Petrographic Characterization and Paleoenvironmental Interpretation of the Carbonate and Siliciclastic Formations of the Nzundu Sector and its Surroundings (Kongo Central, DRC)

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Abstract: This study presents the petrographic characterization and paleoenvironmental interpretation of sedimentary rocks from the Nzundu area. Macroscopic and microscopic analyses identified limestones, shales, and quartzites. Microfacies include mudstones, packstones, and quartzitic arenites, indicating shallow marine to oxidizing continental environments.

Keywords*: Petrography, Microfacies, Paleoenvironment, Schisto-Limestone, DRC.*

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I. INTRODUCTION

In Kongo Central Province, the Neoproterozoic West Congo mountain range is rich in abundant layers of chemical and detrital rocks belonging to the Kwilu (CI) and Lukunga (CII) formations of the Schisto-calcareous Subgroup (Explanatory Note for the Ngungu map sheet; Lepersonne, 1974; Cahen, 1978; Tack et al., 2001; Cibambula, 2016). The interest in studying these rocks stems not only from scientific curiosity but also from the potential to provide new scientific insights, as these rocks are of significant economic importance as reservoirs and reservoirs of hydrocarbons or water, and also as traps for mineralization. These rocks have not yet been the subject of detailed study using modern techniques, and several questions remain unanswered. It is with this perspective that this study was conducted with the following theme: Petrographic characterization and paleoenvironmental interpretation of the carbonate and silicoclastic formations of the Nzundu sector.

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II. LOCATION AND GEOLOGICAL CONTEXT OF THE STUDY AREA

➢ *Geographic Frame*

The study area is located in the province of Kongo Central, Songololo Territory, Secteur de Kimpese, at 5°42'00" at latitude South and 15°05'30" at 15°08'00" at longitude Est (Fig.1) The training area is located in the village of Nzundu.

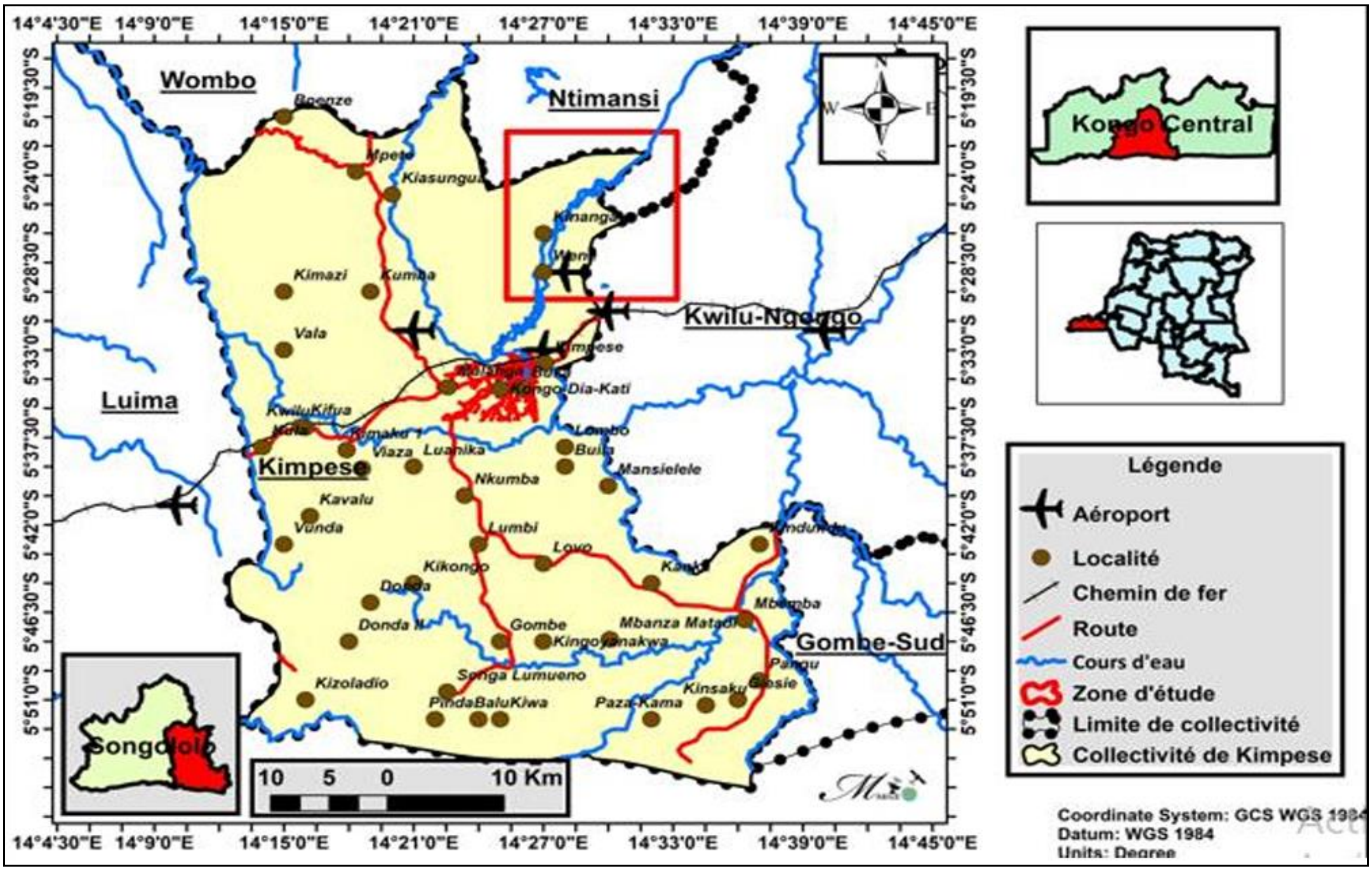

Fig 1 Map Showing the Location of the Study Area.

It is characterized by a tropical Sudanese climate marked by a dry season influenced by the cold Benguela Current from the Atlantic. This dry season results in a strong inversion of the isotherms, such that the average annual temperature (25°C) remains relatively constant. During the rainy season, the average annual temperature reaches 28°C. The temperature variation within a month does not exceed 10°C (Devroey and Vanderlinden, 1951). Lithostratigraphically, the study area lies within the West Congo Group (Cataracts), Schisto-limestone subgroup (Lukala), in the contact zone between the Kwilu (C3) and Lukunga (C4) formations.

These formations include limestones, dolomites, argillites, and oolitic layers, associated with marine and continental deposits.

III. MATERIALS AND METHODS

➢ *Fieldwork was Facilitated by Several Tools and Instruments, Including:*

- Compass: to determine the directions and dips of the strata.
- GPS: to locate ourselves and outcrops.
- Geologist's hammer: to break rocks, determine their freshness, and identify potential schistosity planes.
- Digital camera: to photograph interesting formations.
- Field notebook: to facilitate the recording of field observations. Observations are recorded in a field notebook, accompanied by sketches, which facilitates their subsequent analysis.
- Measuring tape: to help us measure distances between different lithologies and between strata.

We opted for a structured approach to achieve the objectives we set for this work. The work included field observations, sampling, and thin-section analysis using a polarizing microscope. The Folk, Dunham, and Dott classifications were used.

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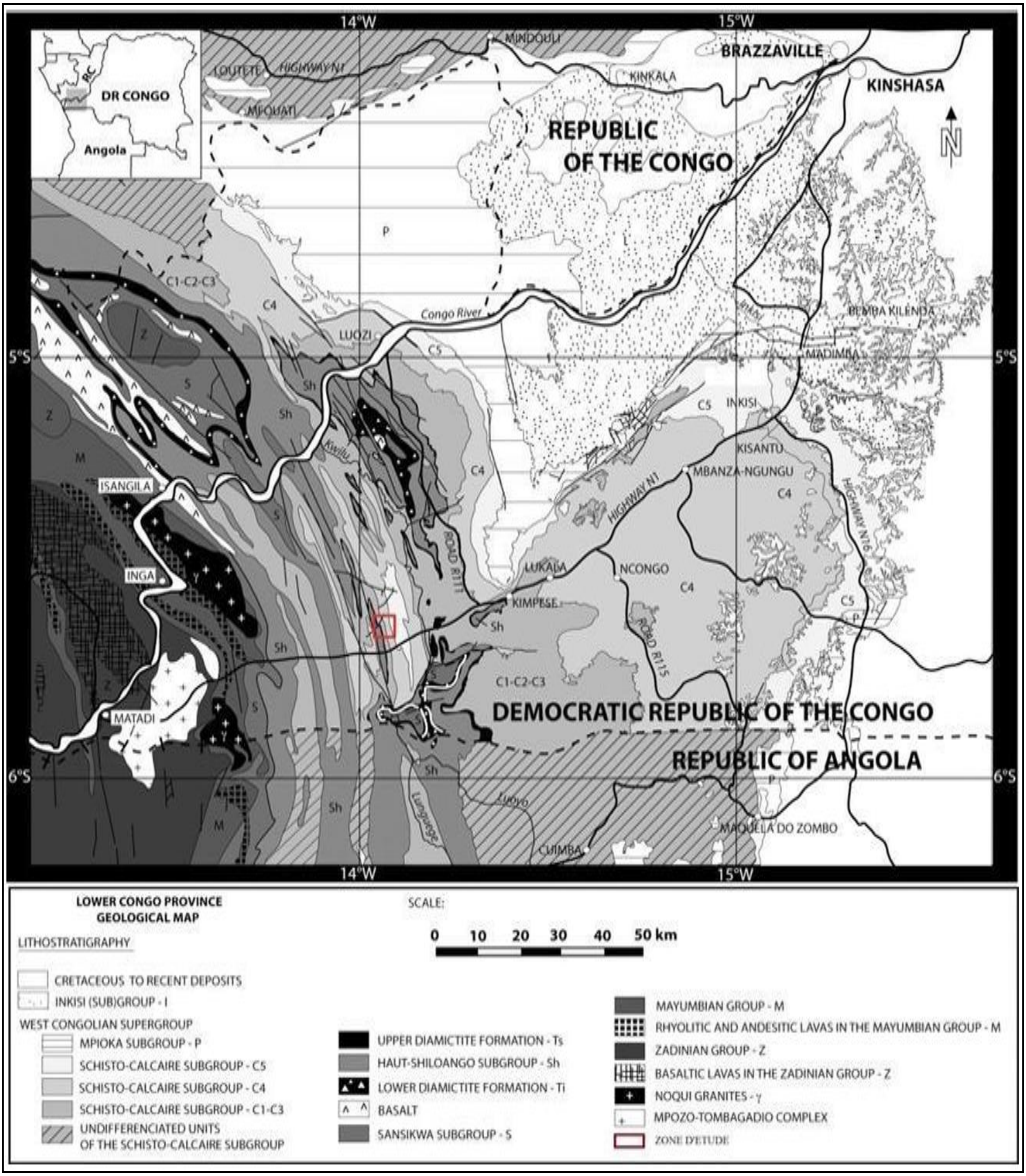

Fig 2 Geographic Distribution of the Cataracts Group, Including the Study Area.

IV. RESULTS

➢ *Presentation of Field Data*

This data, collected along the riverbanks and along the tracks connecting one village to another, includes petrographic data, sedimentary structures, layer thicknesses, and direction and dip measurements taken on bedding planes acquired along two sections.

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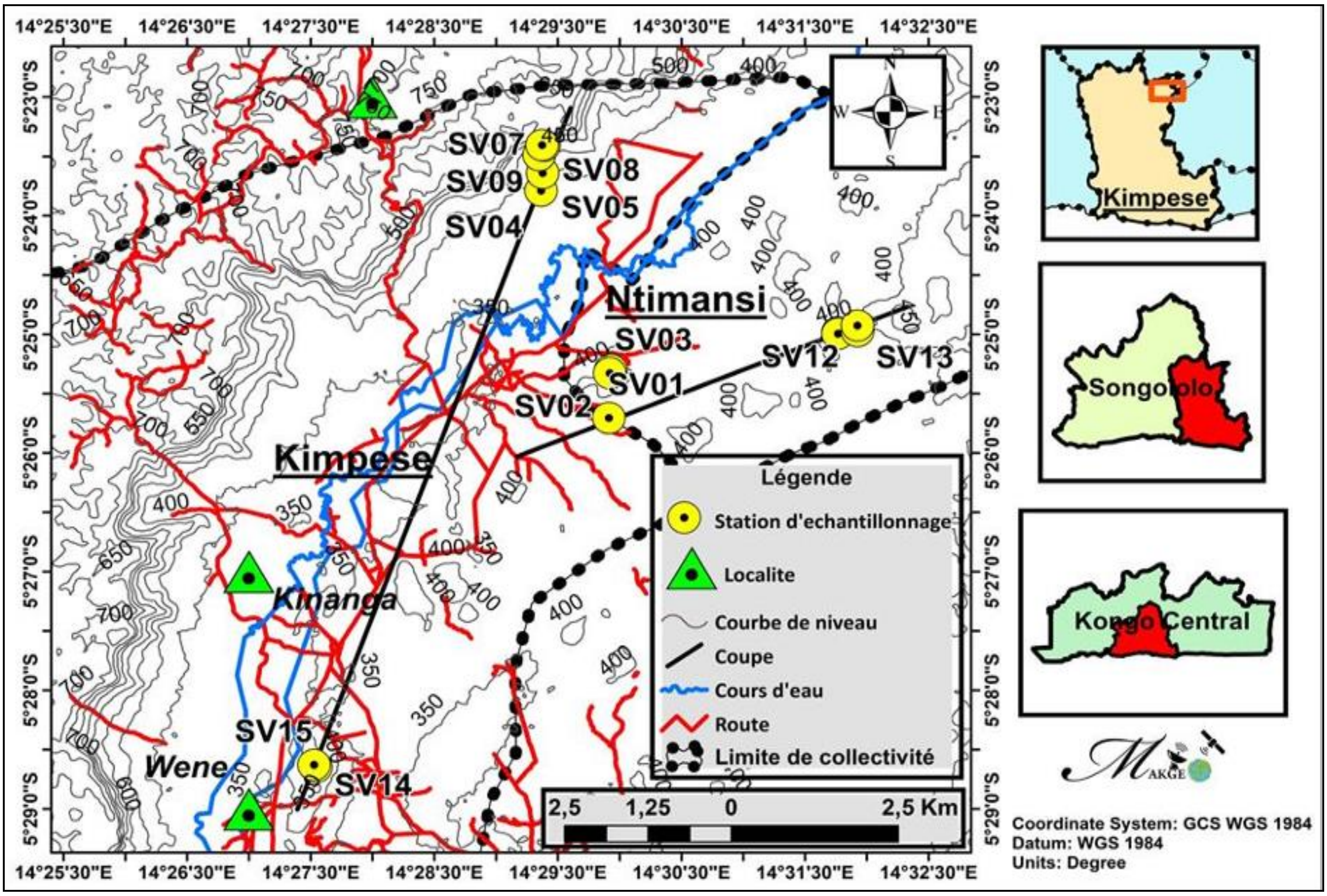

Fig 3 Map Showing the Location of Observation and Sampling Stations

Our mapping in relation to the study area was carried out using two cross-sections: (A-B) and (C-D). These cross-sections are oriented: A-B: (SSW-NNE) and C-D: (WSW-ENE).

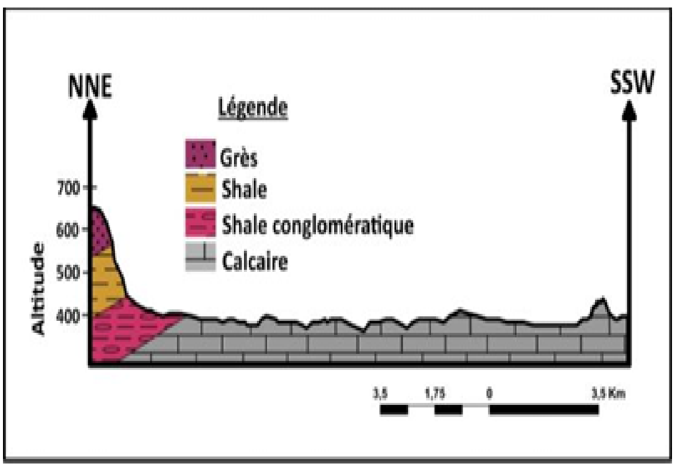

Fig 4a: Coupe A-B

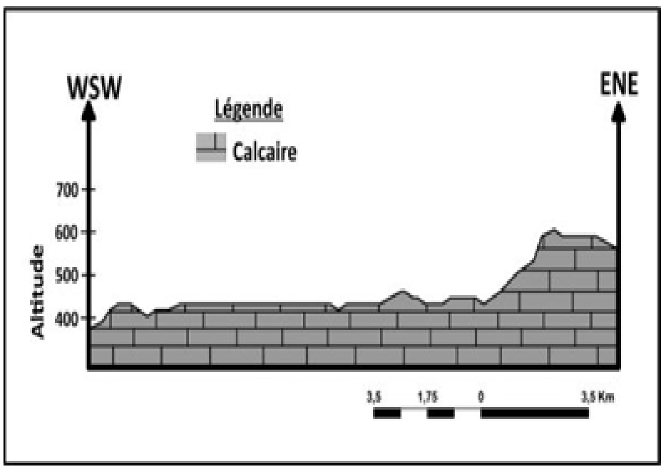

Fig 4b: Coupe C-D

- *The Following Characteristics Should be Noted:*

From a lithological point of view, the Nzundu region and its surroundings contain the following lithofacies:

- ✓ Very finely bedded limestones (Samples SV01, SV04, SV05, SV08, SV10, SV12), massive limestones (Samples SV01, SV02, SV04, SV08, SV10, SV12, SV13, SV14); massive limestones with
- ✓ Coarse bedding (Samples SV02, SV10), massive limestones with lenticular bedding (Samples SV01, SV08, SV12, SV13) and with planar bedding (Samples SV04, SV14);

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- ✓ Shales with rough bedding (Samples SV03, SV06, SV09) and planar bedding (Sample SV07);
- ✓ Quartzites (Sample SV15).

➢ *Macroscopic and Microscopic Description*

- *Limestone Lithofacies*

✓ *Sample SV02*

Figures 05a and 05b show photographs (macroscopic view and thin section).

Macroscopically, this is a sample of coarsely layered, massive, very fine-grained limestone of a dark gray color (Fig. 05a).

✓ *These Rocks are Characterized by the Following Sedimentary Structures:*

- Cross-bedding (Sample SV11);
- Undulating bedding (Samples SV01, SV02, SV13, SV14).

According to the classifications of Folk (1959) and Dunham (1962), this is a packstone-type oomicrosparite.

Fig 5a: Echantillon De Roche Calcaire à Grains Très Fins De Couleur Gris Sombre.

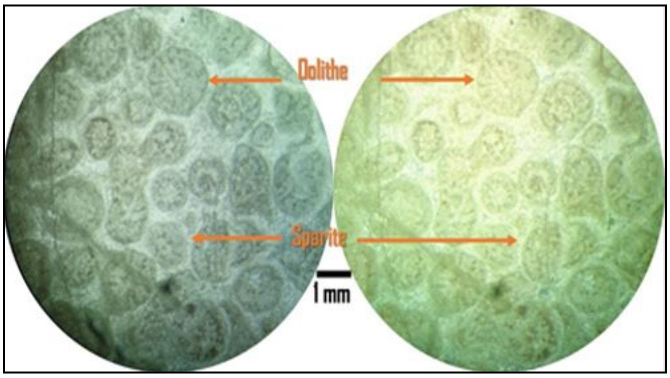

Fig 5b: La Lame Présente Un Ciment Microsparitique Qui Englobe Des Oolithes.

- *Sample SV04*

Figures 6a and 6b show the photographs (macroscopic view and thin section).

Macroscopically, it is a very finely bedded sample of very fine-grained, gray limestone.

Microscopically, the rock exhibits a microsparitic cement containing ooliths. These spherical, subspherical, and ovoid olithes are generally composed of a microsparitic nucleus covered by either a single-layered or multi-layered cortex (Fig. 05b).

Under the microscope, the rock exhibits a rudimentary bedding pattern, evidenced by the alternation of microsparitic layers with iron oxide filaments. According to the classifications of Folk (1959) and Dunham (1962), it is a mudstone-type microsparite.

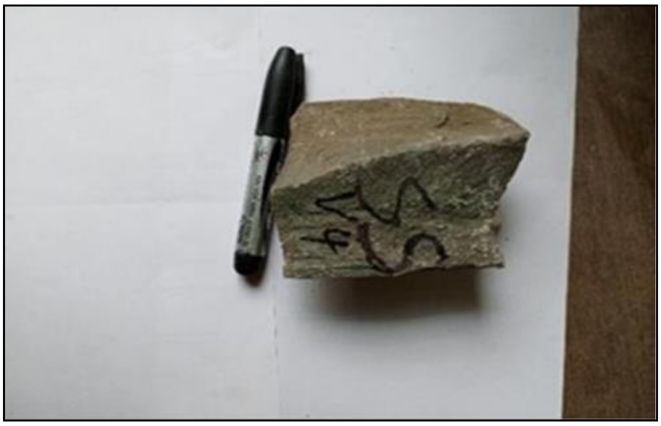

Fig 6a: Echantillon De Calcaire Massif De Couleur Grise

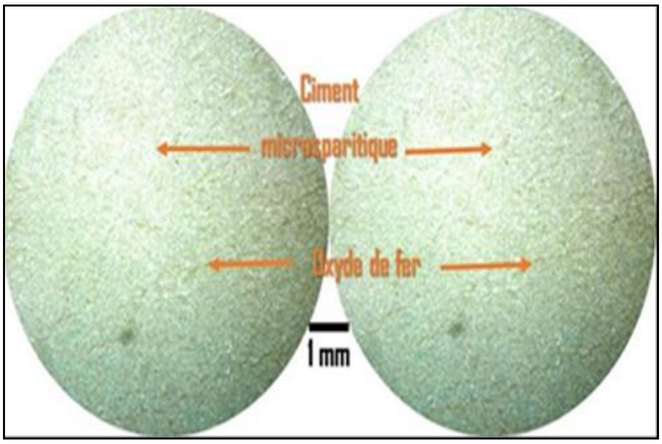

Fig 6b: Mudstone Présentant L'interpénétration

- *Sample SV13*

Figures 07a and 07b show photographs (macroscopic view and thin section) of sample SV13:

Macroscopically, it is a sample of very finely bedded, gray, fine-grained limestone.

Under the microscope, sample 13 shows gray and white (LPA) and colorless (LPNA) xenomorphic quartz crystals embedded in a microsparitic cement. It also contains opaque mineral granules disseminated within the same cement. According to the classification of Folk (1959) and Dunham (1962), it is a Mudstone-type microsparite.

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Fig 7a: Echantillon De Calcaire à Litage Lenticulaire De Couleur Grise.

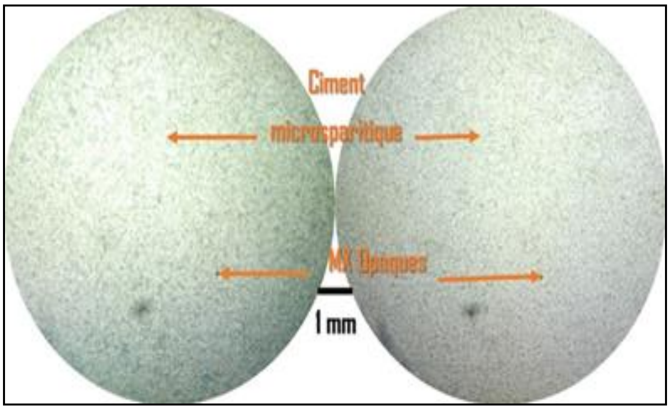

Fig 7b: Mustone Présentant L'interpénétration Des Niveaux Microsparitiques Avec Des Niveaux Micritiques.

Figures 8a and 8b show photographs (macroscopic view and thin section) of sample SV14.

Macroscopically, it is a planarly layered sample of very fine-grained, gray limestone.

Microscopically, the rock shows xenomorphic quartz crystals, gray and white (LPA) and colorless (LPNA), embedded in a microsparitic cement. It also contains opaque mineral granules disseminated within the same cement. According to the classification of Folk (1959) and Dunham (1962), it is a Mudstone-type microsparite..

Fig 8a: Echantillon De Calcaire à Litage Planaire De Couleur Grise.

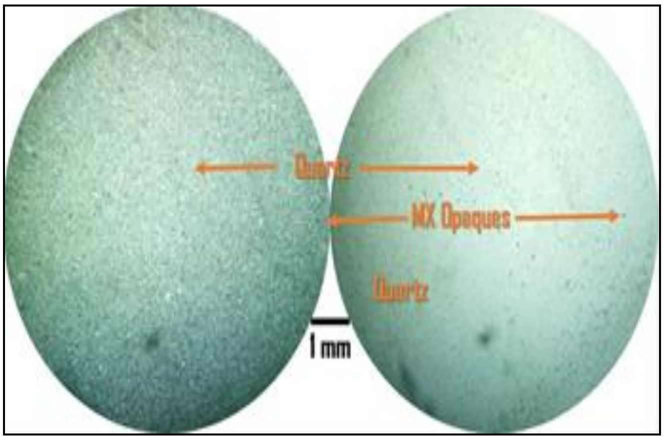

Fig 8b: Mustone Présentant L'interpénétration Des Niveaux Microsparitiques Avec Des Niveaux Micritiques.

- *Shale Lithofacies*

✓ *Sample SV03*

Figures 09a and 09b show photos (macroscopic view and thin section) of sample SV03:

Macroscopically, it is a sample with a rough layering of very fine-grained red shales.

Under the microscope, the sample shows a rough alternation of silty beds with silty-clayey beds. The quartz beds are subangular to angular, non-oriented, elongated, and dispersed within the clay matrix. According to Lundegard and Samuel (1980), this is a shale.

Fig 9a: Echantillon D'un Shale à Grains Très Fins De Couleur Rouge.

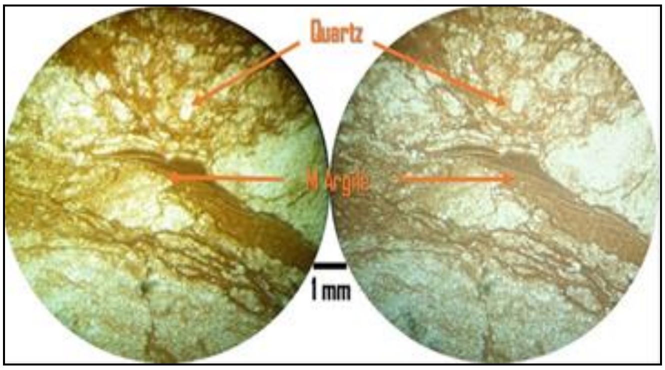

Fig 9b: Vue En Lame Mince D'un Shale à Litage Fruste En LPNA et LPA.

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- *Sample SV06*

Figures 10a and 10b show photographs (macroscopic view and thin section) of sample SV06:

Macroscopically, it is a sample with planar bedding of very fine-grained, red shale.

Folk (1959) and Dunham (1962) classify it as a Mudstone-type microsparite.

Under the microscope, the rock exhibits planar bedding. This is evidenced by the alternation of silty and silty-clay beds.

Under the microscope, the rock shows xenomorphic quartz crystals, gray and white (LPA) and colorless (LPNA), embedded in a microsparitic cement. It also contains opaque mineral granules disseminated within the same cement. According to the Brune classification, the LPA and LPNA crystals are composed of a clay matrix impregnated with iron oxide. According to the Lundegard and Samuel classification (1980), it is a shale.

Fig10a: Echantillon De Shales à Litage Planaire Traduit L'alternance Des Lits De Couleur Par

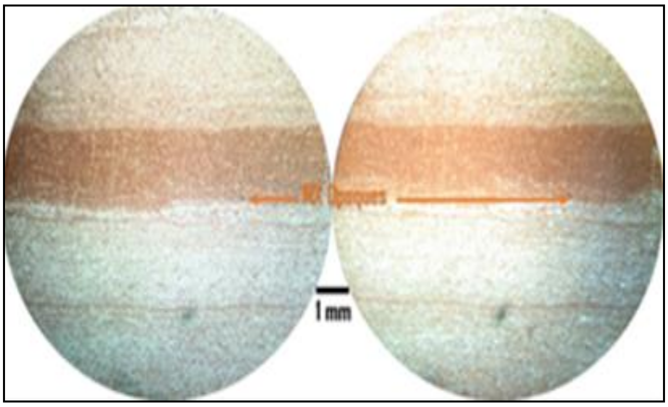

Fig 10b: Lame De Shales Montrant Une Alternance Des Lits Silteux Avec Des Lits Argilo-Silteux

- *Sample SV09*

Figures 11a and 11b show photographs (macroscopic view and thin section) of sample SV09:

Macroscopically, it is a sample with a rudimentary to planar bedding of very fine-grained, red shales.

Under the microscope, the rock shows a rudimentary alternation of silty-clay beds with silty beds.

The silty beds are composed of white or gray quartz crystals (planar polarized) and colorless quartz crystals (planar polarized). These fine quartz crystals are rounded, subrounded, subangular, angular, and sometimes slightly elongated. The brown silty-clay beds (planar polarized and planar polarized) consist of a clay matrix impregnated with iron oxide.

Fig 11a: Echantillon De Shales à Litage Planaire De Shales à Grains Fins De Couleur Rouge.

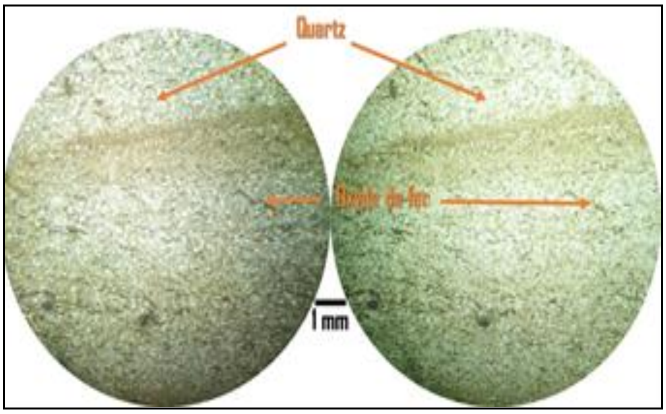

Fig 11b: Lame De Shales Montrant Une Alternance Des Lits Silteux Avec Desits Argilo-Silteux.

- *Quartzite Lithofacies*

Figures 12a and 12b show photographs (macroscopic view and thin section) of sample SV15:

Macroscopically, it is a very fine-grained, white quartzite sample.

Under the microscope, the rock exhibits a granolepidoblastic texture characterized by white or gray quartz crystals (planar polarized light) and colorless quartz crystals (planar polarized light), interspersed with a few rare sericite flakes, brown in color (planar polarized light) and colorless in colorless sericite (planar polarized light).

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These fine and medium-sized quartz crystals exhibit angular, subrounded, and blunt forms with smooth edges. Locally, the rock contains subcircular crystals of opaque minerals. According to Dott's classification (1964), it is a quartzite arenite.

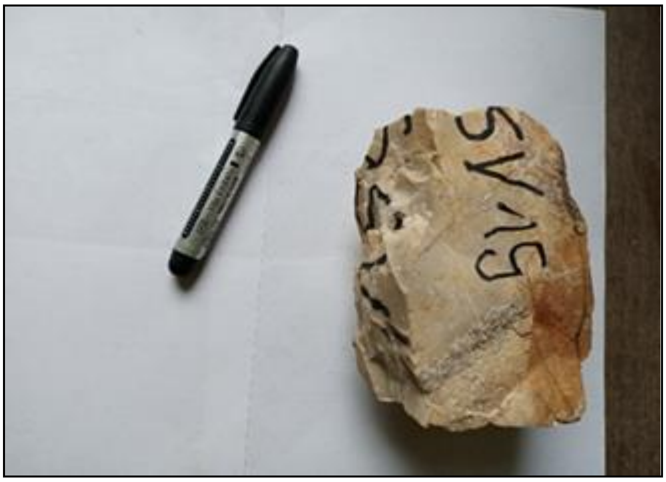

Fig 12a : Echantillon De Quartzite à Grains Très Fins De Couleur Gris Sombre.

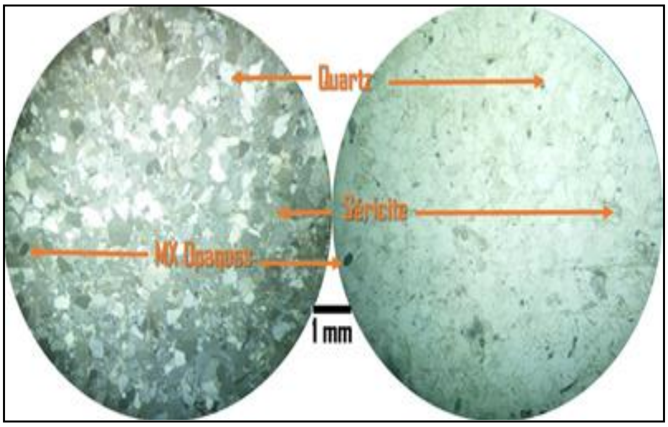

Fig 12b: (A) Quartz De Teinte Blanche Ou Grise, Séricite De Teinte Brune Et Cristaux Des Minéraux Opaques De Teinte Noire En LPA ; (B) Quartz Incolore, Séricite Incolore Et Cristaux Des Minéraux Opaques De Teinte Noire En LPNA.

V. DISCUSSION AND INTERPRETATION OF RESULTS

➢ *Mechanisms and Sedimentary Environments*

From a carbonate texture perspective, the mudstone texture is a low hydrodynamic energy environment favorable to micrite precipitation (Samples SV02, SV04, SV13, SV14), and the microsparite originates from micrite recrystallization (Samples SV02, SV04, SV13, SV14).

The packstone texture is a high hydrodynamic energy environment (Sample SV02).

The iron oxides in the rocks (SV04, SV06, SV09) have a purely sedimentary origin.

Cross-bedding (Sample SV11) is characteristic of a dynamic depositional environment, while undulating bedding (Samples SV01, SV02, SV13, and SV14) is characteristic of a shallow marine, lacustrine, or lagoonal environment.

➢ *Depositional Model*

Based on the information obtained above, it can be deduced that the oolitic limestones (Sample SV02) are typical of an environment characterized by high hydrodynamic energy. The gray color of this rock indicates that the sediments benefited from reducing conditions. This could be a littoral barrier deposit where the sediments sometimes benefited from subaquatic conditions. Thus, the deposition of the limestone lithofacies associated with the Kwilu Formation, which outcrops in the Nzundu region, appears to have occurred cyclically, transitioning from a flat intertidal environment to a lagoon environment.

The alternating silty-clay beds (rich in fine particles) and silty beds (dominated by coarser particles) (samples SV03, SV06, and SV09) reflect, according to Einsele (2000), a fluctuating energy depositional environment. The "silty beds," with their coarser grain size, are generally deposited during periods of higher energy, such as floods, storms, or turbidity current events, when heavier and larger particles can be transported and deposited. In contrast, "silty-clay beds," containing finer particles, generally form under lower-energy depositional conditions, where sedimentation is dominated by the settling of fine particles suspended in the water column (Einsele, 2000).

The transition from shales to sandstone beds occurs as a result of the periodic repetition of hydrodynamic changes. This change in material from coarser to finer does not result from short-term, but rather long-term, changes in hydrodynamic conditions within the depositional basin.

From a climatic perspective, the presence of iron oxides indicates that these rocks evolved under a hot tropical climate. Furthermore, the gray to dark gray hues that characterize the majority of the rocks indicate that they evolved under reducing conditions (Black, 1982).

➢ *Mining and Petroleum Interest*

Regarding sample SV02, the limestone is of the packstone type, with a fine matrix composed of fine carbonate grains and microscopic crystals (microsparite), and the presence of small oolitic structures. This limestone contains primarily calcite with a small amount of dolomite, which improves its physical properties for mining. Its fine grain and compact nature reduce its primary porosity but can be advantageous for obtaining high-purity products.

The high calcium carbonate content of omicrosparitic limestones makes them particularly suitable for cement production. This type of limestone is sought after for its homogeneous calcination properties, essential for obtaining high-quality lime in cement clinker.

Although the primary porosity of this type of limestone is low due to its fine matrix, diagenetic processes such as fracturing and dolomitization can generate secondary porosity. These modifications allow these limestones to function as potential reservoirs for hydrocarbons, especially if natural fractures increase their permeability.

In the case of samples SV04, SV13, and SV14, the limestone exhibits a fine, homogeneous, mudstone-like texture. The high calcium carbonate content of the finely bedded gray limestone makes it a prime raw material for cement production. The limestone's purity is favorable for obtaining high-quality lime in the calcination process, and the fine structure allows for homogeneous firing, essential in cement clinker production.

Due to its low porosity and compact structure, this mudstone-like limestone can serve as cap rock in petroleum systems. Its ability to prevent hydrocarbon migration makes it an effective choice for confining hydrocarbons within more porous underlying reservoirs.

The shale is composed primarily of clay minerals, quartz, and oxidized minerals, mainly hematite, which is responsible for the red coloration. This composition influences its mechanical properties and potential uses, as is the case for samples SV03, SV06, and SV09. Due to its clay content, Kimpese red shale can be used in the production of ceramic materials, such as bricks and tiles. Its natural red color makes it particularly suitable for colored building products.

The shale can contain organic matter, even in small quantities, and could thus serve as source rock for hydrocarbon formation under suitable thermal maturation conditions. However, advanced geochemical analyses are needed to determine the quantity and quality of the organic matter present. Due to its low permeability, it can act as a caprock in a petroleum system. Its ability to block hydrocarbon migration makes it an effective natural barrier, contributing to the trapping of hydrocarbons in underlying reservoirs. For sample SV15, the white quartzite arenite is an important source of silica, a key component in many industries. This silica can be extracted and used in the manufacture of glass, ceramics, and electronic products. The glass industry is particularly interested in this type of quartzite due to its high purity, essential for producing high-quality glass. Quartzite arenite can be crushed to produce high-quality sand, used in construction and civil engineering. Sand from this rock is especially valued for its purity and uniform grain size.

Although quartzite arenite is generally considered a low-permeability rock, it can contain hydrocarbons in fractures or areas of increased porosity. In such cases, hydraulic fracturing could be used to release the oil or gas trapped in these unconventional reservoirs.

VI. CONCLUSION

The Kwilu and Lukunga formations at Nzundu show a sedimentary evolution from carbonate to detrital, marked by variations in the energy regime. Petrographic analysis confirms the existence of a shallow marine environment affected by successive terrigenous inputs. These results enrich the regional geological understanding and open up new perspectives for the exploration of natural resources.

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