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ARTICLE

# Synsedimentary Deformation Characterization of Niamey Sandstones in the Tondibia Area (Man Shield Northeastern Margin, Western Niger, Region of Niamey)

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## ABSTRACT

Niamey sandstones belong to a group of formations of Neoproterozoic-age, located on the Man shield northeastern margin. They sporadically outcrop along the Niger river valley. These geological formations, which occupy a central position in relation to the Taoudenni basin (further north) and the Voltas basin (further south), share similarities with the formations of the aforementioned basins. The research objective is to determine the synsedimentary deformation that has affected these Niamey sandstones in the Tondibia area. The methodological approach used focuses, firstly, on field measurements of synsedimentary deformation structures, and secondly, on projecting these measurements into the Win-Tenseur program in order to calculate stress tensors ($\sigma1$, $\sigma2$, $\sigma3$). Synsedimentary deformations appear during the early stages of lithification, i.e. when the sediment is still loose and contains a high percentage of water. The analysis of these deformations is of great interest for the tectonic-sedimentary analysis of basin deposits. Deformation analysis reveals that the synsedimentary deformation phase affecting the Niamey sandstones is characterized by a NNW-SSE to NNE-SSW direction of elongation. This phase of deformation is marked in the field by normal faults with an average orientation of N80°. This extensive episode is concomitant with the extension of the Neoproterozoic Ocean (870 to 800 Ma).

***Keywords:*** Synsedimentary deformation; Normal faults; Neoproterozoic Ocean; Niamey region; Niger

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ARTICLE INFO

Received: 12 June 2024 | Revised: 27 August 2024 | Accepted: 4 September 2024 | Published Online: 18 September 2024

DOI: https://doi.org/10.30564/jees.v6i3.6750

CITATION

Maharou, H.I., Idi, K.L., Ganiou Amadou, S.A., Konaté, M., 2024. Synsedimentary deformation characterization of Niamey sandstones in the Tondibia area (Man shield northeastern margin, western Niger, region of Niamey). 6(3): 104-110. DOI: https://doi.org/10.30564/jees.v6i3.6750

# 1. Introduction

"Niamey sandstones", named by [1], are attached to a group of sporadically arranged Neoproterozoic-age formations on the Man shield northeastern margin, following the Niger River [1–4]. These sandstones are similar to the Neoproterozoic formations of the Voltas and Taoudenni basins [1, 5]. Based on [1], these two West African basins were connected during the Infracambrian. From north to south, the following outcrops can be distinguished: Firgoun sandstone (in the Firgoun region), Gassa sandstone (in the Gassa region), Niamey sandstone (in the Niamey region) and Kirtachi sandstone (in the Kirtachi region) (**Figure 1**).

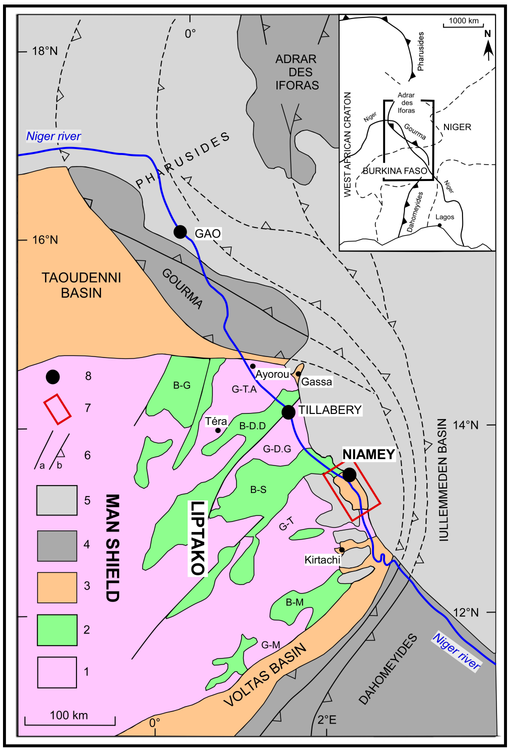


**Figure 1.** Liptako geological formations [5]. (1) Paleoproterozoic-age granitoids. (2) Paleoproterozoic-age greenstones. (3) Neoproterozoic to Paleozoic-age deposits. (4) Pan-African-related deposits (around 600 Ma). (5) Mesocenozoic to Quaternary-age deposits. (6) Fractures or thrust faults (a) and overthrusts (b). (7) Study area. (8) Towns. B-G: Belt of Gorouol; G-T.A: Granitoid of Téra-Ayorou; B-D.D: Belt of Diagourou-Darbani; G-D.G: Granitoid of Dargol-Gotheye; B-S: Belt of Sirba; G-T: Granitoid of Torodi; B-M: Belt of Makalondi; G-M: Granitoid of Mossipaga.

Niamey sandstone deposits (Niamey region) are located on both banks of the River Niger [1]: on the left, the Tondibia deposits and on the right, the Karey Gorou deposits (**Figure 2**).

These are deposits, mainly fine to medium quartzite sandstones [1–3, 5]. These are sandstones deposits younger than the Paleoproterozoic (Birimian) basement, on which they rest in major unconformity, and older than the Terminal Continental 3 and Quaternary deposits, which overlie them by a gully unconformity [1–3, 5, 6].

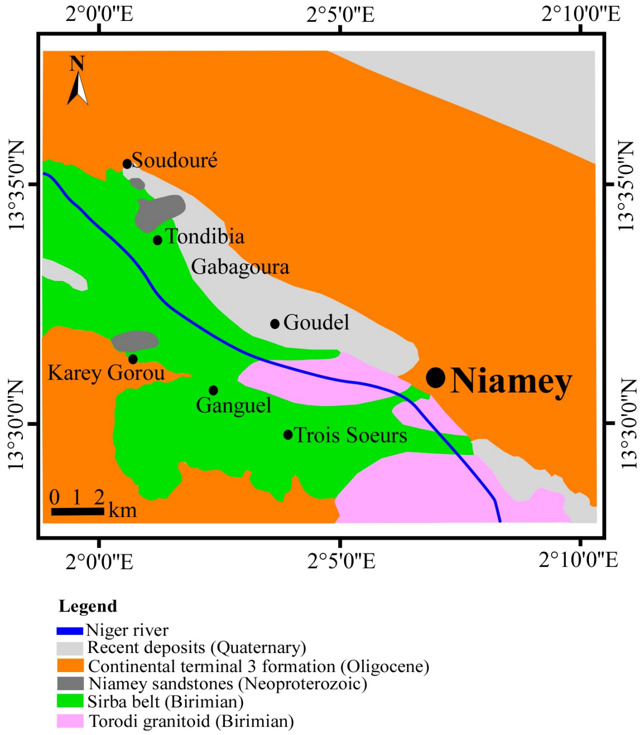


**Figure 2.** Location of the Tondibia and Karey Gorou Niamey sandstone deposits ([1] modified).

Previous work on structural design has shown that two major families of fractures, oriented N20° and N135°, that affected the Niamey sandstone deposits in the Karey Gorou sector [7].

- An extensive NNW-SSE submeridian phase, resulting from the reactivation of Mesoproterozoic fractures (around 1400 Ma) during the Pan-African cycle;
- Three compressive phases of NNW-SSE, WNW-ESE, ENE-WSW direction, matches respectively the Pan-African deformation stages D1 (680 Ma), D2 (600 Ma) and D3-D4 (560–530 Ma) described in the Pharusides and Dahomeyides by [8] and [9].

Unlike the Karey Gorou area, previous work on the Niamey sandstones has not revealed any deformation phases in the Tondibia area. Focusing on the analysis of synsedimentary deformation of the Niamey sandstones, the present study aims to fill this gap in the Tondibia sector. In particular, this project is designed to characterize:

- the directions and dips of the main synsedimentary fault planes;
- the deformation phase that generated these synsedimentary faults.

## 2. Geological setting

Niamey area belongs to the Niger Liptako province, which lies on the northeastern border of the Man Dorsal (Paleoproterozoic area)[1, 5, 6, 10].

Liptako is delimited respectively to the North, East and South-East by the Gourma Basin, the Iullemmenden Basin and the Voltas Basin (**Figure 1**). Two main geological formations stand out in this province:

(1) the Paleoproterozoic basement (age between 2300 and 2000 Ma[11]), which occupies most of the region[1, 12–18]);

(2) sedimentary deposits including: Neoproterozoic-age deposits (Niamey sandstone deposits), Oligocene-age deposits (Continental Terminal 3 (Ct3) deposits) and Quaternary-age deposits[1–6].

### 2.1 Paleoproterozoic formations

Paleoproterozoic formations of the Niger Liptako area are characterized by greenstone belts alternating with granitoid plutons[1, 1, 1, 2, 11, 12] (**Figure 1**).

Greenstone belts include metabasalts, amphibolites, granitic rocks (ultramafic to mafic), talchists, chloritoschists, sediments and metamorphosed volcanic sediments[1, 1, 11–14].

The granitoid plutons are mainly composed of granites, TTG (Tonalite, Trondhjemite, Granodiorite), diorites and quartz diorites, monzonite and syenite[1, 11, 14, 15]. From northwest to southeast, the following belts and plutons can be distinguished (**Figure 1**): Gorouol belt, Téra-Ayorou pluton, Diagorou-Darbani belt, Dargol-Gothèye pluton, Sirba belt, Torodi pluton, Makalondi belt, Fayra-Mossipaga pluton.

### 2.2 Sedimentary cover

#### *Neoproterozoic formations of the Niamey sandstones*

In western Niger, the Neoproterozoic formations are located on the eastern part of the West African craton. From north to south, they are found respectively in the regions of: Firgoun (Firgoun sandstone), Gassa (Gassa sandstone), Niamey (Niamey sandstone, subject of the present study) and Kirtachi (Kirtachi sandstone)[1].

From base to top, three facies can be distinguished in the Niamey sandstones: (1) mamelonitic quartzite sandstones, (2) quartzite glauconitic sandstones and (3) faceted pebble diamictites[1].

#### *Oligocene-age formation (Ct3)*

Oligocene-age deposits constitute the upper levels of the large Iullemmeden basin[16]. From base to summit, three series of deposits can be distinguished: (1) the siderolithic series of the Ader Doutchi (Continental terminal 1 (Ct1)), the lignite-bearing sandy-clay series (Continental terminal 2 (Ct2)) and the clayey sandstone series of the Middle Niger (Continental terminal 3).

Ct3 is the only Continental Terminal series found in the Niger Liptako[6, 17, 18]. These are Oligocene deposits[19], comprising clayey sandstones alternating with oolitic ferruginous sandstones showing indurated levels, sometimes associated with termite tubules[6, 17, 18]. Ct3 deposits are found either above Infracambrian-age formations (separated by a gully unconformity) or on Paleoproterozoic-age basement formations (separated by a major unconformity)[2, 3, 6, 17, 18, 20].

#### *Quaternary formations*

Quaternary-age deposits include alluvium, ferruginous lateritic formations (sometimes reworked) and dunes. This package overlies either formations of Oligocene age (separated by a gully unconformity) or basement formations of Paleoproterozoic age[6, 16–18, 21].

## 3. Materials and methods

The methodological approach is based essentially on field work involving measurements of synsedimentary structures. It should be noted that synsedimentary deformation occurs during the early stages of sedimentary, i.e. when sediments contain a high percentage of water[22, 23].

Synsedimentary deformation of the Niamey sandstones, in the Tondibia, area is represented by normal faults. The directions and dips of the main planes of these faults were measured using a clinometer compass; a total of 200 measurements were made. The various measurements obtained were then projected into the Win-Tenseur program[24] (version 5.8.9) by to calculate the stress tensors ($\sigma 1$, $\sigma 2$, $\sigma 3$). These measurements are first entered into a data entry sheet and then processed automatically. Automatic processing produces several results: (1) the projection of the various fault planes measured in the Schmidt diagram[24]; (2) the synthetic result of automatic processing using the so-called optimal stress method (PBT) and that corresponding to automatic processing using the right dihedral method[24]. These two processing results show the distribution of the axes of the calculated stress tensor ($\sigma1$, $\sigma2$, $\sigma3$)) and the average direction of extension[24]. (3) Mohr's circle representation. This representation indicates the mechanical reliability of the proposed solution. It uses a failure criterion[24].

# 4. Results

## 4.1 Deformation analysis

Synsedimentary deformation, in the Tondibia area, is represented by normal faults (**Figure 3**). These normal faults, direction N70° to N110° and inclination 50° to 80° NW. Their slickensides, multi-decimetric to metric, relatively curved, (**Figure 3B**) show several types of slickensides features. These include grooves (**Figure 3C**), striaes (**Figure 3C**), marks left by striating object (**Figure 3D**).

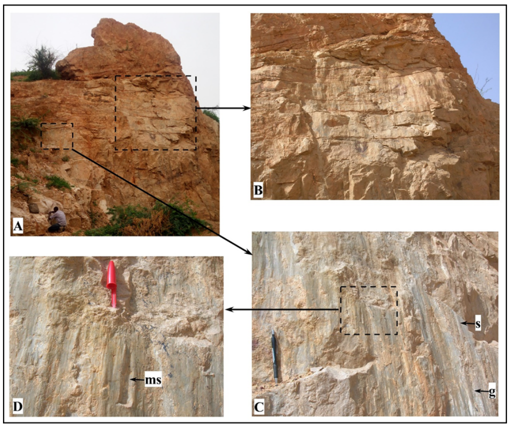


**Figure 3.** Normal synsedimentary faults affecting the Niamey sandstones in the Tondibia area. **A** : Normal faults zone with several slickensides, averaging N75° and inclination 75° NW. **B** : Normal synsedimentary fault with curved slickenside. **C**,**D** : Various types of slickensides features on a normal syn-lithification fault slickenside. s : Striae ; g : Groove ; ms : marks left by striating objects.

Marks left by striating objects have enabled us to deduce the normal directions of the faults observed. The high pitch values observed, between 50° and 80° W or NW, are consistent with the normal directions of these faults. The curved mirrors indicate the high ductility of the material at the time of deformation. These observations confirm the synsedimentary nature of these normal faults.

## 4.2 Paleostress conditions characterizing the deformation phase

Synsedimentary normal faults direction (N70°–N110°) and inclination (50°–80° NW) were projected in the Win-Tenseur program. The stereodiagrams obtained indicate a stress direction $\sigma3$ ranging from N156° to N007° **(Figure 4)**, defining the extensive deformation phase, synsedimentary, of the Niamey sandstones.

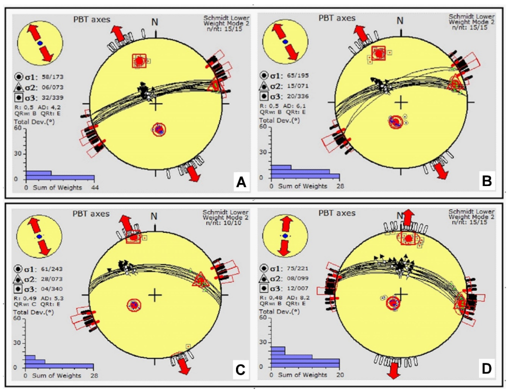


**Figure 4.** Niamey sandstones synsedimentary normal faults treatment results : the stereodiagrams obtained indicate a direction of extension ranging from N156° to N007°. A: N159° (Station 1); B: N156° (Station 2); C: N160° (Station 3); D: N007° (Station 4).

# 5. Discussion

synsedimentary normal faults (mirrors of synsedimentary normal faults) running between N70° and N110° and dipping between 50° and 80° NW. The fracturing study of the Karey Gorou sandstones by[5] yielded a similar result, i.e. submeridian extension (NNW-SSE), as the first deformation phase. In the Firgoun region in Niger,[4] highlighted an extensive (D1) phase running N140° (NW-SE), almost identical to the approximately N160° extensional direction obtained by the present study. In contrast to these results, no extensive deformation phase was highlighted by[25] in the Béli basin in Burkina Faso. However, age and geodynamic context of this period of extension are open to debate. For[5], this submeridian extension (D1) is due to the replay of Mesoproterozoic-age fractures, which had conditioned basin formation during the Neoproterozoic.The genesis of the Taoudenni and Voltas basins thus dates back to the early stages of this reactivation[5]. For these authors, this submeridian (D1) extension is therefore linked to a fragmentation stage of the West African Craton, for which dolerite veins are 1,378 ± 36 Ma old[13]. According to[4], this age, mentioned by[5], is not very consistent. For these authors, sedimentation in the aforementioned basins began around 1000 Ma with the deposition of Supergroup 1[3, 25]. According to[4], the extensive (D1) phase obtained in the Firgoun region is contemporary with the Neoproterozoic ocean formation around 850 Ma[26].

It should also be pointed out that the series of lineaments with N70° to N80° fractures running through the

Guinea plate in Sudan [27] are identical to the lineaments running through the Gourma basin [25]. These major fractures, linked to a deep-seated volcano, would have replayed extensively, involving periods of later extension in the Middle and Upper Liassic, the Upper Jurassic and a period of compression of intra-Eocene age [27]. These extensive post-Neoproterozoic episodes are thought to be linked to the formation of the South Atlantic, and the episode linked to intra-Eocene age compression is thought to be the result of the African-European collision [25]. These various studies show that the first phase of extensive D1 deformation, probably pre-Pan-African, was concomitant with the opening of the Neoproterozoic ocean, which is thought to have occurred between 870 and 800 Ma [26]. However, these results reflect the first phase of syn-sedimentary deformation that affected the Niamey sandstones. Further investigations are required to analyze syn- to post-lithification and post-lithification deformation.

## 6. Conclusions

The analysis of synsedimentary deformation is of great interest for the tectonic-sedimentary analysis of basin deposits. In the case of the Niamey Neoproterozoic sandstones in the Tondibia erea, this deformation is characterized by a NNW-SSE to NNE-SSW direction of extension. In the field, this synsedimentary deformation of the Niamey Neoproterozoic sandstones is materialized by normal faults with a mean orientation of N80°. This extensive, pre-Pan-African episode is concomitant with the formation of the Neoproterozoic Ocean, around 850 Ma.

## Author Contributions

Hassan Ibrahim Maharou: Chief of Investigation, fieldworks, data analysis, cartography and writing manuscript leader, Karimou Laouali Idi: Permanent assistant during fieldworks, data analysis and cartography operations, Salissou Abdoul Ganiou Amadou: Permanent assistant during fieldworks, data analysis and cartography operations, Moussa Konaté: Research supervisor and permanent assistance during manuscript writing.

## Conflict of Interest

No conflict of interest.

## Funding

This research received no external funding.

## Acknowledgments

This work was supported by the Department of Geology of Abdou Moumouni University of Niamey, Niamey, Niger.

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