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Geological Mapping of Oxidized and Reduced Zones Associated to Sandstone Hosted Uranium Deposit in the Akouta, Niger

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ABSTRACT

The objective of this work, is to study the sedimentary dynamics of Akouta uranium deposit in order to improve the geological knowledge related to the uranium deposit in this sector of the middle district 18 (Q.18^M). The methods implemented consist of facings survey that allow us to interpret the dynamics of the emplacement of the main sedimentary bodies. The obtained results show that the Akouta Sud sector has 6 lithological levels and 5 facies. The first level (N1) corresponds to gray sandstones with medium oxidized-reduced, presenting oblique, oblique arcuate stratifications tangential to the base, pyrite balls, carbonate spots, cockades and hematite spots. The second level (N2) consists of a set of mediums to fine grey sandstones with a leached appearance, with horizontal to subhorizontal stratifications and micro-wrinkles towards the top. The third level (N3) is a dark to medium grey reduced-oxidized sandstone deposit. This level (N3) presents asymmetric spoon stratifications, mega-wrinkles, slumps, spoon stratifications, sub-undulate stratifications, pyrite balls, clay and silt pebbles, cockades, carbonate spots, black spots of organic matter and hematite spots. The latter is frequently leached laterally. The fourth level (N4) corresponds to a channel with clay pebbles with a leached appearance of variable thickness. The fifth level (N5) consists of fine-grained subhomogeneous levy sandstones, with fine subhorizontal stratifications, micro-wrinkles, white carbonate spots, clay pebbles and pyrite balls. The sixth level (N6) is represented by greyish to medium oxidized-reduced sandstones. This level (N6) contains oblique, spoon-shaped, slump stratifications, micro-wrinkles, carbonate spots, black spots of organic matter, silt and clay pebbles and hematite spots.

Key words: Akouta Sud deposit, lithological levels, facings surveys, oxido-reduction phenomena, sedimentary dynamics.

1- INTRODUCTION

Niger is a mining country that is full of significant resources, particularly uranium. According to [1], during the period between 1958 and 1967, the Atomic Energy Commission (CEA) undertook prospecting campaigns in the Agadez region through its subsidiary COGEMA (Compagnie Générale des Matières Atomices). These exploration campaigns led to the discovery of the Azelik (1960), Madaouela (1964), and Arlit-Akouta (1966) deposits in the Tim Mersoï basin. The Arlit-Akokan deposits, exploited by Somaïr (1969) and that of Akokan by Cominak (1974) are the results of this exploration work.

The exhaustion of the deposits in operation around the 2000s, favored an increase in the price of uranium oxide [2]. From then on, it seemed appropriate to undertake new explorations to develop new uranium reserves. Cominak, which has already exploited the Akouta (northern part) and Akola sectors of the Carboniferous formation of Guézouman, is currently exploiting the Akouta Sud sector (another sector of the Carboniferous formation of Guézouman). The exploitation of the deposits depends on the depth and dip of the geological layers, the morphology of the stratigraphic units and the tectonic context [2, 3, 4].

These different operating parameters are likely to change from one sector to another, within the same deposit [3, 4, 5]. This is why geological studies of the deposit are carried out throughout its exploitation. The general objective of this study of the oxidation-reduction phenomena associated with the study of the sedimentary dynamics of the Akouta Sud sector of the middle district 18 (Q.18^M) ». More specifically, this study aims to improve the geological knowledge on the carboniferous formation of Guézouman in the Akouta Sud sector.

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2- METHODOLOGY

2.1 Contexte géologique

The study area is located in a desert region, in the northern part of the Tim Mersoï basin, approximately 250 km northwest of Agadez, 1,200 km northeast of Niamey and 2,000 km from the port of Cotonou (**Figure 1**). The main urban area of the region corresponds to the mining town of Arlit. Two mining companies have been exploiting uranium deposits in this region for several decades. These are SOMAÏR (open-pit mines) based in Arlit since 1968 and COMINAK (underground works) based in Akouta since 1974. The uranium deposits exploited by SOMAÏR and COMINAK are distributed on either side of the N70°E accident corresponding to the Tin Adrar [1, 4, 6]. To the north of the fault is the SOMAÏR deposit and to the south are those of COMINAK (**Figure 2**). The COMINAK uranium deposits are located in the carboniferous formation of Guézouman. They are arranged parallel to the major N-S accident of Arlit. These are the deposits of: Akola, Akouta, Akouta Sud, Ebba Nord, Ebba Sud and Ebène. The sector studied in the framework of this study corresponds to the Akouta Sud deposit, which is attached to the Akouta permit. It is located approximately 1 km north of the Afasto permit (**Figure 1**). Like the other COMINAK deposits, the Akouta Sud deposit is also exploited in an underground mine at a depth of more than 250 m.

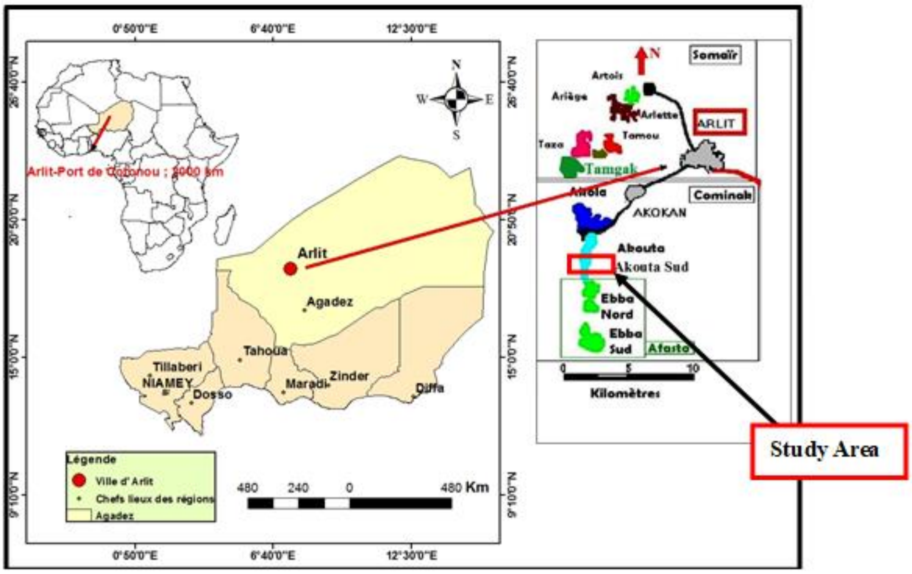

Figure 1: location of the study area

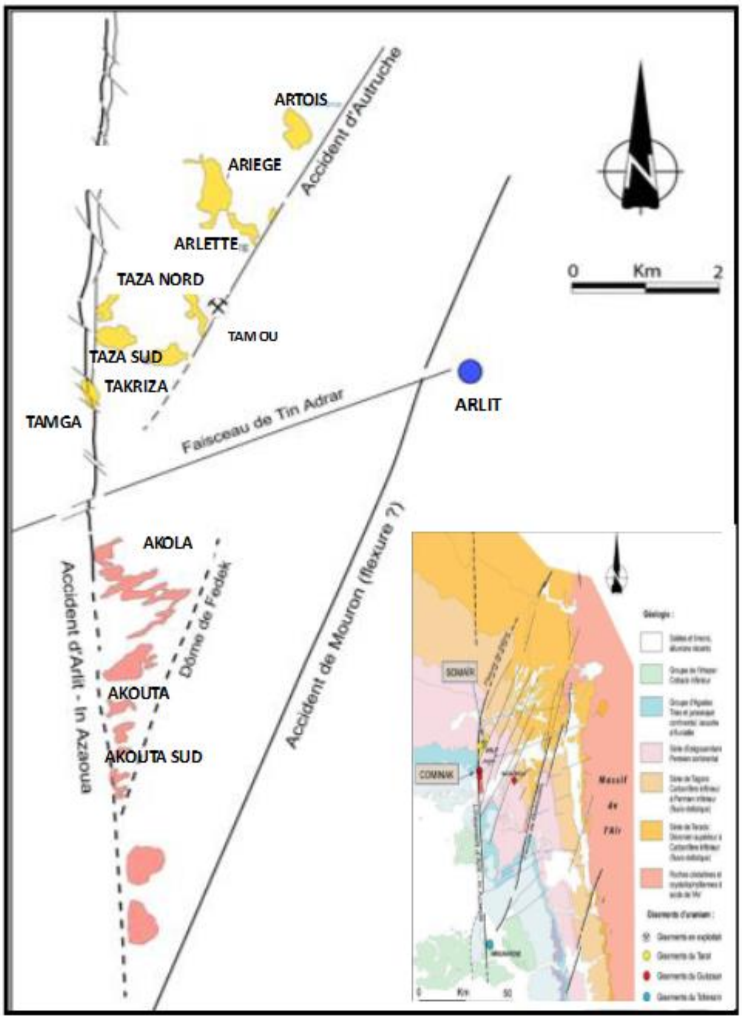

Figure 2: Location of the study area of the deposits hosted in the Guézouman sandstones [5] showing in yellow the SOMAÏR deposit and in red the COMINAK.

2.2 Field work and data acquisition

To characterize the dynamics of deposit development in the Akouta Sud sector, the methodological approach adopted in this work consists of: developing face and face surveys, analyzing and interpreting face surveys and producing block diagrams to determine the direction of paleocurrents. Numbering is one of the most important steps because it allows you to orient yourself in an underground mine. In the COMINAK mine, the numbering of the galleries is done in the north-south and east-west direction, the distance between the axes is generally 24 m (**Figure 3**).

The face survey is an operation that consists of representing the different levels (litho-facies) as well as the associated tectonic and sedimentary structures. The work consists of first measuring the actual dimensions of the face, namely the height and width, which will be reported on the survey sheet at a scale of 1/50. The operator then represents on the same sheet, the characteristic features of the lithology, the texture and the different structures observed on the face (stratifications, discontinuities, oxidized zone, reduced zone, color, mineralogy, leaching, etc.) Radiocoring consists of taking radiometric measurements through the drill holes at a working face, in order to observe the distribution of the radioactive content. Using a GMT meter (the radioactivity measuring device) connected to a small probe sealed with an aluminum tube, the mineralized zones of a face are determined by introducing and pushing a probe into the drill holes every 20 cm before being blasted. This device also allows miners to be guided on the contents of the uranium ores before blasting. Before this operation, the drill holes must be unblocked using a tamper.

This is a step that comes just after the radiocoring, it consists of calculating the average contents. Average content of a hole (Tt): Tt = Sum of the radioactive values measured in the hole / n×A and the Average content of a front Tf: Tf = Sum of the radioactive values measured at the front / N × A (With: n: number of measurement steps per hole (=15 for a 3 m deep hole) N: total number of measurement steps for all the radiocored holes (except GO).

A: the radioactivity value corresponding to the 1‰ cut-off. (A= 45 for GMT-1200)) The data from the radiocoring are accompanied by a color code called zonéo (**Table 1**). The latter consists of coloring the radiocoring data according to their content by following the locally defined order.

The extraction of ore in underground mining is done in the form of galleries, 5 to 6 m wide, which isolate pillars of approximately 17 to 20 m on each side and 3 to 5 m high. Cleaning consists of washing the facing using a hose to remove all dust and mud from mining activities and to allow the lithological limits to be seen. On the other hand, the topographic survey consists of precisely measuring the dimensions of the layers on the facing, using a double decameter and a transparent pipe filled with water [7].

The process of carrying out surveys consists of first identifying the base levels of the different facies: argillite, conglomerate, sandstone. Then it is a question of describing the rock in detail and representing the sedimentary figures (type of bedding, slumps and wrinkles). The direction of paleocurrents is indicated as well as the presence of accompanying elements (organic matter, pyrite, traces of iron oxides).

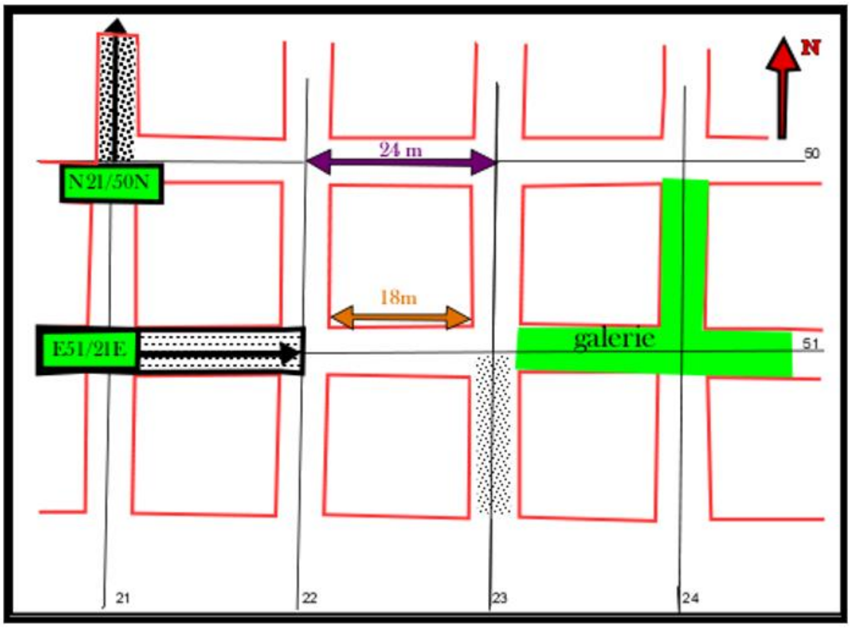

Figure 3: Mode of location in the COMINAK mine [7], the black arrows indicate the direction of progress of the site: N 21/50 N: means that the site is located in gallery N21 and advances towards the North from gallery E50; E 51/21 E: means that the site is located in gallery E51 and advances towards the East from gallery N21.

Table 1: COMINAK color scale

Cps	Color	Category
From 0 to 49	Green	Sterile Zone
From 50 to 89	Yellow	Poor Zone
From 90 to 149	Orange	Relatively Rich Zone
From 150 to 299	Red	Rich Zone
From 300 to 899	Violet	Rich Zone
More than 900	Black	Very Rich Zone

3. RESULTS AND DISCUSSION

The methodological approach adopted in this research work consists of:

- facing surveys, for the description of the different lithological levels as well as the different sedimentary, tectonic structures characterizing the depositional environments,

- produced block diagrams, for the determination of the direction of paleo-currents

3.1 Description of the different lithological levels observed at Akouta Sud

3.1.1 East-West direction facings

The activities carried out within the framework of this report consisted of carrying out six face surveys in the Akouta Sud sector in the 18 Moyen district of Guézouman (numbering code: Q.18^{M}): three face surveys carried out in the East-West direction (**Figures 4, 5 and 6**) and three others in the North-South direction (**Figures 7, 8 and 9**). According to these surveys, several lithological levels were distinguished. This type of division does not allow correlations to be made between the stratigraphic levels based on their numbering.

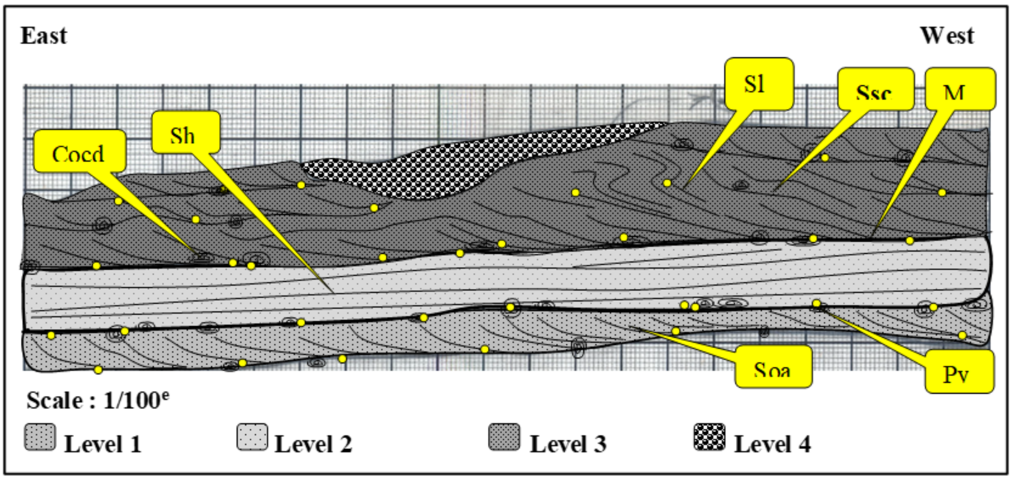

Figure 4: Facing survey (E 152– 52 bW) (South Pt.) showing four lithological levels (Level 1; Level 2; Level 3, Level 4), which are made up of several types of sedimentary structures such as horizontal stratifications (Sh) , slumps (Slp), subundulate spoon stratifications (Ssc) and oblique arcuate stratifications (Soa). These levels are often rich in pyrite balls (Py) and roundels (Cocd).

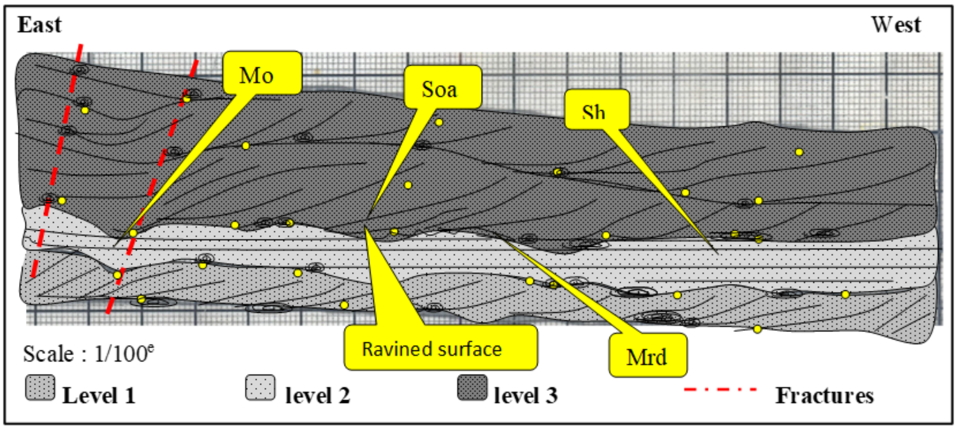

Figure 5: Face survey (E 152–52 bW) (North Pt.) showing three lithological levels (Level 1; Level 2; Level 3), which consist of several types of sedimentary structures such as horizontal stratifications (Sh), oblique arcuate or trough stratifications (Soa) and microwrinkles (Mrd). These levels may occasionally contain organic matter (Mo).

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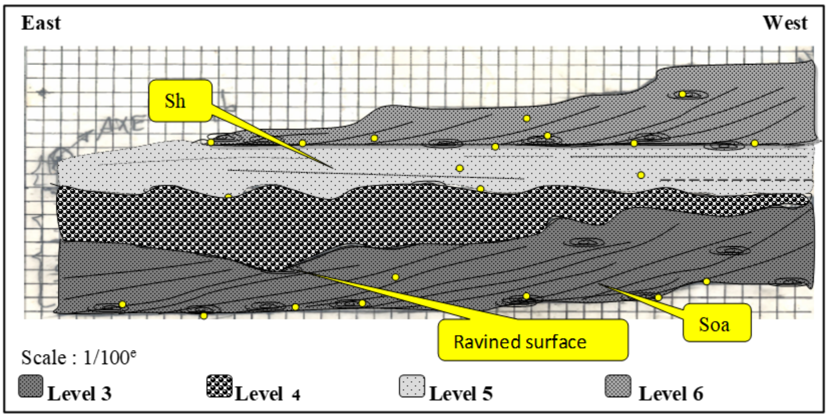

Figure 6: Facing survey (E 151 b – 54bE) (North Pt.) showing four lithological levels (Level 3; Level 4; Level 5, Level 6), which are made up of several types of sedimentary structures such as poorly visible subhorizontal stratifications (Sh) and oblique arcuate or trough stratifications (Soa).

3.1.2 North-South direction facings

Only 2 to 3 lithological levels are distinguished on the facings, following the North-South direction. The observed succession, from the base to the top, is as follows: The third level (N3) is dominated by dark gray sandstones, approximately 2 to 3 m thick. It is characterized by an average grain size. The sediments present asymmetrical metric to plurimetric spoon stratifications, megarides, slumps and metric to plurimetric spoon stratifications, showing a transition to sub-undulated stratifications. Level (N3) is often separated by a fine sandstone level with micro rides. Centimetric and millimetric black spots due to a reducing potential (organic matter), clay and silt pebbles and several pyrite balls (FeS2) were observed at the base of this level. Towards the top, roundels, some white carbonate spots (CaCo3) millimetric to centimetric, silt pebbles, some pyrite balls (FeS2) and red discolorations due to hematite (Fe2O3) were observed. Such observations indicate that this is a channel filling deposit. On some facings this level (N3) is completely leached, it does not carry mineralization. The fifth level (N5) presents subhomogeneous light gray sandstones with fine grain size, having a leached appearance.

The sediments present a fine subhorizontal stratifications more or less visible and slightly wrinkled which can evolve to a set of micro wrinkles. They are also accompanied by white carbonate spots (CaCo3) millimetric to centimetric, clay pebbles and pyrite balls (FeS2). These sandstone deposits are not mineralized (sterile). The sixth level (N6) corresponds to grayish sandstones, about 0.9 m thick. This level has black spots of organic matter (reduced facies) and red spots of oxidation (oxidized facies) at the base. Towards the top, a few balls of pyrite (FeS2), white carbonate spots (CaCo3) and red discolorations due to hematite (Fe2O3) were observed. The sediments also contain silt and clay pebbles, oblique, spoon-shaped, slump stratifications and microwrinkles [8]. This level can be linked to a channel-fill deposit.

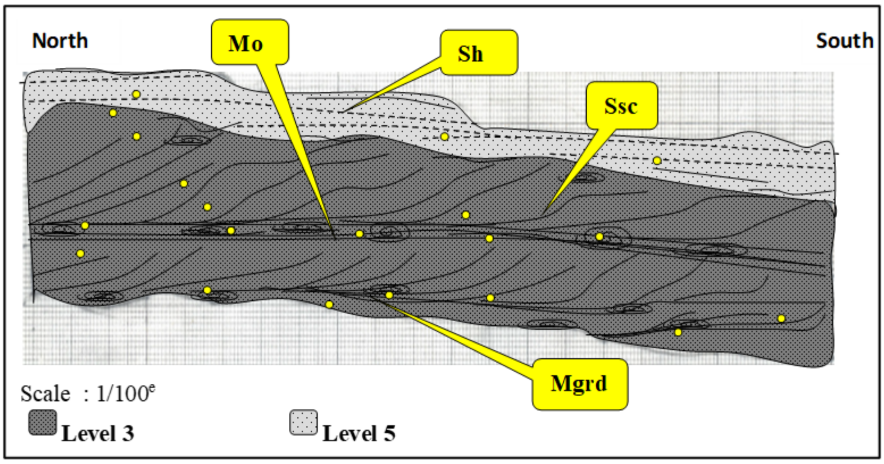

Figure 7: Face survey (N50c –147 N) (East Pt.) showing two lithological levels (Level 3; Level 5), which consist of several types of sedimentary structures such as poorly visible subhorizontal stratifications (Sh), subundulate spoon-shaped stratifications (Ssc), megarides (Mgrd) and oblique arcuate or trough-shaped stratifications (Soa).

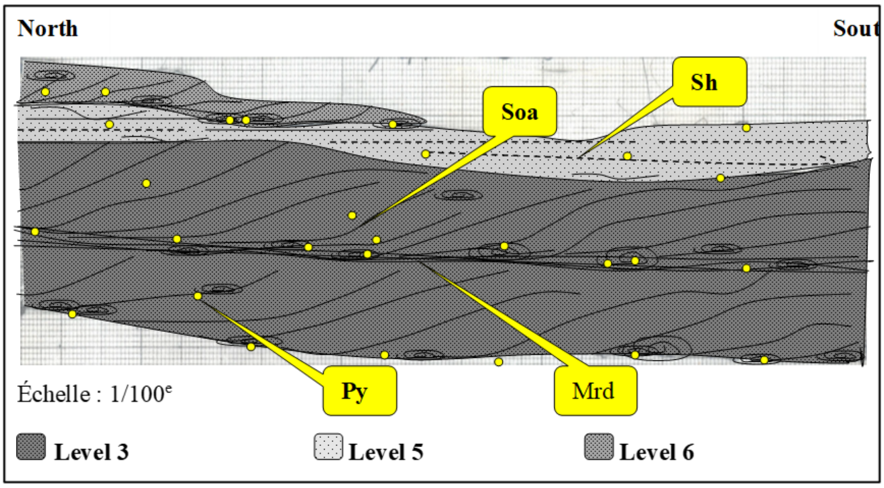

Figure 8: Face survey (N 53a – 147 N) (East Pt.) showing three lithological levels (Level 3; Level 5; Level 6), which are made up of several types of sedimentary structures such as barely visible horizontal stratifications (Sh) and oblique arcuate or trough stratifications (Soa).

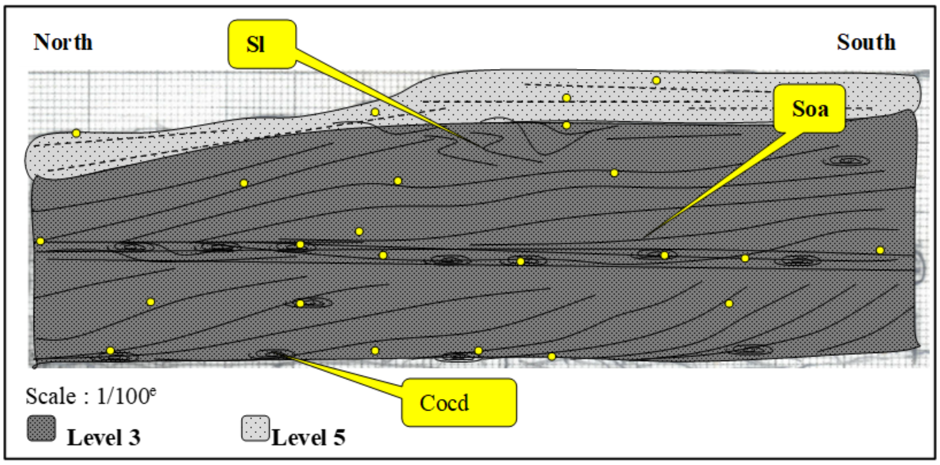

Figure 9 : Levé de parement (N51c –147 N) (Pt. Ouest) montrant deux niveaux lithologiques (Niveau 3 ; Niveau 5), qui sont constitués de plusieurs types de structures sédimentaires telles que des stratifications subhorizontales peu visibles (Sh), des slumps(Slp), des microrides (Mrd) et des stratifications obliques arquées ou en auges (Soa).

The synthetic analysis of the middle district 18 allows us to identify 6 lithological levels. From the base to the top, we can distinguish: The first level (N1) is made up of gray sandstone with medium grain size, with a thickness of approximately 0.8 to 1.8 m. The sediments have oblique and oblique arcuate stratifications tangential to the base. This level (N1) has some black reduction spots (reduced facies), red oxidation spots (oxidized facies), cockades, white carbonate spots (CaCo3) and pyrite balls (FeS2). These characteristics have made it possible to link this deposit to a channel filling. The second level (N2) corresponds to gray sandstone with medium to fine grain size, with a leached appearance. The thickness of (N2) is approximately 0.3 to 1.2 m. This level is often gullied by overlying spoons of the level (N3) and the contact surface is punctually marked by numerous nodules of pyrite (FeS2) and red spots of hematite (Fe2O3) in roundel. The sediments present horizontal to subhorizontal stratifications and some microwrinkles towards the top. Due to these characteristics, this level has been linked to deposits of longitudinal or transverse bars. These sandstone deposits are not mineralized (sterile). The third level (N3) is predominated by dark gray sandstones, approximately 2 to 3 m thick. It is characterized by an average grain size.

The sediments present stratifications in asymmetrical spoons metric to plurimetric, megarides, slumps and stratifications in spoons metric to plurimetric, showing a transition to subundulated stratifications. Level (N 3) is often separated by a fine sandstone level with micro-wrinkles. Centimetric and millimetric black spots due to a reducing potential (organic matter), clay and silt pebbles and several pyrite balls (FeS2) were observed at the base of this level. Towards the top, cockades, some millimetric to centimetric carbonate white spots (CaCo3), silt pebbles, some pyrite balls (FeS2) and red discolorations due to hematite (Fe2O3) were observed. Such observations indicate that this is a channel filling deposit. On some facings this level (N3) is completely leached, it does not carry mineralization. The fourth level (N4) is a channel with clay pebbles of variable thickness, the base of which is made up of centimetric to decimetric pebbles, these pebbles are made up of black clays with fine intercalations of silts or very fine sandstones. Above come fine to medium white sandstones with more or less visible internal stratification with a few clay pebbles still visible. This channel sometimes ravines the unit of dark to medium gray sandstones of the level (N3). It is always sterile apart from the base which can often shelter some mineralizations (hematized pebbles). The fifth level (N5) presents subhomogeneous light gray sandstones with fine to medium grain size, having a leached appearance.

The sediments present fine subhorizontal stratifications more or less visible and slightly wrinkled which can evolve up to a set of microwrinkles. They are also accompanied by millimetric to centimetric carbonate white spots ($CaCo3$), clay pebbles and pyrite balls ($FeS2$). These sandstone deposits are not mineralized (sterile). The sixth level (N6) corresponds to grayish sandstones, approximately 2.5 m thick. This level has black spots of organic matter (reduced facies) and red oxidation spots (oxidized facies) at the base. Towards the top, a few pyrite balls ($FeS2$), carbonate white spots ($CaCo3$) and red discolorations due to hematite ($Fe2O3$) were observed. The sediments also contain silt and clay pebbles, oblique stratifications, in metric spoons, with more or less subhorizontal slumps and microwrinkles. This level can be linked to a channel filling deposit.

3.2 Oxidation-reduction phenomena mapping and associated minerals

In the Akouta Sud sector, five (5) oxidation-reduction facies were observed in the different lithological levels. These are the reduced, oxidized, oxidized-reduced, reduced-oxidized and leached facies [9, 10, 11, 12, 13, 14, 15].

3.2.1 Reduced facies

The reduced facies is characterized by the dark color of the sediments. This type of facies, which is mineralized, was observed in the $Q18^M$ district more specifically in level 3 (set of dark gray sandstones with medium grain size, with pyrite balls, clay and silt pebbles, cockades, white carbonate spots, black spots of organic matter and hematite spots) and in level 6 (set of grayish sandstones with oblique, spoon-shaped, slump stratifications and microwrinkles). These sandstone deposits generally contain pyrite and millimeter to centimeter-sized white spots. These whitish spots could correspond to carbonates or kaolinite (**Figure 10**).

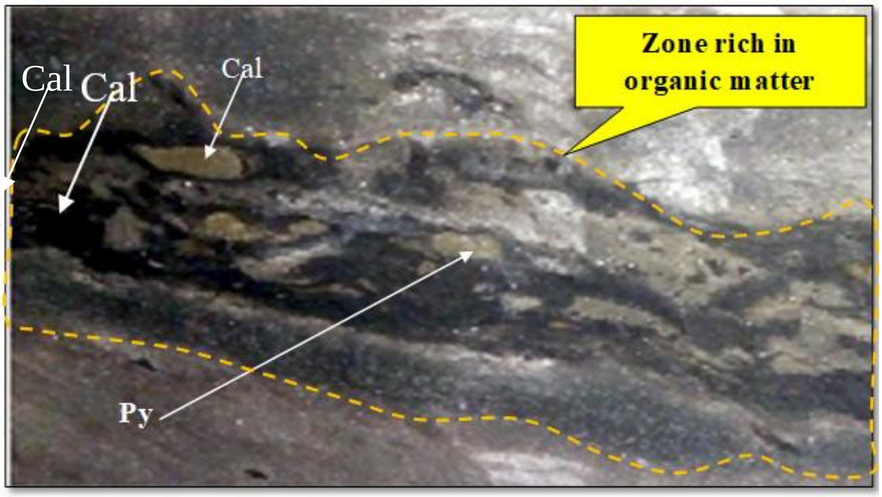

Figure 10: Reduced facies presenting calcite (Cal), organic matter (Mo) and pyrite balls (Py), observed in the gallery (E 147–$53a^W$).

3.2.2 Oxidized facies

This type of facies is characterized by pinkish sandstone bodies with hematized sedimentary joints, bearing uranium. It was also observed in level 3 (set of dark gray sandstones with medium grain size, with pyrite balls, clay and silt pebbles, cockades, white carbonate spots, black spots of organic matter and hematite spots) and in level 6 (set of grayish sandstones with oblique, spoon-shaped, slump stratifications and microwrinkles). In this facies, pyrite is almost absent (**Figure 11**).

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Figure 11: Oxidized facies showing red hematite spots (Hem) and roundels (Cocd), observed in the gallery (E 147–53aW).

3.2.3 Oxidized-reduced facies

The oxidized-reduced facies, less mineralized than the previous one, is characterized by a predominance of oxidized pink sandstones. It is remarkable in level 1 (medium-grained gray sandstone, with pyrite balls, carbonates, cockades and hematite spots), in level 3 (set of medium-grained dark gray sandstones, with pyrite balls, clay and silt pebbles, cockades, white carbonate spots, black spots of organic matter, black spots of organic matter and hematite spots) and in level 6 (set of grayish sandstones with oblique, spoon-shaped, slump stratifications and microwrinkles). The main markers of such a facies are the color zonations (red, black and yellow) which correspond respectively to hematite, organic matter and the cockade. In such a facies, pyrite is not expressed (**Figure 12**).

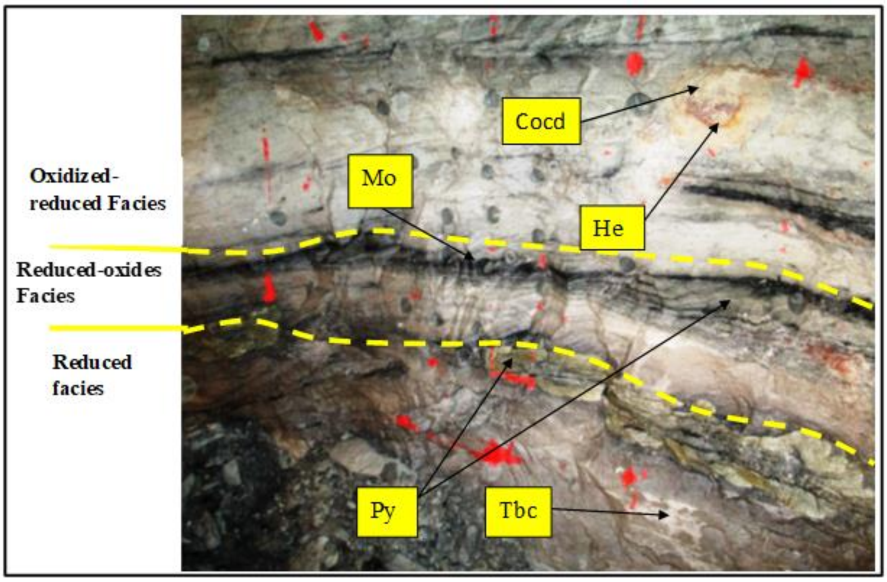

Figure 12: Oxidized-reduced facies showing hematite spots (Th), cockades (Cocd) and organic matter (Mo), reduced-oxidized facies and reduced facies, observed in the gallery (E 152– 52 bW) of the Akouta Sud sector.

3.2.4 Reduced-oxidized facies

The reduced-oxidized facies is marked by a predominance of black sandstones. This facies has brick-red hematite cockades. It is the most mineralized facies in the Q 18M district. This type of facies was observed in level 3 (set of medium-grained dark gray sandstones, with pyrite balls, clay and silt pebbles, cockades, white carbonate spots, black spots of organic matter and hematite spots). The sandstone bodies have pyrite balls with brown hematite halos at their base. (**Figure 13**).

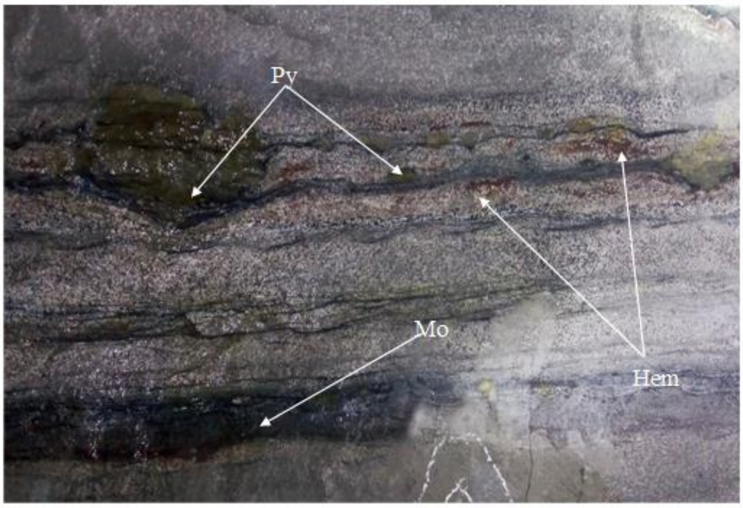

Figure 13: Reduced-oxidized facies showing pyrite balls (Py), organic matter (Mo) and red hematite spots (Th), observed in the gallery (E 147–53a^{W}).

3.2.5 Leached facies

The leached facies consist of sterile (non-mineralized) white sandstones. It was observed in the Q 18^{M} district more precisely in level 2 (set of gray sandstones, with some fine subhorizontal plane stratifications), often in level 3 (set of dark gray sandstones with medium grain size, with pyrite balls, clay and silt pebbles, cockades, white carbonate spots, black spots of organic matter and hematite spots), in level 4 (channel with clay pebbles of variable thickness) and in level 5 (subhomogeneous light gray sandstones with fine grain size, with fine subhorizontal stratifications and microwrinkles). The sediments are rich in clay pebbles and pyrite balls.

3.3 Minerals associated with the Guézouman formation

The different minerals found in the Akouta Sud sector are: pyrite, calcite and hematite more or less associated with organic matter. They play an important role in the formation of Uranium deposits [12, 13, 16, 17]. However, it has been distinguished:

- Pyrite (FeS_2), is present in the form of centimetric to decimetric nodules sometimes associated with organic matter. It is very often observed at the base of oblique or trough stratifications (**Figures 14A, 14B, 14C, 14E and 14F**).

- Calcite ($CaCo_3$), not very abundant, is observed in the form of millimeter to centimeter white spots with a diffuse outline (**Figure 14E**).

- Hematite (Fe_2O_3), abundant, is responsible for the brick red color (**Figures 14A, 14B, 14D and 14F**). According to some authors [3, 18], the oxidation of pyrite forms hematite and gives the reddish color. Hematite can also be formed from iron hydroxides (limonite and goethite) of yellow-ochre color [9]. All these minerals have been observed in both Akouta and Akola.

Pyrite is generally in the form of nodules observed at the base of the sheets, while calcite is more abundant in Akola than in Akouta. The uranium minerals encountered in the Akouta South sector deposit are shown in **Figure 14**. According to [19], the red (hematite) and white (calcite) zones occupy the outermost parts of the roundels. It should be noted that organic matter plays an important role in the genesis of uranium deposits. Black in color, sometimes in the form of black spots, this organic matter comes from the accumulation of plant debris (**Figures 14C and 14E**). It is considered a reducing agent of uranium [19].

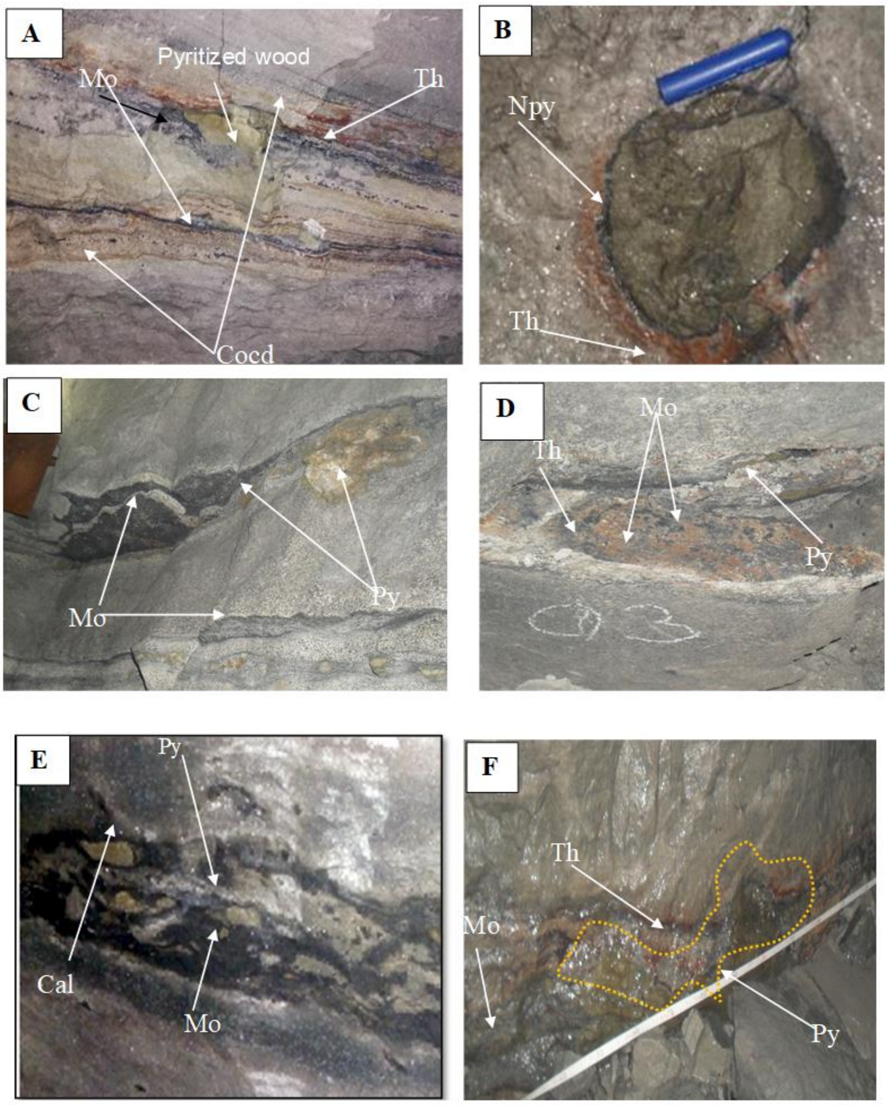

Figure 14: Different minerals visible on the facings: a) pyritized wood accompanied by cockades (Cocd), organic matter (Mo), and hematite (Th). b) Pyrite nodule (Npy) of sometimes variable golden-yellow color giving hematite (Th) by altering. c) organic matter (Mo). d) hematite in the form of a red-orange area associated with organic matter. e) organic matter (Mo) in the form of a black area associated with calcite (Cal) and pyrite (Py). f) pyrite in the process of altering to give hematite (Py).

4. CONCLUSION

The analysis and interpretation of surveys of facing and sedimentary structures carried out in the Akouta Sud sector, show the vertical and lateral sequence of 6 lithological levels and 5 facies in the carboniferous formation of Guézouman.

The first level (N1) corresponds to gray to medium sandstones, with oxidized-reduced facies, presenting red spots of hematite (Fe_2O_3), some black spots of reduction (organic matter), oblique stratifications and oblique arcuate stratifications tangential to the base. It is assimilated to channel filling deposits. The second level (N2) consists of a set of medium to fine grey sandstones with a leached appearance, often gullied by overlying spoons from level three and presenting horizontal to subhorizontal flat stratifications and some microwrinkles towards the top. This level has been linked to deposits of longitudinal or transverse bars. These sandstone deposits are not mineralized (sterile).

The third level (N3) is a dark to medium grey reduced-oxidized sandstone deposit, comprising black reductant spots (organic matter), cockades, some red hematite spots (Fe_2O_3), white carbonate spots or kaolinite, clay and silt pebbles and several pyrite nodules (FeS_2). These sediments exhibit asymmetrical metric to plurimetric spoon stratifications, slumps, metric to plurimetric spoon stratifications and subundulated spoon stratifications. These deposits often pass laterally to a leached level (barren). Such observations indicate that it is a channel-fill deposit. The fourth level (N4) is a channel with clay pebbles of variable thickness, with fine intercalations of silts or very fine sandstones. This channel sometimes ravines the dark to medium gray sandstone unit of level three. It is always sterile (Leached Facies) apart from the base which can often host some mineralizations (hematized pebbles).

The fifth level (N5) consists of fine-grained subhomogeneous levy sandstones, with fine subhorizontal stratifications, microwrinkles, white carbonate spots (CaCo3), silt pebbles and pyrite balls (FeS2). These sandstone deposits are not mineralized (barren). The sixth level (N6) is represented by greyish to medium oxidized-reduced sandstones, with some black spots of organic matter (reduced facies), red spots of hematite (oxidized facies) at the base, some pyrite balls (FeS2), white carbonate spots (CaCo3) and silt and clay pebbles. It also has oblique, metric spoon-shaped stratifications, with more or less subhorizontal slumps and microwrinkles. This level is also created at the time of channel filling.

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