest detrital zircons, varies between 518±18 Ma and 558±56 Ma **[20]; [21]**. It is an arkosic sandstone of fluvial origin of 600m to 700m thick **[25]**. Bouity**[26]** distinguishes three lithofacies: the conglomeratic sandstone facies, the coarse and medium quartzo-feldspathic massive sandstone facies and the fine micaceous sandstone facies. The mineralogical composition of these lithofacies is summarized in Table 1. According to Chevalier et al. **[27]**, the heavy minerals in Inkisi sandstone are represented by zircon, tourmaline, apatite, rutile, green beryl and exceptionally corundum. In this profile, the Cover Formation overlies the Inkisi sandstones through an alluvial stone line which itself overlies an Ordovician unconformitypaleosurface**[3]**.

***Table 1**. Mineralogical composition of Inkisi sandstone facies (from Bouity,**[26]**, improved by Miyouna (this work)).*

Facies	Quartz (%)	Microcline (%)	Orthose (%)	Plagioclase (%)	Biotite (%)	Muscovite (%)	Debris of Rock (%)	Tourmaline / zircon (%)
Micaceous	63,86	6,71	0,08	4,4	18,52	6,25	0	0,18
Massif	60,15	21,12	0,98	7.83	3	5,2	1,63	0,09
Conglome-ratic	62,17	31,36	1,82	0,56	0	0,04	4,02	0,03

The Profile of "Main bleue" is located in the Stanley-Pool basin. The Stanley-Pool Series currently known as the Stanleyville Group is part of the Congo Supergroup**[1]**. It occurs in D.R. Congo, Angola and Congo (Brazzaville). It is a continental sedimentary Formation, which outcrops around Brazzaville where it is well known, widely visible and discordant on the Inkisi sandstones **[28]; [29]**. It is a fluvio-lacustrine series **[30]** of Jurassic age in its lower part and Cretaceous in its upper part **[24]**. The Stanley-Pool Series is subdivided into three levels **[30]**. The lower level (SP1), known by sampling at the port of Kinshasa and in the Makélékélé ravine, has red argillites with abundant sandstone flowing upwards, superimposed on more or less sandy marls of similar hue. These argillites are silty and stratified. This level is dated to the Upper Jurassic **[31]**, thanks to fossils of ostracods, phyllopods and fish fragments. The middle level (SP2), at least 20 m thick **[30]**, consists of locally indurated white compact sandstones with large cross stratifications. This level is rich in feldspar and is silicified in its upper part, forming the silicified slabs **[17]; [30]**. Finally, the upper level (SP3), about 90 m thick**[32]**, is formed by very soft, kaolinite-rich, silty white sandstone with cross stratifications. The Stanley-Pool Series is surmounted locally by the silicified aeolian sands of the Tékés Plateau Series or by the Cover Formation.

In the profile of the "Main Bleue", the upper part of the Stanley-Pool (SP3) and the Tékés Series are completely gullied. The Cover Formation is underlain by the sands of SP2 through a palaeosurface marked by a complex stone line **[3]**.

2.2 Methodology used

The methodology consisted of the field and laboratory study. The field study consisted in identifying and describing the Cover Formation and its bedrock and sampling. 22 samples were collected for laboratory studies. In the laboratory, the study consisted of extraction, description, identification and heavy mineral counting, analysis and interpretation of results. As heavy minerals are generally concentrated in the 160 µm to 350 µm fraction **[33]**, we chose to extract them in the 125 µm to 250 µm fraction by density using bromoform and the protocol of Parffenoff*and al.***[34]**. The grains of heavy minerals were treated with 50% diluted HCl and 2N oxalic acid to remove carbonate and ferruginous coatings on the grainsfor their better description under polarizing microscope and binocular loupe. Extraction processes and thin-sheet fixation were carried out at the sedimentology laboratory of the "Centre de RecherchesGéologiques et Minières (CRGM)"of Kinshasa, D.R. Congo. The description, determination and counting of heavy minerals were done under the polarizing microscope and binocular magnifying glass at the Geosciences laboratory of the Faculty of Sciences and Techniques of Marien NGOUABI University of Brazzaville, based on the Atlas of Brochee*t al.***[35]** and Devismes**[36].** The quantification of heavy minerals was done by counting all the identified minerals crossing the reticule wires on a line crossing the thin blade, by sweeping it completely. The percentage of each mineral was calculated as follows:

$$X = \frac{n}{N \times 100} \qquad \text{(Equation 1)}$$

wheren = the number of counted points of a heavy mineral;

N = the total number of counted points of all heavy minerals in the entire thin blade.

The results of the counting allowed the statistical treatment by Principal Component Analysis (PCA) in order to understand the relationships existing between the different heavy mineral species, to identify the mineral parageneses characteristic of the Cover Formation and its bedrock as well as the potential sources of these heavy minerals.

III. Results

3.1 Field Study

The profile of Diosso (**Figure 2a**) shows from bottom to top three lithological sets: the lower set representing the "Série des Cirques", the middle set representing the Stone line and the upper set representing the Cover Formation. The "Série des Cirques" of Diosso consists of five (5) lithological units. Unit I consists of a stack of onlap elemental sequences composed of fine and medium sand topped by very fine sand clay or silty clay. The unit ends in a palaeosol. Units II to V are each made up of a stack of onlap elementary sequences generally starting by a gravelly or conglomerate sand, containing large cross stratifications. Each unit begins with a gullying surface bearing a conglomerate or conglomerate sand with cross and parallel plane stratifications and ends with a palaeosol developed on a fine clayey sand or silty clay.

The middle set is a laterite of 0.40 m to 0.90 m of thickness, heavily armoured in its upper part. It is composed of ferruginous pisolites, round and shiny quartz grains, quartzite pebbles, magmatic and metamorphic rocks. The upper set of 12 m thickness constitutes the Cover Formation. It is a yellow ochre,thin sands with a homogeneous appearance.

The profile of the "Pont du Djoué"cliff **(Figure 2b)** shows three sets. The lower set, of about 3.47 m thick is the Inkisisandstone. It is a succession of lenticular elementary sequences of at least 1 m thick. Each lens begins with an erosive surface bearing flattened pebbles of quartzite, magmatic and metamorphic rocks, silexite, carbonate, oolite and red argillite. Above, from bottom to top, appear coarse wine-redconglomeratic sandstones with large cross stratifications, medium wine-red sandstones with small oblique and herringbone stratifications, and fine micaceous and clayey, wine-red sandstones in 5-10 cm platelets and with current ripples marks.

The middle set, from 3.47 m to 5.02 m, represents the alluvial stone line with a thickness varying from 0.60 m to 1.5 m. It is a polygenic, coarsening conglomerate composed of angular and sub-rounded blocks of multi-centimetric size of the silicified slab and laterite, rounded pebbles of Inkisi sandstone, chert, whitish and flattened pebbles of quartzites, magmatic and metamorphic rocks, granules of indurated laterite with ferruginous cement. That stone line contains worn archaeological tools in its middle part and unworn archaeological tools in its upper part. The upper set (5.02 m to 11 m) represents the Cover Formation. It is an ochre-yellow, fine, silty, clayey sand with no sedimentary structures and a homogeneous appearance.

The profile of the "Main Bleue" is located in Bacongodistrict, on the right bank of the Congo River, not far from the De Gaule hut. The outcrop is a cliff more than 40 m high (**Figure 2c**) which shows three sets representing from bottom to top: the Stanley-Pool Series, the Stone line and the Cover Formation. The lower set of 25.30m thick, shows three units: Unit I **(**0 m - 17 m) is composed of 14 m of medium to fine clayey, whitish-grey sands with cross stratificationsand parallel planes stratificationsshowing alternating beds of fine and medium sand. There are erosion gutters of 10 cm to 15 cm deep and about 1.20 m wide, filled with fine and medium sand showing plane parallel stratifications; 0.5 m of greyish sandy claywith small shrinkage crack at the top, and debris of organic matter. Finally, 3.5 m of silicified slab, consisting of a very fine, much silicified, whitish-grey sandstone with lenticular bedding, locally brecciated beds, containing discontinuous laminae of chalcedony. This slab is strongly silicified, giving in some places a millstone appearance. Unit II (from 17 m to 24.5 m) consists of greyish silty clay with lenticular beddingdrawing festoon cross bedding structures. It contains shrinkage crack in its upper part. It is lightly silicified and also contains discontinuous, whitish, interlayered laminates of chalcedony. This clay is surmounted by 5.50 m of fine to medium, whitish sands with large curved stratifications tangential to the plane parallel stratifications. The plane-parallel stratifications are made up of alternating beds of fine clayey sands with beds of medium to coarse sands. This level contains several erosion gutters, micro faults, slumps and small hydraulic ripples marks. The unit ends with 1 m of very fine, highly silicified clayey sandstone constituting the second slab. Unit III is strongly gullied and is in shreds of about 0.80 m. These are fine to medium, whitish and kaolinic sandstones containing cross stratifications.

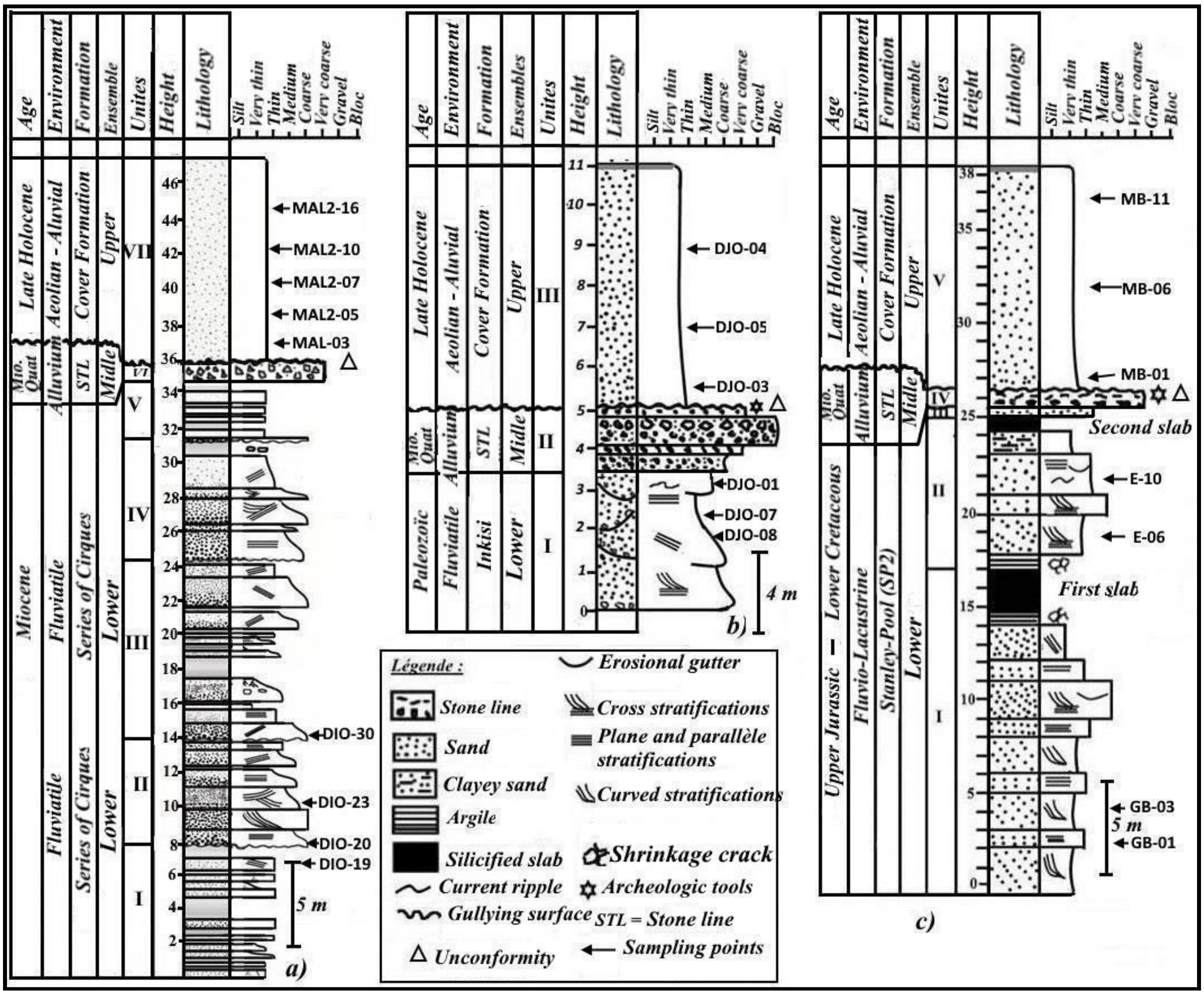

***Figure 2**. Lithostratigraphic log: **a)** Profile of Diosso; **b)** Profile of the "Pont du Djoué"cliff; **c)** Profile of "Main bleue"*

The middle set (from 25.30 m to 26.10 m) represents the stone line. It is a polygenic conglomerate with a sandy-clay matrix, its thickness varying between 0.20 m and 1.20 m. This conglomerate is composed of two levels: the lower level of about 0.20 m thick is composed of rounded and flattened pebbles of quartzite, magmatic and metamorphic rocks, Inkisi sandstone, angular and sub-rounded blocks of the silicified slab, all wrapped in a greyish sandy-clay matrix. The upper level, about 0.50 m thick, is mainly composed of angular gravels and granules of pisolitic laterite. The sorting is poor and the elements are packed in a red ochre sandy-clay matrix. The upper set (26.10 m - 38.4 m) consists mainly of fine and very fine sand, clay-ochre yellowish-silty, homogeneous in appearance. It ends with about 0.20 m of humus soil.

3.2 Laboratory study

3.2.1 Description and identification of heavy minerals

Fifteen minerals species have been identified in the Cover Formation and his bedrock (**Figure 3**).

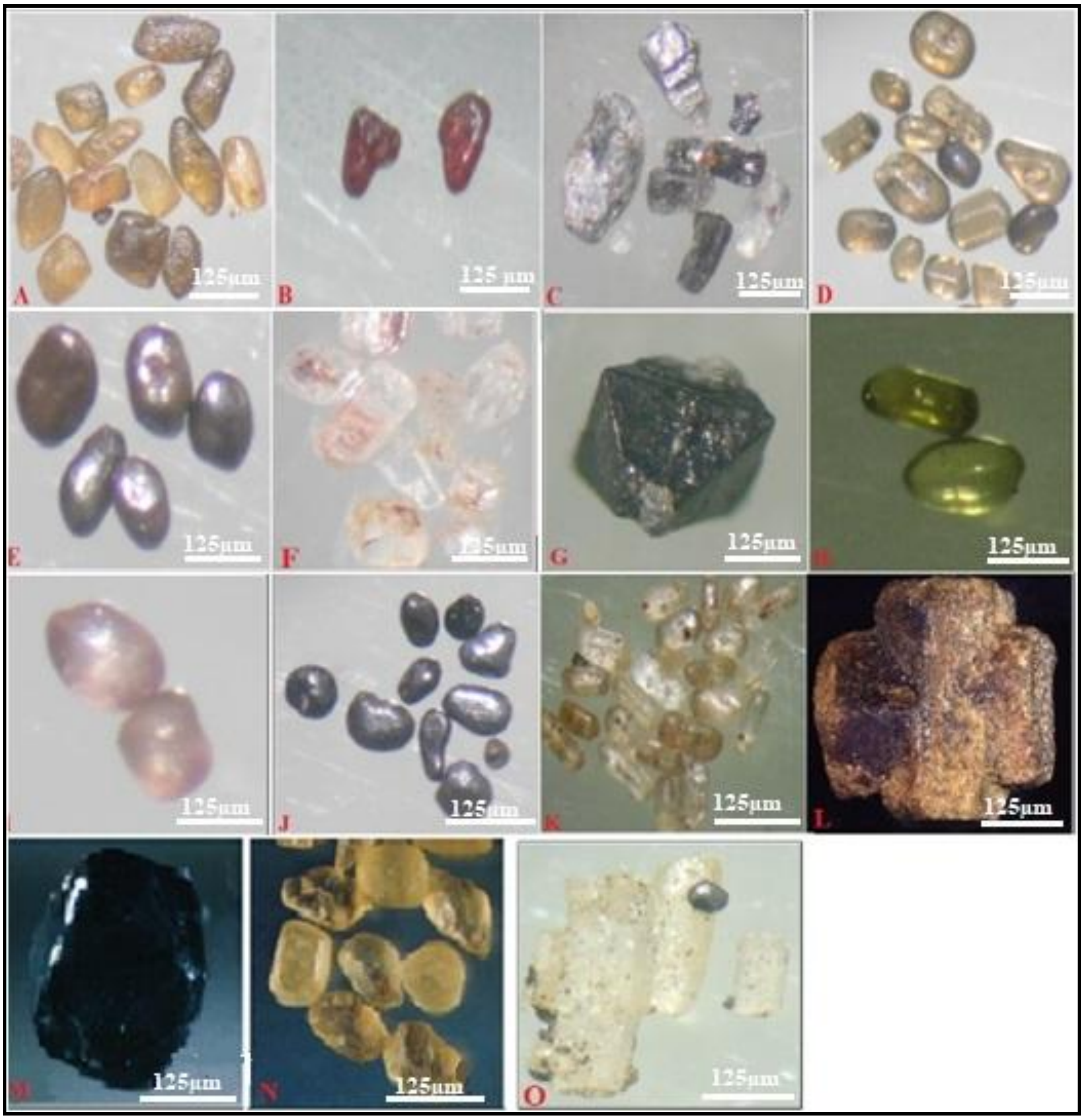

Figure 3 *: Heavy minerals identified in the profiles of Diosso-Malele, "pont du Djoué cliff and "Main bleue":* ***A****) sphene ;* ***B****) rutile ;* ***C****) Kyanite ;* ***D****) tourmaline ;* ***E****) limonite ;* ***F****) sillimanite ;* ***G****) magnetite ;* ***H****) amphibole ;* ***I****) garnet,* ***J****) ilmenite ;* ***K****) zircon ;* ***L****) staurotide ;* ***M****) spinelle ;* ***N****) andalousite,* ***O)*** *mineral not identified (NI).*

3.2.2. Quantification of heavy minerals

Tables 2, 3 and **4** give the results of the heavy mineral count contained in the selective samples from the profiles of Diosso and Malele, "Pont du Djoué cliff and the Blue Main.

Table 2. *Mineralogical composition of the Cover Formation and its bedrock represented by the Série des Cirques of Diosso*

Formation	Samples	Counting	Tourmaline	Zircon	Garnet	Rutile	Sphene	Staurotide	Kyanite	Sillimanite	Amphibole	Spinelle	Ilmenite	Magnetite	Limonite	Mineral N.I.	TOTAL
Cover Formation	MAL2-16	Number	118	28	0	8	120	0	20	125	34	0	122	0	44	0	619
		%	19,06	4,52	0,00	1,29	19,39	0,00	3,23	20,19	5,49	0,00	19,71	0,00	7,11	0,00	
	MAL2-10	Number	59	7	0	5	48	0	22	100	28	0	71	0	11	0	351
		%	16,81	1,99	0,00	1,42	13,68	0,00	6,27	28,49	7,98	0,00	20,23	0,00	3,13	0,00	
	MAL2-07	Number	119	16	4	20	59	0	34	137	22	0	130	0	3	0	544
		%	21,88	2,94	0,74	3,68	10,85	0,00	6,25	25,18	4,04	0,00	23,90	0,00	0,55	0,00	
	MAL2-05	Number	42	8	0	7	115	0	22	48	38	0	115	0	12	0	407
		%	10,32	1,97	0,00	1,72	28,26	0,00	5,41	11,79	9,34	0,00	28,26	0,00	2,95	0,00	
	MAl2-03	Number	138	37	1	15	115	0	24	326	47	1	250	0	50	0	1004
		%	13,75	3,69	0,10	1,49	11,45	0,00	2,39	32,47	4,68	0,10	24,90	0,00	4,98	0,00	
"Serie des Cirques"	DIO-30	Number	99	103	13	12	364	1	65	705	59	2	1145	2	39	4	2613
		%	3,79	3,94	0,50	0,46	13,93	0,04	2,49	26,98	2,26	0,08	43,82	0,08	1,49	0,15	
	DIO-23	Number	106	30	0	0	246	0	7	71	75	0	295	0	74	2	906
		%	11,70	3,31	0,00	0,00	27,15	0,00	0,77	7,84	8,28	0,00	32,56	0,00	8,17	0,22	
	DIO-20	Number	37	12	3	2	155	0	9	25	28	1	285	0	9	2	568
		%	6,51	2,11	0,53	0,35	27,29	0,00	1,58	4,40	4,93	0,18	50,18	0,00	1,58	0,35	
	DIO-19	Number	40	11	0	1	51	0	20	129	17	4	175	0	8	1	457
		%	8,75	2,41	0,00	0,22	11,16	0,00	4,38	28,23	3,72	0,88	38,29	0,00	1,75	0,22	

Table 3. *Mineralogical composition of the Cover Formation and its bedrock represented by the Inkisi sandstones in the profile of the "Pont du Djoué" cliff*

Formation	Samples	Depth (m)	Counting	Tourmaline	Zircon	Rutile	Anatase	Sphene	Staurotide	Kyanite	Garnet	Sillimanite	Amphibole	Ilmenite	Limonite	TOTAL
Cover Formation	**DJO-04**	**9**	Number	132	15	18	0	120	0	20	0	96	5	122	44	572
			%	23,08	2,62	3,15	0,00	20,98	0,00	3,50	0,00	16,78	0,87	21,33	7,69	
	DJO-05	**7**	Number	150	5	23	0	81	7	12	1	45	3	97	37	461
			%	32,54	1,08	4,99	0,00	17,57	1,52	2,60	0,22	9,76	0,65	21,04	8,03	
	DJO-03	**5**	Number	59	7	16	0	48	4	22	0	37	6	56	11	266
			%	22,18	2,63	6,02	0,00	18,05	1,50	8,27	0,00	13,91	2,26	21,05	4,14	
Inkisi	**DJO-01**	**3**	Number	62	4	7	10	0	0	1	2	0	0	52	20	158
			%	39,24	2,53	4,43	6,33	0,00	0,00	0,63	1,27	0,00	0,00	32,91	12,66	
	DJO-07	**2,3**	Number	68	2	5	14	0	0	3	2	0	0	49	23	166
			%	40,96	1,20	3,01	8,43	0,00	0,00	1,81	1,20	0,00	0,00	29,52	13,86	
	DJO-08	**1,95**	Number	94	3	9	23	0	0	1	1	0	0	50	16	197
			%	47,72	1,52	4,57	11,68	0,00	0,00	0,51	0,51	0,00	0,00	25,38	8,12	

Table 4. *Mineralogical composition of the Cover Formation and its bedrock represented by the Stanley-Pool in the "Main Bleue" profile*

Formation	Samples	Counting	Tourmaline	Zircon	Rutile	Anatase	Sphene	Staurotide	Kyanite	Garnet	Sillimanite	Amphibole	Spinelle	ilmenite	Magnetite	Limonite	TOTAL
Cover Formation	MB-11	Number	150	5	23	0	77	12	4	2	45	3	0	210	0	47	501
		%	29,94	1,00	4,59	0,00	15,37	2,40	0,80	0,40	8,98	0,60	0,00	41,92	0,00	9,38	
	MB-06	Number	162	7	4	0	53	13	9	0	40	2	0	182	0	32	451
		%	35,92	1,55	0,89	0,00	11,75	2,88	2,00	0,00	8,87	0,44	0,00	40,35	0,00	7,10	
	MB-01	Number	65	2	2	0	62	9	2	1	9	2	0	120	0	14	226
		%	28,76	0,88	0,88	0,00	27,43	3,98	0,88	0,44	3,98	0,88	0,00	53,10	0,00	6,19	
Stanley-Pool	E-06	Number	49	1	5	0	0	3	0	0	0	0	0	40	0	13	111
		%	44,14	0,90	4,50	0,00	0,00	2,70	0,00	0,00	0,00	0,00	0,00	36,04	0,00	11,71	
	E-10	Number	40	2	4	0	0	0	1	1	0	0	0	80	0	32	160
		%	25,00	1,25	2,50		0,00	0,00	0,63	0,63	0,00	0,00	0,00	50,00	0,00	20,00	
	GB-03	Number	51	2	5	0	0	3	1	0	0	0	0	39	0	14	115
		%	44,35	1,74	4,35	0,00	0,00	2,61	0,87	0,00	0,00	0,00	0,00	33,91	0,00	12,17	
	GB-01	Number	35	3	3	0	0	2	2	1	0	0	3	23	0	15	87
		%	40,23	3,45	3,45	0,00	0,00	2,30	2,30	1,15	0,00	0,00	3,45	26,44	0,00	17,24	

These tables show that heavy minerals are less abundant in the Cover Formation (0.01 to 0.2% of the initial sample mass) than in its bedrock (0.2 to 0.8%). These heavy minerals are dominated by ubiquitous minerals, mainly ilmenite, tourmaline, zircon, rutile, followed by metamorphism minerals such as sillimanite, kyanite, andalusite, garnet and staurotide; magmatism minerals such as spinel, sphene and other common minerals such as magnetite, green amphibole, limonite.

In the Diosso profile (**Figure 4a**)the ilmenite is the most abundant heavy mineral, followed by sillimanite and sphene. This is followed by tourmaline, zircon, green amphibole, limonite, rutile, and garnet. These heavy minerals are rounded except for spinel, sillimanite, staurotide and kyanite, which are sub angular and even prismatic. In the Cover Formation, ilmenite, sillimanite, sphene, and tourmaline are the most abundant heavy minerals. Next come amphiboles, kyanite, zircon, and limonite. Garnet and rutile are scarce. The kyanite, sillimanite, staurotide are sub rounded. Tourmaline and zircon are much worn, while others are still prismatic. Several grains of the heavy minerals of the Cover Formation bear impact marks unlike those of the "Série des Cirques" of Diosso. Red hematite, although very abundant compared to all other minerals, was not considered in the statistical study. Its angular shape and leaf habit show that it results from current pedogenetic processes. The "Série des Cirques" of Diosso is characterized by the following heavy mineral paragenesis: ilmenite, sillimanite, sphene, tourmaline, amphibole and zircon, while the Cover Formation is characterized by the ilmenite, sillimanite, sphene and tourmaline paragenesis (**Figure 4a**).

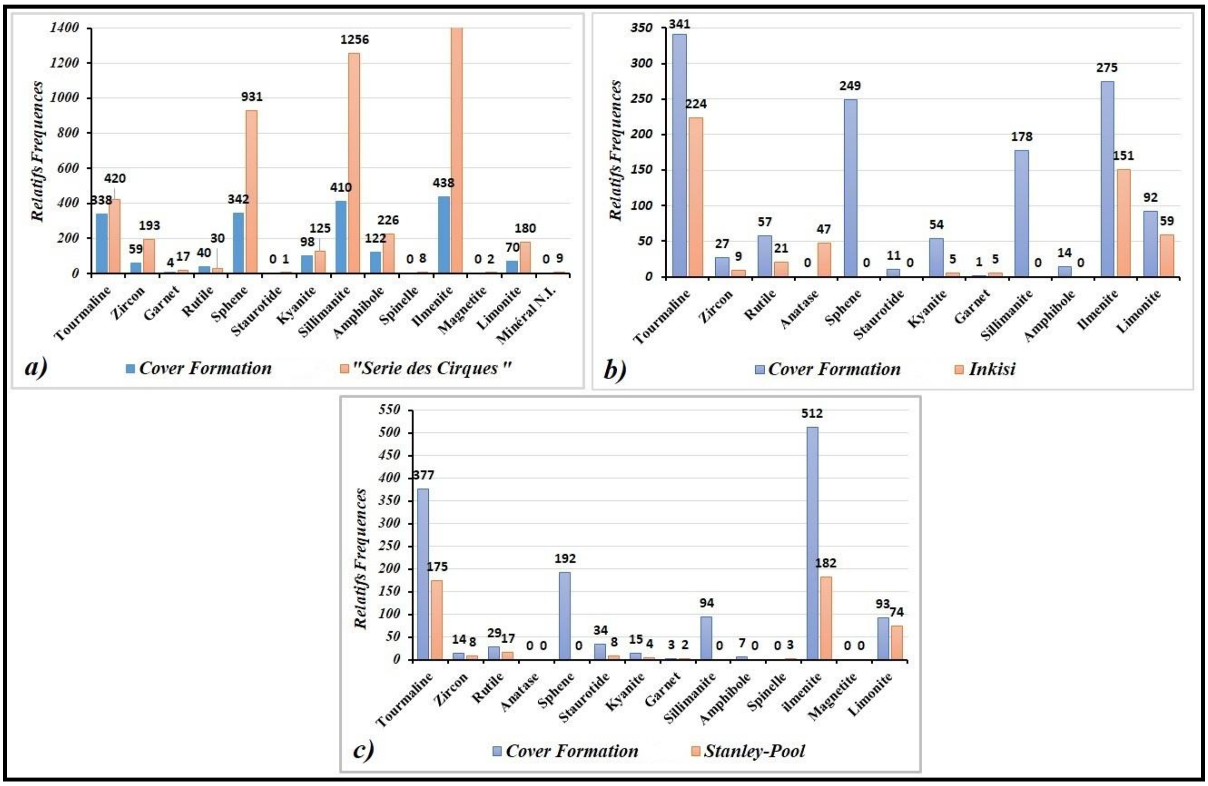

Figure 4. *Relative frequencies of heavy minerals in the Malele Cover Formation and its bedrock: (**a**)Diosso and Malele profile, (**b**)"Pont du Djoué cliff profile, (**c**)Main bleue profile*

In the profile of the "Pont du Djoué" cliff (**Figure 4b***)*, the heavy minerals identified in the Inkisi sandstones are, in order of decreasing abundance: tourmaline, ilmenite, limonite, anatase, rutile, zircon, kyanite, garnet. These minerals are sub angular. Those identified in the Cover Formation are, in decreasing order of abundance: tourmaline, ilmenite, sphene, sillimanite, limonite, rutile, kyanite, zircon, green amphibole, staurotide. Contrary to those described in the Inkisi sandstones, those of the Cover Formation bear shot marks similar to those observed on the heavy minerals of the Malele Cover Formation. Sillimanite and kyanite are either prismatic or sub-rounded. Tourmaline and zircon are much worn out, while others are prismatic or even automorphic. The dominant heavy mineral paragenesis in the Cover Formation is composed of tourmaline, ilmenite, sphene and sillimanite, while that of the Inkisi sandstones is composed of tourmaline, ilmenite, limonite and anatase. Anatase is absent in the Cover Formation, whereas sphene, staurotide, sillimanite and green amphibole are absent in the Inkisi sandstones (**Figure 4b**).

In the profile of "Main bleue" (**Figure 4c**), the heavy minerals identified in the Staley-Pool are, in decreasing order of abundance: ilmenite, tourmaline, rutile, zircon, staurotide, kyanite, kyanite, garnet, spinel. These minerals are much worn out, some grains are rounded.

In the Cover Formation, the heavy minerals identified are the following, in decreasing order of abundance: ilmenite, tourmaline, sphene, sillimanite, limonite, rutile, staurotite, zircon, kyanite, amphibole, garnet. These heavy minerals are angular, broken and bear fresh choc marks. Some zircons and tourmalines are prismatic. The dominant heavy mineral paragenesis in the Stanley-Pool is in decreasing order of abundance: ilmenite, tourmaline, limonite and rutile. The dominant heavy mineral paragenesis in the Cover Formation consists of ilmenite, tourmaline, sphene, sillimanite and limonite. Sillimanite, sphene and amphiboles, present in the Cover Formation, are absent in the Stanley-Pool Series, while spinel and anatase are absent in the Cover Formation. The Cover Formation differs qualitatively and quantitatively from its bedrock represented by the Stanley-Pool.

3.3. Principal Component Analysis (PCA)

3.3.1. Profile of Diosso-Malélé

Principal component analysis shows that the factorial planes (F1, F2) and (F1, F3) account for 78.15% and 73.36% of the total variability of the observation points or variables, respectively. The first two planes represent the variability contained in the data set. The study of the cloud of variables in the (F1, F2) plane (**Figure5a**) reveals mineral parageneses grouped into two clouds: the first cloud relating to the F1 axis is made up of sillimanite, ilmenite, magnetite, zircon, sphene, garnet, rutile, staurotide and the second relating to the F2 axis is made up of tourmaline, amphibole and limonite. Spinel and rutile seem to deviate from these two clouds.

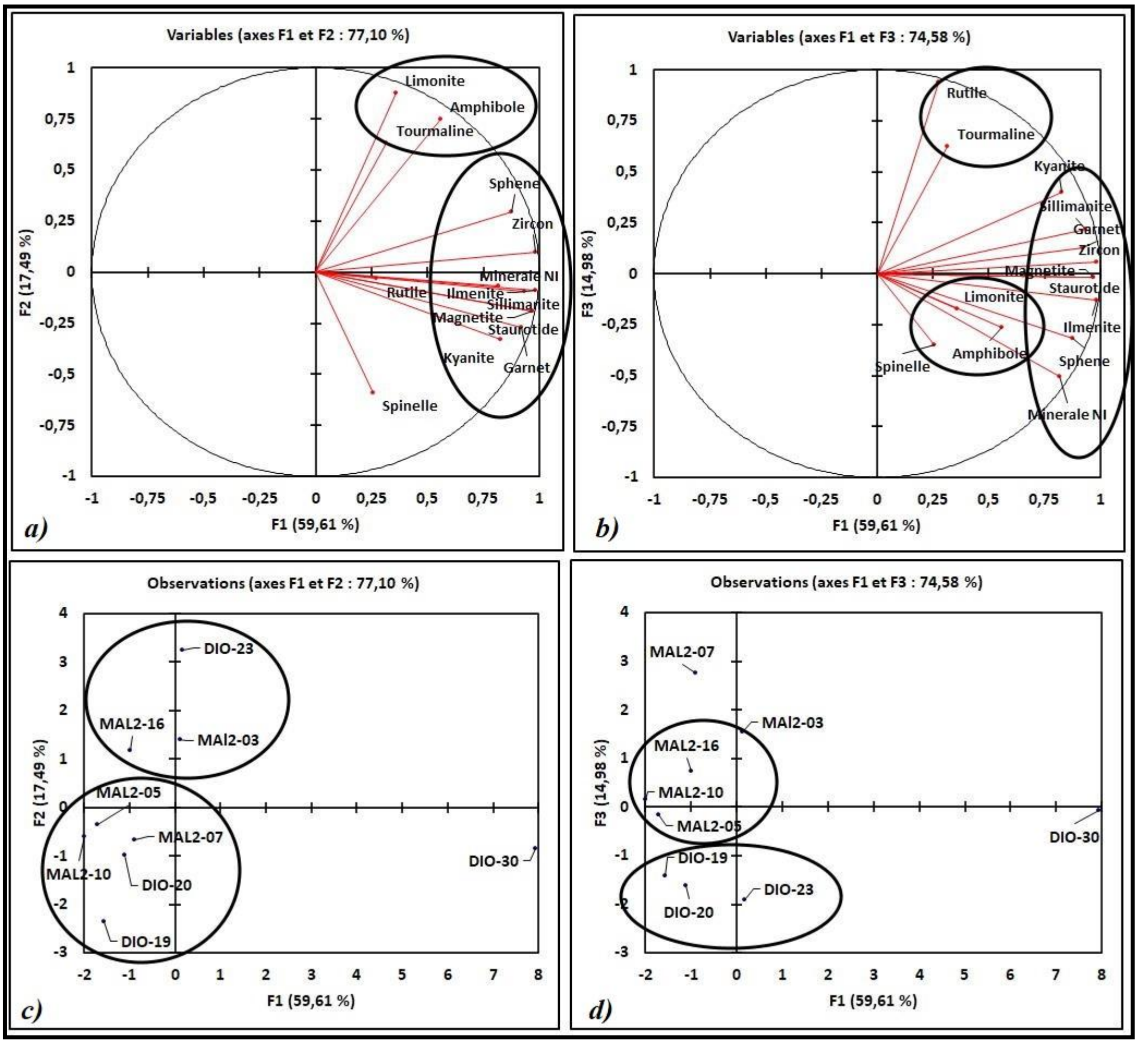

Figure 5*.Cloud of mineral and samples in the (F1, F2) and (F1, F3) planes of the Diosso series of Cirques (DIO-19, DIO-20, DIO-23, DIO-30) and the Malélé Cover Formation (MAL2-03, MAL2-05, MAL2-07, MAL2-10, MAL2-16)*

The plane (F1 and F3) **(Figure 5b)** shows mineral parageneses grouped into three clouds: the first and second clouds refer to the F1 axis and the third to the F3 axis. The first cloud is composed of kyanite, zircon, staurotide, magnetite, garnet, ilmenite; the second cloud by amphibole, limonite and spinel, and the third by tourmaline and rutile.
The study of the observation point cloud (the samples) shows two opposing sample clouds in the plane (F1, F2) (**Figure5c**). The first cloud that is negatively correlated with respect to F1 is composed of samples MAL2-05, MAL2-10, MAL2-07, DIO-20 and DIO-19. This first cloud is strongly opposed to sample DIO-30. The second cloud which is positively correlated with respect to F2 is composed of MAL2-16, MAL2-03 and DIO-23. It negatively opposes the first cloud with respect to F2. The (F1, F3) plane (**Figure5d*)*** shows two sample clouds that stand out clearly and discriminate well between the “Series des Cirques” and the Cover Formation samples. The first cloud relating to the F1 axis consists of samples MAL2-10, MAL2-05, MAL2-16. The second cloud relating to F3 consists of the samples DIO-19, DIO-20 and DIO-23. In this plane, samples MAL2-07 and MAL2-03 strongly oppose the second cloud.

3.3.2. Profile of "Pont du Djoué"Cliff

Principal component analysis shows that the factorial planes (F1, F2) and (F1, F3) account for 95.71% of the total variability of the cloud of observation points or variables. The first two planes represent very well the variability contained in the data set. In the (F1, F2) plane (**Figure6a*)***, the heavy mineral clouds show four clouds: the first relating to the F1 axis is composed of zircon, sphene, rutile and sillimanite. The second referring to axes F1 and F2 is composed of tourmaline, ilmenite and limonite. The third, relating to axes F1 and F2, is composed of staurotide, kyanite and amphibole, and the fourth, which opposes the third, is composed of garnet and anatase.

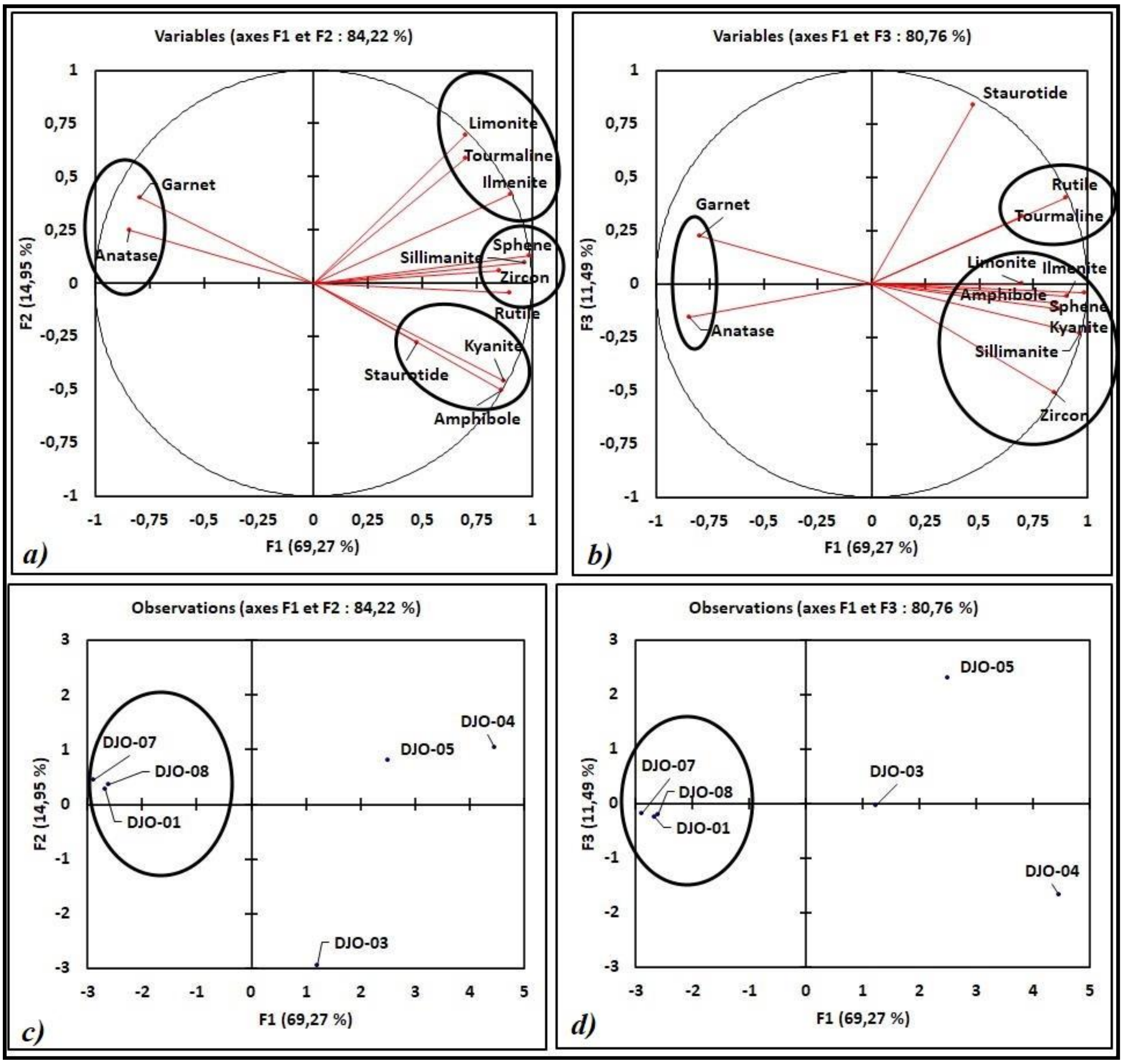

Figure 6*. Clouds of heavy minerals and samples in planes (F1, F2) and (F1, F3) in the Inkisi sandstones (DJO-01, DJO-07, DJO-08) and the Cover Formation (DJO-03, DJO-04, DJO-05) outcropping in the cliff of the "Pont du Djoué".*

The plane (F1, F3) shows three heavy mineral clouds (**Figure 6b*)***: The first is composed of sillimanite, kyanite, ilmenite, sphene, zircon, limonite and amphibole. The second is composed of tourmaline and rutile and the third is formed by anatase and garnet.

With respect to the samples, the (F1, F2) plane (**Figure 6c*)*** shows a cloud composed of samples DJO-01, DJO-07, DJO-08 of the Inkisi sandstones, negatively correlated with the F1 axis and opposing samples DJO-03, DJO-04, DJO-05 of the Cover Formation. The plane (F1, F3) presents an organization identical to that described above and marked by a cloud containing samples DJO-01, DJO-07, DJO-08 of the Inkisi sandstones, negatively correlated with the F1 axis and which opposes samples DJO-03, DJO-04, DJO-05 of the Cover Formation (**Figure 6d).** Principal component analysis shows a clear mineralogical distinction between the Inkisi sandstone and the Cover Formation.

3.3.3. Profile of the "Main bleue"

The (F1, F2) plane (**Figure 7a**) shows two clouds of points. The first one relating to F1 axis is composed of sillimanite, ilmenite, zircon, sphene, staurotide, kyanite, amphibole and tourmaline.

The second cloud, which refers to F2, is composed of garnet and rutile. The spinel deviates negatively from the first cloud. The (F1, F3) plane (**Figure7b*)*** also shows two clouds of points related to F1 axis. The first cloud consists of tourmaline, sillimanite, staurotide, rutile, sphene, amphibole, ilmenite and limonite. The second consists of garnet, zircon and kyanite. According to this plan, the spinel spreads out and also opposes the two mineral clouds.

With respect to the samples, the (F1, F2) plane (**Figure 7c**) shows a cloud which relates to the F1 axis, consisting of samples GB-01, GB-02, E-06 and E-10 all belonging to the Stanley-Pool, and which opposes samples MB-01, MB-06 and MB-11 of the Cover Formation. The (F1, F3) plane (**Figure 7d**) also shows along the F1 axis, a cloud of the samples (E-06, E-10, GB-03) belonging to the Stanley-Pool which opposes samples MB-06 and MB-11 of the Cover Formation. Principal component analysis shows a clear mineralogical distinction between the Stanley-Pool and Cover Formation samples.

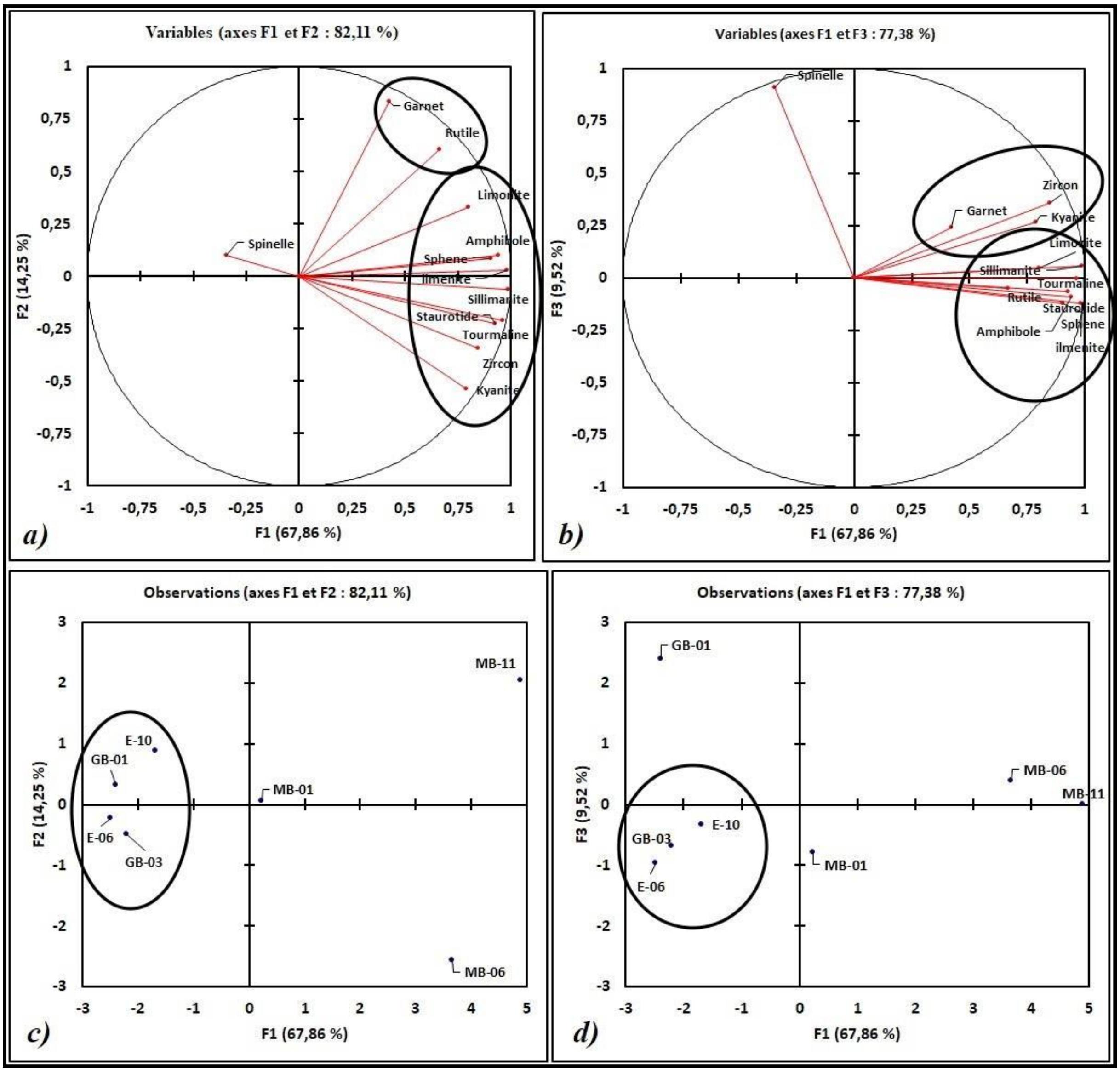

Figure 7*. Clouds of heavy minerals and samples in planes (F1, F2) and (F1, F3), contained in the Stanley-Pool (GB-01, E-06, E-10) and Cover Formation (MB-01, MB-06, MB-11) outcropping in the "Main bleue" profile.*

IV. Interpretation and discussion of results

The field study shows that in all three studied profiles, the Cover Formation overlies its bedrock via a polymictic or polygenic coarsening up orthoconglomerate or via a palaeosol. This coarsening up sorting is indicative of sedimentary dynamics and the increasing of the transport currents competence. These observations confirm those of Thiéblemont **[15]** in Gabon andMiyouna*et al.* (2016, 2019) in Congo, who show that the stone line marks a paléosurface and a gully unconformity. This means that a long time separate the setting up of the Cover Formation of his bedrock.

The study of the heavy minerals of the three studied profiles, shows that heavy minerals are less abundant in the Cover Formation (about 0.01% to 0.3% of the initial sample weight) than in the bedrock (about 0.8% of the initial sample weight). These percentages are identical to those obtained by Le Maréchal **[17]** in the Nganga-Lingoloand Inoni, respectively in Brazzaville and Pool Departments. The heavy minerals identified in the Cover Formation are, in decreasing order of abundance: ilmenite, sillimanite, sphene, tourmaline, amphibole, kyanite, limonite, zircon, rutile and garnet. This list is similar to that obtained by Le Maréchal **[17]** in Congo and by Thiéblemont **[15]** in Gabon, except for the apatite that we did not observe in our samples of the Cover Formation. Figure 4 shows that regardless of the lithological nature of the bedrock, the Cover Formation contains the same paragenesis of heavy minerals, dominated by ilmenite, sillimanite, sphene, tourmaline and zircon. This paragenesis distinguishes it from the bedrock, which contains more diverse and abundant heavy minerals. Regardless of the bedrock, the homogeneity in heavy mineralsof the Cover Formation over long distances from Pointe Noire to Brazzaville, and from Congo Brazzaville to Gabon, regardless of the bedrock, suggests that it does not come from *in-situ*weathering of its basement, contrary to Le Marechal **[17]** and Schwartz **[9]**,**[18]** who believe that the Cover Formation is the product of *in-situ*weathering of its basement. The shot marks on the heavy minerals of the Cover Formation are evidence of their aeolian origin. According to Pojar*et al.***[37]**, it is possible to determine the source or the originof the sediment from the association of heavy minerals containedin a sediment. The angular, sub-rounded sometimes sub-automorphic kyanite, sillimanite, staurotide and green amphibole, associated with garnet, indicate a metamorphic provenance of the green shale and amphibolite facies. Well-rounded tourmaline and zircon show evidence of reworking or recycling of ancient sedimentary or meta-sedimentary rocks. On the other hand, the sub-automorphic zircons and tourmalines associated with rutile undoubtedly suggest magmatic felsicrock origin such as granites, diorites, syenites, granodiorites and associated lavas. Well-worn ilmenite and limonite reveal a long history and several sedimentary cycles. They have been reworked from sediments derived from the alteration of magmatic or metamorphic rocks, rich in ferromagnesian minerals such as diorites, granodiorites, tonalites and their volcanic equivalents. All these characteristics show that the heavy minerals contained in the Cover Formation come from feeding areas that contained mainly metamorphic rocks and secondarily magmatic and sedimentary or meta-sedimentary rocks. Such rocks exist in the Mayombemountain and the Chaillu massif **[23]; [38]**. However, the fact that the Cover Formation retains the same paragenesis of heavy minerals regardless of the geological nature of the bedrock and the fact that these heavy minerals bear shot marks, rule out the hypothesis of *in-situ* alteration of its bedrock and therefore his autochthony. The homogeneity of the paragenesis of the heavy minerals supposes that the sediments of the Cover Formation come from the same distant source.

In the profile of Diosso - Malélé, in the (F1, F2) plane (**Figure5a**), the two clouds formed respectively by the samples (DIO-23 of the "Série des Cirques" and MAL2-16, MAL2-03 of the Cover Formation) (DIO-19, DIO-20 of the "Série des Cirques" and MAL2-05, MAL2-07, MAL2-10 of the Cover Formation) assume that these samples have similar heavy mineral compositions. On the other hand, the (F1, F3) plane (**Figure5b*)*** shows two distinct clouds that discriminate samples DIO-19, DIO-20, DIO-23 of the "Série des Cirques" from samples MAL2-05, MAL2-10, MAL2-16, MAL2-03 and MAL2-07 of the Cover Formation. This shows that from the point of view of heavy mineral content, the sediments of the "Série des Cirques of Diosso and the Malele Cover Formation have similarities and dissimilarities that allow them to be qualitatively and quantitatively distinguished.

In the profile of the "Pont du Djoué" cliff of the heavy minerals identified in the Inkisi sandstones are: tourmaline, rutile, anatase, zircon, ilmenite, limonite, associated with some kyanite, garnet, magnetite and brown hematite. These minerals generally angular, sub-angular and don’t bear shot marks, indicating proximity of the area that supply the sediments and a transport agent other than wind. According to Boudzoumou**[25]**, **[1],[26]** the Inkisi sandstones are of fluvial origin. On the other hand, heavy minerals of the Cover Formation, represented by ilmenite, tourmaline, rutile, zircon, associated with sphene, kyanite, sillimanite, staurotide, garnet, limonite, magnetite and brown hematite, which are strongly worn and still bear visible shot marks, show that they were recycled and transported by wind for a long time before being immobilized in a continental environment. In this profile, the Inkisi sandstones and the Cover Formation are easily distinguished qualitatively and quantitatively by their heavy mineral content. Principal component analysis shows that in the (F1, F2), (F1, F3) planes (**Figure6a, 6b***)*,thedifferent mineral clouds form parageneses point firstly towards metamorphic rocks of green shale grade and amphibolite grade, and secondly towards magmatic rocks. In planes (F1, F2) and (F1, F3) (**Figure6c, 6d)**, the two clouds of samples respectively composed of samples (DJO-01, DJO-07, DJO-08) of the Inkisi sandstones and (DJO-03, DJO-04, DJO-05) of the Cover Formation and which negatively oppose each other with respect to the F1 axis show that the Inkisi sandstones and the Cover Formation have diametrically opposed heavy mineral compositions. This shows that the yellow ochre sands of the Cover Formation overlying the Inkisi sandstones are not the product of *in-situ* weathering of the Inkisi sandstones.

In the "Main bleue" profile, the heavy minerals identified in the Stanley-Pool are ilmenite, tourmaline, rutile, zircon, staurotide, kyanite, garnet, and spinel. The fact that these heavy minerals are well-worn and sometimes bear polished shot marks suggests an aquatic recovery after an aeolian phase. On the other hand, in the Cover Formation the heavy minerals identified are ilmenite, tourmaline, sphene, sillimanite, limonite, rutile, staurotide, zircon, kyanite, amphibole and garnet. These heavy minerals are worn, commonly broken, and bear fresh shot marks indicating that they have been subjected to a final aeolian process before being immobilized. Qualitatively and quantitatively, the Cover Formation differs clearly from the Stanley-Pool by its heavy mineral content.

The two clouds of heavy minerals in the plane (F1, F2) (**Figure7a**) formed respectively by sillimanite, ilmenite, zircon, sphene, staurotide, kyanite, amphibole, limonite and tourmaline for the first and garnet and rutile for the second, point towards metamorphic rocks of the green shale and amphibolite grades. The spinel that deviates negatively from the first cloud indicates an origin from mafic or ultramafic rocks deficient in quartz. In the (F1, F3) plane (**Figure7b**), the two clouds formed respectively of tourmaline, sillimanite, staurotide, rutile, sphene, amphibole, ilmenite and limonite for the first one and zircon, kyanite and garnet for the second one, confirm that the provenance area contains mainly metamorphic and secondarily magmatic rocks.

The distinct clouds (**Figure7c**) formed by the samples (GB-01, GB-03, E-06 and E-10) from the Stanley-Pool and the samples MB-01, MB-06 and MB-11 from the Cover Formation which oppose each other in the (F1, F2), (F1, F3) planes, show that these two formations have mineralogical compositions which clearly distinguish them. In the "Main bleue" profile, the Cover Formation has a much more different mineralogical composition than the Stanley-Pool. It is therefore not the result of theweathering of its bedrock formations represented by the Stanley-Pool.

To sum up, in the three studied profiles, the Cover Formation has the same and homogeneous heavy minerals composition. It is easily distinguished from its bedrock. These heavy minerals, dominated by the ubiquitous, mainly come from the metamorphic rocks of green shale and amphibolite grades, and secondarily, from magmatic and sedimentary rocks. Some of these minerals have undergone several sedimentary recycling processes.

V. Conclusion

The Cover Formation overlies its bedrock of varied lithological nature through a palaeosurfacematerialized by an alluvial or colluvial stone line, polymicte or oligomicte conglomerate. The Cover Formation contains a same and homogeneous paragenesis of heavy minerals dominated by ilmenite, sillimanite, sphene, tourmaline, amphibole, kyanite, limonite, zircon, rutile and garnet, whatever the geological nature of the bedrock. This paragenesis distinguishes qualitatively and quantitatively the Cover Formation from its bedrock. These heavy minerals found in the Cover Formation originate mainly from the weathering profiles of ancient metamorphic rocks of green shale amphibolites grades, and secondarily, from magmatic rocks with felsic tendency rich in ferromagnesium, and finally from the weathering profiles of ancient sedimentary or metasedimentary rocks. These heavy minerals have undergone several sedimentary recyclings and have been transported by the wind. Itappears clearly, according to the heavy minerals, the Cover Formation does not result from *in-situ*weathering of its bedrock. It comes from a distant source and must therefore be stratigraphically separated from its bedrock as proposed by Thiéblemont et *al*. (2009) in Gabon.

VI. Acknowledgements

We would like to thank all the staff of the sedimentology laboratory of the "Centre de RecherchesGéologiques et Minières"of Kinshasa (RDC) for the quality of the extractions and treatments carried out on the heavy minerals, which undoubtedly facilitated their determination. We would like to thank the General Manager of Congo Exploration who provided us with the necessary means during the field study. We thank MrJoachim MIYOUNA for the English translation. We also thank the anonymous reviewer for the quality of the observations and suggestions that improved the quality of this manuscript.

References

[1] **Callec, Y., Beaur H., Paquet F., Prognon F., Issautier B., Schoetter J-M., Thiéblemont D., Boudzoumou F., Guillochau F., KebiTsoumou S., Dah Tolingbonon R. H., NgangaLumuamu F. (2015a)**. Notice explicative de la carte géologique de la République du Congo à 1/100 000, Feuille Brazzaville. *Editions BRGM*. 129 p.

[2] **Miyouna, T., Malounguila-Nganga, D.M., Essouli, O.F., Ndembé-Nbembé, A. J., Moussiessié, J., Kinga-Mouzéo, Boudzoumou, F. (2016)**. Etude Paléoenvironnementale des dépôts détritiques de la Formation de couverture du bassin côtier du Congo. *Rev. CAMES*, Vol. 04, n°01, ISSBN : 2424 – 7235, 35 – 44.

[3] **Miyouna, T., Elenga, H., Boudzoumou, F., Essouli, O. F., IbaraGnianga, A., Sow, E. H. (2019**). Dynamique sédimentaire de la Formation de couverture de Pointe Noire à Brazzaville, sud de la République du Congo. *Afrique Science*, 15 (4), ISSN 1813-548X, 134 – 155.

[4] **Vincent, P.L. (1965)**. Les formations meubles superficielles au sud du Congo et du Gabon. Mission 1964 – 1965. *Rapport BRGM*, 65 BRA 009.

[5] **Vogt, J., Vincent, P.L. (1966)**. Terrains d'altération et de recouvrement en zone intertropicale. *Bull. BRGM*, 4, 1–111.

[6] **Dadet, P. (1969)**. Notice explicative de la carte géologique de la République du Congo Brazzaville au 1/500 000. Mem. *Bur. Rech. Geol. Min*. Orléans, France 70, 103p.

[7] **Sitou, L., Tchicaya, J. (1991)**. L'érosion en cirques dans la région côtière du Congo. *Bulletin de la Société Géographique de Liège*. 27, 77-91, 13p.

[8] **Schwartz, D. (1992)**. Assèchement climatique vers 3000 B.P. et expansion Bantu en Afrique centrale atlantique : quelques réflexions. *Bull. Soc. Géol. France*, 163 (3), pp 353–361.

[9] **Schwartz, D. (1996**). Archéologie préhistorique et processus de formation des stone lines en Afrique centrale (Congo-Brazzaville et zones périphériques). Seminar on Géo-archeology*In*: Tropical and Mediterranean Regions, Brussels, April 1996. Royal Academy of Overseas, Sciences. *Geo-Eco-Trop*, 20 (1-4), 15–38.

[10] **Mercader, J., Marti, R., Martinez, J. L., Brooks, A. (2002)**. The nature of the stone lines in the African Quaternary Record: archaeological resolution at the rainforest site of Mosumu, Equatorial Guinea. *Quaternary International*, 89, 71-96.

[11] **Lecomte, P. (1988)**. Stone line profiles: Importance in geochemical exploration. *Journal of Geochemical Exploration*, 30, 35-61.

[12] Rünge, J. (2001). On the age of stone-lines and hillwash sediments in the eastern Congo basin –palaeoenvironmental implications. *In*: Heine K. (Ed.), Palaeocology of Africa and the surroundings islands. Proc. XVth*INQUA Conference*, pp. 19-36.

[13] Alexander, J. (2002). Les cuirasses latéritiques et autres formations ferrugineuses tropicales : Example du haut Katanga méridional. Musée Royal Afrique centrale, Tevuren. *Ann Sc. Géol.*,107, 2002.

[14] Thiéblemont, D., Castaing, C., Billa, M., Bouton, P., Préat, A. (2009). Notice explicative de la carte géologique et des ressources minérales de la République Gabonaise à 1/1.000.000. 3e édition, *BRGM*, n°249, 260-261p.

[15] Thiéblemont, D. (2013). Evidence for an aeolian origin of the Holocene lateritic surface cover of Gabon. *Quat. Int*. 296, 176–197.

[16] Cauxeiro, C. (2013). Architecture stratigraphique du prisme néogène de La Cuanza, Angola et relations avec les mouvements verticaux. Ph. D. Univ. Montpelier 2, 307 p.

[17] Le Maréchal, A. (1966). Contribution à l'étude des plateaux Batéké (Géologie, géomorphologie, hydrogéologie). Office de la Recherche Scientifique et Technique Outre-Mer, Centre de Brazzaville, Service géologique, Rapport, 78 p.

[18] Schwartz, D. (2014). Comment on: Geochronological arguments for a close relationship between surficial formation profiles and environmental crisis (C. 3000 – 2000 B.P.) in Gabon (Central Africa) – D. Thieblemont*et al*., 2013, *C.R. Geoscience*, 345, 272-283.

[19] Brownfield, M.E., and Charpentier, R.R. (2006). Geology and total petroleum systems of the West Central Coastal Province (7203), West Africa: *U.S. Geological Survey Bulletin* 2207-B, 52p.

[20] Frimel, H. E., Tack, L., Basei, M. S., Nutman, A. P., Boven, A. (2006). Provenance and chemostratigraphy of the Neoproterozoïc West congolian Group in the Democratic Republic of Congo. *Journal of African Earth Sciences*, 46, 221 – 239.

[21] Straathof, G.B. (2011). Neoproterozoic Low Latitude Glaciations: An African Perspective. Unpublished PhD *Thesis*, University of Edinburgh, 285p.

[22] Cahen, L. (1983). Le Groupe du Stanleyville (Jurassique supérieur et Wealdien de l'intérieur de la République du Zaïre) : Révision des connaissances. Rapport annuel du Musée Royal de l'Afrique centrale, Tervuren (Belgique), Département de Géologie et de la Minéralogie, p. 73 – 91.

[23] Desthieux, F., Boudzoumou, F., Mompossa, F., Akiaoue, E., Missamou, A., Malera, M., Kiba, V. (1993). Carte géologique de la République du Congo à 1/100.000. Ministère des Mines et de l'Energie.

[24] Callec, Y., Lasseur, E., Le Bayon, B., Thiéblemont D., Fullgraf, T., Gouin, J., Paquet F., Le Metour, D. J., Delhaye-Brat, V., Giresse, P., Malounguila-Nganga, D. M., Boudzoumou F. (2015b). Notice explicative de la carte géologique de la République du Congo à 1/200 000, Feuille Pointe Noire. *Editions BRGM*. 213 p.

[25] Boudzoumou, F. (1986). La chaine Ouest-Congolienne et son avant- pays au Congo : Relation avec le Mayombien, Sédimentologie des séquences d'âge protérozoïque supérieur. *Thèse de doctorat 3e cycle*. Université d'Aix- Marseille III, 216p.

[26] Bouity, L. (2016). Caractérisation sédimentologique et géotechnique des différents faciès des grès de l'Inkisi. *Mémoire de master*, Faculté des Sciences et Techniques Université Marien NGouabi. 52p.

[27] Chevalier, D., Giresse, P., Massengo, A., Botokou, G. (1972). Le site de Brazzaville ou contribution à une notice explicative de la carte géologique de Brazzaville. *Annale Université Brazzaville*, 8, 17 – 42.

[28] Giresse, P. (1982). La succession des sédimentations dans les bassins marins et continentaux du Congo depuis le début du Mésozoïque. *Sci. Geol. Bull*. 35 (4), 183 – 206.

[29] Mouyoungou, J. (1990). Les silicifications mésozoïques et cénozoïques de la bordure occidentale du Bassin de Paris et de la région de Brazzaville au Congo. *Thèse 3e cycle*, Université d'Angers. UFR Sciences de l'environnement. 242p.

[30] Giresse, P. (1990). Paleoclimatic and structural environment at the end of the Cretaceous along the Western flank of the congo Basin, with application of underground microdiamonds around Brazzaville. *Journal of African Earth* Sciences 10: 399 – 408.

[31] Nicolini, P., et Roger, J. (1951). Sur la présence des fossiles dans le Karroo à Brazzaville (Congo). *Comptes Rendus Académie des Sciences*, Paris 223, 1127 – 1129.

[32] Mestraud, J-L. (1964). Carte géologique de la République centrafricaine au 1/1500000. BRGM, Paris.

[34] Parffenoff, A., Pomerol, C., Tourenq, J. (1970). Les minéraux en grain, Méthodes d’étude et détermination. *Masson, et Cie Paris VI*, 550 p.

[35] Broche, J., Casanova, R., Loup, G. (1977). Atlas des minéraux en grains, identification par photographie en couleur. Société pour le développement Minier de la Côte d’Ivoire (SODEMI). République de la Côte d’Ivoire, 180 p.

[36] Devismes, P. (1995). Atlas photographiques des minéraux des alluvions. Mémoire du BRGM, N°95, Paris, 207 p.

[37] Pojar, I., Zaharia, L., Benea, M. (2014). Heavy mineral distributions in Upper Cretaceous Bozes Formation (Apuseni Mts., Romania). Implications for sediment provenance. *Capathian. Journal of Earth and Environmental Sciences*, 9: 125 -132.

[38] Charles, N., Callec, Y., Preat, A., Thiéblemont, D., Delpondor, F., Malounguila-Nganga, D.M., Gloaguen, E., Petitot, J., Akouala, J., Ndiele, B., MvoulaBoungou, I., MoeboBoungou, M. (2015). Notice explicative de la carte géologique de la République du Congo au 1/20 000. Feuille Madingou. Edition BRGM, 221p.