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Research Paper

Characterisation of the host sequences of uranium mineralisation in the Moradi sector, Tim Mersoï Basin (Northern Niger)

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Abstract
The Moradi Sector, Tim Mersoï Basin (Northern Niger) belongs to the large intracratonic Iullemenden basin. The Tim Mersoï basin is known for its significant uranium resources. In the study area, uranium mineralisation indices were highlighted during previous work, but abandoned in favour of other better known deposits. In order to better understand the mineralisation in the Moradi sector, an in-depth study of the mineralisation's enclosing formations is necessary. The objective of this study is to determine the characteristics of the Anou-Mellé and Aoukaré units, which are recognised as host formations for the uranium mineralisation in the Moradi sector. Drilling data (cuttings description) and logging data (resistivity, spontaneous polarisation, gamma) were used to determine the lithological characteristics, morphology and depositional paleorelief of the Anou-Mellé and Aoukaré sequences. This study shows that the Anou-Mellé unit is a conglomerate with coarse rounded grains and a ferruginous and phosphate cement, whereas the Aoukaré sequence is made up of fine sandstones consolidated by a siliceous, sometimes hematous and locally kaolinous cement. The palaeorelief of these sequences, often associated with syn-sedimentary deformation structures (strike-slip faults), gives the Anou-Mellé and Aoukaré units an anticlinal and synclinal geometry at the scale of the study area. They outcrop to the east of the Moradi sector (hence the surface mineralisation to the East) and plunge to the West where they reach a depth of around 35m.

Key words*: Moradi area, Anou-Mellé and Aoukaré units, uranium mineralisation, Tim Mersoï basin.*

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I. Introduction

The Moradi sector (Northern Niger) is an integral part of the Tim Mersoi basin. This last is bounded to the East by the Aïr Massif and to the West by the In Guezzam ridge **(Figure 1)** (Valsardieu, 1971). The Tim Mersoï Basin is undoubtedly an important crucible for uranium deposits in Niger, where major deposits have already been exploited or have been in operation for some 40 years (COMINAK, SOMAÏR) (Gerbeaud, 2006 ; Mamadou, 2016). In the Moradi sector, uranium mineralisation indices were discovered during the geophysical airborne campaign (TRPAD Azelick) between 1959 and 1960, which revealed surface mineralisation (Alimou, 2012 ; Chékaraou, 2013). In March 1961, the Preliminary drilling down-dip of the surface mineralisation essentially recognised mineralisation at the base of the Teloua sandstone (Alimou, 2012). However, this roughly estimated deposit was abandoned in favour of other better known deposits. Nevertheless, in recent years, a drilling campaign has been undertaken in order to deepen the knowledge of the Moradi deposit (Alimou, 2012 ; Chékaraou, 2013).

As mineralisation was observed in the Teloua and Moradi formations, it was necessary to determine the host facies of this mineralisation within these formations. The objective of this work is to determine the characteristics of the Anou-Mellé and Aoukaré units, recognised as host facies for the mineralisation. Thus, borehole data (description of cuttings) and logging data (resistivity, spontaneous polarisation, gamma) are used first to validate the new stratigraphic division of the formations (Téloua and Moradi) in the Moradi sector. Then, the host facies (Anou-Mellé and Aoukaré) of the mineralisation were identified using Gamma ray logging. Subsequently, mapping techniques were used to understand the morphology of the different sedimentary formations. Specifically, the lithological characteristics of the Anou-Mellé and Aoukaré units, their morphology at the scale of the study area, and their depositional palaeorelief are determined.

II. General geological context

The geology of the region is characterised by two major geological entities: the Aïr Massif and the Tim Mersoï basin. The crystalline basement of the Aïr is formed by an intensely folded complex of metamorphosed rocks in the generally migmatic catazone and crossed by numerous granitic occurrences. This complex, a southern extension of the Suggarian (Hoggar), is composed of biotite gneisses, leptynites, diopside-hornblende leptynitic gneisses and micaschists, with quartzite, amphibolite and cipolin levels intercalated (Diracca, 2005).

The Tim Mersoi basin is a subset of the vast Iullemenden basin. The latter refers to the huge basin south of the Hoggar. The Tim Mersoï basin is almost entirely in Niger, except for its northern part, the Tin Sériríne syncline which closes in Algeria **(Figure 1)** (Valsardieu, 1971). The evolution of the Tim Mersoi basin is linked to the structure of the basement (Wagani, 2007) and to the history of the Iullemenden basin. The sedimentation history of the western edge of the Aïr is mainly marked by marine transgressions. The sedimentary filling is made up of intercalary continental deposits of Permian to Lower Cretaceous age. In this region, significant sedimentation began in the Paleozoic where the sedimentation areas are confined to the Tin Seririne syncline from the beginning of the Primary. There was a shift of central deposits from North-east to south-west, related to the migration of the subsidence pole of the Iullemenden Basin during the Paleozoic-Lower Cretaceous period (Greigert and Pougnet, 1967).

On the eastern edge of the Tim Mersoi basin, movements of the basement structures affect the sedimentary cover (Konaté, 2007 ; Sani, 2020). Generally speaking, the sedimentary layers dip very slightly to the west and the deformations that affect them are numerous and are the attenuated reflection of dislocations of the underlying basement and are expressed in the form of flexures more or less disturbed by faults (Forbes, 1989). The main regional structures are essentially represented by: the Arlit In Assaoua fault flexure of average N-S direction. It's characterised by a sinister drop with a reverse component, which delimits a western compartment lowered by more than 150m, while the eastern compartment is raised. The flexures resulting from the Arlit Fault of N30° direction. These are often disrupted by N75° faults. These are the Madaouela, Izeretaguen, Mouron, Autruche and Aguelal-Zeline fault flexures. These structures correspond to reverse folds and faults. It should be noted that all the known economic mineralisation on the Arlit concession (Northern Niger) is located between the Arlit fault and the Mouron. Clusters of discontinuities of direction N70° to N80°, with as main accident the cluster of Tin Adrar. The N140° to N160° flexures, which are less marked because they are very much obliterated by the overlying series. These structures strongly control some of the Arlit uranium deposits (Northern Niger) by their syn-sedimentary plays (Sani, 2020 ; Forbes, 1989 ; Flotté, 2005).

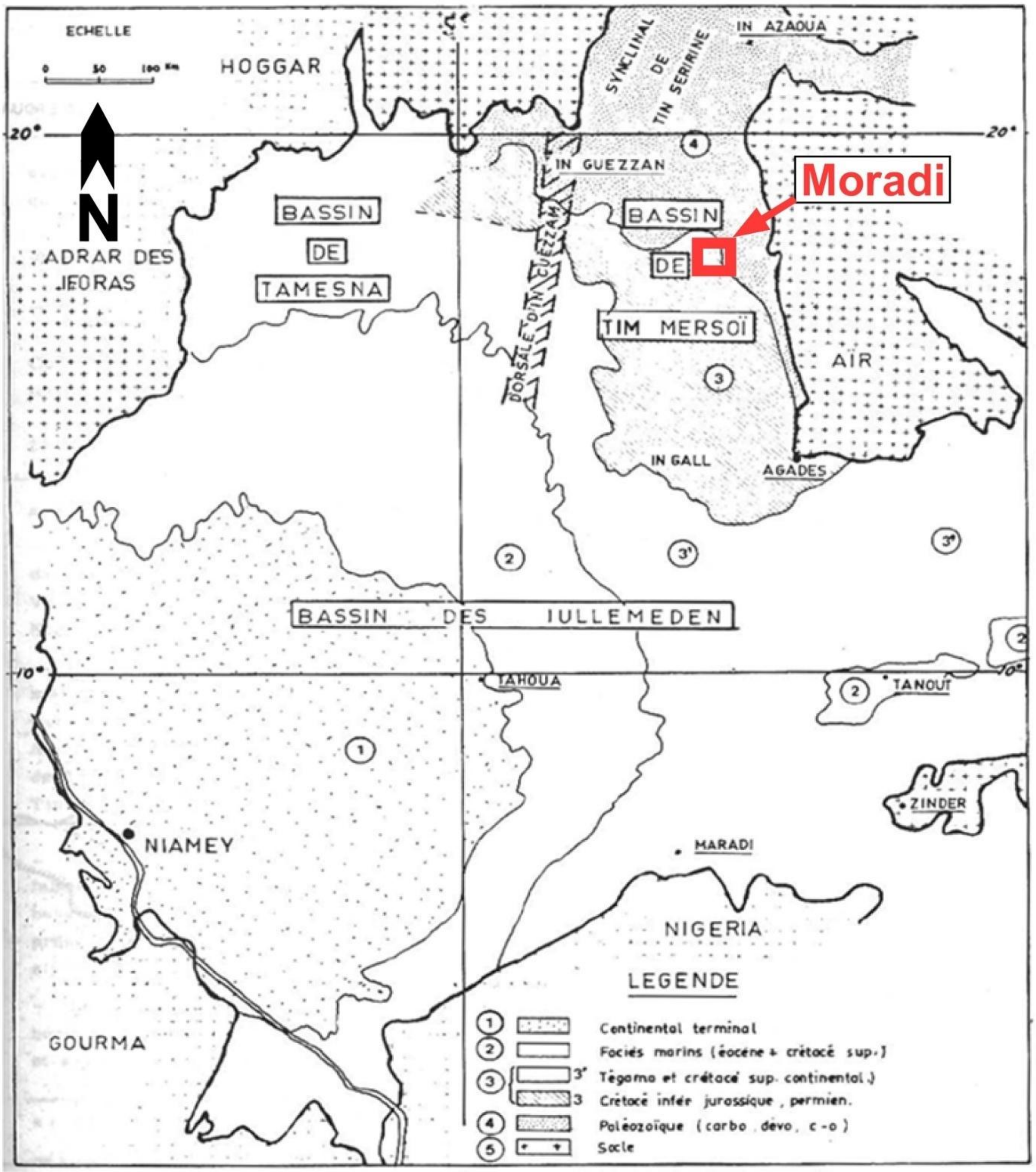

Figure 1: Simplified geological map of the Iullemenden basin and location of the study area (Valsardieu, 1971).

On the edge of the Aïr, the sedimentary cover from the Cambro-Ordovician to the Cretaceous comprises a periodic succession of sedimentary environments with marine and continental trends (Joulia, 1963 ; Moussa, 1992 ; AREAVA NC NIGER, 2010). The attached stratigraphic scale **(Figure 2)** provides a typical cross-section of the terrain encountered in the basin. The following stages and series can be distinguished:

➢The Precambrian: the western edge of the Aïr consists of ancient calc-alkaline granites with some intrusive batholiths, alkaline to hyperalkaline granites;

➢The Carboniferous: which is subdivided into 3 series, the Teradah, Lower Tagora and Upper Tagora series.

➢The Permian: essentially continental, consisting of two powerful red sandstone bars (Izegouande and Téloua 2 and 3) interspersed with several levels of red-brown siltstones (Tejia, Tamamait, Moradi);

➢The Triassic: represented by the fine sandstones of TELOUA 1, covers the ANOU- MELLE conglomerate;

➢The Jurassic: which includes the fluvial sandstone formations of TELOUA 2 and 3, TCHIREZRINE 1 and 2, with lacustrine interlayers (MOUSSEDEN and CARBONATE). These formations, which locally contain analcime levels, are only known to the south and west of the Arlit sector;
➢The Cretaceous: constituted by the clayey lacustrine formation of the IRHAZER with, at its base, the silty and fine sandstone levels of the ASSAOUAS.

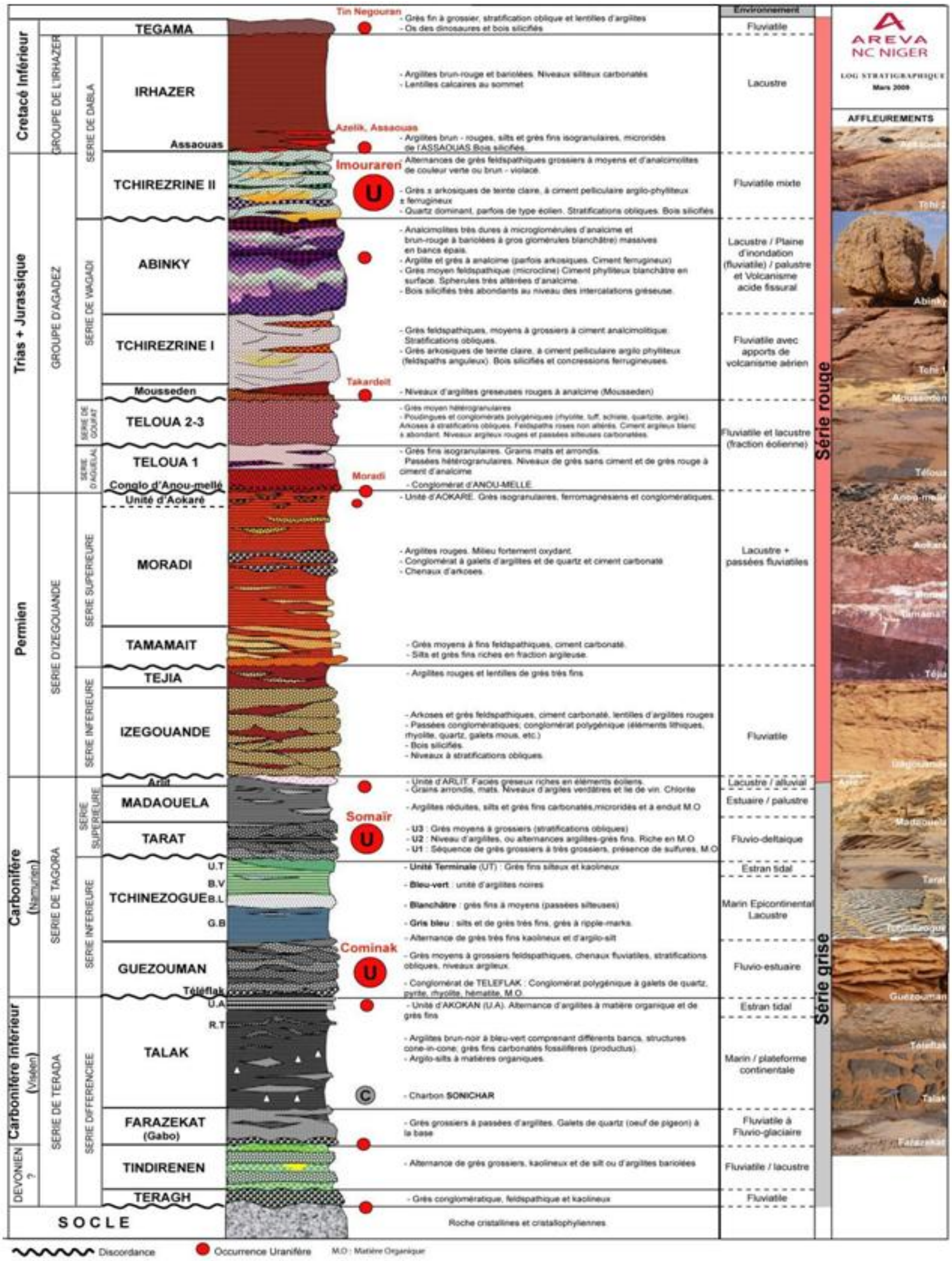

Figure 2: Regional lithostratigraphic column of the Tim Mersoï basin (AREVA NC NIGER, 2010).

III. Main geological features of the Moradi area

The Moradi sector is located between UTM coordinates: 326000m and 331000m (X) and 2038400m and 2042400m (Y). At the level of this, in the Moradi sector, the Teloua sandstone formation (Teloua 1) is outcropping. The Moradi sector is characterised by a structure of synclines, anticlines and rocky escarpments and a series of faults oriented N70° and N150° **(Figure 3)** (Alimou, 2012). The major fault in the area is the Izeretagen (Flotté, 2005 ; Tauzin, 1981). Although not very pronounced, it crosses the whole area in a North-south direction.

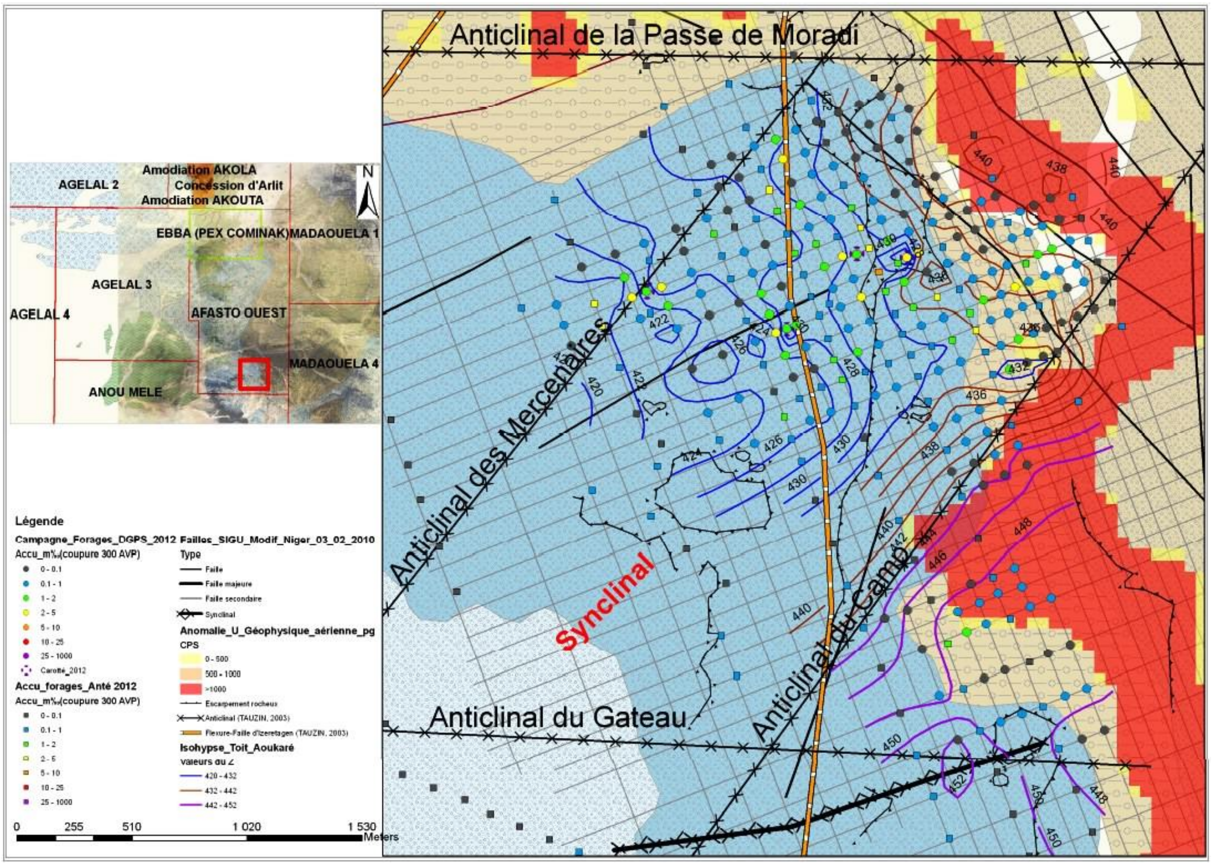

Figure 3: Structural elements of the Moradi area (Alimou, 2012).

The stratigraphic series observed during the various drilling campaigns (Marlyse, 2009 ; Mabicka, 2009) extends from the Carboniferous to the Jurassic **(Figure 2)** (Valsardieu, 1971). In the Moradi area, there are classically two (2) main target formations (which contain the uranium mineralisation): Moradi and Teloua 1 **(Figure 2)**. These formations have already been studied in summary form on a regional basis **(Figure 2)** (AREVA NC NIGER, 2010).

IV. Materials and methods

A multidisciplinary approach including destructive drilling, cuttings description and logging were used in this study.

IV.1. Boreholes and description of lithological facies (Cuttings description)

Destructive drilling was carried out using the direct circulation rotary drilling technique in the Moradi area. The average depth per hole is 21m. During the drilling, samples (rock cuttings) were collected and described. The target formations are: Téloua 1, Anou-Mellé, Aoukaré and Moradi **(Figures 3 and 6)**. All boreholes were stopped at 3m in the Moradi claystone. The description was done hole by hole. The equipment needed to describe the cuttings consisted of: an international colour chart, a grain size scale, survey sheets, 10% hydrochloric acid, SPP-gamma and a magnifying glass.

IV.2. Logging

The logging operations were carried out using an acquisition rig equipped with Geovista and Mine-Gamma Technology equipment for the Gamma probe (DHT27). Logging is carried out directly after drilling (delayed logging). At the end of the logging operation, crucial and precise information about the boreholes is provided to the geologists. These are :

- Tilt and Azimuth (VERT);
- hole diameter (CALX or Caliper) ;
- resistivity (DLL3: RLLS and RLLD);
- lithology (PS);
- natural radioactivity or natural gamma (DHT27 and NGRS).

The "raw" log data are processed in Wellcad software. This software allows geological sections or stratigraphic logs to be made of each borehole **(Figure 4)**.

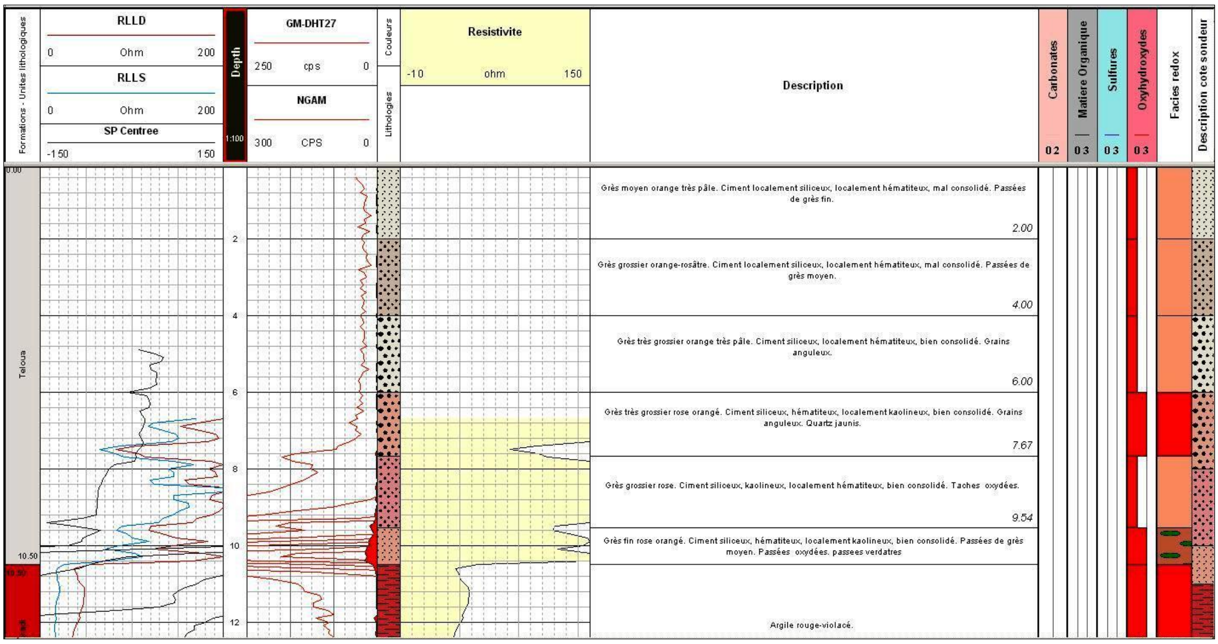

Figure 4: Example of the stratigraphic log from the logging

IV.3. Mapping

Isohypses maps and a 3D terrain model were produced using Mapinfo 10.1 and Surfer 9 software respectively. Thus, using the altitudes of Anou-Mellé and Aoukaré, taken from the different stratigraphic logs of the boreholes, an isohypses map of Anou-Mellé and Aoukaré was established. To do this, the method consists of creating a database with the X, Y and Z_roof_Anou-Mellé/Z_roof_Aoukaré coordinates for each borehole. The Z_roof is calculated according to the following formula (1):

$$\mathbf{Z\_roof = Z - Depth\_roof} \quad (1)$$

Z_roof : Altitude of the roof of Anou_Mellé or Aoukaré
Z: Altitude measured at the topographic surface of the borehole
Depth_roof: Depth of the roof of Anou_Mellé or Aoukaré.

V. Results and discussion

V.1. Result of cuttings description

The description of the cuttings **(Figure 5)** made at the end of the drilling work gives, from top to bottom, the formations crossed as follows :

➢ **Teloua 1**: It consists of fine to coarse sandstones, mostly homogeneous, limpid and of a pinkish to brownish or pale colour. This formation has abundant cement towards the base. The cement is siliceous, hematous, often kaolinous and locally carbonatous. Centimetric to decimetric yellowish or pinkish quartz pebbles have been observed in varying degrees of abundance. The boreholes drilled cross the Teloua 1 over a thickness ranging from 1m to about twenty (20m) meters depending on the location.

➢ **Anou-Mellé Conglomerate**: It's characterised by faceted pebbles embedded in an iron and phosphate cement. It's accompanied by coarse to very coarse sandstones, very pale orange in colour with hematous cement, locally carbonated and poorly consolidated. The grains are often rounded and limpid with an abundance of yellowish or pinkish quartz. The Anou-Mellé conglomerate is not found in all the boreholes in the Moradi sector; it's described mainly in the northeastern boreholes of the study area.

➢ **Aoukaré Unit**: It's characterised by fine sandstones of yellowish-grey or pale pink colour, often purple or purplish. The sandstone is well consolidated, with siliceous cement, often hematous, locally kaolinous and very indurated. Clays, siltstones and very often abundant conglomeratic pebbles and yellow products are found locally. The presence of black mica and oxidised spots is also detectable. The Aoukaré unit is present throughout the study area and its thickness varies between 1m and 3m.

➢**Moradi**: This formation is characterised by red mudstones with siltstones, abundant greenish mudstone chips and black micas. Intercalations of fine sandstone and pebbled conglomerate levels of claystone are also observable.

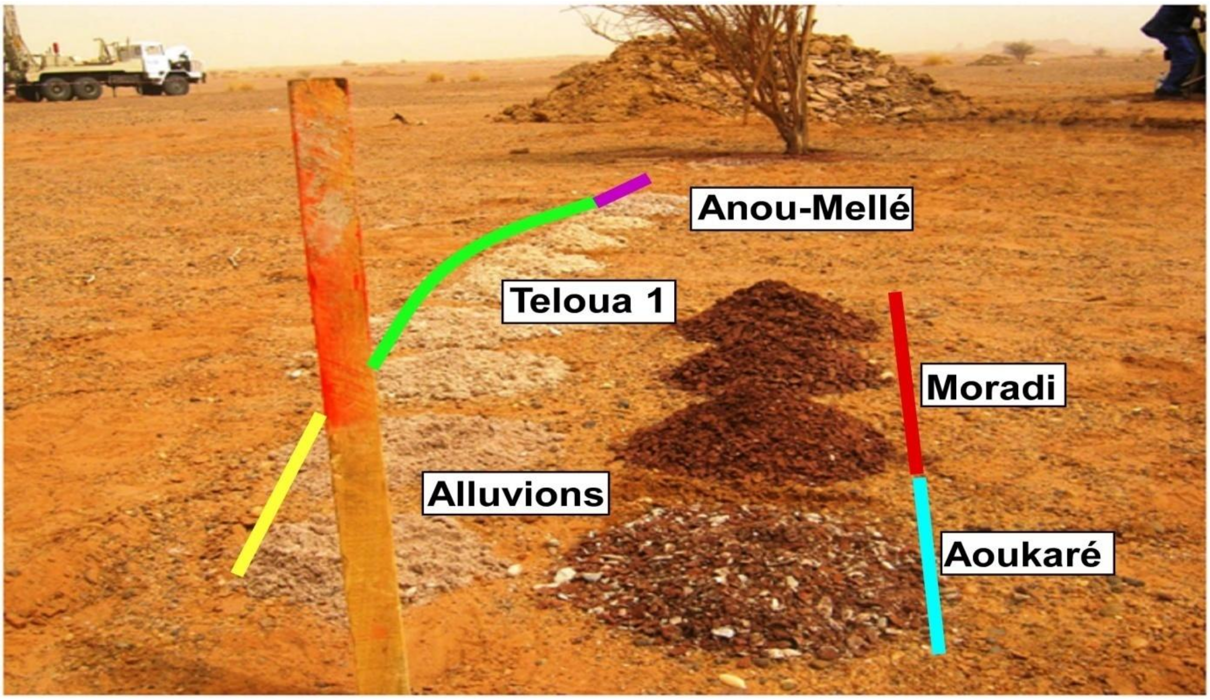

Figure 5: Garden of Cuttings

V.2. Morphology of the Anou-Mellé and Aoukaré units, and depositional paleorelief

In the typical stratigraphic divisions of the Tim-Mersoï basin **(Figure 2)**, the Anou-Mellé and Aoukaré stratigraphic units are not taken into account. The Anou-Mellé conglomerate is described as a facies of the Teloua 1 sandstone formation. The Anou-Mellé thus forms the base of Teloua 1. The Aoukaré unit is an integral part of the Moradi mudstone formation. This unit is the facies that forms the roof of the Moradi formation. Data from destructive drilling (cuttings description) and logging (spontaneous polarisation, resistivities, natural Gamma), enabled a new stratigraphic division to be made including the Aoukaré sandstone and Anou-Mellé conglomerate units **(Figures 7 and 8)**. This new stratigraphic sectioning was carried out with the help of the drillhole sections carried out in the study area **(Figure 6)**.

The stratigraphic logs (cuttings description and logging data) for each hole were used to visualise the Teloua 1 and Moradi formations, the Anou-Mellé and Aoukaré units, and possibly the alluvium **(Figures 7 and 8)**. It should be noted that the uranium mineralisation in the Moradi sector was highlighted in the Anou-Mellé and Aoukaré units **(Figures 7 and 8)**, which facilitated the identification of these units on the various stratigraphic logs. Eight (8) geological sections were made at the scale of the study area **(Figure 6)**. The sections were drawn to intercept the maximum number of boreholes and perpendicular to the major structures in the study area. Two (2) of the most illustrative sections were analysed and interpreted during this study: Sections C1, oriented NW-SE, and C3, oriented SW-NE **(Figure 6)**. The morphology of the Anou-Mellé and Aoukaré units was drawn by joining the roofs and walls of the units identified in each borehole intercepted by the section. This procedure also enabled the depositional palaeoenvironment of these two units to be highlighted, which constitutes the roof of the Moradi formation.

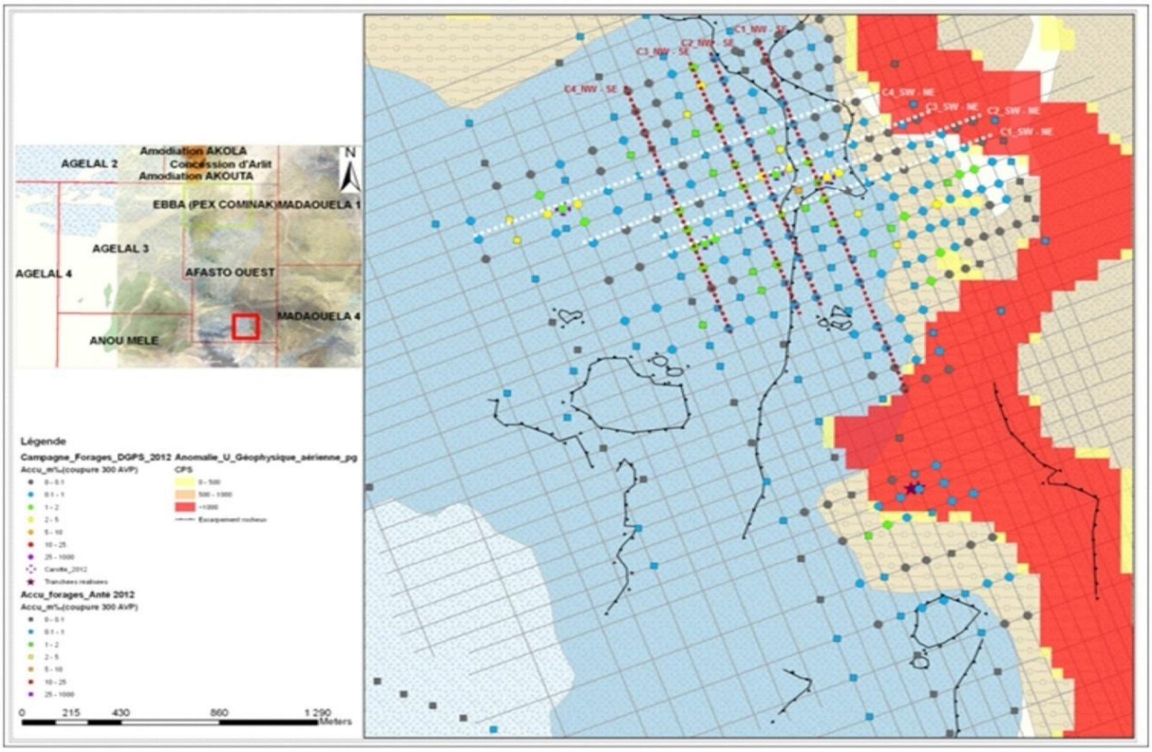

Figure 6: Location of the cuts made in the study area

Analysis and interpretation of the C1 section NW-SE

The NW-SE trending C1 section **(Figure 7)** highlights a stratigraphic cut that shows the shape of the Anou-Mellé and Aoukaré units. For each hole, the stratigraphic sequences of Moradi mudstone, Teloua 1 sandstone and possibly alluvium, and the Anou-Mellé and Aoukaré units are plotted against depth. Resistivity signals are shown in blue and gamma ray signals (DHT27) in red. The green part represents the Aoukaré while the Anou_Mellé is shown in purple. The C1 section shows that, host mineralisation sequences are outcropping at the surface in the SE part of the section, but observed at about 15m depth in the NW part. The Anou-Mellé shows thicknesses ranging from 0m to 3.71m and the Aoukaré shows thicknesses between 1.58m and 5m. The gamma ray logging data clearly shows that the envelopes of uranium mineralisation are located in the Aoukaré sandstone and the Anou-Mellé conglomerate. This study provides further clarification on the host formations (Anou-Mellé and Aoukaré) of the mineralisation as the Teloua and Moradi were previously considered to be host formations. Section C1 also highlights the depositional palaeorelief of the Anou-Mellé and Aoukaré units. Indeed, the palaeorelief highlighted by the roof of Moradi formation constitutes the depositional palaeoenvironment of the Anou-Mellé and Aoukaré units. This palaeorelief indicates a major gully of the Moradi formation which forms a synclinal and anticlinal geometry **(Figure 7)**. Furthermore, the general topography of the study area illustrates that the syncline of the Moradi formation is filled in by the Teloua 1 sandstone, which forms a dome on the topographic surface, forming the flank of the Moradi syncline **(Figures 3 and 7)**. An outcrop fault has been positioned on section C1 **(Figure 7)**. This fault coincides with the flank of the Moradi syncline and probably caused a collapse of the initially gentle slope. This structural fault has obviously influenced the geometry of the Anou-Mellé and Aoukaré units **(Figure 7)**.

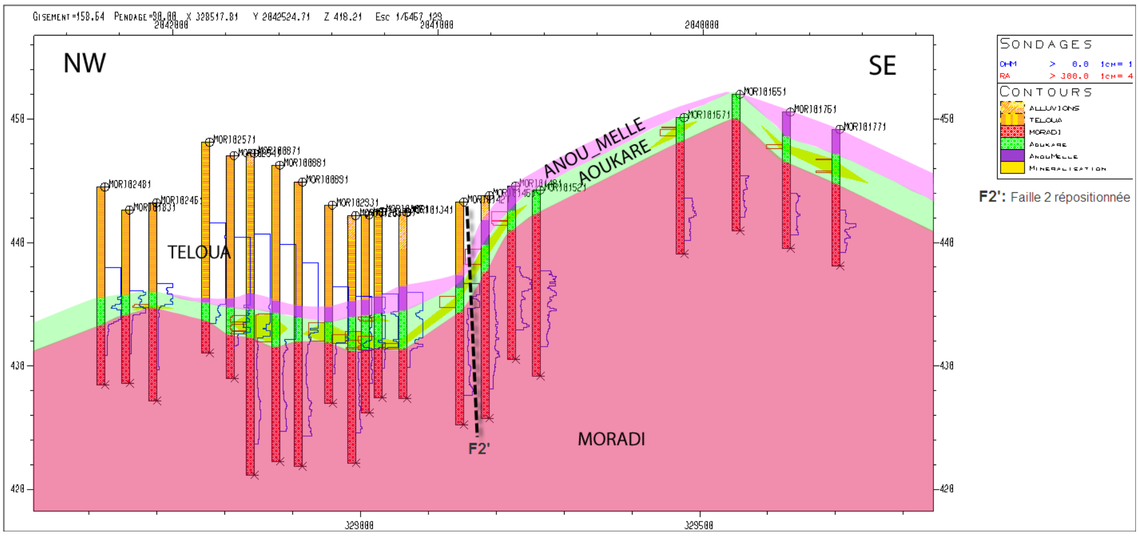

Figure 7: Section C1 (SW-NE)

Analysis and interpretation of the C3 SW-NE section

Section C3 (Figure 8), which trends SW-NE, intercepts seventeen (17) boreholes. This section shows strong gullying of the Moradi formation, resulting in the formation of a synclinal and anticlinal palaeorelief whose basin is located in the western part of the sector. The part of the sector that was drilled covers mainly the syncline of the Moradi formation and its flank. The mineralised envelopes are disseminated in the Anou-Mellé and Aoukaré units. Topographically, the syncline of the Moradi formation is strongly filled in by the Teloua 1 formation which in turn forms an anticline in the form of rocky escarpments at the surface **(Figures 3 and 8)**, in the same direction as the flank of the syncline. The slope of the gully of the Moradi formation is disrupted by a drop in position in section C3. This proves that this deformation structure played a role in the emplacement of the Anou-Mellé and Aoukaré units.

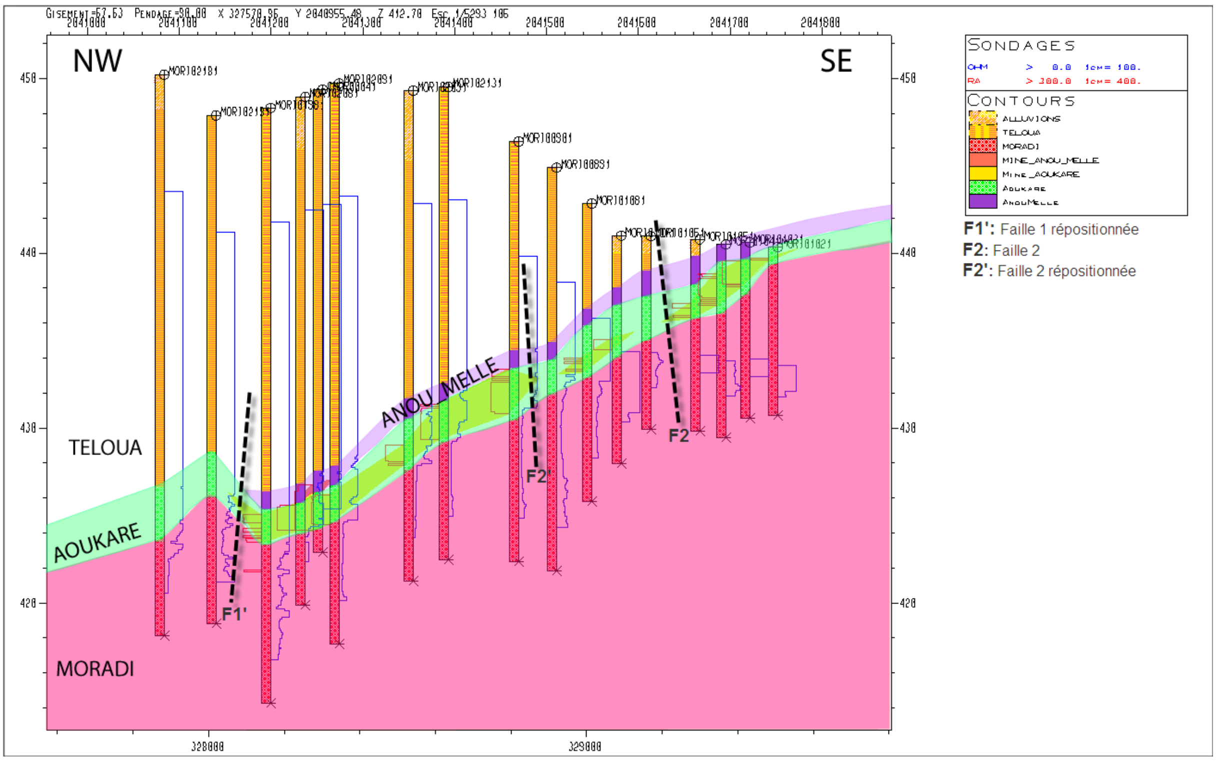

Figure 8: Section C3 (SW-NE)

V.3. Analysis and interpretation of maps
V.3.1. Analysis of isohypses maps
Analysis of the isohypsis map of the Anou-Mellé sequence

The Anou-Mellé isohypsis map **(Figure 9)** shows that the Anou-Mellé coastline is higher in the Eastern and South-eastern part of the area. These hills are marked by yellow and red colouring (from 439m to 456m). In the extreme East and South of the sector, the depths are shallow and vary between 0m and 4m. This is consistent with the observation made in the field where the Anou-Mellé is even outcropping in the North-eastern part. The central part is characterised by colourations ranging from green to light blue, which indicate a coastline of between 432m and 439m. The depths of the Anou-Mellé in this part range from 4m to 19m. This is the area that corresponds to the flank of the Moradi syncline. Finally, the maximum depths ranging from 19m to 30m correspond to the small values of Z_roof (422m and 431m) which are located in the SW of the Moradi sector. These low values are marked on the map by a dark blue colouring, more precisely at the level of the basin of the Moradi syncline.

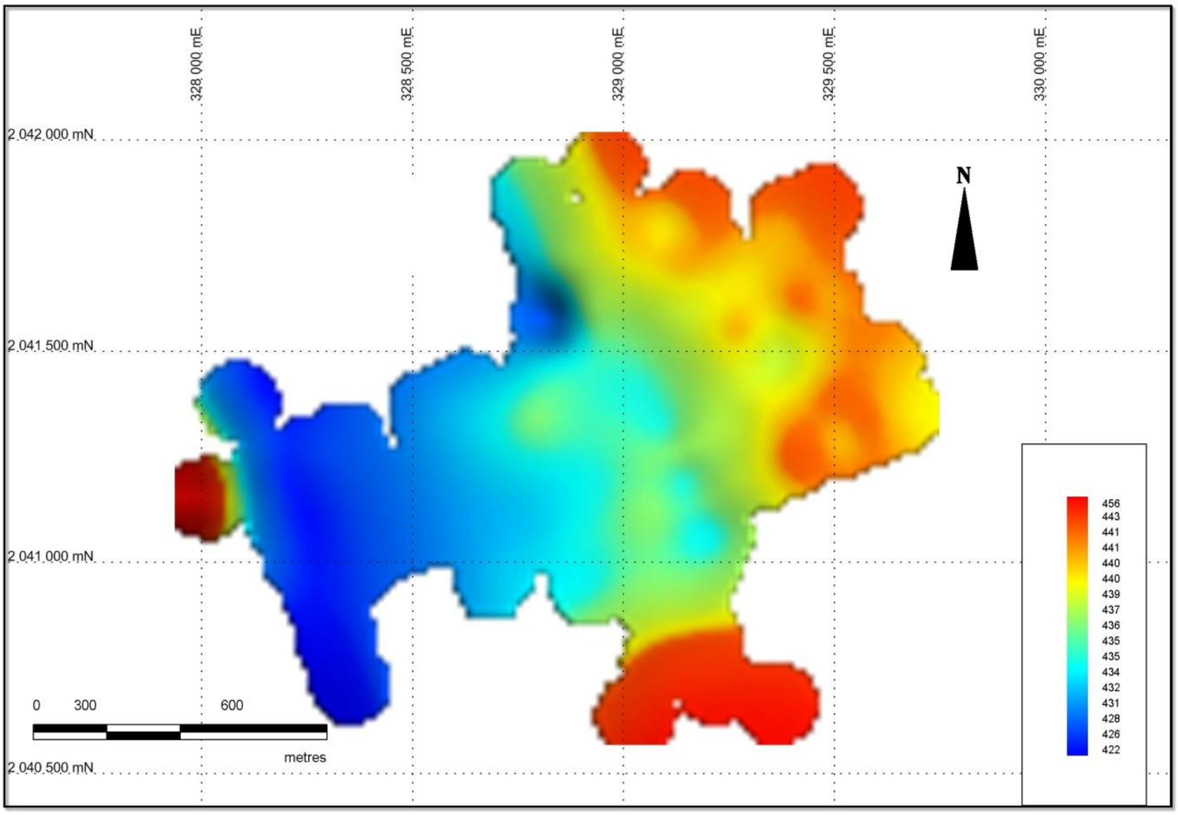

Figure 9: Isohypsis map of the Anou_Mellé sequence

Analysis of the isohypses map of the Aoukaré sandstone

The isohypsis map of Aoukaré **(Figure 10)** shows mainly three (3) zones: A high zone where the depths of Aoukaré hardly exceed 7m (which goes from yellow to red), it means that the slopes of the Aoukaré roof are high (from 434m to more than 446m). In the extreme east, the Aoukaré sandstone often outcrops on the surface. The second medium depth zone (between 7m and 20m) is located in the central part of the Moradi sector and is marked on the map by the green and light blue colours (altitudes 426m to 432m). This zone overlies the syncline of the Moradi formation. Finally, the third zone (in dark blue) has considerable depths (from 20m to 35m) and corresponds to the basin of the syncline of the Moradi formation; here the slopes (altitudes) of the Aoukaré roof are the lowest (between 418m and 425m).

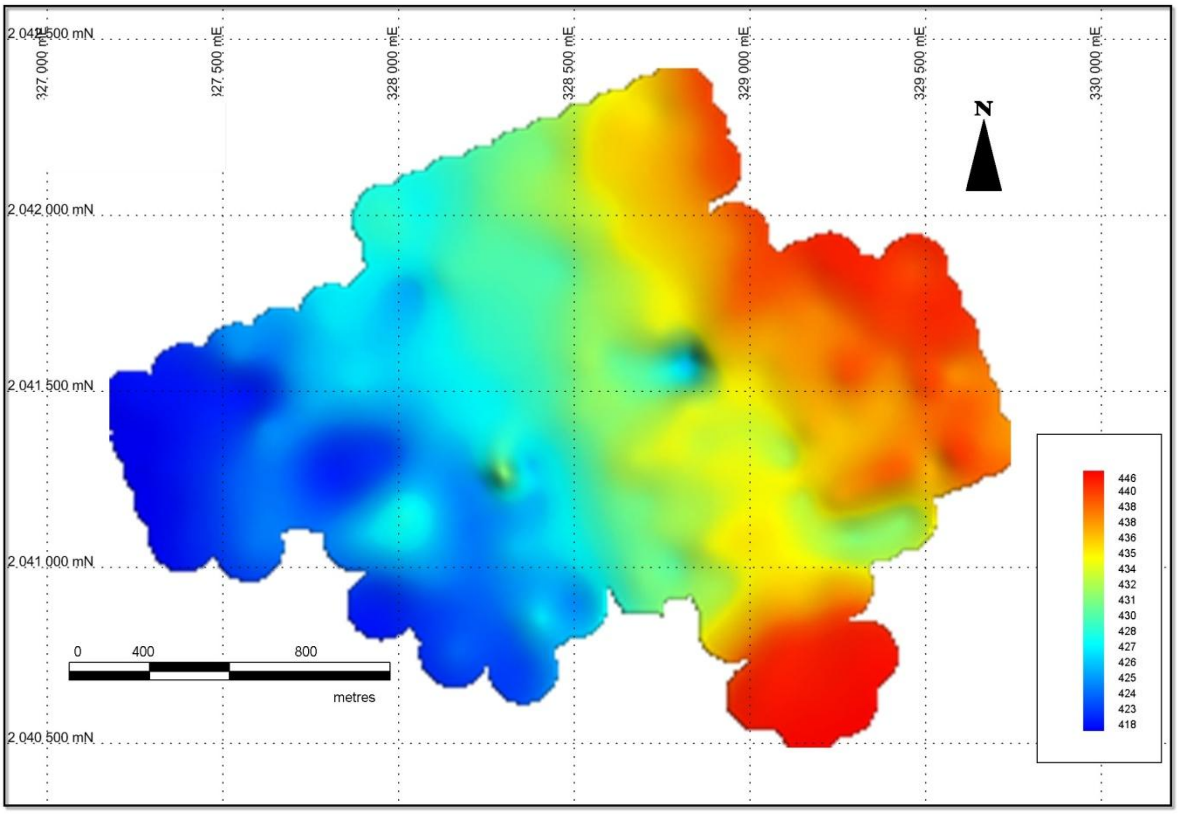

Figure 10: Isohypsis map of the Aoukaré sandstone

V.3.2. General morphology of the Moradi area

The 3D map of the Moradi area **(Figure 11)** is made by considering only the target formations crossed by the drill holes. This visualisation highlights the gullying of the Moradi formation along the SE-NW direction, the main basin of the syncline is located at the extreme NW. The Aoukaré sandstone deposit covers the whole area. In the extreme South-east, it outcrops on the surface. The Anou_Mellé conglomerate is located in the Northern part of the Moradi sector and outcrops at the surface in the extreme North-east. The Teloua 1 constitutes the main filling material of the area ; it's located in outcrop throughout the area. The relief is dominated by small elevations that form rocky escarpments, two anticlines and a syncline **(Figure 11)**.

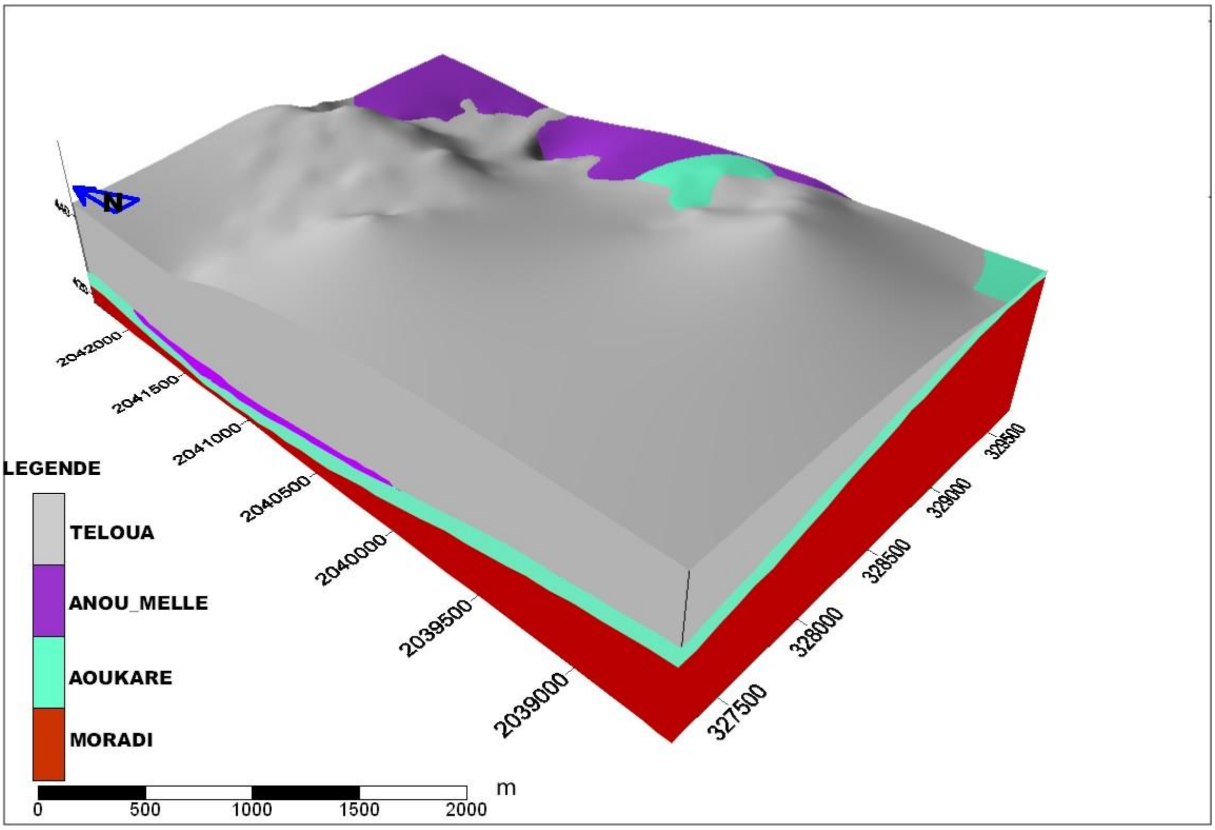

Figure 11: 3D map of the Moradi sector

VI. Conclusion

Knowledge of a mineralisation deposit requires a thorough understanding of the characteristics of the host formations. In the Moradi uranium sector, Tim Mersoï basin (Northern Niger), uranium mineralisation is disseminated in the Anou-Mellé and Aoukaré units. Drilling combined with lithological descriptions and logging have enabled the Anou-Mellé and Aoukaré units to be identified as mineralisation host sequences and their characteristics to be determined. The study revealed that the Anou-Mellé conglomerate is characterised by an assemblage of heterogeneous gravels and pebbles (rounded quartz), some of which have eolian wear facets, all welded together by an iron and phosphate cement. It has a thickness varying from 0m to 3.71m. The Aoukaré sandstones are fine, well consolidated by a siliceous cement, often hematous and locally kaolinous. They are often interspersed with clays, silts and conglomerates. This unit is between 1.58m and 5m thick. The depositional paleorelief of the Anou-Mellé and Aoukaré is characterised by an anticlinal and synclinal pattern established at the top of the Moradi formation. This paleorelief, sometimes influenced by syn-sedimentary deformation structures, has greatly influenced the emplacement and shape of these mineralisation host sequences which form an anticlinal and synclinal structure at the scale of the study area. Thus, these units outcrop to the East of the Moradi sector and show an increasingly steep slope towards the west (down to 35m depth).

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