

# The DASA Graben in Northern Niger: A Case of a Paleo-Mesozoic Basin Evolving from Uplifting to Rifting

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**Abstract:** The N70° DASA graben is a closed-rift that seems to be the deepest part of the Tim Mersoï Basin, which is located in the northwestern part of Niger in West Africa. It contains more than 805 m of Paleozoic-Mesozoic sediments. The tectonic subsidence and uplifting was calculated by using well log data and deducing the variations in sedimentary thicknesses over time. Geological mapping and tectono-sedimentary analysis indicate that the structural evolution of the DASA trough is characterized by two major periods: (1) the first period was marked by an uplift stage ranging from the Carboniferous to the Permian. It was typified by a weak subsidence rate (3.45 m/Ma on average), under a transpressive tectonic regime, with a decrease in the thickness of the sedimentary series along the axial zone of the trough, and an increase of the thickness towards the border areas; (2) the second period was characterized by a higher subsidence rate (4.11 m/Ma on average) related to a change in the tectonic regime. It was marked by a rifting stage preserved over a long period, subjected to an extensive tectonic regime, from the Triassic to the lower Cretaceous, during which the highest thicknesses of the sedimentary series developed in the axial zone of the graben. The structural and sedimentological features defined the DASA graben as a particular type of syn-sedimentary basin evolving from a transpressive tectonic regime during the Paleozoic to an extensive tectonic regime during the Lower Mesozoic. Thus, the second period marked by an extensional regime would probably be related to the opening of the first stages of the Atlantic Ocean.

**Key words:** DASA graben, tectono-sedimentary, uplift, rifting, polyphasic evolution, north Niger.

## 1. Introduction

The Paleo-Mesozoic Tim Mersoï Basin is located in the northeastern part of the Iullemmeden Basin and limited to the East by the Aïr Mountains (Fig. 1).

According to Ref. [1], the Tim Mersoï Basin infilling thickness is about 1,800 m. The detrital material was deposited during the period ranging from Devonian (410 Ma) to lower Cretaceous (96 Ma) [2]. This basin, located on a stable lithosphere, may provide a very good example of an intracratonic basin with a low average subsidence rate preserved over a long period [3, 4].

During several years, the Tim Mersoï Basin has been the subject of uranium exploration and exploitation campaigns. In recent campaigns of mineral exploration, the N70° trending graben of

DASA has been discovered about 120 km of the northern part of Agadez city (Figs. 2 and 3).

Logging data indicate that DASA graben sediment infilling is predominantly from Carboniferous (345 Ma) to lower Cretaceous (99 Ma) which implies a sedimentation duration of 246 Ma. The maximum thickness of the DASA graben deposits is estimated at 850 m, implying an average of subsidence rate of approximately 3.46 m/Ma. In the rest of the Tim Mersoï Basin, for the same period, the thickness of the deposits is estimated at 1,400 m [1-5]. Indeed, for the period ranging from the Carboniferous to the lower Cretaceous (246 Ma), the maximum thickness of the Tim Mersoï Basin deposits is approximately 1,400 m [6].

Therefore, for the same period, the mean subsidence rate of Tim Mersoï Basin is about 5.69 m/Ma. Thus, compared to the Tim Mersoï Basin, the DASA graben, which is its sub-basin, has paradoxically a

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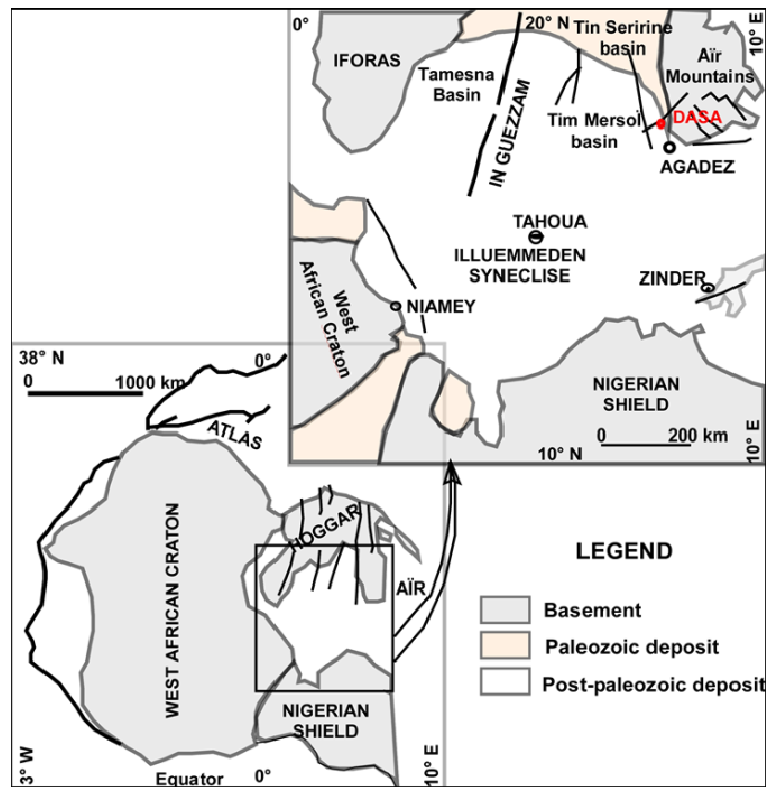


Fig. 1 Geographical location of the Tim Mersoï Basin in the Iullemmmeden syncline ([5], modified).

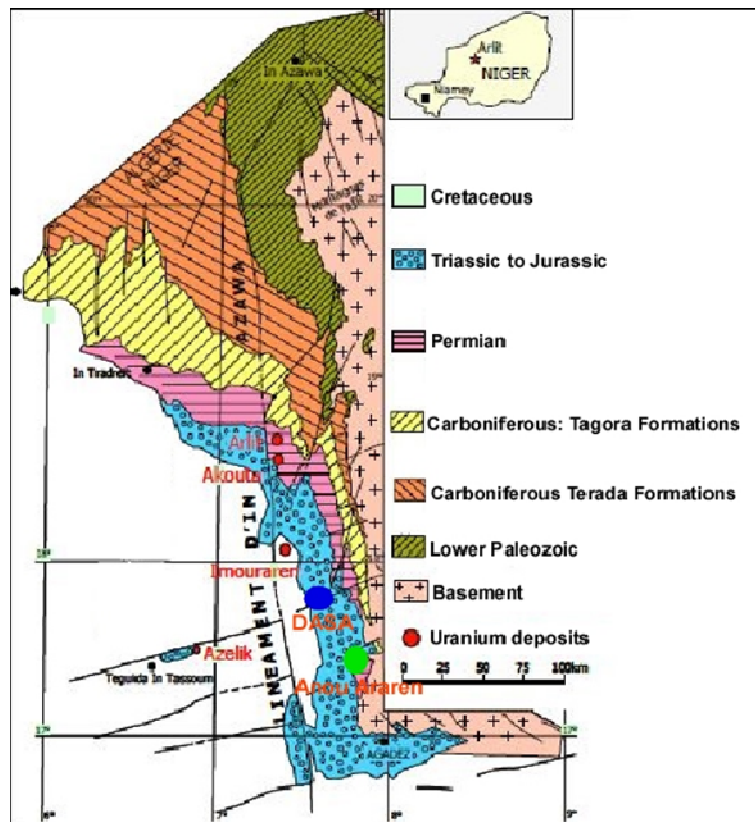
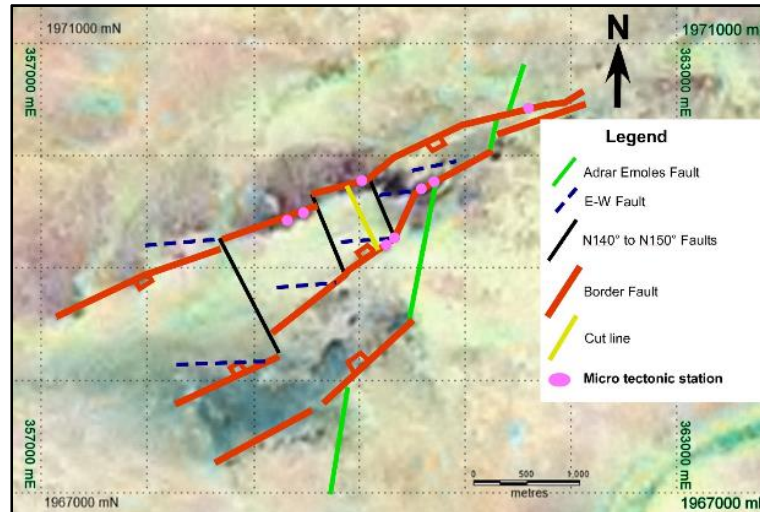


Fig. 2 Simplified geological map of the eastern part of the Tim Mersoï Basin (COGEMA, 2006, modified).



**Fig. 3** DASA graben.

lower subsidence rate. Theoretically, a strong subsidence rate in the graben should be expected, assuming the addition of additional tectonic sub-sidence related to the normal faulting. Hence over, the difference in the subsidence rate of the DASA graben raises questions about the mechanisms or factors about the causes at the origin off subsidence.

The purpose of this article is to provide an overview of the mechanisms or factors that explain the overall reduction of DASA graben collapse, while allowing the reconstruction of tectono-sedimentary history. Concerning the sedimentary infilling, emphasis is placed on the outcropping series, generally represented by lower Cretaceous formations in the graben, and particularly on the Jurassic age series along the edges of the graben. On the other hand, the basal series, Carboniferous to Triassic, do not outcrop. Then, the tectono-sedimentary study requires the use of appropriate methods to access subsurface information. To answer all these questions, we adopted a multidisciplinary approach by integrating geological mapping, borehole and well log data analysis and micro tectonic analysis. In a specific way it involves:

- a structural analysis that will allow characterizing Jurassic and Cretaceous tectonic events;
- a characterization of the syn-sedimentary tectonics markers;

- and to establish a geodynamic model for the DASA graben infilling.

## 2. Geological Setting

The Paleo-Mesozoic Tim Mersoï Basin geological history begins as early as the Cambrian in the Tin Séririne Syncline [7]. Subsequently, the sedimentation areas moved southward, resulting in the deposition of continental and marginal-littoral detrital formations ranging from Cambrian to Miocene (Fig. 3). Along the western edge of the Aïr, these detrital formations exhibit stratigraphic bevels (Fig. 2) from the Devonian to the Jurassic [8]. The Tim Mersoï Basin is characterized by a sedimentary infilling, resting unconformably on the ante-Cambrian basement (Figs. 2 and 3). The basin was infilled during three successive cycles including: Carboniferous cycle, Permo-Triassic to Jurassic one and lower Cretaceous.

The first sedimentary cycle is characterized by the continental shelf facies, directly delivered from the Northeastern (NE) from the Aïr while the second, also platform-dominated, received contributions from the South Southwestern (SSW).

The third cycle is represented by a clayey to sandy-clayey floodplain extending from the west to the center of the previous deposition area, which was gradually uprising in size [6-8].

According to Ref. [9], several deformations affect

the sedimentary infilling. These reflect the attenuation in the sedimentary deposits of the setback sets of the underlying basement. Three main directions of faults have been highlighted:

(a) The N0° trending Lineament of In-Azaoua-Arlit and the N30° trending fault system of Madaouéla. All of exploited uranium deposits are located on the eastern compartment of the Arlit Fault, but uranium deposits have also recently been discovered in the western compartment [4].

The Madaouéla N30° fault system: they express in the basement and in the sedimentary cover in the form of flexure. These accidents are spaced twenty kilometers apart. The most important are the Madaouéla (sector of Arlit) and Adrar-Emoles (sector of DASA) trending faults.

(b) The N130° to N140° trending faults represent the main fault system that affect the Aïr Mountain. In the sedimentary series, these directions are more or less expressed. The Arlit fault is associated with several N150° striking faults in the Arlit mining area [4].

(c) The N70° to N80° trending faults cut the basement intensively and also spread into the sedimentary deposits. The N70° trending faults are reactivated in dextral strike-slip movement during the upper Cretaceous [10]. At the regional scale, the N70° trending faults network plays a fault-damping role on the N30° faults [3].

The DASA graben which means “Dajj Surface Anomaly” is located within the Adrar Emoles 3, claim block in the eastern part of the Azélik dome. Adrar Emoles 3 covers an area of 121.3 km<sup>2</sup>. It is located between latitudes 7°40'00" N and 7°53'00" N and longitudes 17°51'14" E and 17°45'30" E. From a stratigraphic point of view, all known sedimentary series in the Tim Mersoï Basin are represented in DASA area as well. These are Carboniferous, Permian, Triassic, Jurassic and Cretaceous series (Fig. 4).

The main faults observed in the DASA graben are Azouza fault which marked the border of the trough, Adrar-Emoles N30° striking fault, and secondary

faults N130° to N150° trending and E-W striking (Fig. 4). The DASA graben has the same orientation than the Carboniferous coal trough of the AnouAraren region (Fig. 2).

These coal troughs are limited by two major N70° trending dextral strike-slip faults. These are the Isokenwali fault in the northern part and the Aboye one in the southern part. These two faults belong to the same system as the Tin Adrar N70° striking fault system, which is well represented in the Arlit region [11]. Most of works carried out in the Tim Mersoï Basin so far have focused on the tectono-sedimentary evolution of the basin and the uranium metallogeny [1, 4-6, 12-15].

The troughs formed in this Tim Mersoï Basin have been very few studied [11-16].

### 3. Methodological Approach

A multidisciplinary approach has been implemented in this study. It is based on:

(1) Geological mapping of the DASA sector is based on the combined use of satellite imagery and field observations. Ten sections were made along the axis of the DASA graben and seven other sections are disposed perpendicular to the axis of the graben. The use of the MapInfo software enabled to correlate the data collected, resulting in the geo-logical map of the DASA sector.

(2) Tectono-sedimentary analysis is based on cores drilling, cross sections and well log data analysis. In the DASA area more than 1,000 boreholes were carried out. We have used some of these borehole data to perform a model of the structural evolution of the DASA graben. Thus, the cross-sections disposed perpendicularly to the DASA graben axis allow observing its tectono-sedimentary evolution during the main period of infilling (Carboniferous, Permian, Triassic, Jurassic and Early Cretaceous).

(3) To conduct the microtectonic analysis we have chosen on the satellite imagery the stations were outcrops well preserved. Thus, ten (10) stations were

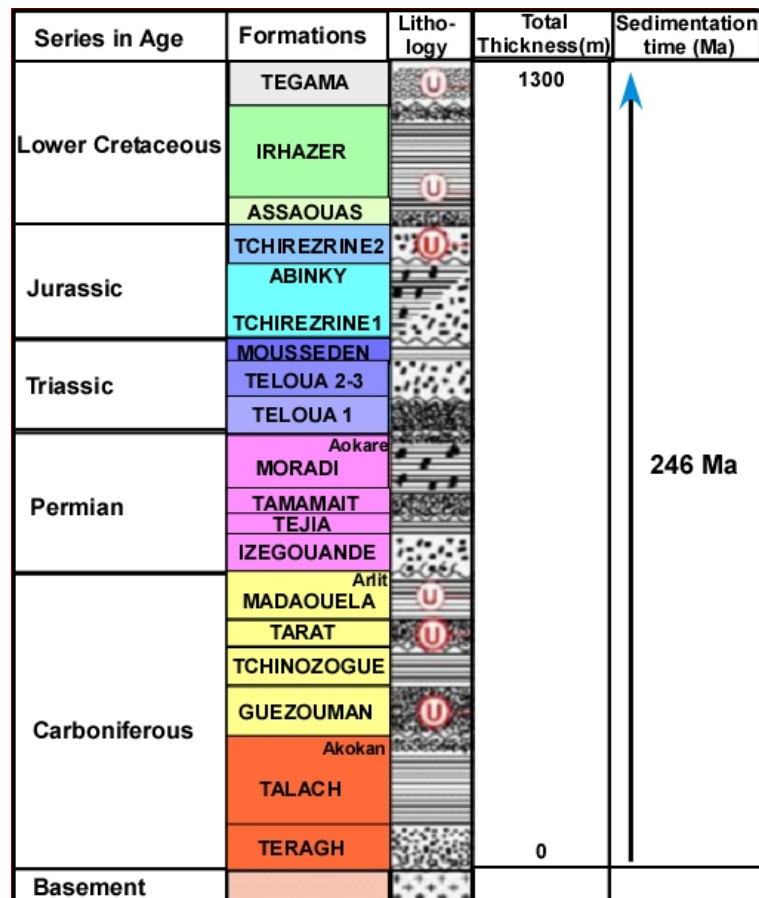


Fig. 4 Simplified stratigraphic log of the geological series of the Tim Mersoï Basin ([3], modified), mean subsidence = 5.69 m/Ma.

chosen along the edge of the DASA graben. Each microtectonic station is characterized by a population of microfaults including 10 to 15 measurements. Nearly 136 striated microfault planes were analyzed. For each striated microfault plane measured, the following characteristics were collected:

- direction (0-180°) and dip (0-90°) of the microfault planes;
- pitch of the striae (0-90°) and its plunging area (0-180°);
- direction of displacement of the microfault plane (N for normal, I for inverse, D for dextral and S for sinistral);
- reference number for each striated plane measured.

Thus, the measurements obtained make it possible to establish a data file according to the model of Table 1.

The different populations of microfault planes were analyzed by using Win tensor (Win tensor 5.9.8) [17].

## 4. Results

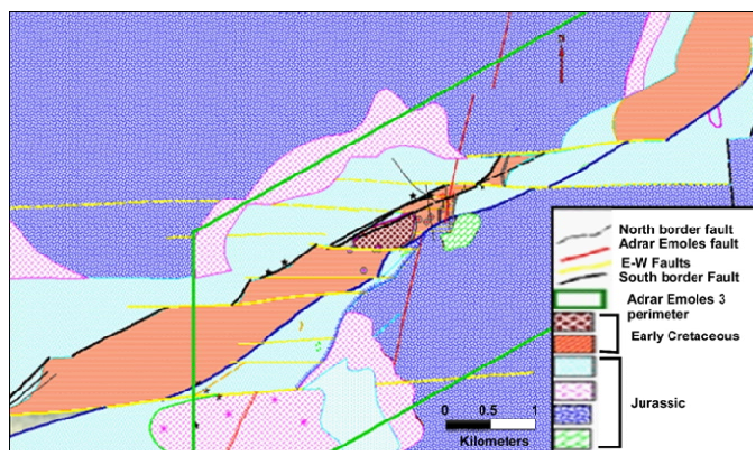
### 4.1 Geological Mapping

Most of the previous mapping in the Tim Mersoï Basin has been restricted to the Arlit area, which was of special uranium mining interest. In the areas previously considered to be of lower uranium potential, such as the DASA sector, no detailed tectono-sedimentary analysis has been conducted so far. In the DASA area, the only maps available are those of Ref. [18] at a scale of 1:500,000e and Ref. [19] at a scale of 1:50,000e. These maps present uncorrelated information; for example, the same facies have been mapped and interpreted differently according to the different authors. These observations



**Table 1** Example of microtectonic data file.

Microfault plan of station No. 2		Dip	Striae pitch	Movement
No.	Direction			
1	70°	46° N	75° N	Normal
2	70°	52° N	65° N	Normal
3	73°	55° N	75° N	Normal
4	75°	45° N	72° N	Normal
5	68°	55° N	70° N	Normal
6	75°	47° N	65° N	Normal
7	76°	40° N	50° N	Normal
8	88°	74° N	55° N	Normal
9	90°	75° N	50° N	Normal
10	72°	55° N	45° N	Normal
11	76°	48° N	60° N	Normal
12	78°	25° N	55° N	Normal
13	74°	20° N	55° N	Normal

**Fig. 5** Geological map of DASA sector.

were also applied to the identification and the interpretation of brittle structures and for the determination of their kinematics. To overcome this lack of concordance, map data were supplemented by the field data. This approach made it possible to update the geological map of the DASA area at a scale of 1:50,000e (Fig. 5).

The mapped area extends over a length of 10 km and a width of 3 km. Seventeen cross-sections were made. Seven of them are parallel to the N70° axis of the graben, and the ten others perpendicularly to its axis. The outcropping sedimentary formations at the DASA sector range from the Permian to the lower Cretaceous. These are the formations of Moradi, Téloua, Mousseden, Tchirezrine 1, Abinky,

Tchirezrine 2, Irhazer and Tégama (Fig. 5). The DASA graben is affected by two major faults, the N70° trending Azouza fault and the N30° Adrar Emoles fault (Figs. 3, 5 and 7).

#### 4.2 Tectono-Sedimentary Analysis

To better understand the DASA graben structuration, synthetic cross-sections from well logs correlation (Figs. 3 and 6) were constructed.

This approach allowed showing the lateral and vertical succession of the different facies and to specify the relationships between tectonics and sedimentation (Fig. 6). The geological section obtained shows that in the axial zone of the DASA graben, the maximum thickness of the sediment is

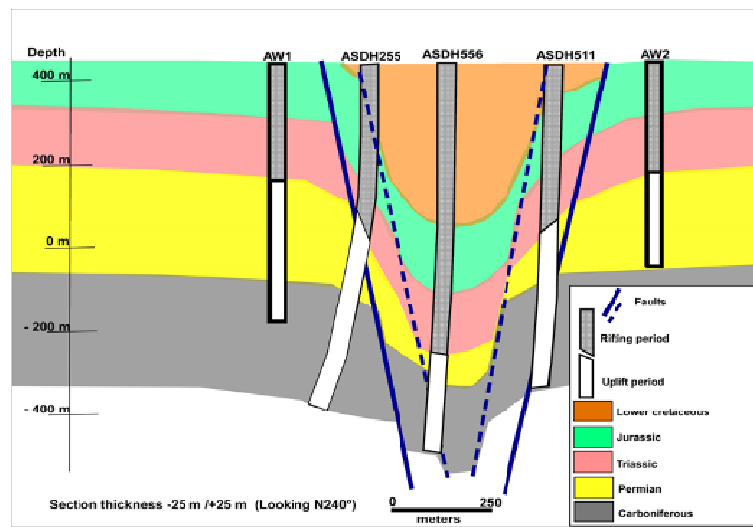


Fig. 6 Geological section of the DASA graben made from survey data.

Table 2 Thickness of sedimentary series at level of DASA graben.

Sedimentary series	NW area (AW2 and ASDH511) in m	Centrale area (survey ASDH556) in m	SE area (ASDH255 and AW1) in m
Lower Cretaceous	76	300	54
Jurassic	160	180	154
Triassic	112	145	126
Permian	215	30	188
Carboniferous	206	150	190
Total thickness	786	805	698

about 805 m, over a sedimentation period of 250 Ma. This implies a lower mean subsidence (3.22 m/Ma) (Fig. 6) compared to the Tim Mersoï Basin for which the average subsidence is in the order of 5.3 m/Ma (Fig. 4). Most sedimentary series of the DASA graben exhibit variations in thickness on both sides of the border faults (Fig. 6). However, these variations in thickness are more or less marked according to the stratigraphic series (Table 2).

The sedimentary infilling of the DASA graben is characterized by two periods of sub-sidence:

- A first period with a lower subsidence rate (3.75 m/Ma on average), which extends from the Carboniferous to the Permian. The Permian series are particularly characterized by large reduction in thickness in the axial zone of the trough (30 m), compared to the edge zones (188-215 m) (Fig. 6).
- A second period marked by a strong subsidence rate (4.11 m/Ma) from the Triassic to the lower

Cretaceous (Fig. 6). The strongest subsidence rate occurred during the lower Cretaceous in the axial zone (6.52 m/Ma) while in the border zones the subsidence rate is very low (1.17 to 1.65 m/Ma) (Fig. 6).

These lateral variations of subsidence and thickness highlight a syn-sedimentary tectonic activity preserved over a long period of time from the Carboniferous to the lower Cretaceous. The subsidence inversions between the axial zone of the DASA graben and the edge zones reflect a morphological inversion related to a change in the tectonic regime.

During the first period from the Carboniferous to the Permian, the axial zone of the DASA graben was affected by an uplift stage. The latter induced a reduced thickness of the Carboniferous and Permian series in the axial zone of the graben, in connection with a reduction of the available space. The axial zone of the trough would then correspond to a paleo-high

with respect to the collapsed border areas. This paleo high would have prevailed from the Carboniferous to the Permian.

During the second period, from the Triassic to the lower Cretaceous, the largest thickness of the deposits is observed in the axial zone of the trough while the thicknesses are lower within the border zones.

The DASA graben would have acquired its “actual” geometry preserved from the Triassic to the lower Cretaceous. Three successive episodes of rifting marked this second period:

- A first episode of rifting during the Triassic, favorizing an increase in the available space in the axial zone. This is explained by a stronger thickening of the Triassic series in the axial zone (145 m) compared to the border zones (112-126 m) (Fig. 6).
- A second episode of Jurassic rifting. This rifting episode presents the same characteristics as the latter one. Highest thicknesses (180 m) are observed in the DASA graben, whereas the border zones display a reduced thickness (154-160 m).
- The third episode of rifting, corresponding to the lower Cretaceous, is marked by a considerable thickness in the axial zone (approximately 300 m) compared to the border zones (54-76 m) (Fig. 6). The lower Cretaceous appears to be the highest subsidence episode at the DASA graben scale, indicating strong tectonic activity.

The succession of uplifting and rifting periods confirms the change in the tectonic regime mentioned earlier. This inversion occurs at the Permian/Triassic boundary.

#### 4.3 Synlithification Microfaults Analysis

In the DASA graben, Paleo-Mesozoic sedimentary deposits are affected by normal microfaults. These determine a microhorst and micro-graben structure (Fig. 7).

Locally, the mirrors of these microfaults have mostly fluted or curved striations (Fig. 8, location St2 and St3 in Fig. 10).

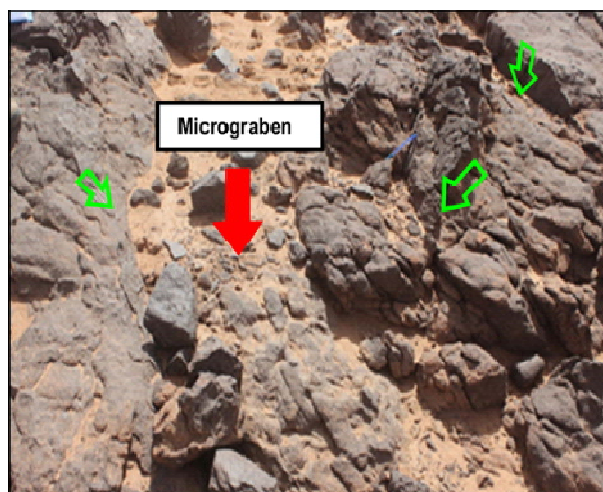


Fig. 7 Secondary micrograben affecting Jurassic sediments in the DASA graben.

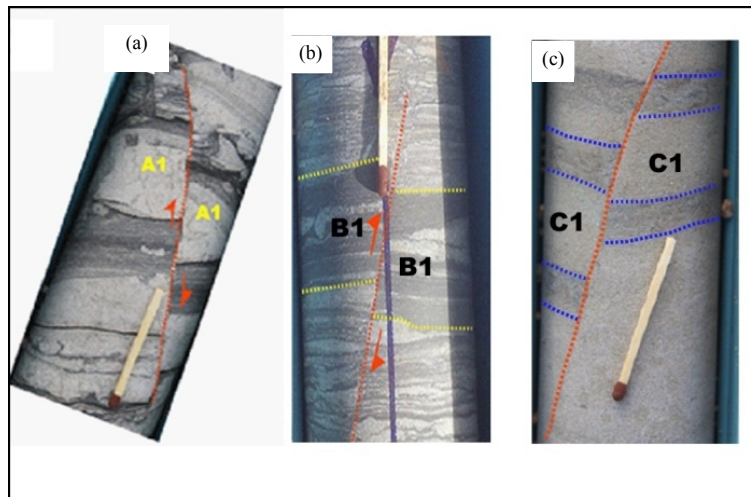


Fig. 8 Normal microfault plane with fluted striae, the lunules indicate that it is a normal fault.

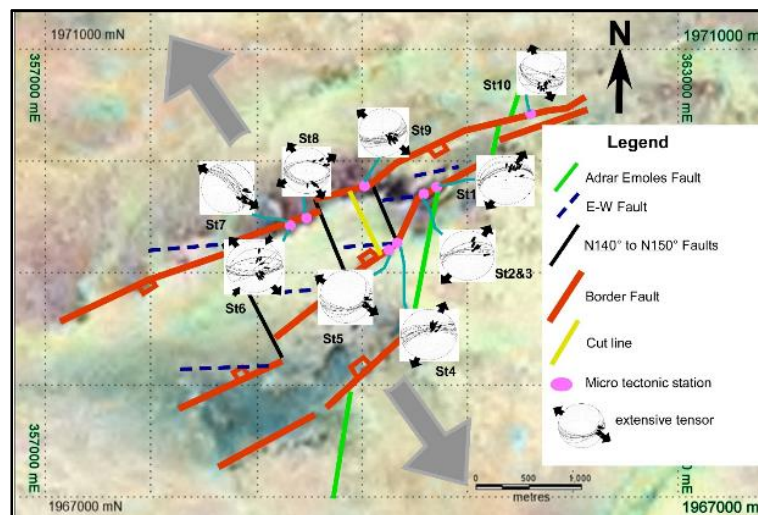
The normal microfaults N70° and N90° are sometimes shifted into sinistral by N140° strike-slip microfaults. The thickness and facies variations on both sides of these microfaults show their synsedimentary character. Figs. 9a and 9b reveal a synsedimentary reverse microfaults affecting carboniferous deposits while Fig. 9c displays synsedimentary normal microfaults affecting the Jurassic deposits.

The only outcropping deposits on the border of the DASA graben are Jurassic. The lower Cretaceous deposits, composed mainly of the Irhazer shales are not observable in outcrop. The synlithification microfaults observed on the outcrops give indications





**Fig. 9** Drill cores showing thickness variations on both sides of the fault planes: (a) and (b) in the Carboniferous formation of Tarat and (c) in the Jurassic formation of Tchi 2.



**Fig. 10** Map of distribution of stress tensors related to the Jurassic-Cretaceous tectonic phase and average direction of extension.

of the episode of synchronous deformation of the Jurassic deposits that were affected after their establishment by a second post-lithification deformation phase. The generated structures include abrasion or cataclase features (Riedel fractures, secondary synthetic fracture, spoon-shaped depression) and syn-kinematic recrystallizations of silica.

The tectono-sedimentary analysis of the lower Cretaceous infilling was derived from borehole and well log data. Microtectonic analysis was carried out onto the brittle faulting zone or semi-ductile deformation areas, which are bordering the trough and were the tectonic structures, are best preserved.

Microtectonic analysis is based on ten stations (St1 to St10) of microfault populations distributed across the Jurassic terrains. About 136 brittles to synlithification microfaults were considered (Fig. 10).

Beside the outcrop, the syn-lithification microfaults can be recognized by the following characters:

- The microfault planes have the same color as the sediment patina (Fig. 8);
- The striae are linear or curved (Fig. 8);
- The faults planes are generally curved (Fig. 8).

The post lithification deformations that affected the trough after lower Cretaceous period were not taken into account.

#### 4.4 Jurassic Synlithification Paleostress

To study the dynamics of synlithifications microfaults, the different populations of microfault planes were projected onto Win tensor program (Win tensor 5.9.8) [17]. Automatic processing result of different striaes from populations of microfaults of the stations No. 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 shows evidence of extensional paleostress tensors (Fig. 10).

The obtained extensional paleostress tensors were plotted onto the map of the DASA area. Each tensor is represented by a pellet characterized by the number of the station reference and the direction of the minimum stress  $\sigma_3$  (Fig. 10).

At the scale of the DASA graben, the processing of the different populations of pre-lithification microfaults made it possible to distinguish three types of extensive paleotensors:

- Extensive paleotensors with  $\sigma_3$  varying from N130° to N170° (St6, 7 and 10, Fig. 10);
- Extensive paleotensors with  $\sigma_3$  varying from N30° to N70° (St2, 3, and 9, Fig. 10);
- Radial extensive paleotensors (St8, Fig. 10).

The paleostress distribution map shows a large variation in the direction of the minimum stress  $\sigma_3$  (Fig. 10). During the Jurassic period, the study area underwent a ~N160° extensional phase which was responsible for the opening of the DASA graben.

## 5. Discussion

The tectono-sedimentary evolution of the DASA graben is the result of the interaction between an uplift phase (from the Carboniferous to the Permian) and a rifting phase (from the Triassic to the lower Cretaceous). The uplift period highlighted in the DASA graben shows that at least one compression period affected the region during the Late Paleozoic. The rifting phases, which occurred from the Triassic to the lower Cretaceous, imply that the region was subjected to a period of distension (Figs. 11 and 12).

To explain the succession of these two phases of structuring (uplift/rifting) over the time, the results of

this study were compared to those realized in other African basins, such as Tim Mersoï, Téfidet (North Niger), Benue trough (Nigeria) and Muglad Basin (Sudan).

According to the bibliographic data, a N40° Visean compression phase has been highlighted in Algeria in the area of Ougarta by Blès [20], in the Béchar Basin by Conrad and Lemosquet [21], in the Illizi Basin by Boudjema [22] and in the Ahnet Basin by Zazoun [23]. In the Tim Mersoï Basin too, a N25° horizontal shortening, upper Visean in age was highlighted by Konaté [5]. During this Visean episode of shortening, the N70° trending Tin Adrar fault system was reactivated as a strike-slip fault.

The uplift observed in the DASA graben, during the upper Paleozoic, indicates that the strike-slip sinistral reactivation of the N70° trending faults has a reverse component. At that time, a transpressive tectonic regime would have affected the DASA graben. This could explain the fact that the thicknesses of the upper Paleozoic series are thinner in the axial zone and corresponded to a paleo-high with respect to the bordering zones, which had collapsed and showed higher thicknesses. The DASA graben shows a relatively low sedimentation rate in the axial zone (1.67 m/Ma), compared to the border zones (3.65 to 3.75 m/Ma) during the upper Paleozoic period. These observations are in agreement with the prevailing uplift episode.

The second structuring period of the DASA graben is marked by a change in the tectonic regime (Figs. 11 and 12). This is characterized by a rifting phase preserved over a long period from the Triassic to the lower Cretaceous.

The structural evolution of the DASA graben during the Jurassic-Cretaceous period was compared to those of the West and Central African Rift Systems, commonly referred to as WCARS. During the lower Cretaceous, these rift systems were affected by extensive to transtensive tectonics regime [24, 25], favoring a strong subsidence (54 m/Ma for the Termit

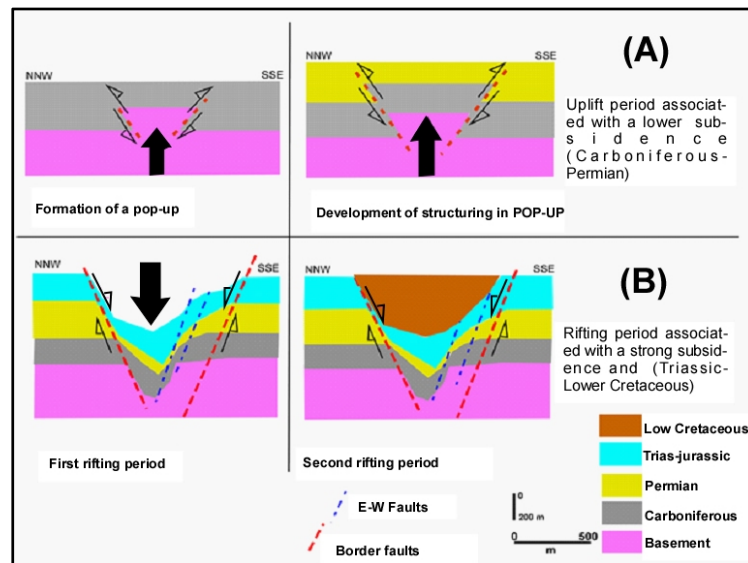


Fig. 11 DASA graben model evolution at Carboniferous to lower Cretaceous.

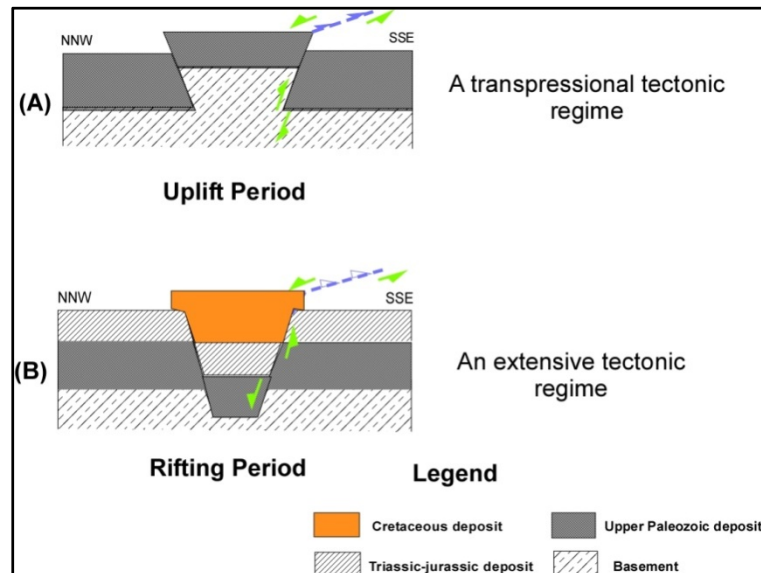


Fig. 12 Geodynamic evolution of the DASA graben showing an inversion of the tectonic regime: (a) uplifting period and (b) rifting period.

Basin [26], 65 m/Ma for the Muglad Basin [27], 43 m/Ma for the Benue trough [28] and 13 m/Ma for the Téfidet trough [16]).

Unlike those Cretaceous rift systems, the DASA graben has a lower subsidence rate (6.52 m/Ma). Given the geodynamic context during the Cretaceous, these extensional tectonics regimes affecting the DASA graben could be associated to the opening of the South Atlantic occurring during that period [25, 29, 30].

The structural evolution of the DASA graben is marked by a tectonics inversion (Figs. 11 and 12).

## 6. Conclusions

This study has integrated several types of data (field, cartography, well log, microtectonics, tectono-sedimentary) and shows that the evolution of the DASA graben is closely related to the polyphase kinematics of the N70° border faults. The sedimentological and structural characteristics of the

DASA graben (e.g., non-homogeneity of the main stresses, stratigraphic gaps, and mismatch in the vertical facies sequence) characterize a particular type of basin evolving from a Paleozoic transpressive regime to an extensive Mesozoic regime (Fig. 12).

The strong subsidence observed within the lower Cretaceous in the DASA graben could be related to the initial stages of opening of the Atlantic.

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## References

- [1] Yahaya, M. 1992. "Dynamique sédimentaire du Guézouman et des formations viséennes sous-jacentes en liaison avec la tectonique, le volcanisme et le climat, paléomilieus des gîtes uranifères d'Arlit (Niger)." Thèse Doctorat troisième cycle, Université de Dijon.
- [2] Billon, S. 2014. "Minéraux argileux dans le gisement uranifère d'Imouraren (Bassin de Tim Mersoï, Niger): implications sur la genèse du gisement et sur l'optimisation des processus de traitement du minerai." Université de Poitiers. <http://theses.univ-poitiers.fr>.
- [3] Gerbeaud, O. 2006. "Evolution structurale du Bassin de Tim Mersoï: Déformations de la cou-verture sédimentaire, Relations avec la localisation des gisements d'uranium du secteur d'Arlit (Niger)." Thèse de doctorat, Université de Paris-Sud.
- [4] Mamane, M. 2016. "Le système métallogénique des gisements d'uranium associés à la faille d'Arlit (Bassin de Tim Mersoï, Niger): diagenèse, circulations des fluides et mécanismes d'enrichissement en métaux (U, Cu, V)." Thèse de doctorat, Université de Lorraine.
- [5] Konaté, M., et al. 2007. "Structuration extensive au devono-dinantien du bassin de Tim Mersoï (Bordure occidentale de l'Aïr, Nord Niger)." Université de Ouagadougou.
- [6] Forbes, P. 1989. "Rôles des structures sédimentaires et tectoniques, du volcanisme alcalin régional et des fluides dia génétiques-hydrothermaux pour la formation des minéralisations A U-Zr-Zn-V-MO d'Akouta (Niger)." Thèse du CREGU, Nancy.
- [7] Joulia, F. 1963. *Carte géologique de reconnaissance de la bordure sédimentaire occidentale de l'Aïr au 1/500000*. Orléans, France: Éditions du BRGM.
- [8] Clermonté, J., et al. 1991. "Un bassin paléozoïque et mésozoïque dans une zone en décrochement: le Tim Mersoï dans la région d'Arlit, à l'Ouest de l'Aïr (Niger)." *C. R. Acad. Sc. Fr.* 312 (10): 1189-95.
- [9] Tauzin, P. 1981. *Cadre géologique des gisements d'uranium de la bordure orientale du bassin sédimentaire du Tim Mersoï*. Rapport interne Minatome, p. 15.
- [10] Guiraud, R., Boureïma, O., and Robert, J. P. 1981. "Mise en évidence de déformations traduisant un raccourcissement dans le Mésozoïque de la périphérie de l'Aïr (Niger)." *Comptes-Rendus Académie des Sciences* 292: 753-6.
- [11] Wright, L. I., Branchet, M., and Alisso, I. 1993. "Notice explicative de la carte géologique du bassin houillier d'AnouAraren/Solomi." Ministère des Mines et de l'Énergie, Niger.
- [12] Valsardieu, C. 1971. "Etude géologique et paléogéographique du bassin de Tim Mersoï: région d'Agadès (République du Niger)." Thèse de doctorat, Université de Nice.
- [13] Sempéré, T. 1981. "Le contexte sédimentaire du gisement d'uranium d'Arlit (République du Niger)." Thèse de l'école nationale supérieure des sciences de Paris.
- [14] Elhamet, M. O. 1983. "Analyse géologique et pétrographique de la formation de Tarat dans les carrières Somaïr (Paléozoïque supérieur). Essai d'interprétation paléoclimatique à la lumière de l'épisode glaciaire dévono-carbonifère (Région d'Arlit-Niger septentrional)." PhD thesis, Université de Dijon (France) et Université de Niamey (Niger), p. 279.
- [15] Wagani, I. 2007. "Potentialités uranifères des sources volcaniques envisageables pour la formation des minéralisations de la région d'Arlit (Niger)." Université de Paris Sud.
- [16] Konaté, M., et al. 2019. "Structural Evolution of the Téfédet Trough (East Aïr, Niger) in Relation with the West African Cretaceous and Paleogene Rifting and Compression Episodes." *Comptes Rendus Geoscience* 351 (5): 355-65. <https://doi.org/10.1016/j.crte.2018.11.009>.
- [17] Damien, D., and Sperner, B. 2003. "New Aspects of Tectonic Stress Inversion with Reference to the TENSOR Program." The Geological Society of London, 75-100.
- [18] Joulia, F. 1959. "Les séries primaires au N et au NW de l'Aïr (Sahara-Central); Discordances observées." *Bull. Soc. Géol. Fr.* (2): 192-6.
- [19] PNC. 1987. *Rapport de fin de campagne exploration*.
- [20] Blès, J. L. 1969. "Les relations des microfractures avec le plissement dans la région du Djebel Ben Tadjineet au 'km 30' (Chaînes d'Ougarta-Sahara occidental, Algérie)."

- Publication Service Géologique Algérie* 39: 193-204.
- [21] Conrad, J., and Lemosquet, Y. 1984. "Du cratonverssa marge: evolution sédimentaire et structurale du bassin Ahnet-Timimoun-Béchar (Sahara algérien) au cours du Carbonifère. Données paléo-climatiques." *Bulletin Société Géologique France* 26 (6): 987-94.
- [22] Boudjema, A. 1987. "Évolution structurale du bassin pétrolier 'triasique' du Sahara Nord Ori-ental (Algérie)." Thèse Doctorat Etat, Paris XI-Orsay, France.
- [23] Zazoun, R. S. 2001. "La tectogenèsehercynienne dans la partie occidentale du bassin de l'Ahnetet la région de Bled El-Mass, Sahara algérien: un continuum de déformation." *Journal of African Earth Science* 32 (4): 869-87.
- [24] Liu, B., et al. 2015. "Hydrocarbon Potential of Upper Cretaceous Marine Source Rocks in the Termit Basin, Niger." *Journal of Petroleum Geology* 38 (2): 157-76.
- [25] Ye, J. 2016. "Evolution Topographique, Tectonique et Sédimentaire Syn-à Post-rift de la Marge Transformante Ouest Africaine." Université Toulouse 3 Paul Sabatier.
- [26] Guiraud, M. 1993. "Late Jurassic Rifting-Early Cretaceous Rifting and Late Cretaceous Transpressional Inversion in the Upper Benue (NE Nigeria)." *Bull. Soc. ElfAquitaine Prod.* 17 (2): 371-83.
- [27] Yassin, M., et al. 2017. "Evolution History of Transtensional Pull-Apart, Oblique Rift Basin and Its Implication on Hydrocarbon Exploration: A Case Study from Sufyan Sub-basin, Muglad Basin, Sudan." *Marine and Petroleum Geology* 79: 282-99.
- [28] Guiraud, R., and Maurin, J. C. 1992. "Early Cretaceous Rifts of Western and Central Africa: An Overview." *Tectonophysics* 213: 153-68.
- [29] Genik, G. J. 1992. "Regional Framework, Structural and Petroleum Aspects of Rift Basins in Niger, Chad and the Central African Republic (C.A.R.)." *Tectonophysics* 213: 169-85.
- [30] Guiraud, R., et al. 2005. "Phanerozoic Geological Evolution of Northern and Central Africa: An Overview." *J. Afr. Earth Sci.* 43: 83-143. <https://doi.org/10.1016/j.jafrearsci.2005.07.017>.