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A Study of the Tectonic Evolution of the Agadem Block, Termit Basin, Southeastern Niger

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Abstract

The Agadem block, located in the southeastern Niger portion of the Termit Basin, represents a key segment of the West and Central African Rift System (WCARS). This study, based on seismic data interpretation, aimed to reconstruct the tectonosedimentary evolution of the block from the Early Cretaceous to the Cenozoic, and to constrain the spatial variability of its structural architecture. Interpretation of four 2D seismic transects distributed from north to south across the block, from the northern Soudana uplift to the southern Yogou fault zone, reveals a polyphase rift evolution characterized by two major extensional episodes (Early Cretaceous and Paleogene), separated by a Late Cretaceous subsidence phase marked by marine transgressions. Our results show that the basin geometry varies significantly along strike: a symmetric graben bounded by two major listric faults dominates the northern part, whereas a strongly asymmetric half-graben controlled by a western master fault characterizes the central and southern sectors. The Paleogene reactivation generated dense secondary fault networks (Y- and X-shaped configurations), with evidence of local compressional inversion expressed by reverse faults and flower structures. These observations may indicate a change in the extension direction from west-east to oblique, with a possible transtensional strike-slip component that could have enhanced structural heterogeneity; this is presented as a working hypothesis, since 2D sections alone cannot demonstrate strike-slip kinematics. Faults connect Upper Cretaceous Yogou source rocks to Paleogene Sokor-1 reservoirs, and some extend into the Neogene-Quaternary section; their sealing or leaking behavior remains to be tested through fault-seal analysis. This study provides a revised tectonostratigraphic framework for the Termit Basin, suggesting that inherited Pan-African basement anisotropies, multiphase reactivation, and along-

strike strain partitioning collectively control the complex rift architecture. These findings may have implications for exploration strategies in underexplored deep Cretaceous plays and may serve as a reference for analogous rift basins within the WCARS.

Keywords

Termit Basin, Agadem Block, Polyphased Rift, Tectonosedimentary Evolution, Structural, WCARS, Petroleum System

1. Introduction

Intracontinental rift basins represent major study objects in geosciences, characterized by a complex tectonosedimentary history often governed by polyphase rifting and deep structural inheritance (Nottvedt, Gabrielsen, & Steel, 1995; Henstra et al., 2016; Strugale & Cartwright, 2022). The architecture of these basins, defined by large-scale structural components and associated sedimentary systems, results from a close interaction between fault evolution, subsidence, and sediment supply (Withjack et al., 2002). In West Africa, the eastern Niger rift system, and more particularly the Termit Basin, constitutes an exceptional natural laboratory for understanding the interaction between extensional dynamics, fault geometry, and sedimentary filling. This basin, recognized as a superimposed rift basin, has recorded several phases of extension separated by periods of relative relaxation, making it an ideal example to study the influence of structural inheritance on sedimentary cycles and the petroleum system (Zhou et al., 2017; Yuan, Lirong, & Wenzhu, 2023). Within this system, the Agadem block holds scientific and economic importance (Fu & Sun, 2012).

The Termit Basin experienced two successive phases of rifting: in the Early Cretaceous and Paleogene, which generated two systems of faults with NE-SW and NNE-SSE directions (Liu et al., 2019). The Agadem block, which covers the central and southern part of the Termit Basin, has been the subject of intensive exploration by the China National Petroleum Corporation (CNPC) since 2003, leading to the discovery of several major oil fields.

However, despite numerous exploration phases, the spatiotemporal evolution of the structural architecture of the Agadem block remains complex to fully understand. The longitudinal (North-South) geometric variations materialized by the transition from symmetric graben structures to asymmetrical half-graben geometries raise the question of stress kinematics and the evolution of accommodation space during the Cretaceous and Paleogene extensional cycles. This knowledge is essential to guide new exploration targets, particularly in less prospected zones or deep Upper Cretaceous reservoirs.

The general objective of this study is to analyze the tectonosedimentary history of the Agadem block from the Early Cretaceous to the Cenozoic. Specifically, it involves:

1) characterizing the geometry and spatial distribution of major and secondary faults across the entire block; 2) identifying structural variations across the entire block; 3) evaluating the respective role of the different tectonic phases of the basin.

To do this, seismic sections were selected from North to South within the basin; they intersect the block from West to East, which allows for a precise understanding of its structure through its tectonic evolution.

2. Locations of the Study Area

The Termit Basin is located in the north-central part of the Chad Basin. It extends from the Northwest to the Southeast over a length of approximately 400 km and a width of more than 60 km, following the NE-SW direction (Zhou et al., 2017). The Agadem block constitutes the central and southern part of the Termit Basin. It is part of the West African Rift System (WARS), itself part of the vast ensemble of Meso-Cenozoic rifts of Central and West Africa (WCARS).

Based on Geology and Geophysics (G&G) studies carried out by the operating company on the block (China National Petroleum Corporation, CNPC), the Agadem block is subdivided into several structural units. These are, respectively, from North to South: the Soudan uplift, the Araga graben, the Madama slope, the Dinga graben, the Dinga fault zone, the Fana fault zone, the western platform, the Trakes fault zone, the Moul graben, and the Yogou fault zone (**Figure 1**).

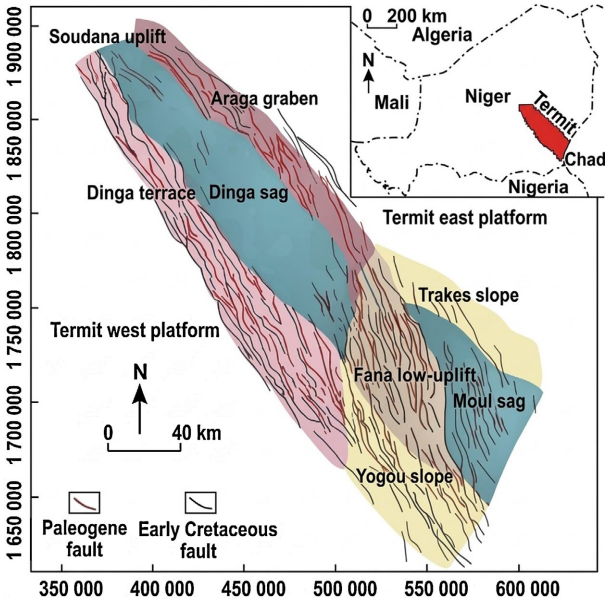


Figure 1. Geographic location of the Agadem block and its structural units (Wang, Wan, Jiang, & Liu, 2017).

3. Tectonic Evolution of the Agadem Block

The synthesis of structural analysis from several authors (Guiraud, Binks, Fairhead, & Wilson, 1992; Zanguina, Bruneton, & Gonnard, 1998; Harouna, Pigott, & Philip, 2017; Konaté, Yacouba, & Moussa, 2019) shows that the Termit Basin has

experienced five major tectonic phases:

- Pre-rift Phase I: Precambrian (750 - 550 Ma);
- Pre-rift Phase II: Cambrian to Early Cretaceous (539 - 130 Ma);
- Rifting Phase I: Cretaceous (130 - 66 Ma);
- Rifting Phase II: Paleogene (66 - 23 Ma);
- Post-rift Phase: Neogene-Quaternary (23 - 0 Ma).

The ages follow the International Chronostratigraphic Chart (Cohen, Finney, Gibbard, & Fan, 2013): the Cretaceous-Paleogene boundary is placed at about 66 Ma and the Paleogene-Neogene boundary at about 23 Ma. Accordingly, the Campanian Yogou formation (about 83.6 - 72.1 Ma) and the Maastrichtian Madama formation (about 72.1 - 66 Ma) both belong to the Late Cretaceous subsidence period, which ends at the Cretaceous-Paleogene boundary.

3.1. Precambrian Pre-Rift Phase I (750 - 550 Ma)

This phase is linked to the assembly of the Gondwana supercontinent and the stabilization of the African plate. The large faults inherited from this orogeny, oriented N-S and NW-SE, structure the African basement. They gave rise to rift-type basins and contributed to the formation of the West and Central African Rift System (WCARS) (Genik, 1993).

In the Termit Basin, this Pan-African basement is mainly composed of gneiss, pegmatites, schists, quartzo-schists, phyllites, and granites. Subsequently, it served as a substrate for the Mesozoic and Cenozoic sediments of the basin (CNPC, 2012; CNPC, 2013).

3.2. Pre-Rift Phase II from the Cambrian to the Jurassic (550 - 130 Ma)

After the establishment of the crystalline basement, the first sedimentary deposits accumulated starting in the Jurassic. These are essentially sandstones and argillites, deposited in a continental and fluvial environment (CNPC, 2012; CNPC, 2013).

3.3. Rifting Phase I, Cretaceous Period (130 - 75 Ma)

This is the major structuring phase of the Termit Basin. It is characterized by the opening, in a NW-SE direction, of the Termit Graben, facilitated by the normal activity of inherited Pan-African faults. The sedimentary infill comprises two rifting episodes separated by a period of subsidence (Binks & Fairhead, 1991).

3.3.1. The First Rifting Period (130 - 98 Ma)

This first period of rifting coincides with the Lower Cretaceous, with the opening of the South Atlantic, marked by the progressive separation of the South American and African plates (Guiraud, Binks, Fairhead, & Wilson, 1992).

The Lower Cretaceous of the Termit Basin is mainly composed of thick continental deposits (K1), the thickness of which varies from 2000 to 5000 m depending on the location (Fairhead & Green, 1989).

3.3.2. The Subsidence Period (98 - 66 MA)

In the Upper Cretaceous, the Termit Basin underwent two marine transgressions: one from the north, by the Tethys Ocean passing through Algeria and Mali; the other from the south, by the Atlantic Ocean, via the Benue Trough (Genik, 1993).

During the Late Cretaceous, part of the African plate underwent subsidence, favoring the incursion of the Tethys and the South Atlantic, which led to the formation of marine deposits (CNPC, 2012; CNPC, 2013; Burke, 1996).

It was during this transitional phase of rifting and subsidence from the Cenomanian to the Santonian that the Donga Formation was emplaced. Its base consists of sandstone and clay in its middle part, and its top evolves into grey-black mudstones (Liu et al., 2019; Genik, 1993; Ning, 2018).

The Yogou Formation was deposited in the Campanian (about 83.6 - 72.1 Ma); it consists of marine argillites alternating with fine to coarse sandstones, constituting the main parent rock on a regional scale (Yuan, Lirong, & Wenzhu, 2023; Genik, 1993; Wang et al., 2017). The Madama Formation, on the other hand, was deposited during the Maastrichtian (about 72.1 - 66 Ma), corresponding to a period of marine regression (Genik, 1993). It is essentially composed of medium to coarse sandstones and conglomerates. In places, dark clays mark the base of this formation (Yuan, Lirong, & Wenzhu, 2023).

3.4. Paleogene Rifting Phase II (66 - 23 MA)

During the Paleogene, the Termit Basin underwent a new phase of rifting, associated with episodes of uplift and subsidence. Sedimentologically, the Paleogene is characterized by alternating layers of sand (Sokor-1) and clay (Sokor-2), together forming the Sokor Series. The Sokor-1 Formation consists of fluvio -deltaic sediments, represented by coarse sandstones with clay intercalations (Sokor-1 Sandstone). This formation is subdivided into six groups, from bottom to top: E5, E4, E3, E2, E1, and E0. These six groups constitute the main potential reservoirs of the Termit Basin (Zhou et al., 2017; Zanguina, Bruneton, & Gonnard, 1998; Genik, 1993; Wang et al., 2017).

The Sokor-2 Formation is primarily composed of lacustrine mudstones with local sandstones in its upper part (Zhou et al., 2017; Wan et al., 2014). In the center of the basin, the deposits can reach a thickness of 1,000 m. On a regional scale, the Sokor-2 Formation represents the main cap rock (Zhou et al., 2017; Ning, 2018; Wan et al., 2014).

3.5. Post-Rift Phase of the Neogene-Quaternary Period (23 - 0 Ma)

The Neogene-Quaternary corresponds to the post-rift stage. During this period, the entire basin was covered by recent deposits of fluvial, lacustrine, and eolian origin (Zhou et al., 2017; Genik, 1993).

4. Materials and Methods

To trace the tectonic evolution of the Agadem block, this study relies exclusively

on the analysis of subsurface geophysical data. Although limited, these data were selected for their strategic distribution, as they intersect the block along its westward and eastward extensions. Before presenting the interpretive approach, it is essential to specify the nature of the technical platforms and tools used.

4.1. Materials Used

The seismic sections analyzed are available in two distinct formats: the raw SEGY format and the vectorized data format. To make the best use of these two types of data, a dual approach was adopted. On the one hand, Petrel software is used for the interpretation and analysis of data in SEGY format, and on the other hand, Canvas software is used to work on the vectorized data, facilitating the structural interpretation of the corresponding seismic sections.

4.1.1. Data Source and Acquisition

The 2D seismic data were provided by the Ministry of Petroleum through the Petroleum Data Center (PDC) and were acquired by former operators on the block (Elf in 1978 and 1992; BGP in 2009). The acquisition parameters of each line are compiled in Table 1. All lines were processed up to post-stack time migration and are displayed in two-way time (TWT).

4.1.2. Line Spacing and Selection Criteria

The first three lines (A-A', B-B' and C-C') are spaced by an average of 74 km, whereas line D-D', which has a distinct orientation, is located at an average of 31 km from line C-C'. The four transects were selected because 1) together they cross, from north to south, all the structural units of the block; 2) they are oriented approximately perpendicular to the main fault trends; and 3) their data quality allows interpretation down to the basement. Horizon correlation between lines relies on the regional consistency of the seismic reflection character of each formation (Section 4.2).

4.2. Methodology

With these tools, a rigorous structural interpretation methodology, structured around three key steps, was implemented to reconstruct the tectonic history of the block through seismic interpretation.

- Step 1: Tracking Horizons

Initially, the work involved tracking and correlating seismic reflectors (horizons) across all lines. This fundamental phase aims to identify the various geological formations within the basin. Horizons were identified in Petrel from the seismic reflection character of each formation, which constitutes a regionally recognized signature of the Termit basin. The formation tops (K1, Donga, Yogou, Madama, Sokor-1, and Sokor-2) were first defined from lithostratigraphic reports and from the CNPC geological and geophysical study (CNPC, 2012; CNPC, 2013); each formation was found to exhibit a distinctive seismic facies signature. Within each line, the lateral continuity of the horizons was followed by coherence-based

picking in Petrel, which exploits the coherence of the reflection responses across the interfaces.

Table 1. Acquisition parameters of the 2D seismic lines used in this study.

Parameters	A-A'	B-B' (Segment a)	B-B' (Segment b)	C-C'	D-D'
Operator	Elf	BGP	Elf	Elf	BGP
Year	1992	2009	1992	1978	2009
Energy source	Vibroseis	Vibroseis (Sercel)	Vibroseis	Weight drop	Vibroseis
Sweep frequency	6 - 66 Hz	8 - 96 Hz	6 - 66 Hz	NA	8 - 96 Hz
Sweep length	8 s	12 s	8 s	NA	12
Sweeps or drops per point	4	4	4	16	4
Source point spacing	50 m	25 m	50 m	100 m	25 m
Source configuration/offset	NA	NA	NA	Center shot, 2 × 550 m	NA
Fold (coverage)	60	120	60	NA	120
Line orientation	SW-NE	SW-NE	SW-NE	SW-NE	W-E
Sampling interval	2 ms	2 ms	2 ms	NA	2 ms
Record length	5 s	6 s	5 s	5 s	6 s
Receiver (trace/group) spacing	50 m	25 m	50 m	50 m	25 m
Geophones per trace/group	36	12	36	48	12
Geophone frequency	10/14 Hz	10 Hz	10/14 Hz	NA	10 Hz
CDP interval	25 m	12.5 m	25 m	NA	12. 5 m
Total line length	61. km	33.5 km	28.5 km	74 km	40 km

NA: Not available or not applicable. Line B-B' is a composite of two segments: segment a (BGP, 2009) crosses the Fana fault zone, the Dinga depression, and most of the Dinga fault zone; segment b (Elf, 1992) crosses the remaining part of the Dinga fault zone.

To reinforce this approach, line D-D' was displayed as an instantaneous frequency section (Figure 2, bottom). Compared with the initial amplitude display of the same line (Figure 2, top), this attribute better reveals the limits and internal characteristics of the formations, clearly distinguishing the reflection characteristics at their boundaries. The coherence of the responses across the different interfaces is then exploited by coherence-based picking to follow the lateral continuity of each horizon in Petrel. The seismic character and termination pattern of each horizon are summarized in Table 2.

- Step 2: Mapping and Analyzing Faults

Once the horizons have been mapped, the next step involves mapping the faults. The mapping process begins with the identification and highlighting of major faults, followed by the secondary ones. This step-by-step approach has made it possible to link these structural lineaments to major deformation phases and, consequently, to the regional geodynamics of the basin.

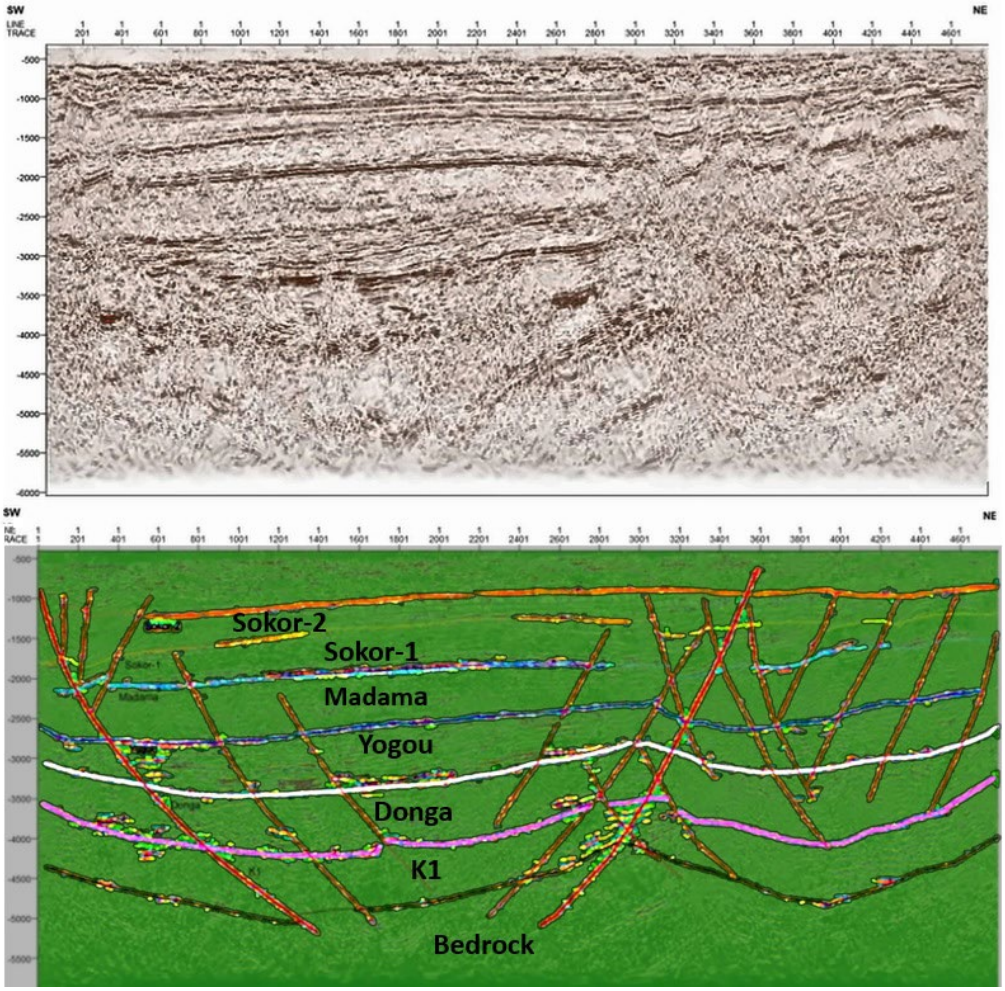
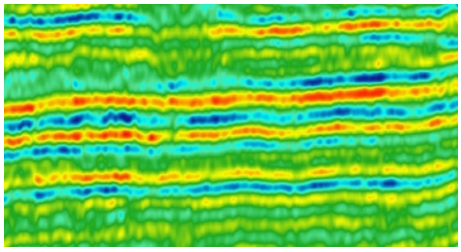
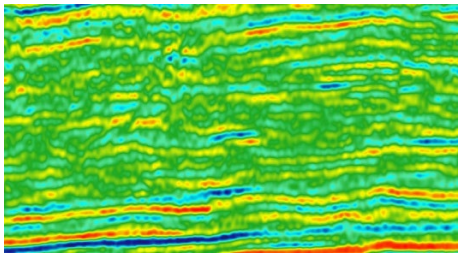
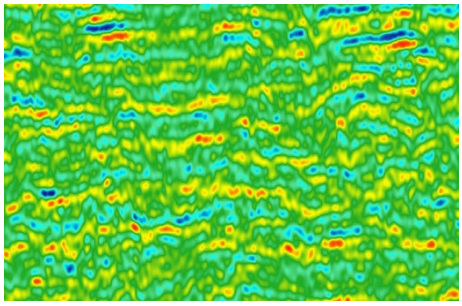
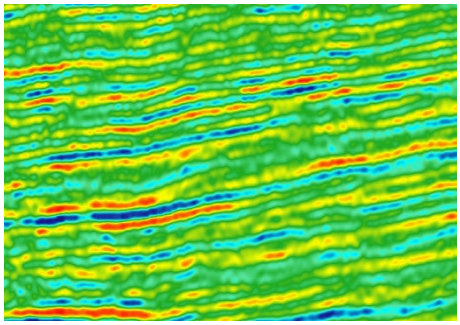
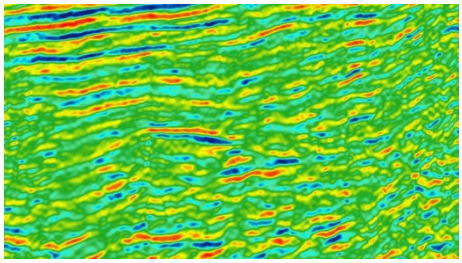
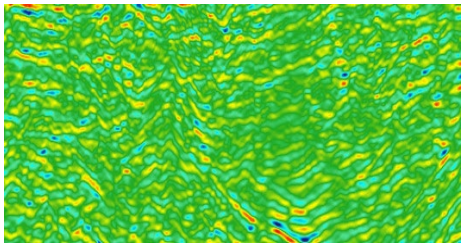


Figure 2. Line D-D' is displayed as an amplitude section (top) and as an instantaneous-frequency section (bottom), with the interpreted horizons (Sokor-2, Sokor-1, Madama, Yogou, Donga and K1) and faults.

Table 2. Seismic character of the formations on the instantaneous-frequency section of line D-D' (zoomed views).

Formation	Instantaneous-Frequency Response	Seismic Character and Interpretation
Sokor-2		Top marked by a strong reflection. Seismic section characterized by a series of high-energy peaks traceable over most of the mapped area. These successions of continuous reflections within Sokor-2 indicate a homogeneous alternation of lithological deposits.
Sokor-1		Within the Sokor-1 formation, a succession of continuous, parallel reflections is also observed at the top and toward the base of the formation. It is likewise characterized by an alternation of successive deposits with strong acoustic-impedance contrast at the layer boundaries, which points to deposition in a low-energy setting.

Continued

Madama		The Madama formation is characterized by a transparent layer without sub-parallel reflections, indicating that it is predominantly composed of a homogeneous layer. The absence of chaotic internal reflections indicates deposition in a low-energy and stable setting.
Yogou		Within the Yogou formation, a succession of continuous, sub-parallel reflections is observed. This succession corresponds to the alternation of sand and clay layers within the formation, confirmed by the master log data of wells from the block.
Donga		The Donga formation is characterized by an alternation of sub-parallel reflections from syn-rift deposits toward the top and relatively chaotic reflections at the base, indicating deposition of sediments in a high-energy setting. The sediments carried by the transgression were deposited first; as the water level rose, the depositional energy progressively became lower.
K1		The K1 formation is characterized by a transparent layer without reflections, indicating that it consists essentially of a homogeneous layer.

The robustness of this analysis rests on the regional persistence of these reflection signatures: continuous, parallel to sub-parallel reflections in Sokor-2, Sokor-1 and Yogou; transparent responses in Madama and K1; and an alternation of sub-parallel and chaotic reflections in Donga.

- Step Three: Division into Structural Units

However, the interpretation cannot be limited to an analysis of the profiles alone. The seismic lines, arranged from north to south, cut across the block in several zones with different tectonic characteristics. The interpretation strategy therefore consisted of isolating these different zones along each line, treating them as distinct structural units. This spatial division aims to highlight the unique tectonic characteristics of each sector, while providing an overall view that allows for an assessment, at the scale of the Agadem block, of the distribution and intensity of the deformations.

Limitations of the approach: The interpretation is qualitative and based on 2D sections only. No displacement (throw) analysis, fault-seal or fault-transmissibility analysis, or hydrocarbon-flow data were included in this study. Statements on the role of faults as migration conduits or seals therefore rely on published petroleum-system studies and are not results of this study.

5. Results and Discussion

To enhance the understanding of the evolutionary dynamics of the Termit Basin and the factors controlling its infilling process, we undertook the interpretation of four 2D seismic lines (A-A' to D-D') distributed from north to south across the Agadem block (Figure 3). These lines were processed up to post-stack time migration; their resolution varies with the acquisition parameters (Table 1).

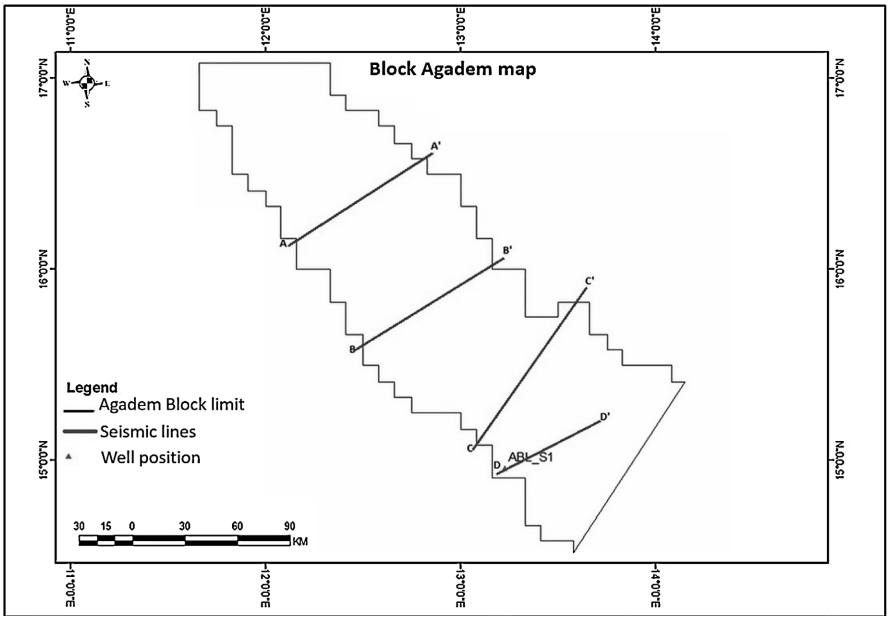


Figure 3. Position of seismic lines on the Agadem block.

The chosen seismic lines intersect the basin from West to East; they are far enough apart to allow us to grasp the structure of the block on both sides of its edges. Line spacing averages 74 km between A-A', B-B' and C-C', and 31 km between C-C' and D-D' (Section 4.1).

5.1. Interpretation of Line A-A' to the North

The A-A' line (Figure 4) is located north of the Agadem block and intersects from West to East: the western platform, the Dinga fault zone, the Dinga depression, the Araga graben, and the Eastern platform.

The general trend in the seismic section of line A-A' reveals a relatively symmetric graben controlled on either side by two major listric faults. Similarly, a significant distribution of secondary faults branching off from the listric faults towards the top of the basin is observed in the seismic section. Tectonic variation is noted across

the different zones, as well as variation in sediment thickness, with a substantial deposit in the center of the basin.

5.1.1. The Platform-East on Line A-A' to the North

The eastern platform on the seismic section (Figure 5) defines the eastern boundary of the Agadem block and is characterized by undeformed horizontal layers. Seismic reflections in this area are clear and allow for good delineation of the horizons.

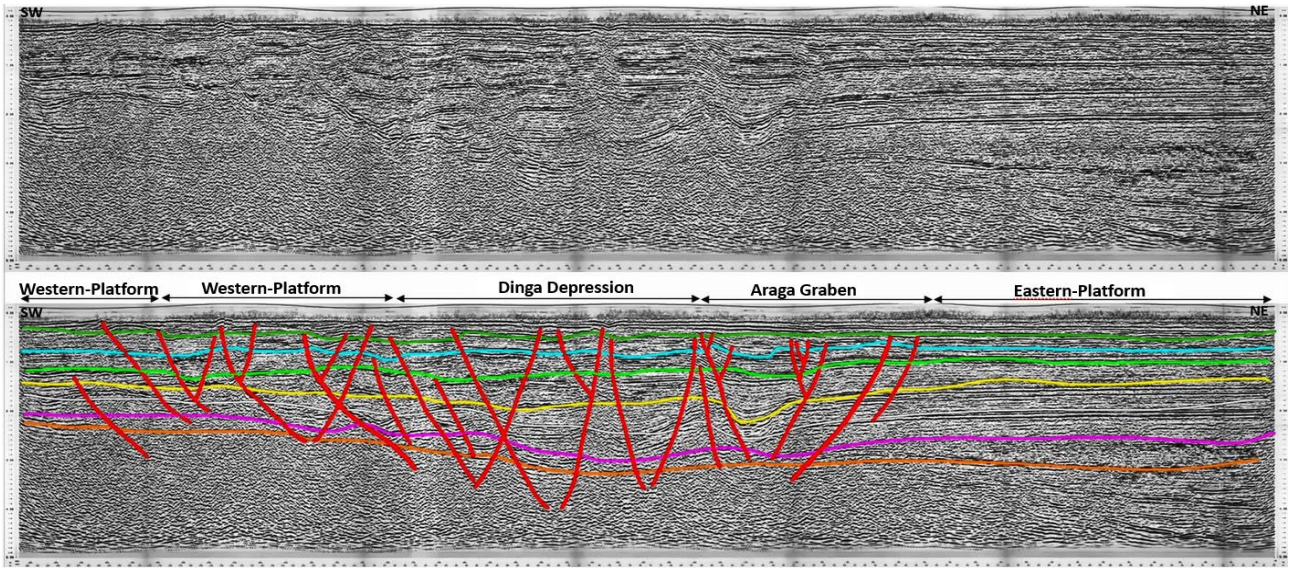


Figure 4. Line A-A' interpreted.

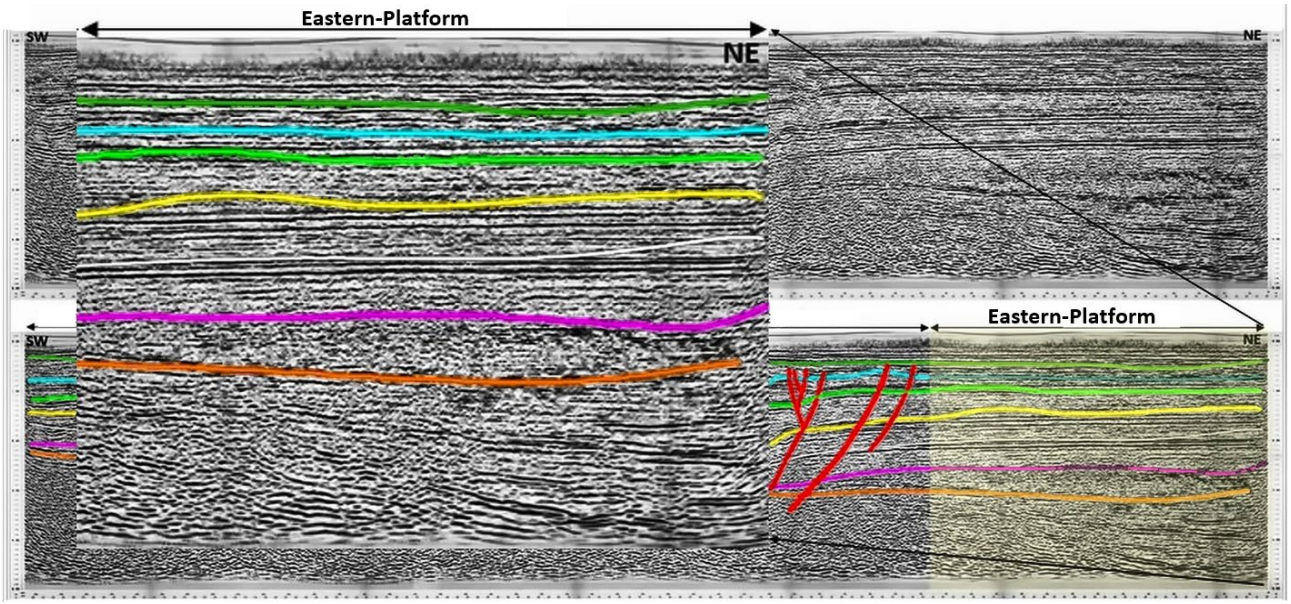


Figure 5. Eastern platform of the Agadem block.

5.1.2. Araga Graben on the A-A' Line to the North

Araga Graben is controlled by major, multi-stage faults that define a graben (Fig-

ure 6). An initial synsedimentary extensional period affected the Lower Cretaceous deposits (K1 deposits). This was followed by compressive tectonics (reverse movement) during the Paleogene. The significant thickening associated with synclinal deformations, without offset, indicates a period of subsidence (Yogou and Madama deposits). The second subsidence period was followed by a third synsedimentary extensional period: variations in synsedimentary thickness affected the Paleogene deposits (Sokor 1 deposits). Secondary faults developed during the Paleogene, Y-shaped, intersecting the major faults initiated during the Lower Cretaceous. The Cenozoic formations preserve the earlier deformations.

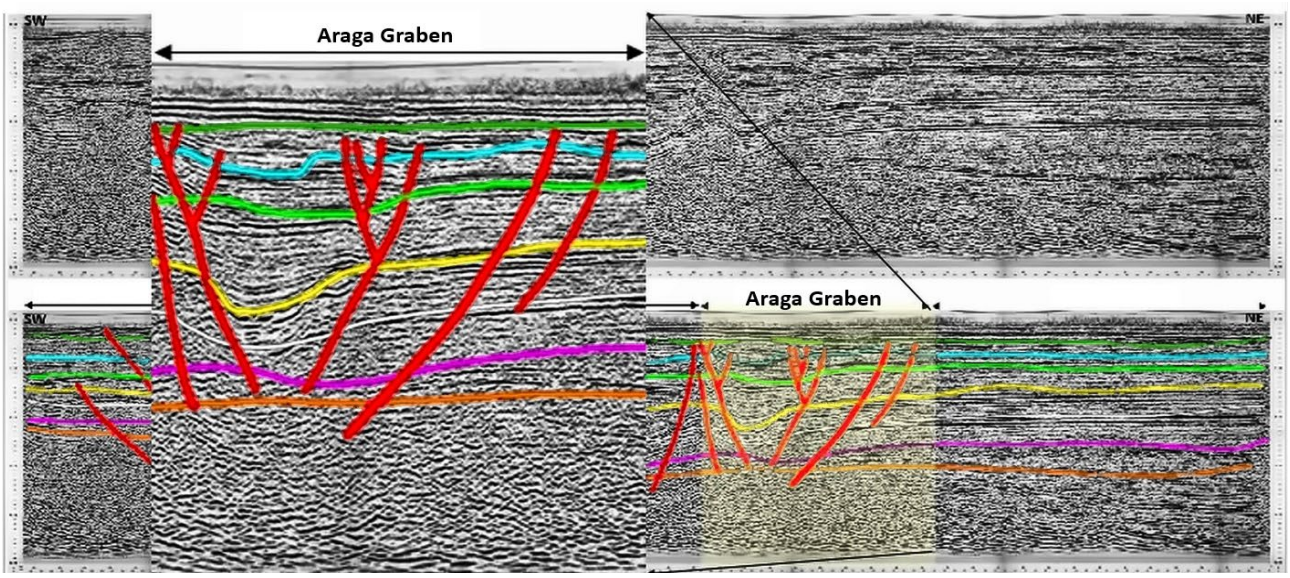


Figure 6. Araga graben north of the Agadem block.

5.1.3. The Dinga Depression on the A-A' Line to the North

The Dinga depression occupies the central part of the basin and exhibits a horst and graben structure, implying essentially extensional tectonics (Figure 7). It records the most important sedimentary deposit on the block.

5.1.4. The Dinga Fault Zone on Line A-A' to the North

The Dinga fault zone exhibits a predominantly half-graben structure associated with a secondary micro-horst structure known as the Iaguil platform. Extensional tectonics are dominant, as evidenced by the presence of tilted blocks; however, slight reverse reactivation can be observed (Figure 8).

5.1.5. The Western Platform on the A-A' Line to the North

The western platform represents the western edge of the Agadem block (Figure 9). It is only slightly affected by extensional tectonics. Deep faults that developed during the Cretaceous period are visible.

5.2. Line B-B' in the Center of the Block

Line BB' was acquired in the center of the Termit Basin; it passes through the Fana

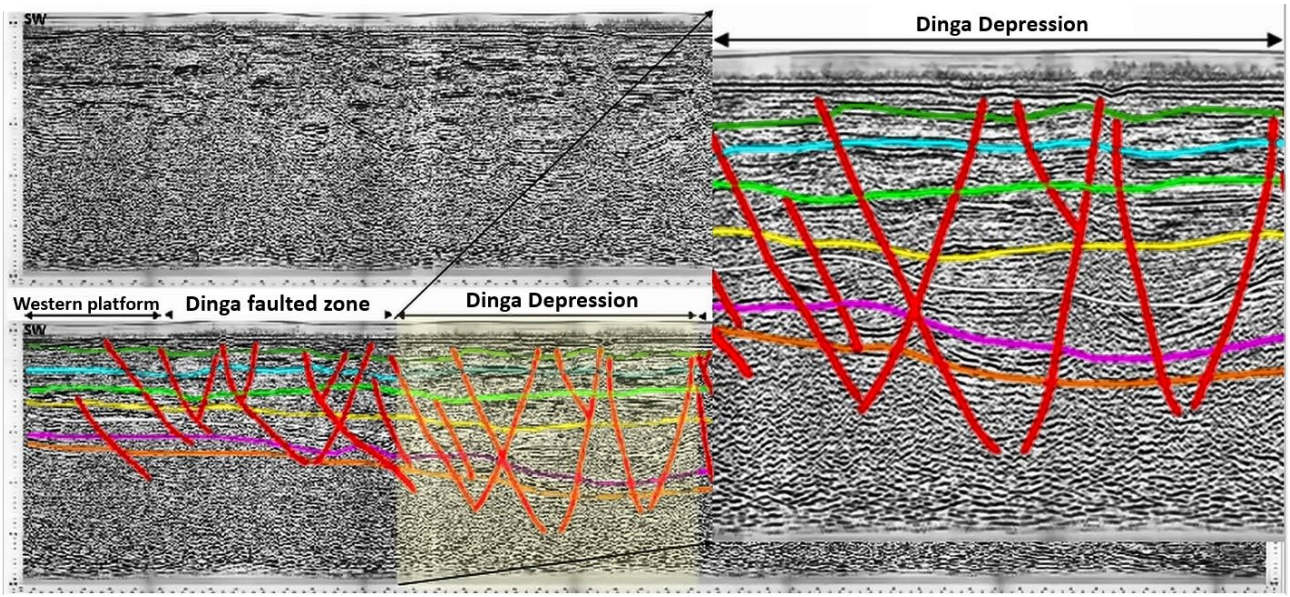


Figure 7. Position of the Dinga depression north of the Agadem block.

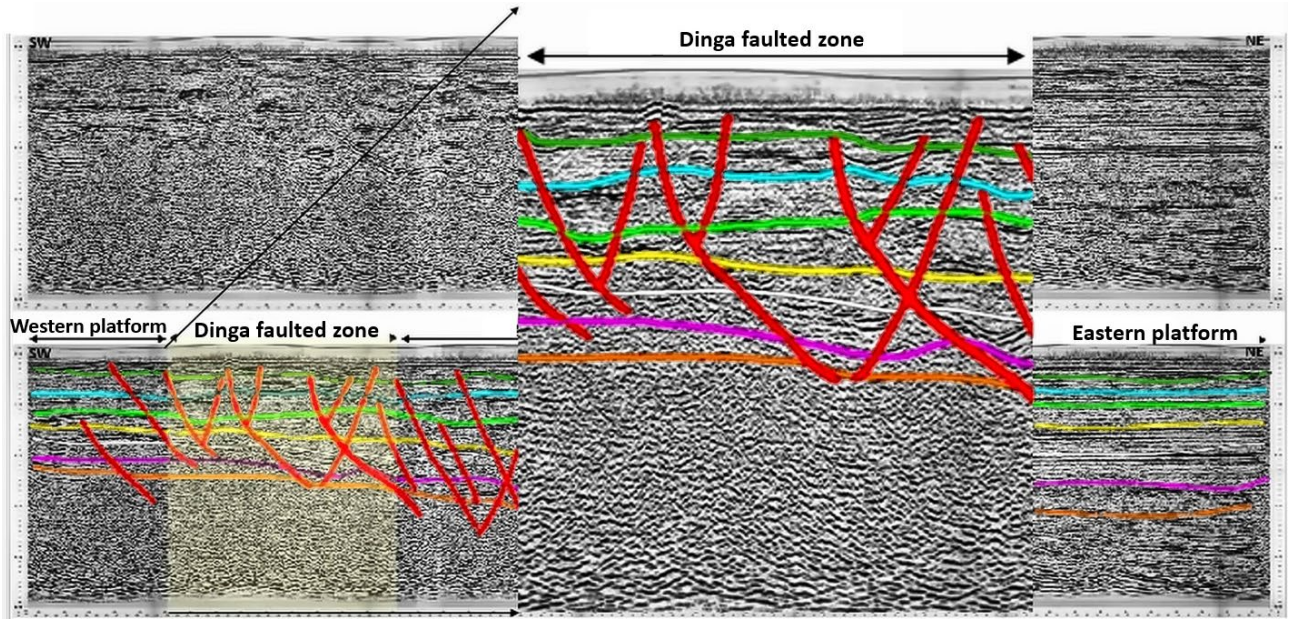


Figure 8. Position of the Dinga fault zone north of the Agadem block.

Fault Zone to the east, the Dinga Depression, a large part of the Dinga fault zone, and the western platform (Figure 10). Line B-B' is a composite of two seismic lines, both post-stack migrated and displayed in two-way time (TWT). The first segment crosses the Fana fault zone, the Dinga depression, and most of the Dinga fault zone; the second crosses the remaining, smaller portion of the Dinga fault zone. The two segments were acquired in different years, by different contractors and with different acquisition parameters (Table 1), so they differ in resolution and seismic texture. However, migration repositions reflectors and fault planes to their correct shapes and extensions, so these differences do not affect the structural interpretation.

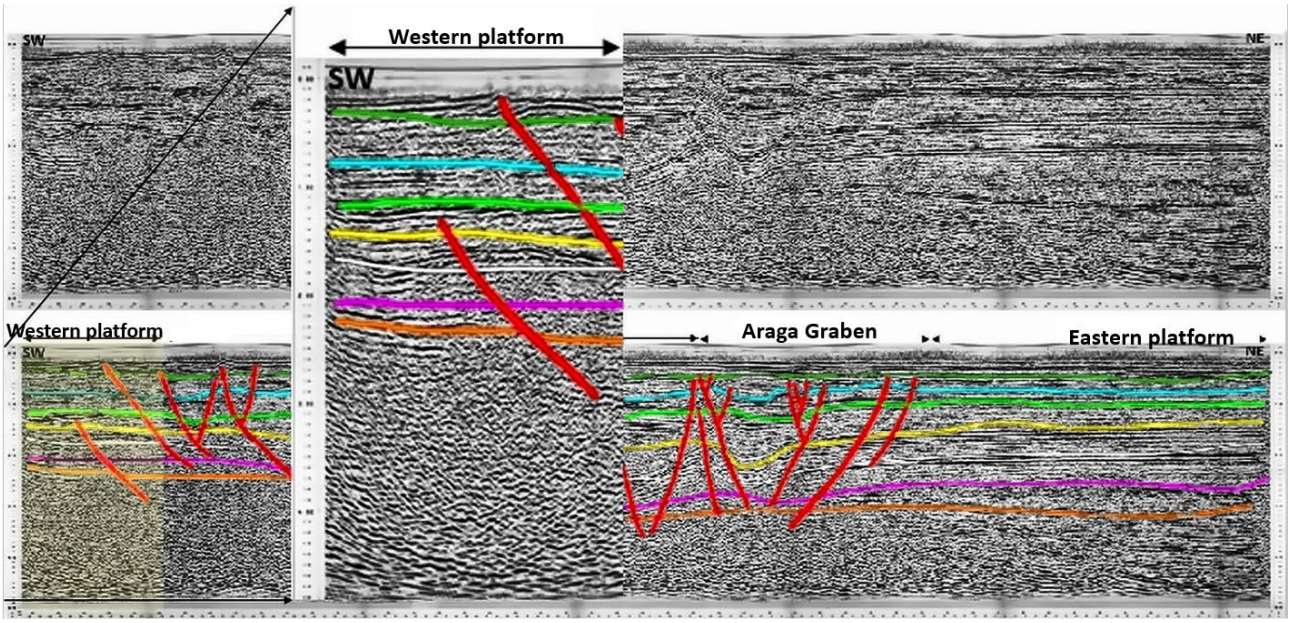


Figure 9. Position of the Western platform north of the Agadem block.

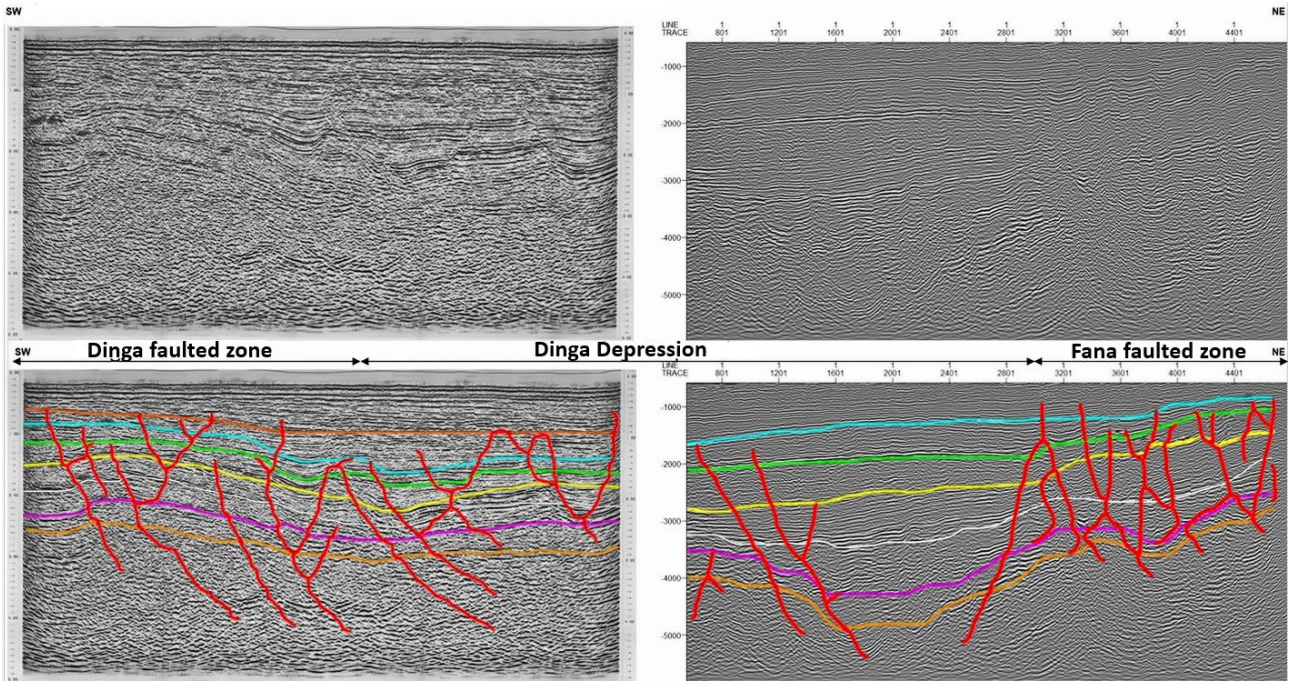


Figure 10. Position of line B-B' on the Agadem block.

Horizons were correlated across the junction using reflector continuity and the same stratigraphic markers on both segments. Thickness variations discussed for this line are expressed in TWT.

5.2.1. The Fana Fault Zone on the B-B' Line in the Center of the Block

The area, also known as the Fana uplift, is essentially a fault zone containing major Cretaceous faults which, together with those of the Paleogene and Mesozoic eras,

form horsts and grabens. These major reverse faults also intersect at the Y and X axes, creating a structurally deformed zone (Figure 11).

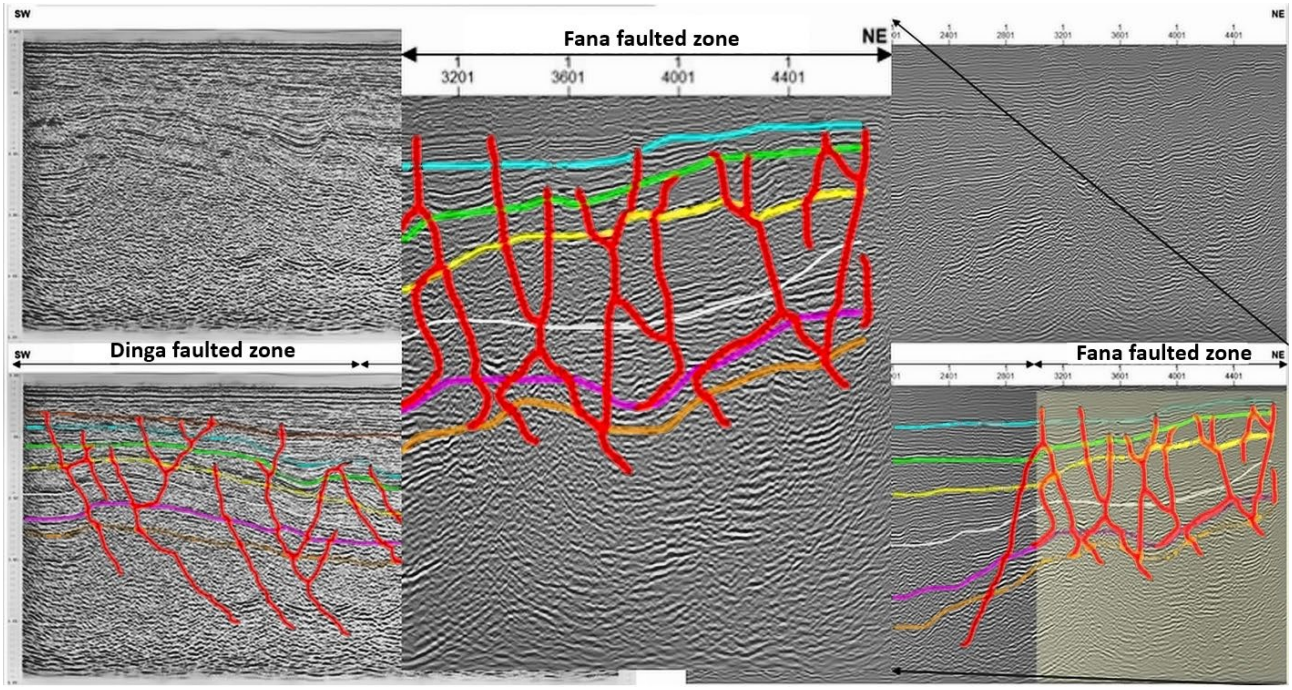


Figure 11. The Fana fault zone in the center of the block.

5.2.2. The Dinga Depression on the B-B' Line in the Center of the Block

In the center of the basin, the Dinga depression exhibits very significant sedimentary deposits. The area is a graben controlled on both sides by major listric faults (Figure 12). These faults, which cut through the basement down to the Paleogene deposits, evolved with the infilling of the basin.

5.2.3. The Dinga Fault Zone on the B-B' Line in the Center of the Block

In the center of the basin, there are significant Paleogene deposits, as well as Upper Cretaceous Madama deposits, forming a new depression within the Dinga fault zone. Multiple faults and tectonic inversion are observed across the reverse faults, highlighting a compressional regime during the Paleogene and on the Cretaceous deposits (Figure 13).

5.3. The C-C' Line in the Central-South Block

The CC' line, SSW-NNE trending, acquired south of the Agadem block, crosses from East to West the Trakes zone, the Moul depression, the Fana fault zone and the Yogou zone (Figure 14).

5.3.1. Trakes Area on the C-C' Line in the Central-South Block

Trakes is located in the eastern part of the Agadem block, in the southern part of the basin. The trake zone is essentially stable. The zone lies on a slope with limited fault development (Figure 15). There is a thinning of the strata to the east, which

become progressively thicker towards the west. The faults have a steep appearance, cutting across Cretaceous and Paleogene strata.

5.3.2. The Moul Depression South of the Block

The Moul depression is controlled by major faults on both sides. To the east of

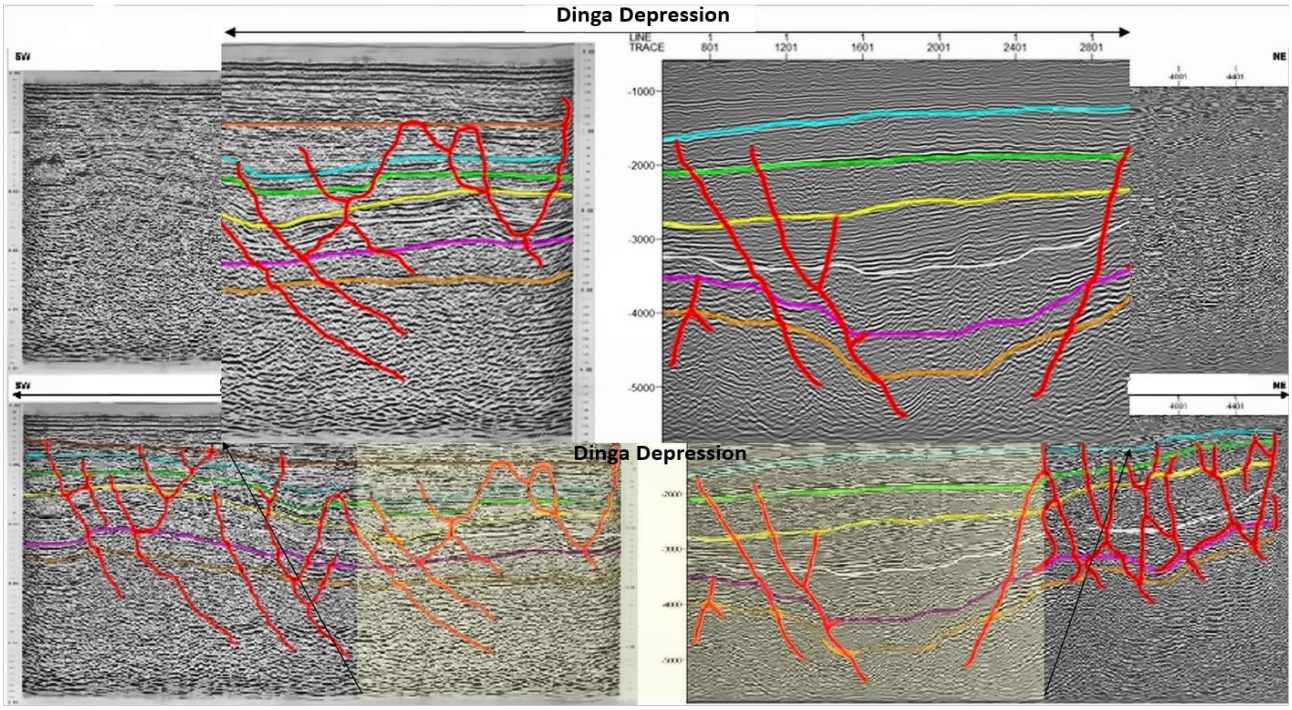


Figure 12. The Dinga depression in the center of the Agadem block.

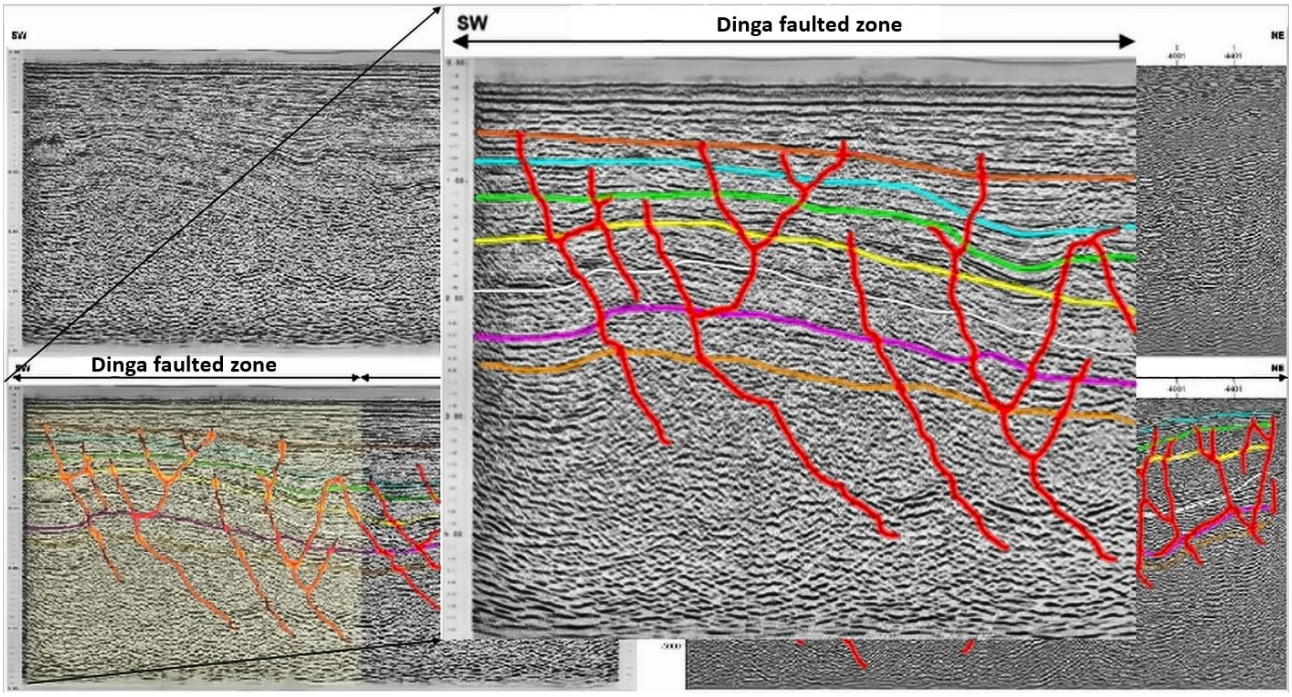


Figure 13. The Dinga fault zone in the center of the block.

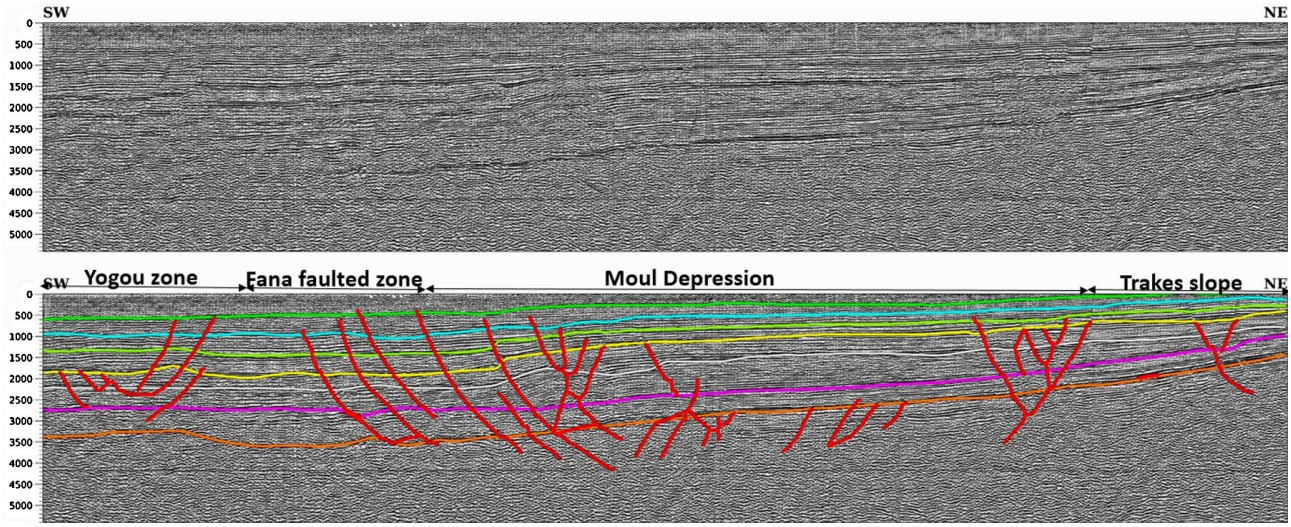


Figure 14. Position of line C-C' on the Agadem block.

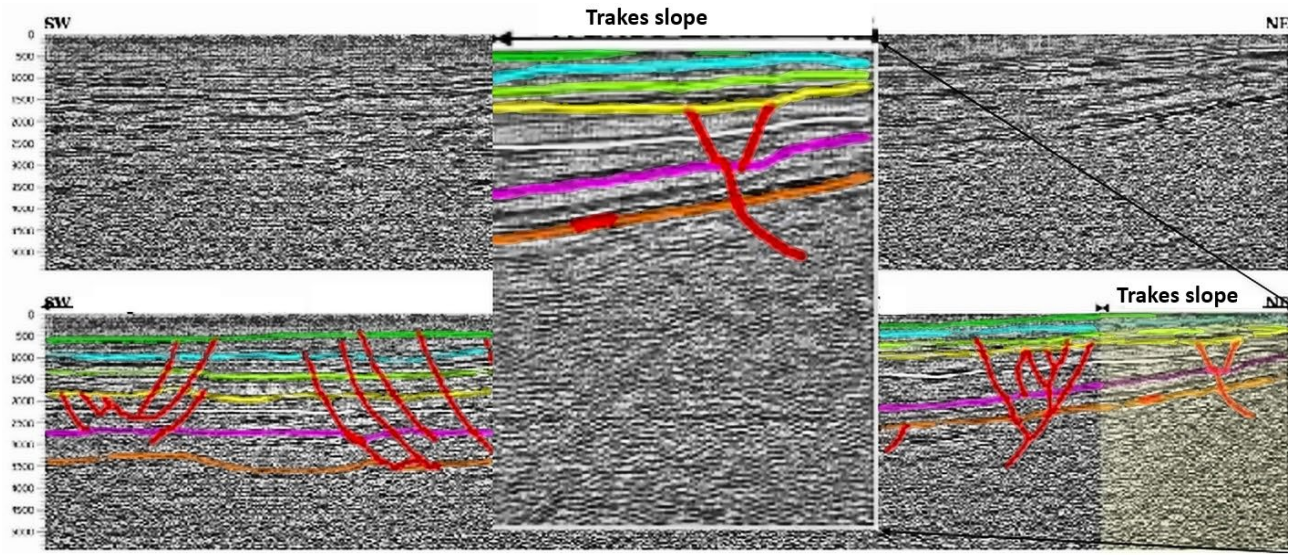


Figure 15. Trakes area south of the block.

the depression, secondary faults connect to the major Y-shaped faults. The layers are thinner to the east than to the west (Figure 16).

5.3.3. The Fana Fault Zone on the C-C' Line in the Central-South Block

The area exhibits a high density of normal and reverse faults with alternating grabens and horsts (Figure 17). The layer thicknesses in the area are uniform, and this part of Fana appears to be central to the deposits in the basin south of the block.

5.3.4. The Yogou Area on the C-C' Line in the Centre-South Block

The Yogou area is located in the western part of this southern basin. Normal faults give the area a graben structure. There is a development of Paleogene faults affecting the Cretaceous layers down to the basement (Figure 18).

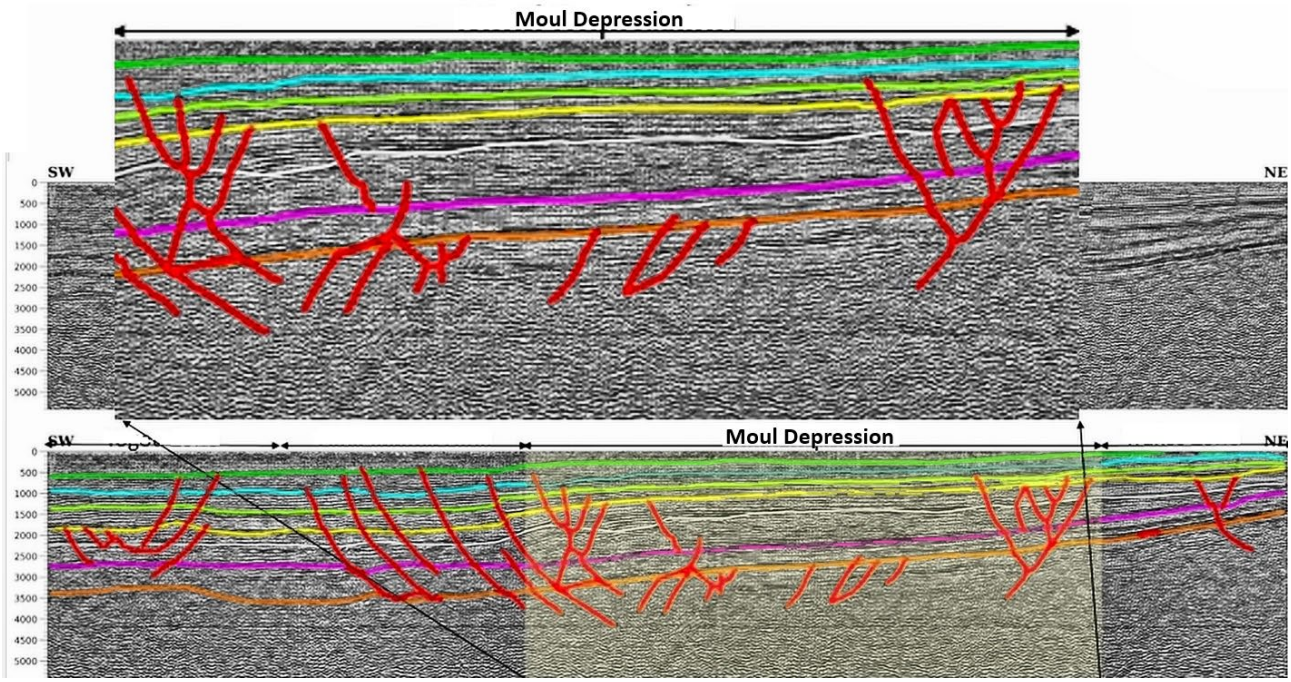


Figure 16. The Moul depression area south of the block.

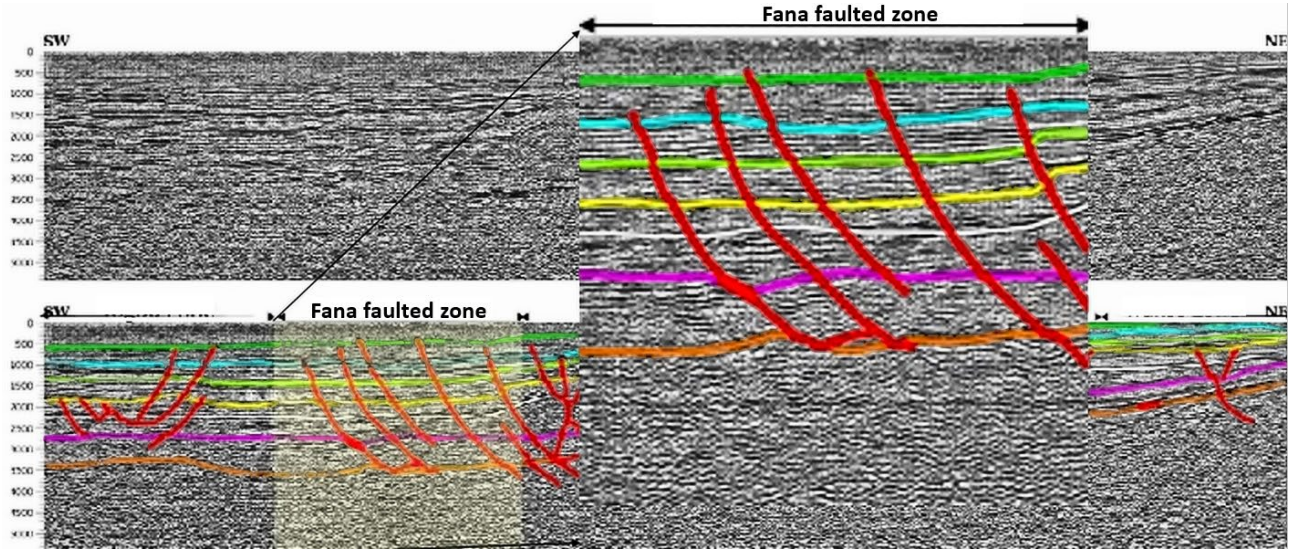


Figure 17. The fault zone of Fana south of the block.

5.4. The D-D' Line South of the Block

The D-D' line, running west-east, was acquired at the extreme south of the block (Figure 19). It crosses the Yogou slope to the west and a large part of the Moul depression to the east. The well Abl-s1 master log and wireline logging data were used to enhance horizon interpretation.

These data were used to confirm the formation crossing by the well.

5.4.1. The Yogou Slope on the D-D' Line South of the Block

South of the Agadem block, the Yogou slope is a graben with extensively developed

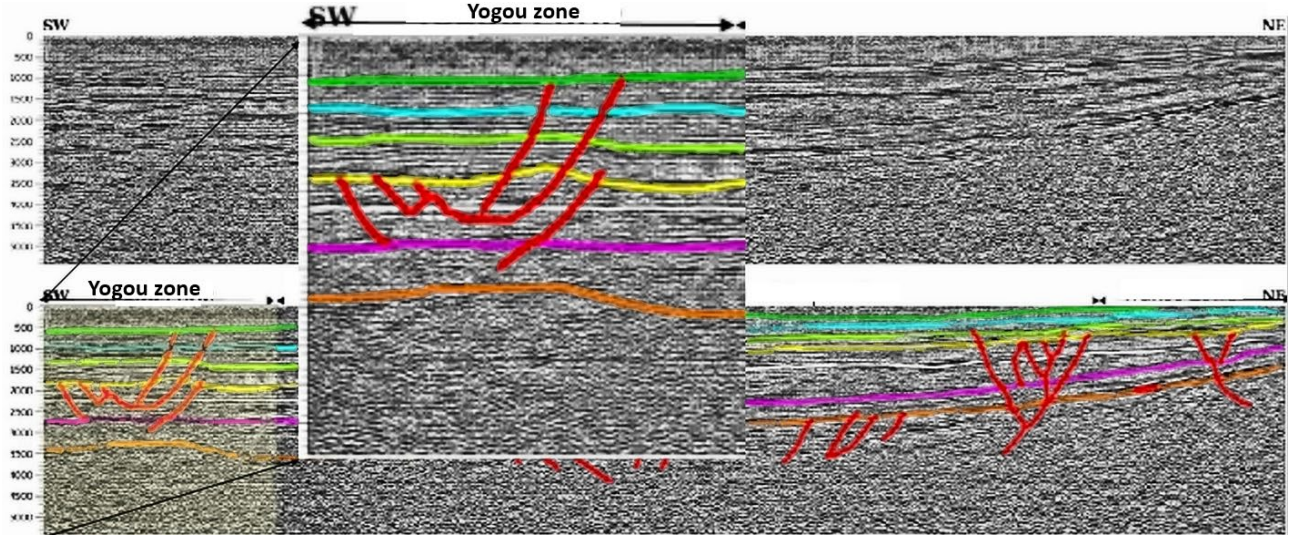


Figure 18. The Yogou area south of the block.

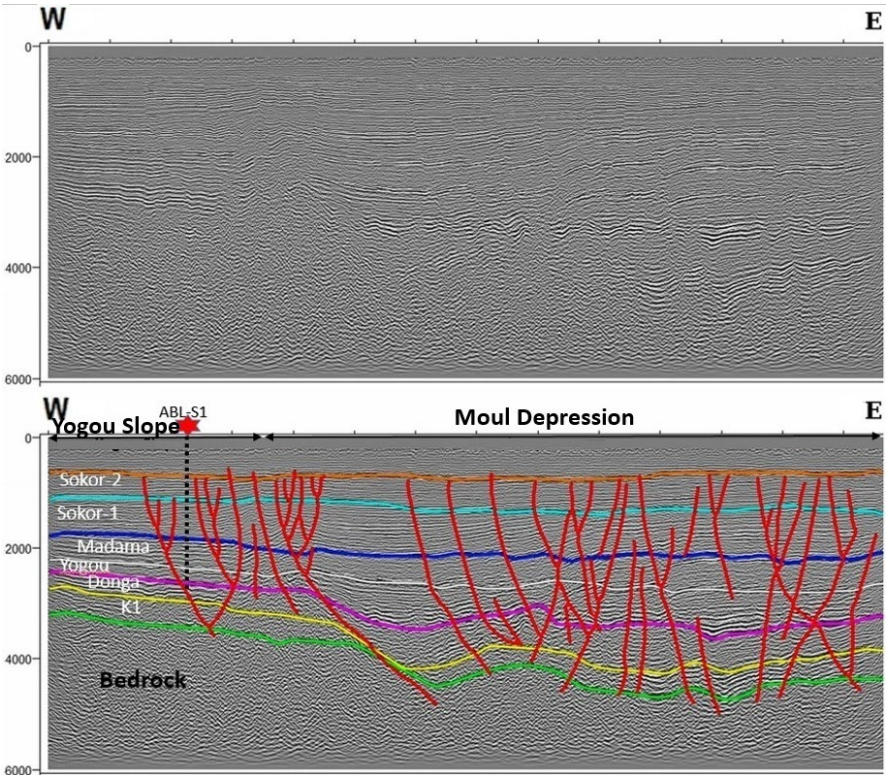


Figure 19. Position of line D-D' on the Agadem block.

secondary faults from the Paleogene. These faults intersect the major Cretaceous faults that control the area. The layers thicken from west to east with a gentle slope (Figure 20).

5.4.2. The Moul Depression on the D-D' Line South of the Block

The Moul depression in this part of the Agadem block exhibits a strong development of secondary faults during the Paleogene. Normal and reverse faults alternate

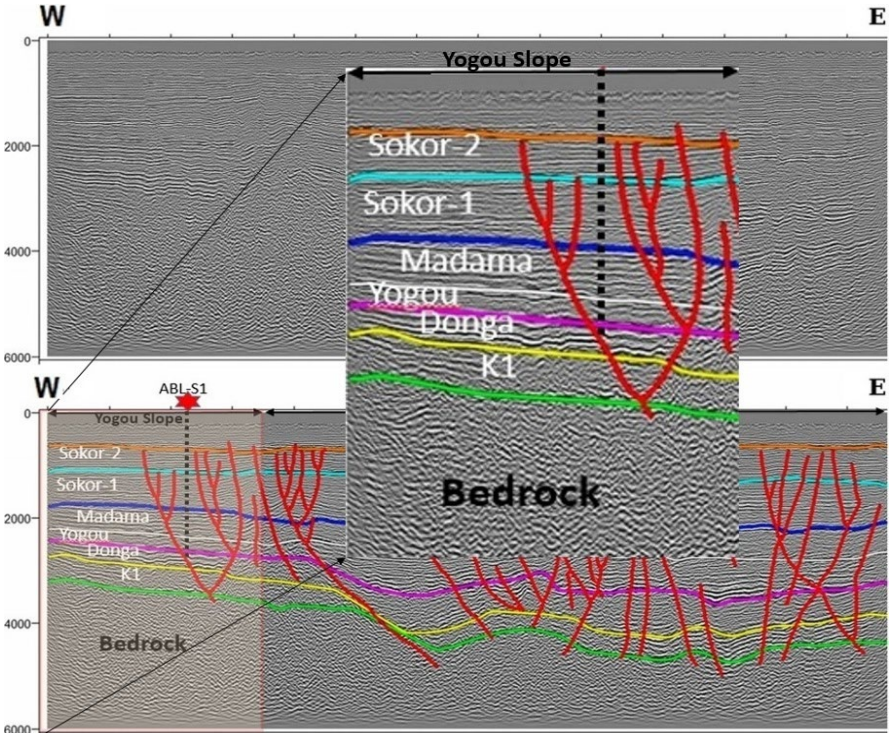


Figure 20. The Yogou slope at the extreme south of the block.

within the depression, forming horsts and grabens. Moul constitutes a central deposit in the southern part of the basin, with significant sedimentary layers (Figure 21). The major Listric fault to the west has controlled the infilling of the basin since the Cretaceous.

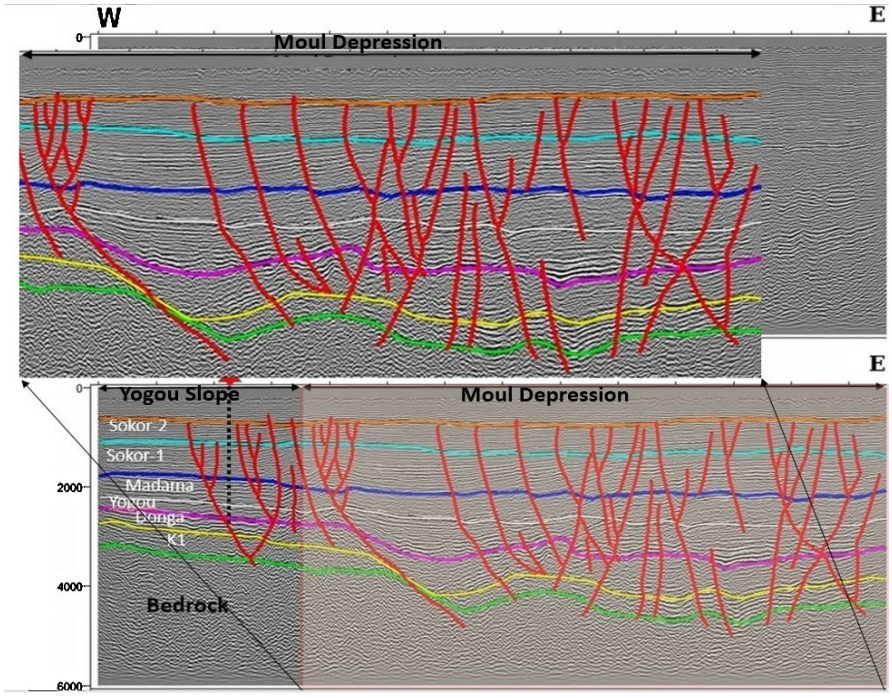


Figure 21. The Moul depression in the extreme south of the Agadem block.

The fault system of the Termit Basin, mainly in the Agadem block, is characterized by an evolution of Early Cretaceous faults that determined the configuration of the basin from the base. They were reactivated in the Paleogene, controlling the deposits across the entire basin, which were even more significant in its center.

The different zones crossed by the seismic lines from the North to the South of the basin show a difference in the tectonics across the entire Agadem block.

The structures identified on the seismic lines are:

- Grabens and half-grabens;
- Horsts;
- Normal and reverse faults;
- Faults in Y and X configurations.

The multiple phases of rifting of the Termit Basin have given it a complex, variable shape from north to south.

In the north of the block, the basin presents itself as a symmetric graben controlled by two major faults, highly developed from the basement to the recent layers (Figure 22).

Multiple phases of rifting in the Termit Basin have given it a complex, variable shape from north to south.

To the north, the Termit Basin is a graben controlled by two major, highly developed faults extending from the basement to the recent layers (Figure 22).

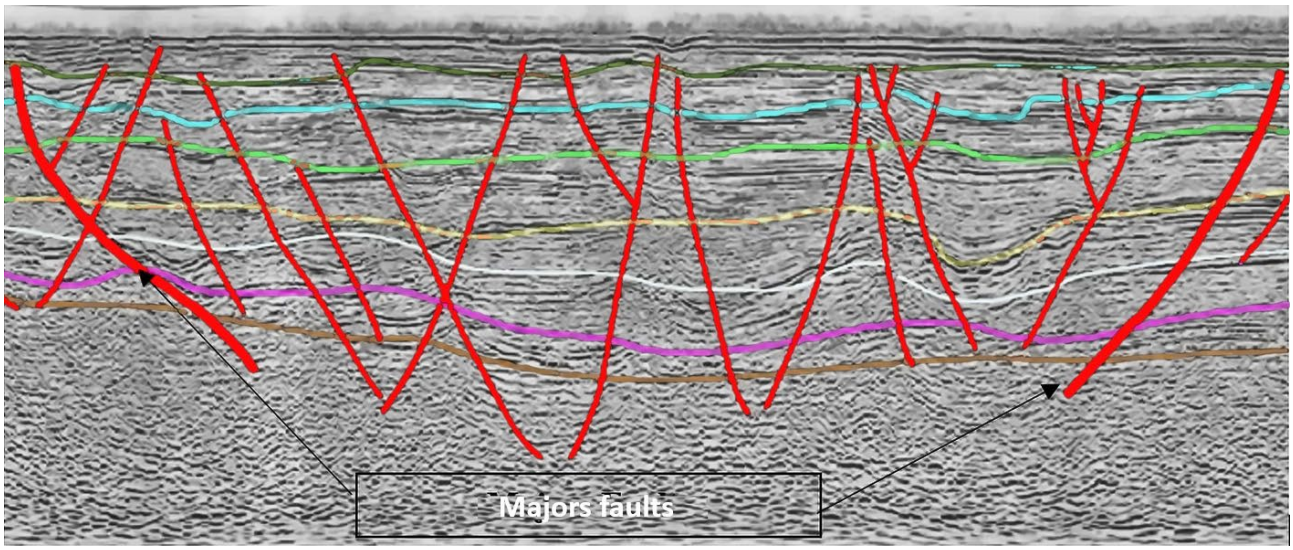


Figure 22. Graben north of the Termit Basin.

This graben is the result of the extensional phases of the basin from the Early Cretaceous to the Paleogene. The tilted blocks found within the graben and the birth of Y-shaped faults in the Sokor 1, Sokor 2, and even Upper Cretaceous formations in the Madama are the signatures of this episodic extension of the basin. On the other hand, the compressive context is linked to the presence of reverse faults and their flower configuration locally.

In the center of the block, the major fault to the west is more developed than the one to the East, which may reflect a variation in the intensity of extension across the basin (Figure 23).

In the south of the block, a more asymmetrical aspect of the basin emerges. Moving towards the East, the basin is more elevated due to the local tectonic uplift of Fana in the basin (Figure 24).

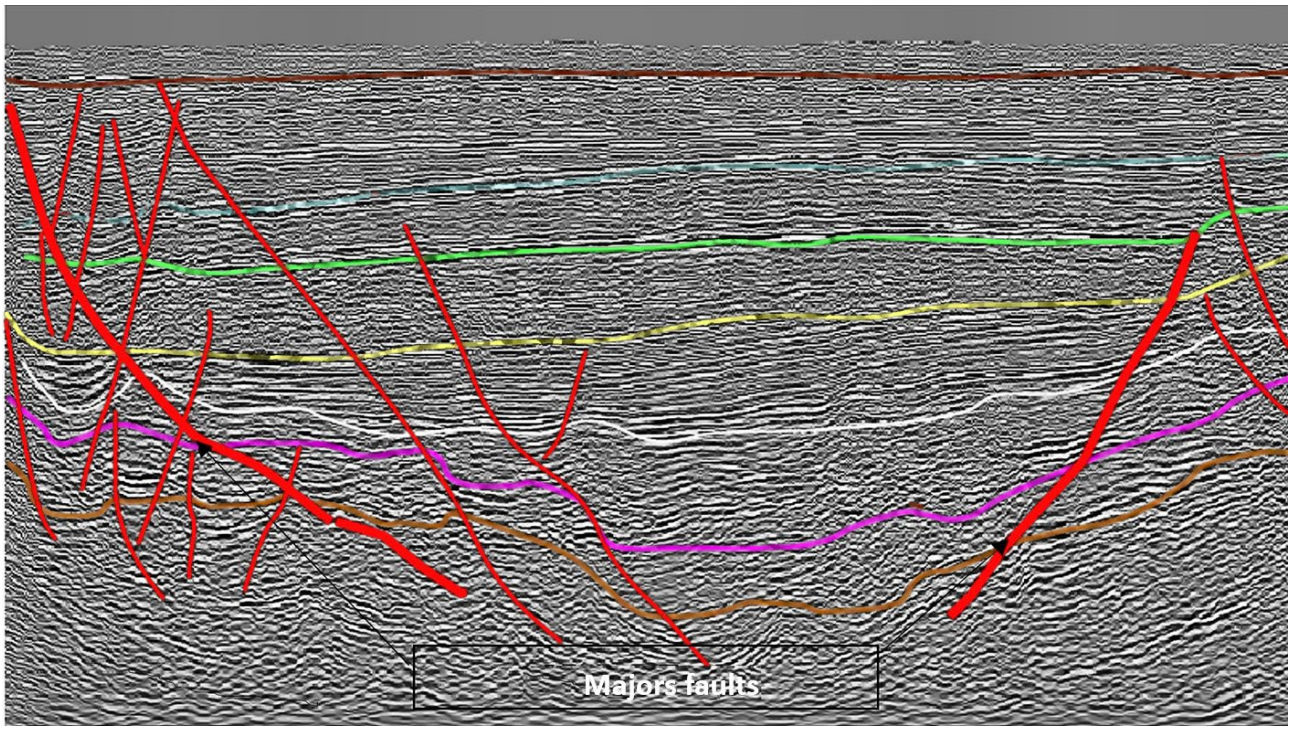


Figure 23. Asymmetrical graben in the center of the Termit Basin.

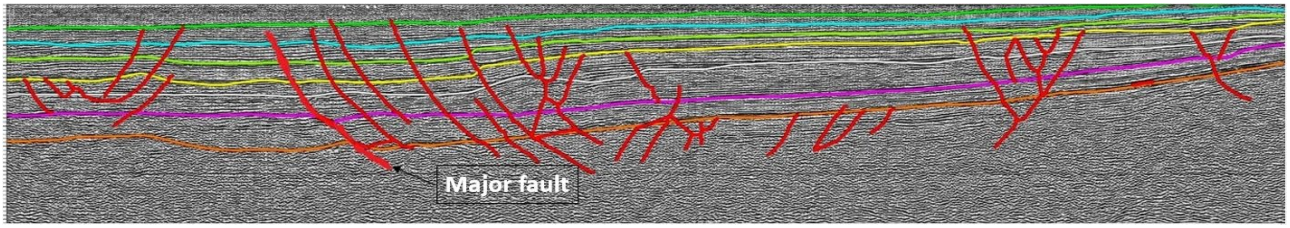


Figure 24. Half-graben south of the Termit Basin.

At the extreme South of the block in the Moul depression, the basin becomes deeper towards the east, and the layers consequently become thicker (Figure 25). The basin presents itself as a half-Graben.

The first phase of Early Cretaceous rifting, which resulted in the deposition of K1, is identifiable in seismic sections where large horizon offsets reflect the significant faulting activity during this period. The Late Cretaceous phase is characterized by a high rate of subsidence across the entire basin, with sediment size and burial depth being higher in the Dinga and Moul depressions. Furthermore, the substantial sedimentary deposits of this period were only possible thanks to sufficient

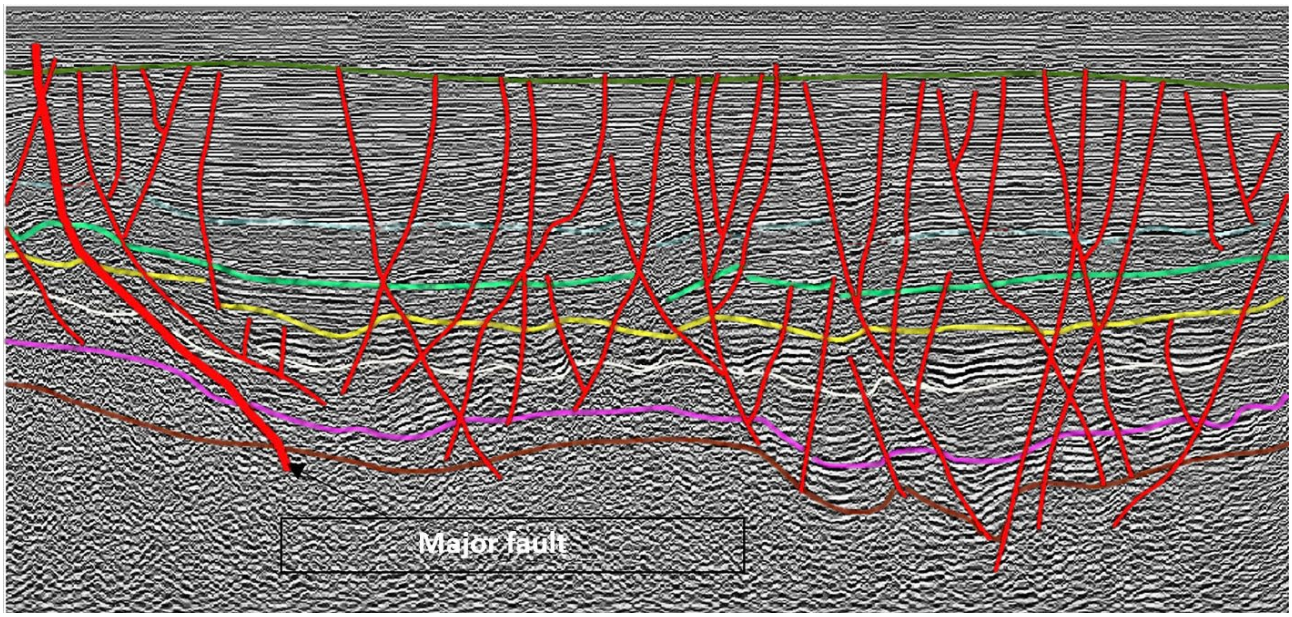


Figure 25. Half-graben at the extreme south of the Termit Basin.

accommodation created by basin expansion. The Late Cretaceous, marked by variations in the layers deposited with normal faulting, is indeed a period of low rifting compared to other phases coinciding with subsidence in a favorable context of sedimentary input linked to a global Phanerozoic rise in sea level.

The compilation of the geographical distribution of the lines on the block allows us to appreciate this spatial variation of the tectonosedimentary history on the basin (Figure 26).

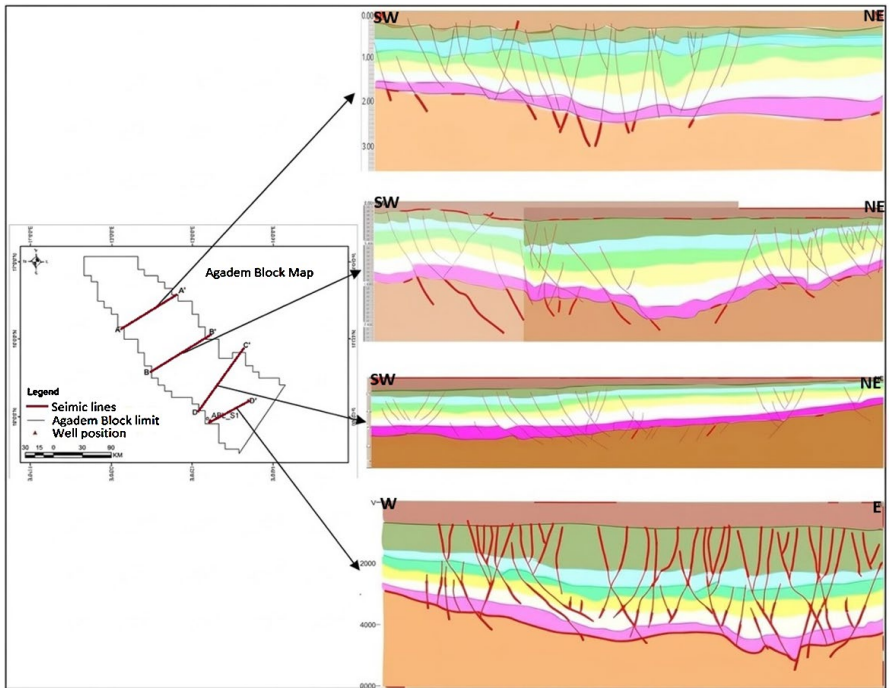


Figure 26. Structural variation of the Termit Basin from North to South.

The seismic sections show that the major faults and those resulting from Paleogene rifting connect the Upper Cretaceous Yogou source-rock interval to the Sokor-1 reservoirs, and that some faults extend into the Neogene-Quaternary section. Their role as conduits or seals is a structural prerequisite consistent with published petroleum-system studies (Zhou et al., 2017; Liu et al., 2019), not a result of this work. Sokor-2, which is the regional cap rock, is also affected by the fault system; fault-seal and transmissibility analysis was not part of this study.

6. Conclusion

The tectonosedimentary analysis of the Agadem block, based on the interpretation of seismic sections, has significantly refined the architecture and evolutionary dynamics of the Termit Basin. Our results indicate that the block's structure resulted from a complex, multiphase history, initiated in the Early Cretaceous by a major extensional phase that emplaced the listric faults inherited from the Pan-African paleogeography. These deep structures, oriented NW-SE to NNW-SSE, not only controlled the initial geometry of the basin but also shaped the spatial distribution of sedimentary deposits, with maximum thicknesses recorded in the Dinga and Moul depressions. The originality of this study lies in highlighting a marked lateral structural variation from north to south of the block: The basin goes from a relatively symmetrical graben in the north, limited by major faults, to an asymmetrical half-graben system in the center and south, where the western fault becomes predominant in controlling sedimentary accommodation. The reactivation of Cretaceous-Paleogene faults during the second phase of rifting generated a dense network of secondary faults in Y and X configurations, particularly developed in the Fan and Dinga zones. These recurrent tectonic events, associated with localized compressive episodes manifested by reverse faulting and flower structures, indicate a more complex geodynamic evolution than a simple linear extension model. The observations are consistent with, but do not demonstrate, a change in the direction of extensional stresses during the Paleogene, shifting from pure west-east extension to oblique south-southwest to north-northeast extension with a possible transtensional strike-slip component. This is proposed as a working hypothesis that may partly explain the observed structural heterogeneity; testing it requires 3D data, fault-plane mapping, throw analysis, or independent kinematic indicators. This interpretation provides a working framework that may help to understand the distribution of structural and mixed traps within the block.

The Agadem block illustrates the complexity of polyphasic intracontinental rift basins, where deep structural heritage, successive tectonic reactivations, and possible spatial variations in the stress regime shape a mosaic architecture. The perspective opened up by this work concerns, on the one hand, fault-seal and transmissibility analysis, throw analysis, and 3D seismic data to test fault Kinematics and the role of faults as conduits or seals, together with the 3D numerical modeling of the basin's tectonic evolution and, on the other hand, the application of seismic attribute techniques for a more detailed characterization of the deep Up-

per Cretaceous reservoirs, which remain largely unexplored in the block.

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Author Contributions

Alpha, D.I.: Conceptualization, methodology, investigation (seismic interpretation), writing, original draft, and visualization. Konaté, M.: Supervision, validation, and review & editing. Alfazazi, I.M.: Formal analysis and review & editing. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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