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(Review Article)

Structural relationships of the younger granites of Tirmini (Damagaram south-east, Niger)

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Abstract

The Tirmini anorogenic ring complex is located approximately 25 km west of the town of Zinder, in the pan-African province of Damagaram-Mounio, the southeastern terminus of the Benin-Nigeria Shield. The aim of this study is to characterise the anorogenic deformation affecting the Tirmini younger granites. The petrography of Tirmini evolves from rhyolites to microgranites, granites and quartz alkaline syenite emplaced during anorogenic magmatism in the Permian (295 Ma). Very little structural data is available on the Tirmini complex. Only a cursory study of deformation has been carried out, without characterisation of the stages of anorogenic deformation or structural interpretation. The aim of this study is to characterise the structural evolution of the Tirmini younger granites. The methodology used is based on the exploitation of satellite imagery and mapping, supported by an analysis of deformation carried out in the field using Canvas software. The geological structures revealed include 360° schistosities, fracture schistosities, detachments (dexter and sinistral) anµ diaclases. The rheology of these structures has revealed two chronologically marked stages of anorogenic deformation (i) semi-ductile to brittle, Sd1, and (ii) frankly brittle, Sd2. The first stage of deformation is contemporaneous with magmatic activity, producing 360° schistosities linked to magma swelling and fracture schistosities (S1: N45°-N60° and S2: N75°-N95°) associated with the emplacement of granites and syenite. The second brittle stage, Sd2, is characterised by a system of conjugate dextral and sinistral detachments and two families of diaclases (F1: N45°-N60° and F2: N120°-N150°) associated with the emplacement of the pluton and the cooling of the magma.

Keywords: Younger granites; Tirmini; Damagaram-Mounio; Niger-Nigeria province; Magmatic deformation

1. Introduction

The Paleozoic to mesozoic province of Niger-Nigeria is considered to be an impressive example of continuous anorogenic complexes over 1300 km in a continental environment, with a progressive decrease in age from the Aïr in the north to the Jos plateau in the south [1]–[10]. The intraplate felsic magmatism of the Damagaram-Mounio province, emplaced along the submeridian lineaments of Raghane[11], forms an important link between the younger granites of the Aïr in the north and those of Nigeria in the south. Paleozoic magmatism in Damagaram began in the Carboniferous with the emplacement of the Badaraka, Zinder and Zarnouski younger granites and ended in the Permian with the emplacement of the Gouré younger granites [1], [6], [12]. The present study focuses on the Tirmini complex, which has been the subject of many studies. The Tirmini complex has been extensively studied from the petrological, geochemical and geochronological points of view [1]. Very little structural data is available on the Tirmini complex. Only a summary study of deformation has been carried out [13], without characterisation of the stages of anorogenic deformation or

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structural interpretation. The aim of this study is to characterise the structural evolution of the Tirmini younger granites in order to specify the anorogenic deformation associated with them.

1.1. Geological context of Tirmini

The Tirmini complex (Figure 1) is one of a dozen complexes in the Damagaram, a province that represents the north-eastern terminus of the Benin-Nigeria shield [14], [15]. The Damagaram also corresponds to the southern trans-saharan segment of the Pan-African chain that extends from the Hoggar in the north to the Gulf of Benin in the south [14], [16]–[19]. The Tirmini host rock is the peralkaline Zinder massif, a riebekite granite emplaced in the Carboniferous at 330 Ma. From a lithological point of view, two magmatic lines have been identified at Tirmini [1]. The first line is characterised by a petrographic sequence ranging from alkaline rhyolite to alkaline microgranite, granite and alkaline quartz syenite. Of peralkaline chemism, the second lineage evolves from comenditic rhyolite to peralkaline microgranite and peralkaline granite. According to [1], this petrographic evolution in each of the two lines, is typical of a petrogenetic model based on subsidence : volcanic phase, hypovolcanic phase and plutonic phase. These petrographic formations are overlain by (i) Hamadian sandstones of Cretaceous age and (ii) Quaternary alluvium [20] (Figure 1).

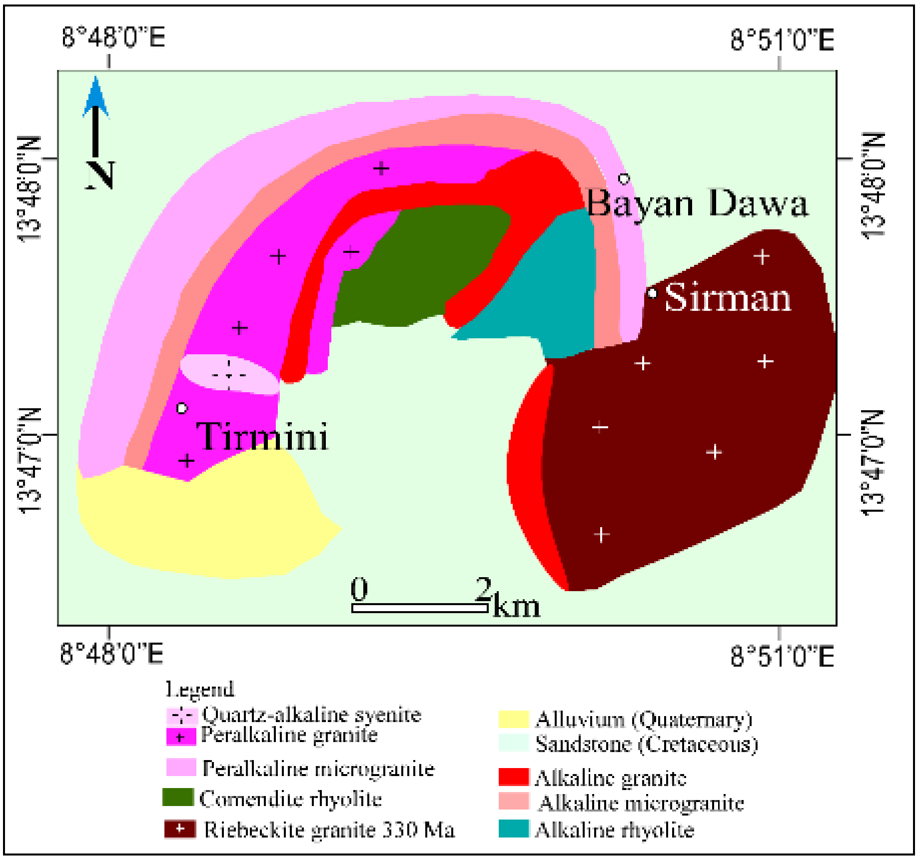

Figure 1 Geological map of the Tirmini ring complex [1]

2. Methodological approach

The methodology implemented is based on the use of satellite imagery and mapping supported by an analysis of deformation carried out in the field (structural measurements) and using Canvas software. The structural measurements were taken using a compas and a clinometer. A total of 400 measurements were taken on fracture schistosities and 100 on diaclases. These measurements were used to characterise the different stages of deformation. Lineament mapping is a technique that consists of determining the major orientations of the structures on the one hand, and validating the measurements carried out manually on the other. The image processing results from [21] were used and the exercise involved extracting the study area from the processed image covering the entire Damagaram province. ENVI 4.1 (Environment for visualising image) software was used to analyse and process the satellite images. ArcGIS 10.8 GIS software was used to vectorise (digitise) the information extracted from the Landsat 8 image, overlay the information layers and produce the lineament map.

3. Results

3.1. Structural analysis

The geometry of the Tirmini complex is the result of emplacement in an extensive anorogenic context marked chronologically by deformation structures with semi-ductile to brittle rheology. The deformation structures include 360° schistosities, fracture schistosities, dexter & sinistral conjugate detachments and diaclases. The rheology of these structures indicates that they were emplaced in an extensive context. Field observations did not reveal any clearly ductile deformation, nor any distortion of the structures characteristic of stress (orogeny). This explains why the deformation structures revealed at Tirmini are anorogenic. Taking into account the rheology of the different structures, two stages of deformation were identified: a semi-ductile to brittle stage (Sd1) and a frankly brittle stage (Sd2).

3.2. Semi-ductile to brittle deformation stage, Sd1

The first stage of deformation, Sd1, is characterised (1) by schistosities in the granites (Figure 2a). These schistosities describe a variation of orientations ''N65°, N90°, N130°, N115°'' showing a 360° contour. This is linked to the swelling of the magma, demonstrating that the 360° schistosities are contemporary with magmatic activity. The Sd1 is also characterised (2) by fracture schistosities, mainly in the rhyolites. These schistosities are linked to the emplacement of granites and syenites. The geometric relationships between the fracture schistosities have revealed two generations of schistosity (Figure 2b). The first generation S1, the most dominant at Tirmini, trends N70° to N100°. It is intersected by S2, which trends N40° to N60°.

3.3. Brittle deformation stage, Sd2

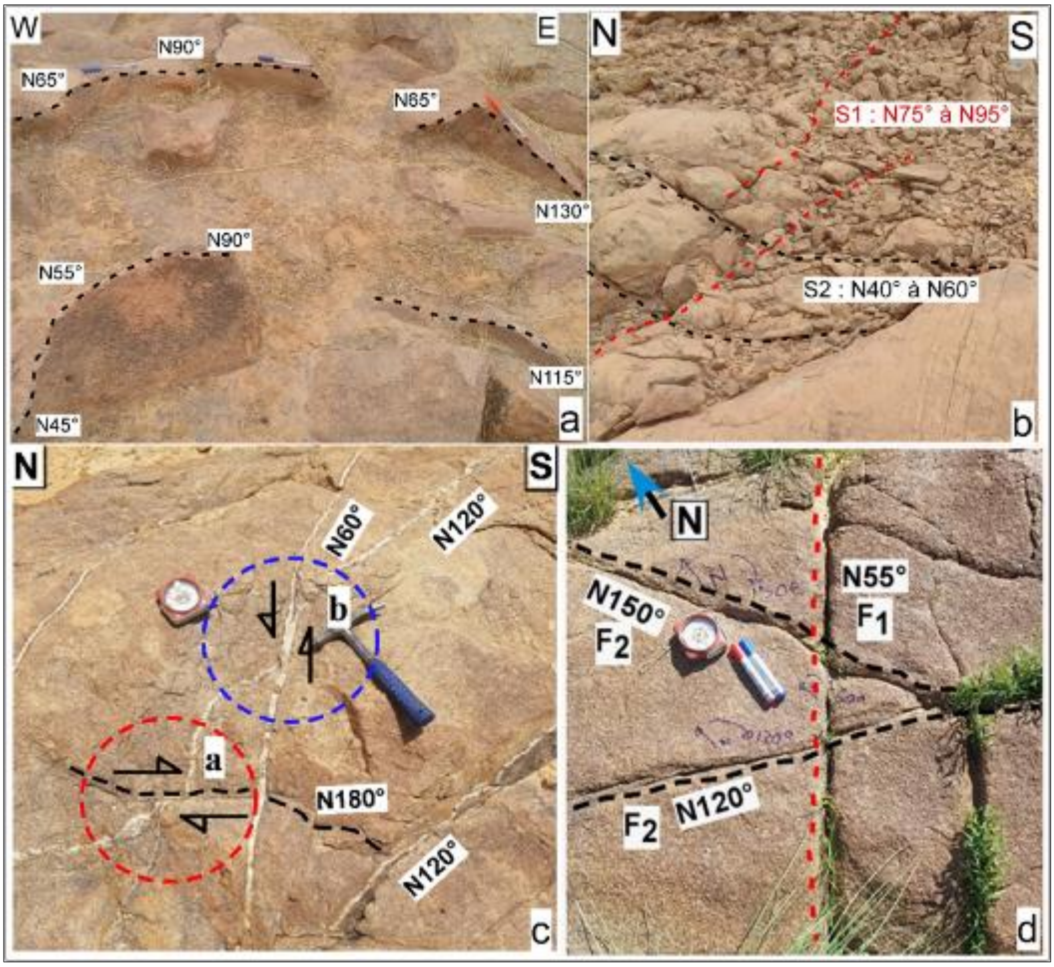

Figure 2 Geological structures revealed in the younger granites of Tirmini. a: 360° schistosities showing an annular outline; b: fracture schistosities; c: dextral (red) and sinistral (blue) step-offs; d: diaclases

The brittle deformation stage Sd2 is characterised by a system of conjugate dextral (E-W) and sinistral (ENE) detachments locally clogged by quartz occurrences (Figure 2c). The brittle nature of these structures indicates that they were emplaced in an extensive context. Similar structures have been found in granites (Figure 2c). This brittle stage is also characterised by two families of diaclases (Figure 2d), designated F1 (N45° to N60°, dip: N55° to the SE) and F2 (N120° to N150°, dip: N30° to the NE). These structures have been demonstrated in the granites.

3.4. Linear analysis

Satellite imagery was processed by [21] for the entire Damagaram province, from lithology mapping using supervised classification to aeromagnetic image processing. Extraction of the study area was used to characterise the lineament networks in the study area **(Figure 3)**. Analysis of all the fractures revealed two main directions corresponding to diaclases at Tirmini: NE-SW and NW-SE and fractures at Badaraka: NE-SW and NW-SE. These types of structures are identical to the directions measured in the field. These two major directions have been extensively described in the Aïr [22] and Fobur in northern Nigeria [23].

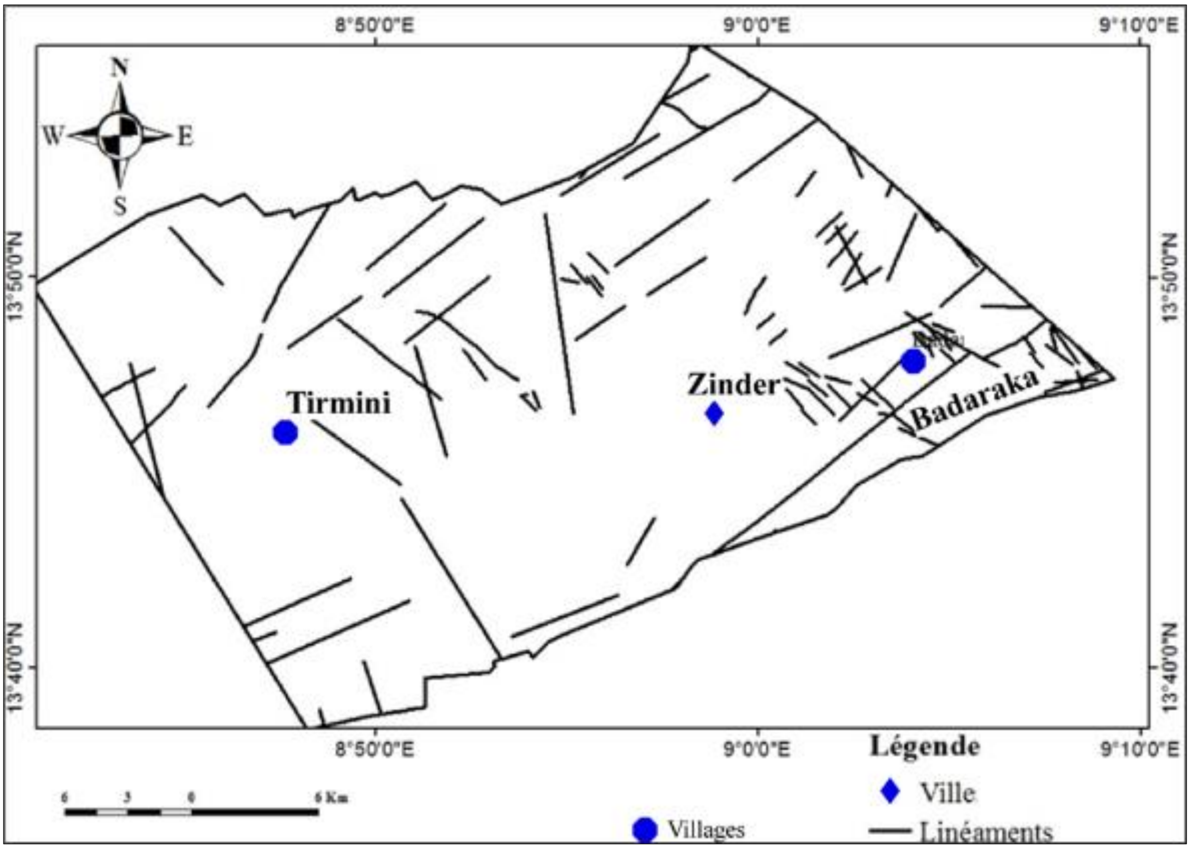

Figure 3 Linear map deduced from Landsat 8 images and aeromagnetic images of the study area

4. Discussion

Processing of the structural data from the Tirmini complex has revealed two stages of deformation: (i) a semi-ductile to brittle stage and (ii) a frankly brittle stage. The deformation structures associated with these two stages include 360° schistosities, fracture schistosities, conjugate sinistral and dextral decays and diaclases. On the other hand, at Mounio, on the basis of the presence of fiammes,[6] highlighted a third stage of deformation (ductile stage). The semi-ductile to brittle behaviour of the geological structures shows that the Tirmini younger granites were discovered in an extensive anorogenic context. This same context has been proposed for the Aïr younger granites [9], [22], of the Damagaram younger granites [1], [4], [6] and Fobur in northern Nigeria [23]. However, schistosities describing a 360° contour are characteristic of the emplacement of a pluton. Such structures are comparable to the schistosities highlighted on the Palaeoproterozoic pluton in Burkina [24]. The annular contour (360°) suggests that these schistosities are contemporary with magmatic activity, whereas the fracture schistosities are associated with the emplacement of granites and quartz alkaline syenite. The diaclases can be interpreted as the product of the cooling of anorogenic magma.

Many authors agree that after the Pan-African orogeny, the emplacement of younger granites was favoured by deformation structures with semi-ductile to brittle rheology [22], [25].

5. Conclusion

Based on the semi-ductile to brittle rheology of the geological structures, two stages of deformation have been revealed at Tirmini: (i) semi-ductile to brittle stage of deformation and (ii) brittle stage of deformation.

- The first stage of deformation, Sd1, is characterised
  - By schistosities describing a 360° contour linked to the swelling of magmas. These schistosities are contemporary with magmatic activity. It is also characterised
  - By two generations of fracture schistosities (S1: N45°-N60° and S2: N75°-N95°) associated with the emplacement of granites and syenites.
- The second stage of deformation, Sd2, is characterised
  - By a system of conjugate detachments (dextral E-W and sinistral ENE-WSW) and
  - By two families of diaclases (F1: N120° to N150° and F2: N45° - N60°) associated with the emplacement of the pluton and the cooling of the magmas.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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