

**PETROGRAPHIC, GEOCHEMICAL AND PETROPHYSICAL
CHARACTERIZATION OF NEOPROTEROZOIC CARBONATE LITHOFACIES
OF THE LUKALA SUBGROUP IN THE WEST CONGO BASIN**

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ABSTRACT

This study focuses on the petrographic, geochemical and petrophysical characterization of Neoproterozoic carbonate lithofacies belonging to the Lukala Subgroup, in the West Congo Basin. The main objective is to characterize these lithofacies petrographically, geochemically and petrophysically to assess their petroleum potential. The methodology combines several complementary approaches: field observations allowed a detailed geological survey and the identification of the main lithofacies. Petrographic analysis (optical microscopy) was used to determine rock textures (grainstone, wackestone, mudstone), and sedimentary structures were also identified (fenestrae, oblique laminations, rhythmities). The analysis of the thin sections revealed a highly advanced diagenetic process (aggrading neomorphism, stylolites, cementation). Geochemical analysis indicates impure limestones lithofacies with notable non-carbonate fraction consisting of clays and silts. Petrophysical parameters were measured using the hydrostatic weighing method (adapted from NF EN 1936 / ISRM / API RP 40) for porosity, and the constant-head permeameter method for permeability. These rocks exhibit relatively very low porosity and permeability values: porosity < 4%, permeability < 10 mD.

Keywords: West Congo Basin, Neoproterozoic, limestone lithofacies, petroleum potential, Lukala Subgroup.

INTRODUCTION

The Lower Ediacaran (635-541 Ma) post-Marinoan carbonate succession (635-615 Ma) of the Lukala Subgroup (around 1,100 m thick) in the West Congo Basin is considered post-glacial carbonates of cap carbonate type and is overlaid by the upper Diamictite Formation [1]. It was deposited on a carbonate ramp from an outer ramp environment (deep marine) to an inner ramp environment (shallow marine) with an oolitic shoal barrier, stromatolitic bioherms and lagoon and sabkha type environments [2]. This Subgroup was deposited in a complex depositional environment with different depth zones and different environmental conditions which determine the distribution of lithofacies and the initial heterogeneity of reservoir properties. But petrographic analysis shows that carbonates have undergone extensive diagenesis (e.g.,

aggrading neomorphism, stylolites and cementation phases) and are far from being a product of a simple carbonate sequence. These diagenetic processes have in fact profoundly modified the primary porosity and permeability of these facies.

While the cement potential of the West Congolian carbonate series in the D.R. Congo is well established, direct data on their petrographic, geochemical, and petrophysical properties remain fragmentary. The West Congo Basin, and more particularly the Lukala Subgroup, thus constitutes a privileged object of study for improving scientific knowledge on the evolution of porosity and permeability, within a context of growing interest in petroleum exploration.

GEOLOGICAL SETTING OF THE STUDY AREA

Our study area is situated in Kongo Central Province, within the Cataractes District (Figure 1). It stretches northwest of the town of Kimpese and covers a hinge zone that lies between the territories of Songololo and Mbanza-Ngungu. Specifically, it is located between the coordinates 14°13' and 14°21' E and 5°3' and 5°9' S.

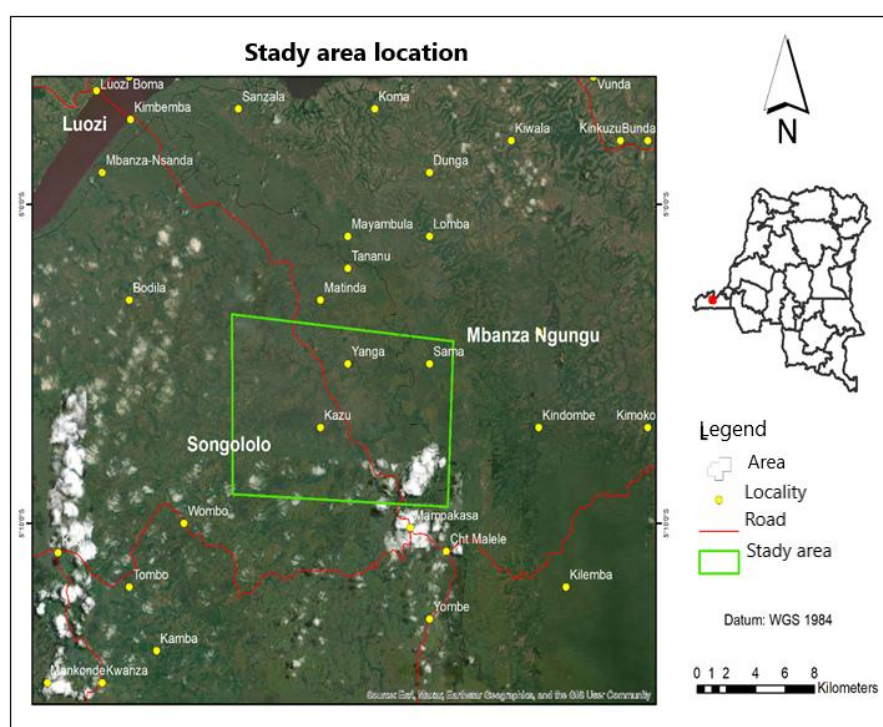


Figure 1. Geographical location of the study area.

From the lithostratigraphic point of view, the Cataracts Group belonging to West Congolian Supergroup (Figure 2) is subdivided into Subgroups [16],[14]. From base to top, the following units are distinguished: the Sansikwa Subgroup, Lower Diamictite Formation, Haut Shiloango Subgroup, Upper Diamictite Formation, Lukala Subgroup and Mpioka Subgroup [18],[12].

The Lukala Subgroup (about 1,100 m thick) is divided into four members from the base to the top: Kwilu Member (CI), Lukunga Member (CII) or Formation C4, Bangu Member (CIII) or Formation C5, and Ngandu Member (CIV) (Figure 3). The sedimentation starts with cap carbonates (pink and grey dolomite) and becomes calcareous as one moves up the succession

[21]. The geologic record, particularly the borehole DH8 [19], indicates a complex diagenesis. Its geologic history is characterized by two main stages: early diagenesis (associated with surface environmental conditions at the time of sedimentation (sedimentary environment), and middle-late to late diagenesis associated with burial (increased pressure and temperature) and circulation of fluids with varying physico-chemical properties [22].

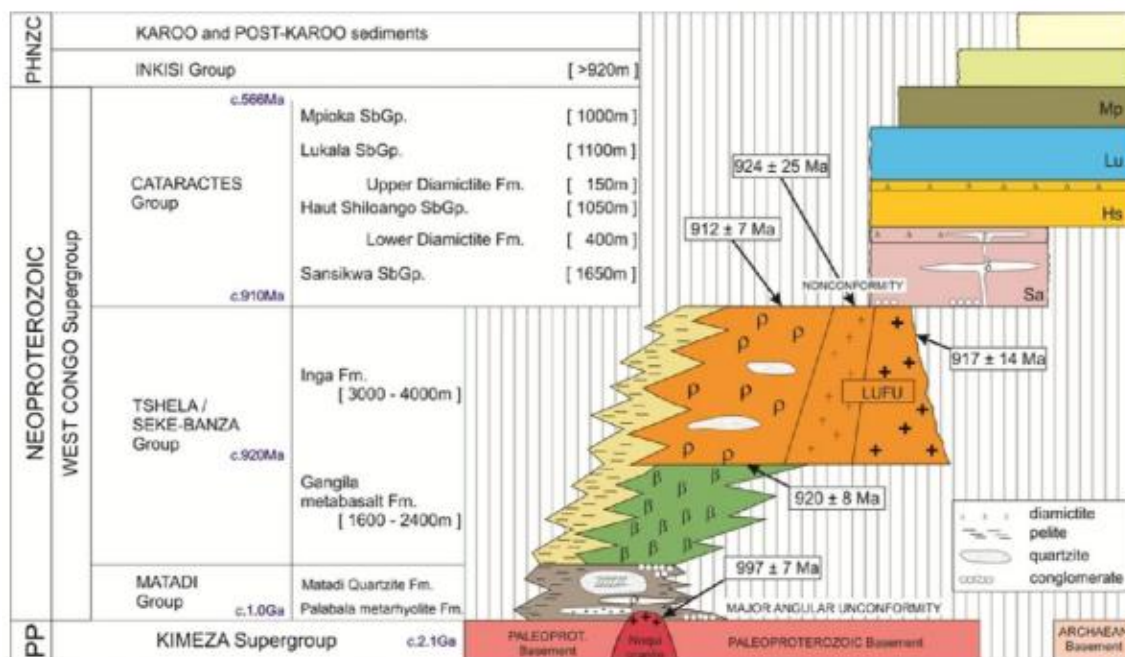


Figure 2. Lithostratigraphy of the West Congolian Supergroup [18].

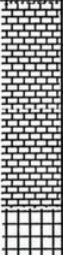
Supergroup	Group	Subgroup	Formation		Lithology	Age (Ma)		
Karoo and Post-Karoo								
Inkis						556 ± 29		
West Congo	West Congolien (Cataracts)	Mploka	Liansama Kubusi	PI	Shales, Quartzite and quartzitic sandstones	556		
			Vampa	PI	Shales, quartzites and conglomerates			
		Lukala (Schisto-calcareous)	Ngandu	C5	Limestones, shales, dolomite, ...	575		Limestone with algae, ooids and cyanobacteria
			Bangu		Oolites, limestones, shales, dolomites, ...			Stromatolitic limestone
			Lukunga	C4	Limestones, shales, dolomites, stromatolites, ...			Oolitic and pisolitic limestone
			Kwilu	C3	Limestones, shales, dolomite argillaceous, ...			Limestone with cyanobacterial mats
				C2	Limestones, siliceous shales, intercalations of sandstones			
				C1	Dolomite			
		Haut-Shiloango	Diamictite Supérieur	Ds	Marinoan diamictite	635		Cap carbonate
			Sekeloko	Shl	Limestone, quartzite, shales, dolomite	645		
			Petite Bemberi	Shl	Shales, limestones, quartzite conglomerates	650		
		Sansikwa	Diamictite Inférieur	DI	Diamictite sturtian	>700		
			Swll	Swll	Phyllite, shales, ...	923 ± 43		
			Swl	Swl	Arkose, conglomerates			
		Mayumbien						

Figure 3. Lithostratigraphy of the Lukala Subgroup [20–24].

The approach started with a review of local and regional geology in literature. A base map was prepared to plan our routes, landmarks, and geological cross-sections (Figure 4). In the field, we undertook geological studies based on observation of outcrops and sample collection. The collected samples were then subjected to petrographic, geochemical, and petrophysical analyses in the laboratory. The equipment used included a compass, a geological hammer, a GPS, various maps, plastic bags, a hand lens, a marker, a notebook, a tape measure, 10% diluted hydrochloric acid, and a camera. In the laboratory, we used a polarizing optical microscope (POM) with a magnification of 4X/0.10 (0.1 mm), a binocular loupe, and a portable X-ray fluorescence spectrometer (XRF).

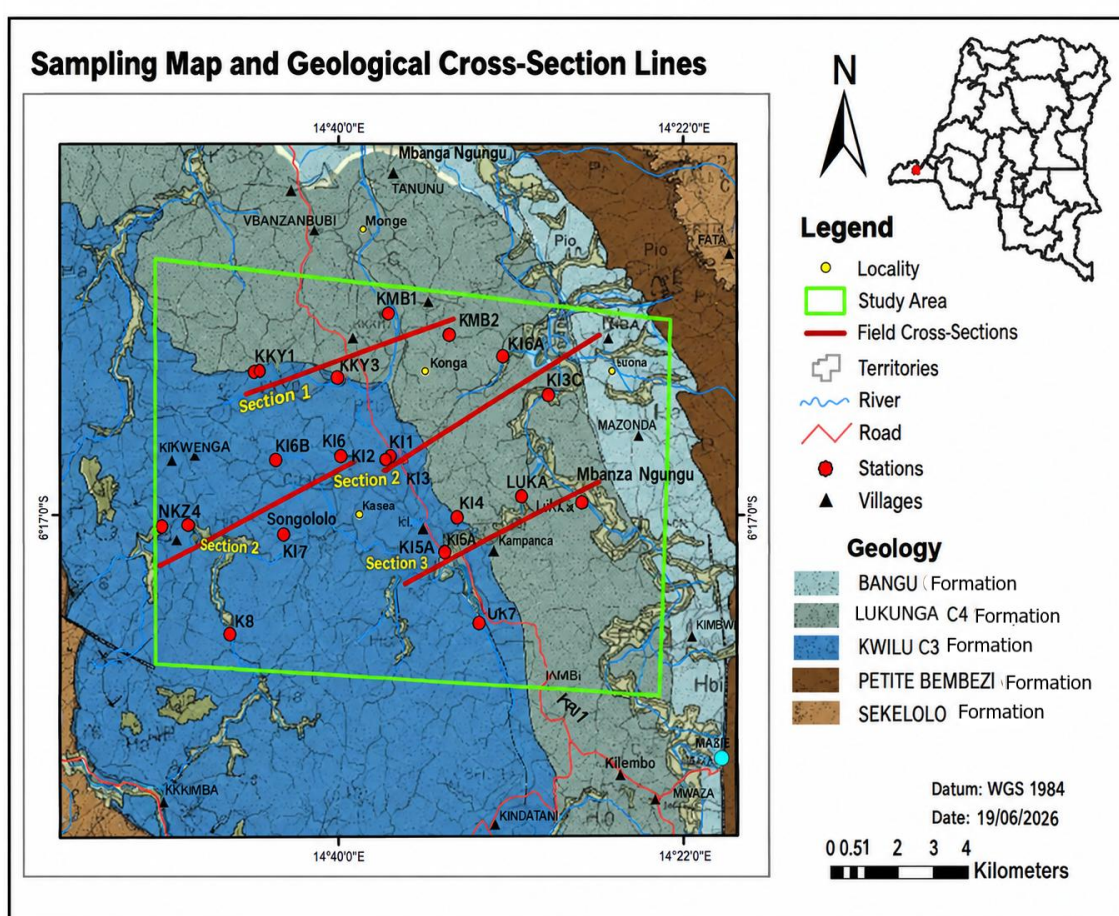


Figure 4. Geological map and cross-sections [16].

OUTCROP OBSERVATIONS AND SAMPLE COLLECTION

A compact rock massif, whose colour varies from light grey to whitish. This massif is irregularly sculpted at the surface, forming a small relief in the landscape. Cavities and rounded hollows of variable sizes (centimetric to decimetric) are organized into pockets on the rock surface. Between the cavities, more or less fine and sharp ridges are visible, also sculpted by water runoff. These complex structures are characteristic of a karstic micro-relief similar to lapies-type structure [11]. The rock is covered by a darker patina, grey to blackish, visible mainly on the raised areas.

The rock contains elongated greyish clasts about 5 mm, grey in colour, that effervesce in cold 10% dilute hydrochloric acid. Small red aggregates of fine, non-coalesced crystals are also observed, probably due to the alteration of pyrite. The parallel planar laminations are clearly visible, with light grey and dark grey beds locally speckled with fine pyrite crystals. This is the light grey massive limestone lithofacies.

RESULTS AND DISCUSSIONS

Petrographic analysis

Thin sections examination was done in the laboratory of the Faculty of Sciences and Technology by a polarizing microscope that allows a systematic description based on Dunham and Folk's classification to determine the petrographic designation of each facies encountered.

Dark grey limestone lithofacies

The rock exhibits a very fine-grained, millimetric texture with black ferruginous minerals and is affected by intense meteoric alteration. These spots are interpreted as aggregates or grains of sulphides (probably pyrite). The first sample, from the village of Kiyadi (Plate 1a), shows signs of intense alteration, revealed by bands and pockets whose colour varies from ochre to rust. This colouration indicates the oxidation of primary iron-bearing minerals into iron hydroxides (limonite, hematite). These oxidation zones follow irregular subhorizontal geometries.

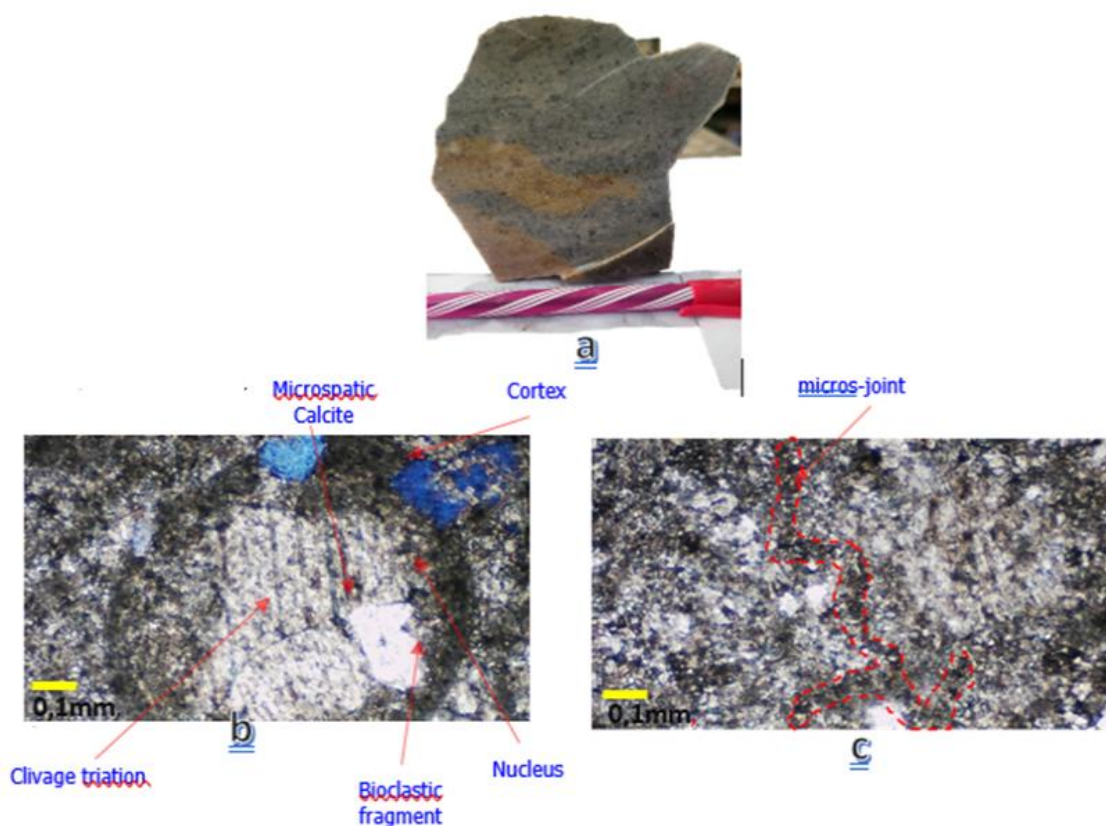


Plate 1. Macroscopic and microscopic views of oolitic microsparite lithofacies of wackestone type.

Under the microscope, a heterogeneous texture is observed, characterised by the presence of large-sized figured elements embedded in a dark micritic matrix. The figured elements are ooids whose nuclei are occupied by clear patches of microsparite (Plate 1b), surrounded by a thick and irregular micritic cortex. The latter consists of a granular assemblage of microsparitic calcite showing first-order grey-white interference colours. The rock is locally cut by joints. Calcite crystals (or carbonate clasts) as well as bioclasts (Plate 1c) are embedded in a micritic matrix; some crystals show very distinct parallel cleavage striations (Plate 1b). Micro-joints (stylolite) and transparent calcite crystals (sparite) are also observed in the micritic matrix. According to the classifications of [4] and [5], this is an oolitic microsparitic Wackestone type.

Dark grey to blackish-gray limestone lithofacies

The compact rock with very strong plane-parallel laminations (Plate 2a) consists of a stack of layers one mm thick. This suggests a slow sedimentary regime of fine particles in a low-energy environment. There are small colour variations in the light grey and dark grey which is probably due to cyclic input of organic matter or fine detrital debris [13] during the transition to the small-scale sedimentary environment.

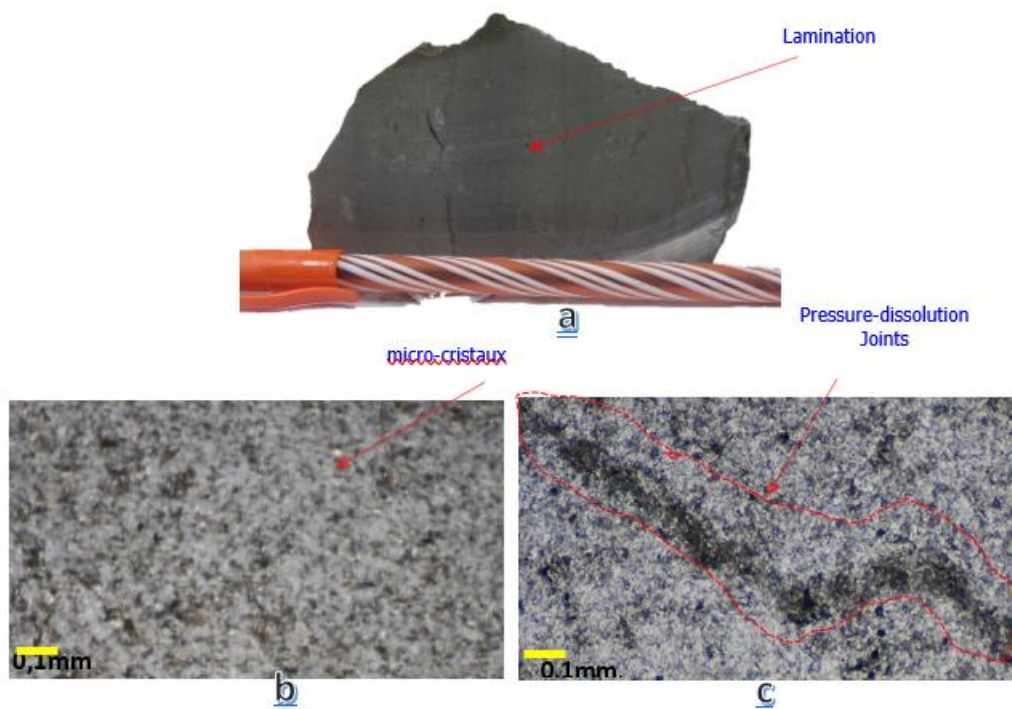


Plate 2. Macroscopic and microscopic views of crystalline limestone.

The field is essentially composed of a contiguous collection of calcite microcrystals and microsparite (Plate 2b). The crystals are xenomorphic and interlocking forming a dense mosaic texture due to aggrading neomorphism. The thin section is furrowed by micro-joints (dark, sinuous suture lines) (Plate 2c) indicating pressure dissolution. According to [4],[5], this is a microsparite and because there are no grains this is a crystalline limestone.

Whitish limestone lithofacies

The rock has a fine-grained, homogeneous (Plate 3a), and compact matrix. Its structure is massive, with no apparent sedimentary organization (absence of stratification). Under a magnifying glass, the texture is aphanitic (individual crystals are not discernible). Locally, the rock has developed secondary vug-like porosity, which shows as small, irregular cavities on the order of a millimeter, resulting from dissolution processes.

The rock consists of a mosaic of relatively uniform-sized crystals (equigranular), with sharp, straight to curved contacts. This texture results from total aggrading neomorphism of the original matrix (Plate 3b). There is an almost total absence of intergranular porosity. Fine opaque (black) interstitial particles persist, and in places, residual ooids are found in a floating position, without contact between them. Their nuclei are preserved, while their micritic cortices have been assimilated by recrystallization, leaving only ghost structures. According to [5], this is a pseudosparite, and [4] classifies this rock among the crystalline limestones.

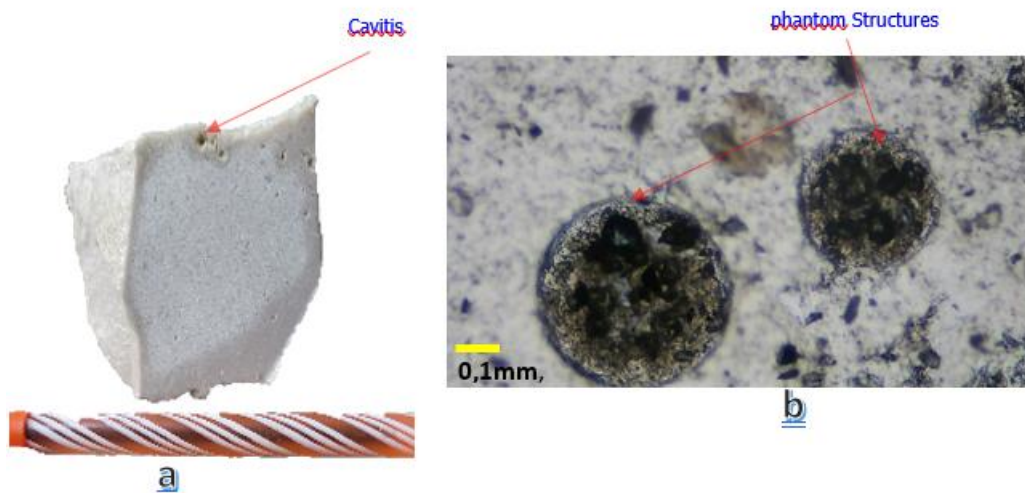


Plate 3. Macroscopic and microscopic views of crystalline limestone.

Dark grey to light grey limestone lithofacies

The rock exhibits a crystalline and granular (micritic) texture organised into undulating laminations at the millimetre scale, of the stratiform microbialite type (Plate 4a). Unlike flat hydrodynamic structures or cross-laminations, these laminations show smooth, regular, and continuous undulations, characteristic of accretion by microbial mats (cyanobacteria). Convex morphologies facing upwards (dome nuclei) are observed, indicating positive phototropism during growth. The geometry of the layers, which maintain a constant thickness while conforming to the palaeorelief, confirms active biological colonisation of the substrate.

The rock displays a crystalline and granular texture, organised into a mosaic of crystals several tens of microns in size, indicating marked aggrading neomorphism, reflecting the transition from original micrite to microsparite, or even localised pseudosparite. The thin section reveals large micritised ooids (Plate 4b). Their dark, irregular, and eroded micritic envelopes testify to the action of endolithic organisms [2] that erased the primary concentric stratifications. The interior of these grains has been entirely replaced by grey microsparite, rich in organic and

clayey inclusions. The entire texture is crossed by a micro-vein of transparent spathic calcite (Plate 4c). The larger size and clarity of the crystals present in this fracture indicate late cementation by circulating fluids after compaction. According to the classifications of [4], [5], this is an oomicrosparite and a crystalline limestone containing relict ooids.

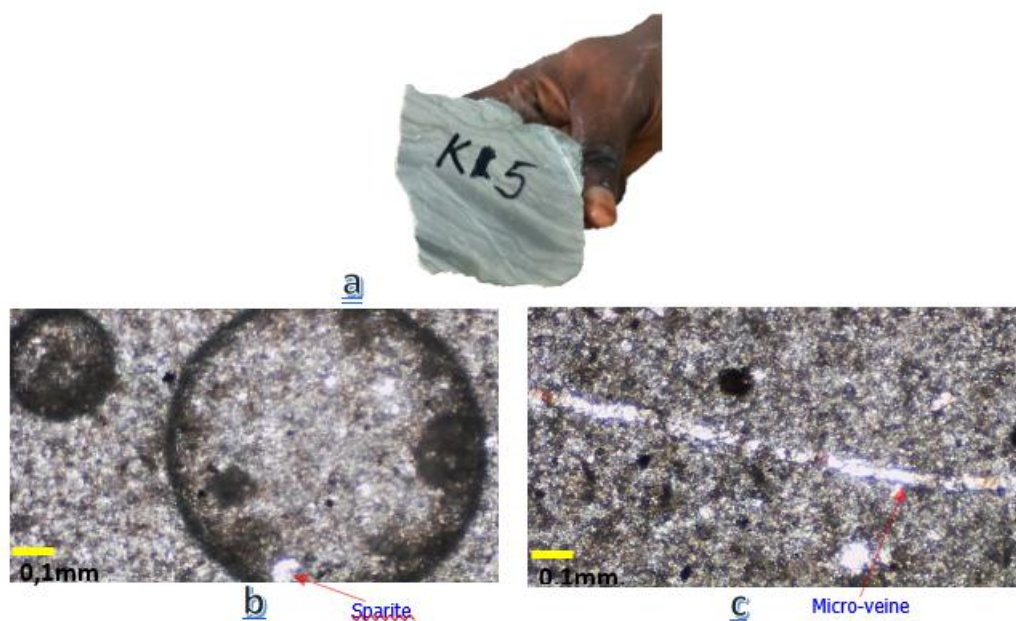


Plate 4. Macroscopic and microscopic views of crystalline limestone.

Dark grey to greenish-grey limestone lithofacies

The rock exhibits a very pronounced rhythmic laminar structure (Plate 5a). An alternation of regular, horizontal layers, on the order of a millimetre in thickness, is observed, with colours ranging from white to greenish grey. The rock has an aphanitic texture (very fine-grained) and fractures preferentially along bedding planes (platy cleavage). This structure suggests deposition by sedimentation in a low-energy environment, subject to cyclic sediment supply.

The rock displays a heterogeneous microsparitic texture (Plate 5b), consisting of a mosaic of xenomorphic and interlocking calcite crystals. The matrix is speckled with opaque minerals of less than one millimetre in size. A marked contrast is observed between dark micritic zones (rich in clay-organic impurities) and clearer, better-crystallised neomorphic zones (Plate 5c). An elongated granular ghost, with ovoid to subangular morphology, indicates a former bioclast whose internal structure was erased by dissolution followed by recrystallisation (mouldic cementation). The rock exhibits oblique micro-laminations (prograding downward and to the right), accentuated by accumulations of insoluble material and micro-dissolution seams (microscopic stylolites). These structures suggest initial deposition under the influence of low-energy currents (micro-cross-bedding). According to the classifications [4],[5], this is a laminated microsparite of mudstone type.

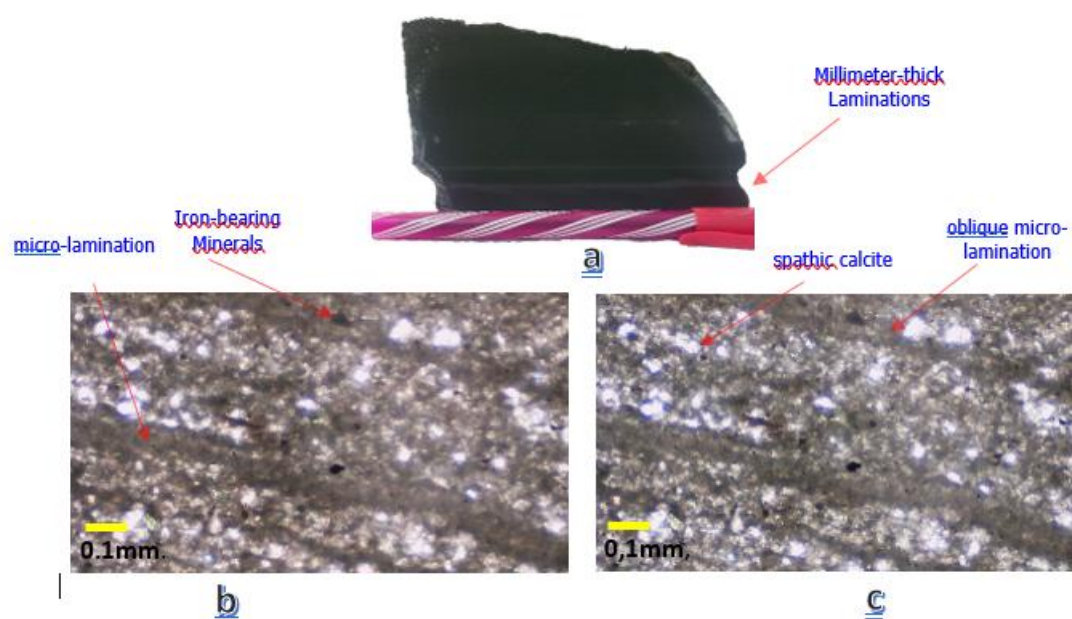


Plate 5. Macroscopic and microscopic views of mudstone-type limestone.

Dark grey lithofacies

The rock is massive with extremely fine grains, exhibiting a very pronounced rhythmic laminar structure (Plate 6a). An alternation of millimetric, horizontal and regular laminae is observed. This structural homogeneity suggests sedimentation by continuous deposition in a very low-energy environment.

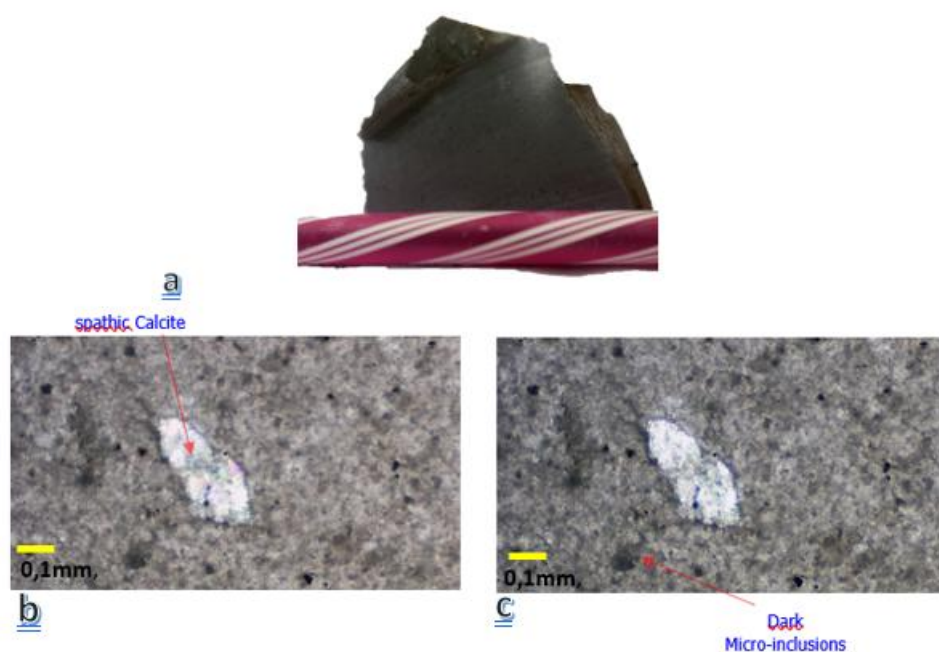


Plate 6. Macroscopic and microscopic views of mudstone-type limestone.

The rock consists of fine- to medium-grained microsparite (Plate 6b). The calcite crystals display a grey-white speckled appearance, characteristic of advanced aggrading neomorphism from an original micritic mud. Numerous dark micro-inclusions (organic matter or clay minerals) are observed (Plate 6c). An isolated crystal located in the centre is identified; it is probably transparent spathic calcite; its automorphic to sub-automorphic shape suggests the filling of a microcavity (mould or vug porosity) by secondary sparite. According to the classifications [4],[5], this is a mudstone-type microsparite.

Whitish grey to beige limestone lithofacies

The rock exhibits a very fine-grained texture in which the constituent grains are not visible to the naked eye. The matrix is speckled with black and brownish spots on the millimetre scale, randomly distributed (Plate 7a). The lower part of the sample shows very distinct parallel horizontal laminations, characteristic of a sedimentation regime by settling. Discreet pressure-dissolution joints (stylolites), slightly darker in colour, indicate initial chemical compaction.

The thin section reveals large, well-calibrated circular to ellipsoidal ooids (ooliths). The cortex has a cloudy, greyish appearance due to neomorphic recrystallisation (microsparite rich in organic or clayey inclusions) that has partially masked the original concentric stratifications (Plate 7b). The nucleus, located at the centre of these grains, consists of recrystallised bioclasts. The intergranular space is entirely filled by clear sparite (spathic cementation). The calcite crystals are transparent (Plate 7c), well developed, and display vivid second- to third-order interference colours. The total absence of micritic mud between the grains indicates a sediment transported by active currents during sedimentation (high-energy environment). According to the classification of [9], [7], this is an oolitic grainstone-type oosparite.

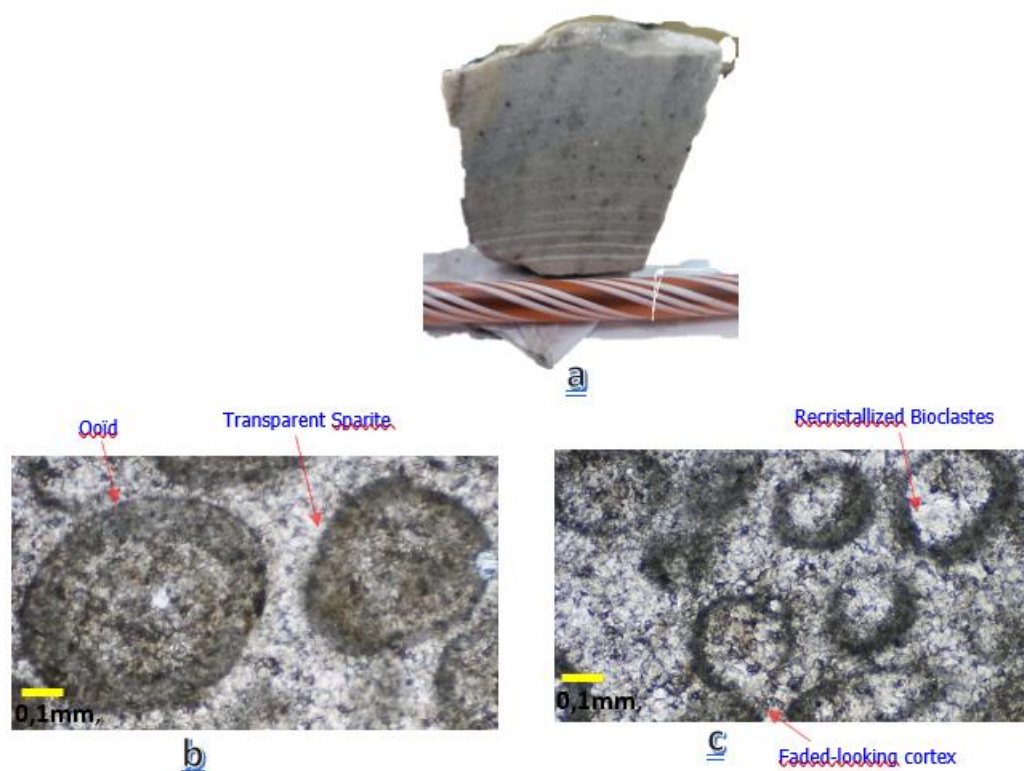


Plate 7. Macroscopic and microscopic views of oolitic grainstone-type oosparite.

Grey to ochre limestone lithofacies

This is a sample exhibiting lithological heterogeneity (Plate 8a). The upper part, grey in colour, displays a very fine texture, while the lower part, beige-ochre in colour, exhibits a microconglomeratic texture. This variation in colour and grain size suggests a facies transition, possibly accentuated by differential alteration. Within the mass, fine alternations of one-millimetre-thick layers are observed, indicating rhythmic deposition. The contact between the two facies is sharp but irregular, which could correspond to an erosion surface or a sudden change in the hydrodynamics of the environment.

The rock displays a heterogranular texture dominated by a dense mosaic of transparent calcite crystals. Crystal size varies from microsparite (speckled grey facies) to true sparite (Plate 8b), reflecting advanced aggrading neomorphism. Granular ghosts (peloids or ooids) with diffuse outlines persist within this crystalline mass, locally accompanied by residual micritic clouds.

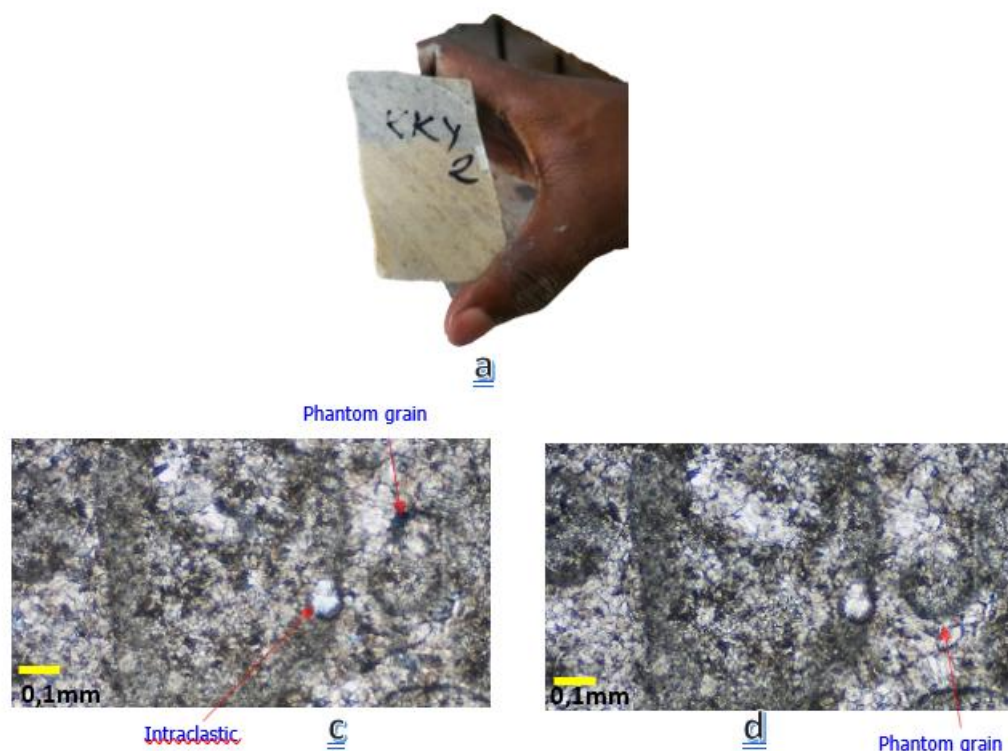


Plate 8. Macroscopic and microscopic views of oolitic grainstone-type oosparite.

The main constituents are spherical to ovoid ooids (0.2 to 0.8 mm) with a dark micritic cortex showing fine concentric layers. The alternation of dark micritic layers and clear recrystallised layers testifies to a complex diagenetic evolution. Rounded micritic intraclasts or peloids (Plate 8c), devoid of internal structure, are dispersed among the ooids. The good sorting of the grains indicates effective hydrodynamic sorting in a high-energy environment.

The intergranular space is entirely filled by a transparent mosaic sparry cement, indicating complete cementation in the phreatic zone. However, partial recrystallisation of the oolitic cortices is observed, replaced by neomorphic microsparite. According to the classifications of [4],[5], this is an oolitic grainstone-type oosparite.

Bluish grey to greenish lithofacies

The rock exhibits a very fine texture (lutitic to micritic) and a colour ranging from grey to greenish (Plate 9a). The sample is compact and homogeneous, with no distinct grains visible to the naked eye. The structure is characterised by parallel, flat, and very regular laminations, ranging from millimetre to sub-millimetre scale (Plate 9b). These laminations are accentuated by subtle variations in contrast and colour shades. The greenish tint suggests the presence of fine silicate minerals (clays) or reduced iron, indicating a sedimentary deposit formed by settling in a low-energy environment, potentially deep and oxygen-poor.

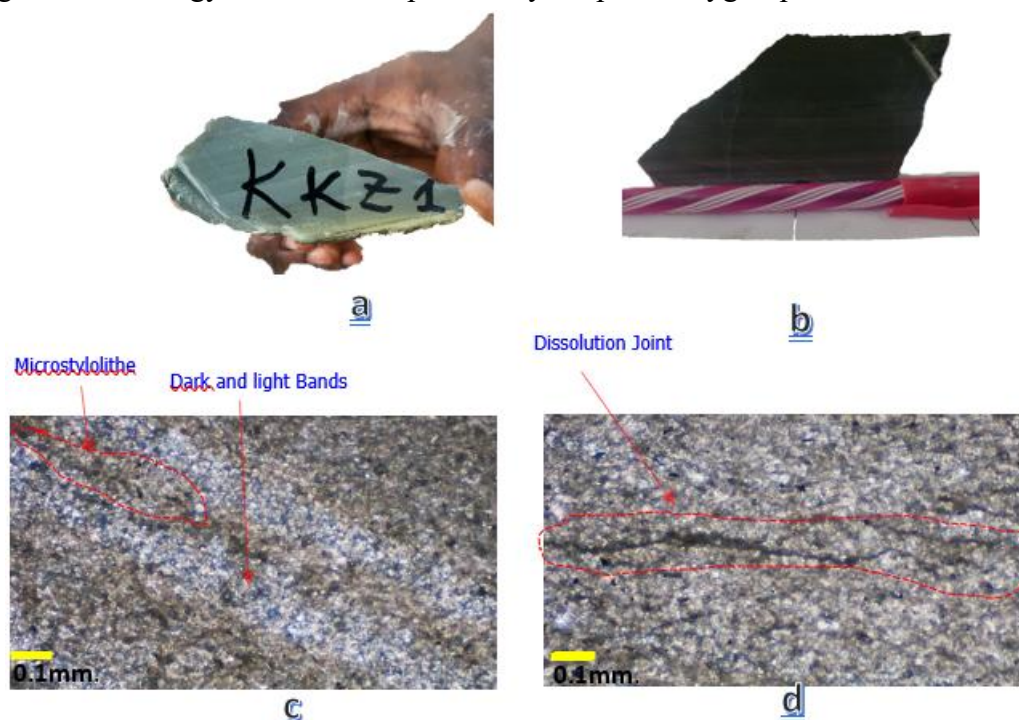


Plate 9. Macroscopic and microscopic views of mudstone-type limestone.

The rock displays very pronounced ribbon-like (or laminar) structures, characterised by a regular alternation of dark and light bands (Plate 9c). This pattern suggests primary rhythmic sedimentary stratification, which has been preserved despite widespread recrystallisation. The light bands consist of a mosaic of calcite microcrystals, indicating the transition from an original mud to a microsparitic texture. The dark bands, on the other hand, are rich in fine opaque elements (organic matter and clays). The boundaries between these bands show local micro-undulations and, in places, transform into micro-stylolites where pressure-dissolution processes have concentrated insoluble residues [25] (Plate 9d). According to the classifications of [4] and [5], this is a laminated mudstone-type microsparite.

The microfacies observed in our study area are strongly affected by a complex diagenetic history, extending from the early eogenetic phase, marked by intense biological and physico-chemical interaction at the water-sediment interface. This phase is manifested by the micritisation of high-energy grains by endolithic organisms (algae, fungi), observed in the microfacies (Plate 4b). This process is described by Bathurst [26].

The advanced mesogenetic phase (burial) is characterised by sutured contacts and interlocking grains within the oolitic bars. The microstylolites observed (Plates 9d and 2c) are scars of intense chemical dissolution. They concentrate insoluble minerals (clays, oxides) and testify to significant burial. According to Choquette & James [27], this process is the main driver of porosity reduction in deep settings. Finally, telogenesis (late diagenesis) is characterised by micro-veins of spathic calcite cross-cutting the facies (Plate 4c), which proves post-lithification fracturing.

Geochemical Analyses

Major element analysis

Major element analysis by X-ray fluorescence spectrometry (XRF) is an essential instrument in sedimentology and carbonate rock geochemistry. It is essential for moving from a simple description of the petrographic environment to a quantitative description of the diagenetic and palaeoenvironmental aspects. It enables the objective verification of the textural and sedimentological interpretation of the lithofacies studied.

Major element concentrations (Table 1) were determined by energy-dispersive X-ray fluorescence spectrometry (ED-XRF) at the Centre de Recherches Nucléaires de Kinshasa (CRENK) laboratory with a SPECTRO XEPOS spectrometer (SPECTRO Analytical Instruments). The methodology involved four main phases:

- **Grinding:** The carbonate rock samples were first crushed using a steel jaw crusher and then ground in a fine mill until small particles less than 63 μm were measured. The equipment was then cleaned with compressed air and ethanol between each sample to eliminate cross-contamination.
- **Loss on ignition (LOI):** Loss on ignition was measured by gravimetry after drying at 105 °C, and calcination of the powder at 1,000 °C for 2 hours in a muffle furnace. Dried powder was weighed at 5 g, and was then homogeneously mixed with 1 g of organic binder made of polyethylene wax (C-Wax/Hoechst Wax) (16,7% by mass of total mixture).
- **Pelleting:** The mixture was compacted into a cylindrical pellet of 32 mm diameter by a manual CARVER hydraulic press with a load of 15 tonnes for 90 seconds.
- **XRF acquisition and quality control:** The pellets were measured in a helium atmosphere. The calibration of the instrument and the control of the analytical precision were verified with certified reference materials (CRMs) of geological origin. The matrix and binder dilution corrections were carried out automatically by SPECTRO XEPOS acquisition software.

The analysis of the material shows that among the main elements in the 10 samples listed in Table 1, calcium oxide (CaO) is the most prevalent and it is found to have the highest contents (35.21% in NKZ1 and 48.16% in KI1) that the limestone rocks are from. The KI series (KI1, KI2, KI5, KI3C, KI6A and KI6B) have the most CaO contents (> 45%). The MgO contents (0.89% to 2.10%) are generally low and this means that they are calcitic limestones and not dolomites [10]. The loss on ignition is high (38.85% to 42.61%) which is mainly due to the release of CO₂ from the decay of calcite (CaCO₃). However, the ratio is not all that high. The Al₂O₃ (4.80% and 3.59%) and SiO₂ (9.50% and 9.24%) contents are higher in KKY2 and NKZ1 samples and the ratio of SiO₂/Al₂O₃ (2.0 to 2.6) is moderate. They are clayey to silty limestones (mixed detrital fraction) [5]; KI1 contains high SiO₂ content (7.88%) but low Al₂O₃ (1.67%) which indicates a silty limestone (mainly detrital quartz, little clay) [7].

KI5 and KKY4 sample show the lowest SiO₂ (< 4%) and Al₂O₃ (< 2.2%) contents, suggesting limestones are almost entirely pure (no detrital fraction). The ignition loss is high (38.85% to 42.61%). This is mainly caused by the release of CO₂ from calcite decomposition (CaCO₃). Silica (SiO₂) and alumina (Al₂O₃) are present in the sample which is associated with silicate minerals (quartz and clays) and samples KKY2 (9.50% SiO₂) and NKZ1 (9.24% SiO₂) are high in silica and alumina (4.80% and 3.59% respectively). The latter sample is indicative of clayey to silty limestones [8].

Table 1. Results of chemical analysis by X-ray fluorescence spectrometry (XRF) (major elements).

Parameters	Content (%)									
	KKY2	NKZ1	KKY1B	KI5	KI1	KI2	KI3C	KI6A	KI6B	KKY4
SiO ₂	9,50	9,24	4,30	3,21	7,88	5,69	6,05	8,01	7,88	7,22
Al ₂ O ₃	4,80	3,59	3,23	2,11	1,67	2,54	3,07	1,89	1,75	1,20
Fe ₂ O ₃	2,31	1,90	4,55	0,35	1,17	1,56	1,68	1,96	1,63	1,51
CaO	35,41	35,21	42,71	48,04	48,16	47,68	45,97	47,01	47,56	46,22
K ₂ O	0,46	0,70	0,23	0,14	0,61	0,89	0,58	0,56	1,00	0,78
MgO	2,10	1,24	1,70	1,31	0,93	1,01	1,00	1,02	0,89	0,95
Na ₂ O	1,02	1,00	0,62	0,52	0,09	1,25	0,75	1,06	0,79	1,01
SO ₃	0,04	0,02	0,04	0,02	0,06	0,04	0,05	0,05	0,07	0,04
TiO ₂	0,02	0,07	0,10	0,10	0,01	0,05	0,01	0,02	0,02	0,03
MnO	0,01	0,01	0,01	0,03	0,01	0,01	0,01	0,02	0,01	0,02
LOI at 1000°C	42,51	41,70	40,57	42,61	38,96	39,10	39,02	39,05	39,10	38,85

Petrophysical Analyses

Petrophysics is the study of the physical and structural properties of rocks as well as their interactions with the fluids they contain. Porosity and permeability are the two important parameters we study here to evaluate the potential of our rocks as oil reservoirs.

Porosity

Porosity is the quantity of small volumes (or pores) that can be filled by fluids inside a rock. It is a petrophysical quantity that is used to understand the capacity of a porous medium to hold a volume of fluid. Porosity (ϕ) is also a numerical quantity that is the ratio of the volume of voids or pores (V_v or V_p) to the total volume (V_t) of a porous medium [15].

$$\phi = V_v / V_t \text{ (in \%)} \quad (1)$$

where: ϕ = porosity;

V_v = volume of voids;

V_t = total volume of the rock.

According to René [15], porosity (ϕ) is evaluated as follows:

- Low: if $\phi < 5\%$;
- Poor: $5\% < \phi < 10\%$;
- Average: $10\% < \phi < 20\%$;
- Good: $20\% < \phi < 30\%$;
- Excellent: if $\phi > 30\%$.

Porosity was determined by the hydrostatic weighing method (adapted from NF EN 1936 / ISRM / API RP 40). The carbonate samples were first dried in an oven at 105°C until the dry mass (M_s) stabilised. They were then saturated by prolonged immersion in distilled water until the wet mass (M_h) stabilised. The immersed mass (M_i) was measured by suspending the saturated sample in a hydrostatic bath. The effective porosity (ϕ) was calculated using the gravimetric relationship:

$$\phi (\%) = (M_h - M_s) / (M_h - M_i) \times 100 \quad (2)$$

where: M_h = mass of the saturated sample in air;

M_s = dry mass;

M_i = mass of the saturated sample immersed in water.

Permeability

The permeability K of a rock characterises its capacity to allow the fluids contained in its pore space to flow. This space only allows fluid movement insofar as its pores are interconnected; it is then said to be permeable [15].

The first known experiments on permeability were conducted by Darcy in 1856. A homogeneous porous filter was placed in a tube of cross-sectional area (S), into which an incompressible fluid of viscosity (μ) was introduced; the flow rate (Q) and the fluid pressure were measured using two lateral manometers placed at the inlet (P_1) and outlet (P_2) of the tube. Darcy observed a relationship between the pressures (P_1) and (P_2) indicated by the manometers, the geometric characteristics of the tube (cross-section S and length L) and the flow rate. Permeability is given by the improved Darcy's law:

$$Q = S \times K / \mu \times (P_2 - P_1) / h \quad (3)$$

where: Q = fluid flow rate;

K = permeability (mD);

μ = fluid viscosity;

$(P_2 - P_1) / h$ = pressure drop along the entire length of the sample;

S = cross-sectional area of the cylindrical sample.

The range of permeabilities observed in reservoir rocks is very wide; it varies from 0.1 mD to 10 mD. The following terms can be used to qualify the permeability value [15]:

- $K < 1$ mD: very low;
- 1 to 10 mD: low;
- 10 to 50 mD: medium;
- 50 to 200 mD: good;
- 200 to 500 mD: very good;
- $K > 500$ mD: excellent.

Permeability was determined using the constant-head permeameter method on cylindrical cores previously saturated with distilled water at 20°C. The steady-state flow of water through a sample of cross-sectional area A (cm²) and length L (cm) under a constant hydraulic head Δh (cm) allows the volumetric flow rate Q (cm³/s) to be measured.

The hydraulic conductivity K (cm/s) is first calculated using Darcy's law:

$$K = Q \times L / (A \times \Delta h) \quad (4)$$

The intrinsic permeability of the rock (k) is then deduced and converted to millidarcys (mD) by integrating the dynamic viscosity of water ($\mu \approx 1.002 \times 10^{-3} \text{ Pa}\cdot\text{s}$ at 20°C), the density of water ($\rho = 1000 \text{ kg/m}^3$) and the acceleration due to gravity ($g = 9.81 \text{ m/s}^2$) according to the relationship:

$$k = K \times \mu / (\rho \times g) \quad (5)$$

The sedimentary matrix is extremely closed, dense and compact (Table 2). This is the result of major burial diagenesis combined with early and late cementation (calcitization or silicification) that sealed the primary pore network of the carbonate ramp.

Table 2. Porosity and permeability results.

N°	Sample	Porosity ϕ (%)	Permeability K (mD)	Qualifications
1	KI5	0,45	8,8	$\phi < 5\%$ Low and $K < 10\text{mD}$ Low
2	KKY2	1,25	5,1	$\phi < 5\%$ Low and $K < 10\text{mD}$ Low
3	KI1	2,77	4,6	$\phi < 5\%$ Low and $K < 10\text{mD}$ Low
4	KKY3	1,10	5,4	$\phi < 5\%$ Low and $K < 10\text{mD}$ Low
5	KI6B	1,90	6,9	$\phi < 5\%$ Low and $K < 10\text{mD}$ Low
6	NKZ1B	0,82	6,4	$\phi < 5\%$ Low and $K < 10\text{mD}$ Low
7	KI2	1,28	6,9	$\phi < 5\%$ Low and $K < 10\text{mD}$ Low
8	KI6A	0,32	8,3	$\phi < 5\%$ Low and $K < 10\text{mD}$ Low
9	KKY1B	3,75	6,8	$\phi < 5\%$ Low and $K < 50\text{mD}$ Low
10	KI3C	0,99	2,0	$\phi < 5\%$ Low and $K < 10\text{mD}$ Weak

CONCLUSIONS

This study combines petrographic, geochemical and petrophysical approaches to the carbonate facies of the Lukala Subgroup in the West Congo Basin. It allowed the limestones lithofacies to be characterised and their potential petroleum interest to be evaluated.

Petrographically, the studied rocks fall into two main types of carbonate lithofacies. On the one hand, oosparites (grainstones) with well-sorted ooids, clear spathic cement and devoid of micritic matrix, testify to a high-energy depositional environment. On the other hand, laminated microsparites, of mudstone to wackestone type, exhibit parallel laminations, microbial activity and clayey intercalations, characteristic of a calm, low-energy environment. All these facies subsequently recorded a complex diagenetic history, marked by micritisation, aggrading neomorphism, early to late calcitic cementation and the development of stylolites, leading to strong transformation of the rock matrix and clogging of the primary pore network.

Geochemical analysis by X-ray fluorescence spectrometry (XRF) shows that the studied facies are dominated by calcitic limestones, with CaO contents ranging from 35.21% to 48.16% and MgO contents below 2.10%. These values confirm the calcitic and non-dolomitic nature of the carbonates, but they remain lower than those of a pure limestone (about 56% CaO). They therefore indicate impure facies, of marly-argillaceous to silty type, containing a notable non-carbonate fraction consisting of clays and silts.

Petrophysically, these carbonates exhibit very poor petrophysical properties: porosity below 5% and permeability below 10 mD. This low reservoir quality results from intense burial diagenesis and early to late cementation (calcitic or siliceous) that obliterated the primary pore

network. The matrix is compact and dense, which excludes these lithofacies as conventional reservoir rocks. However, their potential as cap rocks remains to be evaluated by additional analyses.

Thus, this study paves the way for future research and targeted exploration work, contributing to a better understanding of the petroleum systems of the West Congo Basin.

REFERENCES

- [1] Cahen, L., Lepersonne J., La stratigraphie et la tectonique du Supergroupe Ouest-Congolien dans les zones médiane et externe de l'orogénèse Oust-Congolienne (Pan-African) au Bas-Zaïre et dans les régions voisines, *Annales du Musée Royal de l'Afrique Centrale*, Tervuren/Belgique, in-8° Sci. Géol., n° 83, 150 p., 1978.
- [2] Delpomdor, F., Caractérisation sédimentologique et évolution diagenétique des carbonates du Néoprotérozoïque (Groupe du Schisto-Calcaire, Bassin Ouest-Congolien, RDC), Thèse de doctorat, Université Libre de Bruxelles, Belgique, 245 p., 2007.
- [3] Alvarez, P., Sedimentology and basin evolution of the Neoproterozoic West Congolian Group in Central Africa, *Journal of African Earth Sciences*, vol. 21, n° 2, pp. 163-181, 1995.
- [4] Folk, R.L., Spectral subdivision of limestone types, in : Ham W.E. (Ed.), *Classification of Carbonate Rocks*, AAPG Memoir, n° 1, pp. 62-84, 1962.
- [5] Dunham, R.J., Classification of carbonate rocks according to depositional texture, in: Ham W.E. (Ed.), *Classification of Carbonate Rocks*, AAPG Memoir, n° 1, pp. 108-121, 1962.
- [6] Lukas, K.J., Halley, R.B., Micritization of carbonate grains by microboring organisms: process and implications for porosity evolution, *Journal of Sedimentary Petrology*, vol. 55, n° 4, pp. 495-503, 1985.
- [7] Espitalié, J., Laporte, J.L., Made, M., Marquis, F., Leplat, P., Paulet, J., Boutefeu A., Méthode rapide de caractérisation des roches mères, de leur potentiel pétrolier et de leur degré d'évolution, *Revue de l'Institut Français du Pétrole*, vol. 32, n° 1, pp. 23-42, 1977.
- [8] Ali, S.A., Wagneich, M., Petrographic and geochemical characterization of carbonates: implications for provenance and tectonic settings, *Geological Quarterly*, vol. 65, n° 2, pp. 45-58, 2019.
- [9] Gehman, H.M., Organic matter in limestones and shales with respect to source rock potential, *Geochimica et Cosmochimica Acta*, vol. 26, n° 8, pp. 885-897, 1962.
- [10] Qin, J., Tenger, B., Evaluation criteria and geochemical characteristics of high-maturity marine carbonate source rocks, *Petroleum Geology & Experiment*, vol. 26, n° 5, pp. 471-477, 2004.
- [11] Canfield, D.E., Raiswell R., Carbonate precipitation and dissolution, *Secondary Diagenesis of Carbonate Rocks*, Vol. 46, pp. 411-453. 1991.
- [12] Cailleux, J.L.H., Kampunzu, A.B., Batumike, M.J., Lithostratigraphic position and correlation of the Neoproterozoic Roan Group in the Democratic Republic of Congo and Zambia, *Journal of African Earth Sciences*, Vol. 42, pp. 134-158, 2015.
- [13] Liang, D., Ouyang, J., Problems on the evaluation of ancient marine carbonate source rocks in China, *Marine and Petroleum Geology*, vol. 29, n° 1, pp. 152-165, 2012.

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- [14] Cahen, L., La stratigraphie du système Ouest-Congolien, Annales du Musée Royal du Congo Belge, Vol. 8, pp. 1-44, 1978.
 - [15] Cossé, R., Techniques d'exploitation pétrolière: Le gisement. Publications de l'Institut Français du Pétrole, Éditions Technip, Paris, 329 p, 1988.
 - [16] Lepersonne, J., Notice explicative de la carte géologique à l'échelle du 1/200.000 : Feuille Ngungu (degré carré S6/14 = SB 33.9). Département des Mines, Direction du Service Géologique, Kinshasa, 67 p, 1973.
 - [17] Delhay, F., Sluys, M., Les grands traits de la tectonique du Congo occidental. Structure et stratigraphie du bassin schisto-calcaireux. Annales de la Société Géologique de Belgique, Publications relatives au Congo Belge et aux régions voisines, t. XLIV (1920–1921), Liège, pp. C45–C58, 1921.
 - [18] Baudet, D., Tack, L., Delpomdor, F., Prétat, A., Le Supergroupe Ouest-Congolien (République Démocratique du Congo) : un état de la question. Géologie Africaine, Vol. 21, pp. 45-63, 2013.
 - [19] Bongwele, O.J., Delpomdor, F., Prétat, A., Microfacies and sequence stratigraphy of the Neoproterozoic Kwilu Subgroup (West Congolian Group, Democratic Republic of the Congo). Journal of African Earth Sciences, Vol. 139, pp. 102-121, 2018.
 - [20] Cahen, L., Géologie du Congo belge. Imprimerie Vaillant-Carmanne, Liège, 575 p., 1954.
 - [21] Lepersonne, J., Carte géologique du Zaïre au 1/2 000 000 et Notice explicative. République du Zaïre, Département des Mines, Direction de la Géologie, Kinshasa, 67 p., 1974.
 - [22] Tack, L., Wingate, M.T.D., Liégeois, J.-P., Fernandez-Alonso, M., Deblond, A., Early Neoproterozoic magmatism (1000–910 Ma) of the Zadinian and Mayumbian Groups (Bas-Congo): onset of Rodinia rifting at the western edge of the Congo Craton. Precambrian Research, vol. 110, n° 1-4, pp. 277–306, 2001.
 - [23] Kadima, E., Delvaux, D., Sebagenzi, S.N., Tack, L., Kabeya, S.M., Structure and geological history of the Congo Basin: An integrated interpretation of gravity, magnetic and reflection seismic data. Basin Research, vol. 23, n° 5, pp. 499–527, 2011.
 - [24] Cailleux, J.L.H., Delpomdor, F.R.A., Ngoie Ndobani, J.-P., The Neoproterozoic West-Congo “Schisto-Calcaire” sedimentary succession from the Bas-Congo region (Democratic Republic of the Congo) in the frame of regional tentative correlations. Geologica Belgica, vol. 18, n° 2-4, pp. 126–146, 2015.
 - [25] Canfield, D.E., Raiswell, R., Carbonate precipitation and dissolution, Secondary Diagenesis of Carbonate Rocks, Vol. 46, pp. 411-453, 1991.
 - [26] Bathurst, R.G.C., Boring algae, micrite envelopes and lithification of molluscan biosparites, Geological Journal, Vol. 5, pp. 15-32, 1966.
 - [27] Choquette, P.W., James N.P., Diagenesis in limestones: the deep burial environment, Geoscience Canada, Vol. 14, pp. 3-35, 1987.

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