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Original Paper

Contributions of Aeromagnetic and Field Surveys to Geological and Structural Mapping of Pan-African Province of South Maradi, Southern Niger

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Abstract

This study focused on geological and structural mapping of Pan-African Province of South Maradi by using the aeromagnetic and filed surveys. The study zone corresponds to the northern part of the Benin-Nigerian Shield, belonging to the Pan-African mobile zone in the East of West African Craton. Previous geological work dates from the 1970s and limited to the summary geological map. According to this work, basement formations crop out discontinuously and are not subject by a structural study. In addition, the use of this map reveals a problem of correlation between the geological contours described on the existing map and those observed in the field. A combined analysis of aeromagnetic and field data led to complete then correct the petrographic and structural gap existing in the previous summary geological map since 1970s, which allowed to produce a new geological and structural map of studied zone (South Maradi Pan-African province). Petrographic and structural analysis of this new map shows that the spatial distribution of geological formations is characterized by the alternating Schist Belts and mylonitic gneiss Shear zones associated with migmatites panels and granitoïd intrusions. Thus, the different petrographic facies mapped are represented by schists-micaschist, mylonitic gneiss, migmatitic gneiss and intrusive porphyric granites. Previous data revealed a petrographic and structural continuity between South Maradi Pan-African formations with those of contiguous Pan-African province of North Nigeria.

Keywords

Aeromagnetic surveys, Field work, Geological mapping, Schist Belts, Shear Zones, Pan-African Province, South Maradi, Niger

1. Introduction

The South Maradi basement represents the northern part of the Benin-Nigerian Shield, belonging to the Pan-African mobile zone in the East of West African Craton (WAC, Fig. 1a). Previous geological work was limited to the summary geological map of South Maradi (Fig. 1b, Mignon, 1970). According to this map, the South Maradi basement formations (magmatic and metamorphic rocks) outcrop discontinuously along the border with Federal Republic of Nigeria. The basement formations disappear northwards under the Hamadian Continental sedimentary cover. In addition to this work, aeromagnetic mapping (PRDSM, 2005) highlights the existence of major ductile deformation structures such as ductile shear zones. Thus, two cartographic problems were identified between these pre-existing maps and field observations. The first one is that the ductile shear zones described by the aeromagnetic map (PRDSM, 2005) were not represented on the summary geological map of Mignon (1970). The second problem is related to the mismatch between the geological contours represented on the geological map (Mignon, 1970) and those observed during the fieldwork. This study aims of to fill in these gaps and produce a new geological and structural map of the studied area. To achieve this objective, a methodological approach integrating aeromagnetic data interpretation combined with geological field surveys was implemented.

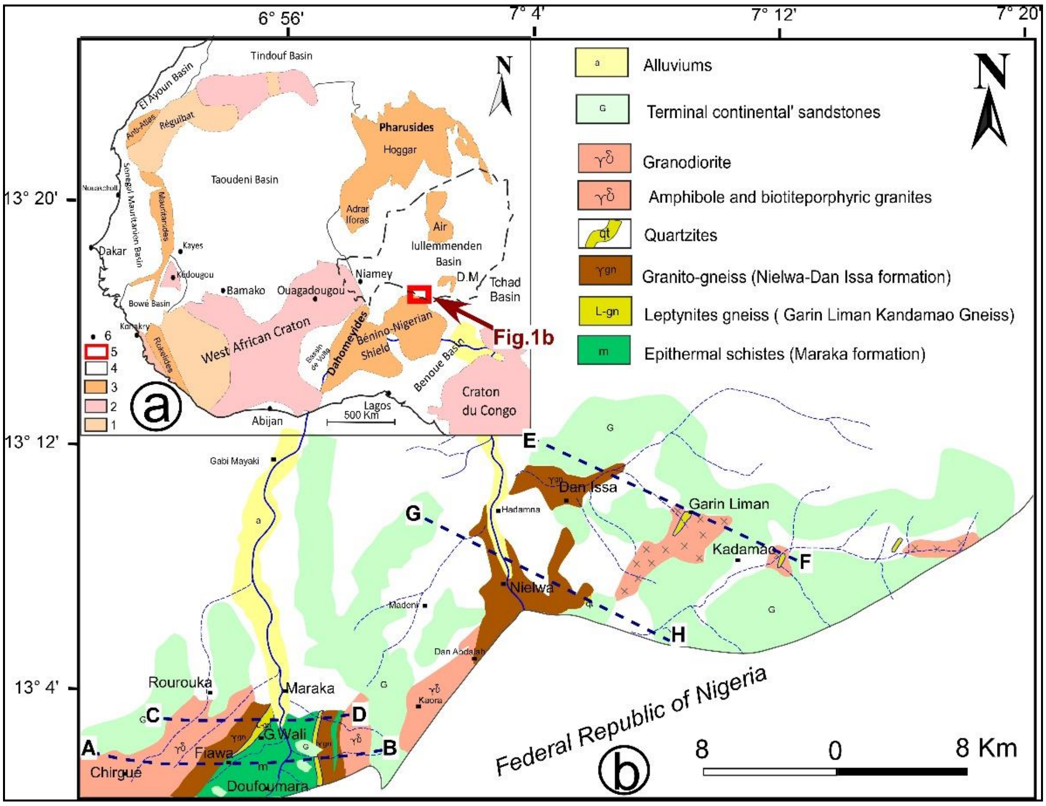

Figure 1. Location of the Study Area within the Simplified Geological Map of West Africa (Fig. 1a, after Trompette (1973), modified). Geological Map of South Maradi (Fig. 1b, after Mignon (1970))

Note. Legend figure 1a: 1: Archean; 2: Birimian; 3: Pan-African mobile zones; 4: Neoproterozoic to Paleozoic sedimentary basins; 5: study area; 6: towns.

Legend figure 1b: γδ: granodiorites; gn: granitogneiss; L-gn: leptynites and fine banded gneiss; m: epi-metamorphic schists; G: Cretaceous and Continental Terminal sandstones; qt: quartzite and sandstones; a: clay alluvium.

2. Method

The methodological approach integrates the interpretation of pre-existing cartographic data, particularly the geological map of South Maradi (Mignon, 1970) and the aeromagnetic map PRDSM (2005), supplemented by geological field surveys carried out in the case of this study.

2.1 Field Work

The field work consisted of geological cross-sections, petrographic descriptions and structural measurements of encountered formations. The geological cross-sections were surveyed perpendicularly to the major structures, which are oriented NE-SW or E-W (Fig. 2). Along each cross-section, the formations encountered were studied. This stage aimed to determine the different geological contours, describe the identified petrofacies and measure their geological structures. The summary geological map of South Maradi produced by Mignon (1970) was used to plot the obtained petrographic and structural data obtained during the field work.

2.2 Aeromagnetic Survey

Well known for mapping sub-surface structures (Grauch et al., 2006), the aeromagnetic map of the area (PRDSM, 2005) are used to get a good correlation between geological structures and petrographic facies described during the field survey. Therewith, the structural interpretation of the aeromagnetic map (PRDSM, 2005) allowed a better interpretation of the tectonic structures (Fig. 2b). The compilation of cartographic data (Mignon, 1970) and (PRDSM, 2005) and field data into the Geographic Information System (GIS), WGS. 1984, enabled to modify and complete the summary geological map (Mignon, 1970). The approach led to produce the new geological and structural map of this northern part of Benin-Nigerian shield.

3. Result

3.1 Structural Interpretation of Cartographic Data

This step included combining the geological map (Fig. 2a, Mignon, 1970) and the aeromagnetic map (PRDSM, 2005), all of the studied zone. The geological map (Fig. 2a) shows discontinuous basement outcrops unaffected by a preferential orientation structures. The structural continuity of geological formations, not identified on the summary geological map (Fig. 2a), was deduced from the total aeromagnetic field map (Fig. 2b). The extraction of magnetic lineaments from this map revealed the existence of major ductile shear zones forming a NE-SW trending beam. These shear zones are cutted by a posterior NW-SE-trending fracture systems affecting the region (Fig. 2b). The petrographic interpretation of aeromagnetic map of South Maradi (Fig. 2c, PRDSM, 2005) has shown three major lithostratigraphic units: the Garin Wali gneissic and migmatitic complex (BAggn et BAmig), the Maraka Schist Belt (MSpmt) and the Pan-African granitoïds (PAgrn) represented by Chirgué, Nielwa-Dan Issa mylonitic gneiss, showing a relative petrographic continuity with summary geological map (Fig. 2a, Mignon, 1970).

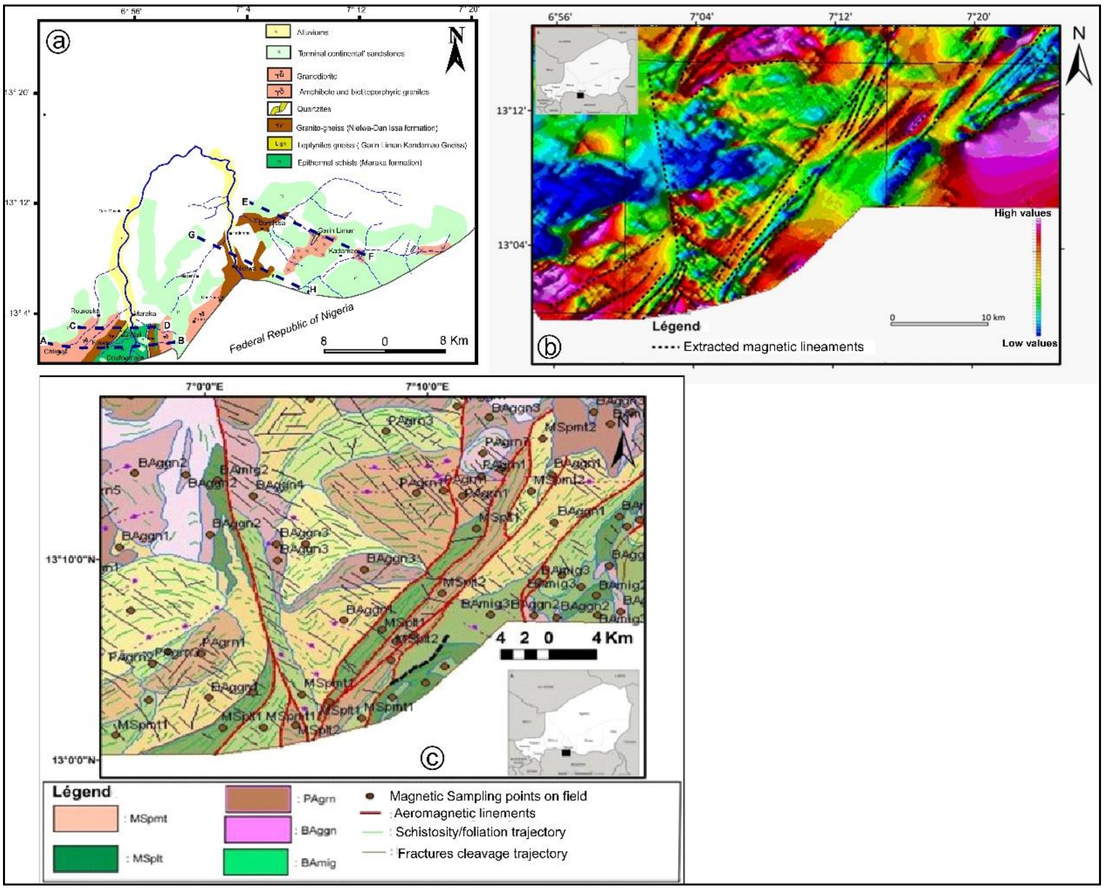

Figure 2. Compilation of Cartographic Data

Note. (a) Geological map (from Mignon, 1970) showing the discontinuous basement formation, (b) aeromagnetic map (PRDSM, 2005), showing a continuity of magnetic lineament in sub-surface, (c) pseudo-geological map from interpretation of magnetic map (PRDSM, 2005).

3.2 Petrographic and Structural Interpretation of Field Data

The petrographic and structural analysis of four surveyed cross-sections (A-B, C-D, E-F and G-H, Fig. 3) in the study area provided an idea on the deep distribution of the geological formations, as well as their geological structures (Fig. 3). Indeed, the distribution of geological formations shows a gradual transition from gneiss to migmatites (Fig. 3). The schists form a NE-SW bands alternatively juxtaposed with gneissic shear zones trending in the same orientation (Fig. 3). The correlation between the corresponding geological contours identified on the cross-sections, allowed to correct the poor outcrop quality highlighted on the summary geological (Fig. 2a) and produce a new geological map of the study area (Fig. 4). Four schist belts, alternating with four gneissic shear zones, were mapped and named according to the different localities where outcrops are most important (Fig. 4). From Southwest to Northeast, one can observe the Maraka Schist Belt (MSB), the Goumata Schist Belt (GSB), the Garin Liman Schist Belt (GLSB) and the Mai Dabaro Schist Belt (MpSB). The four gneissic shear zones cartographied are: the

Fiawa-Garin Wali Shear Zone (FGSZ), the Goumata shear zone (GSZ), the Nielwa-Dan Issa Shear Zone (NDSZ) and the Garin Liman shear zone (GLSZ) (Fig. 4). These two lithofacies of metamorphic rocks are intruded by undeformed granitoïds.

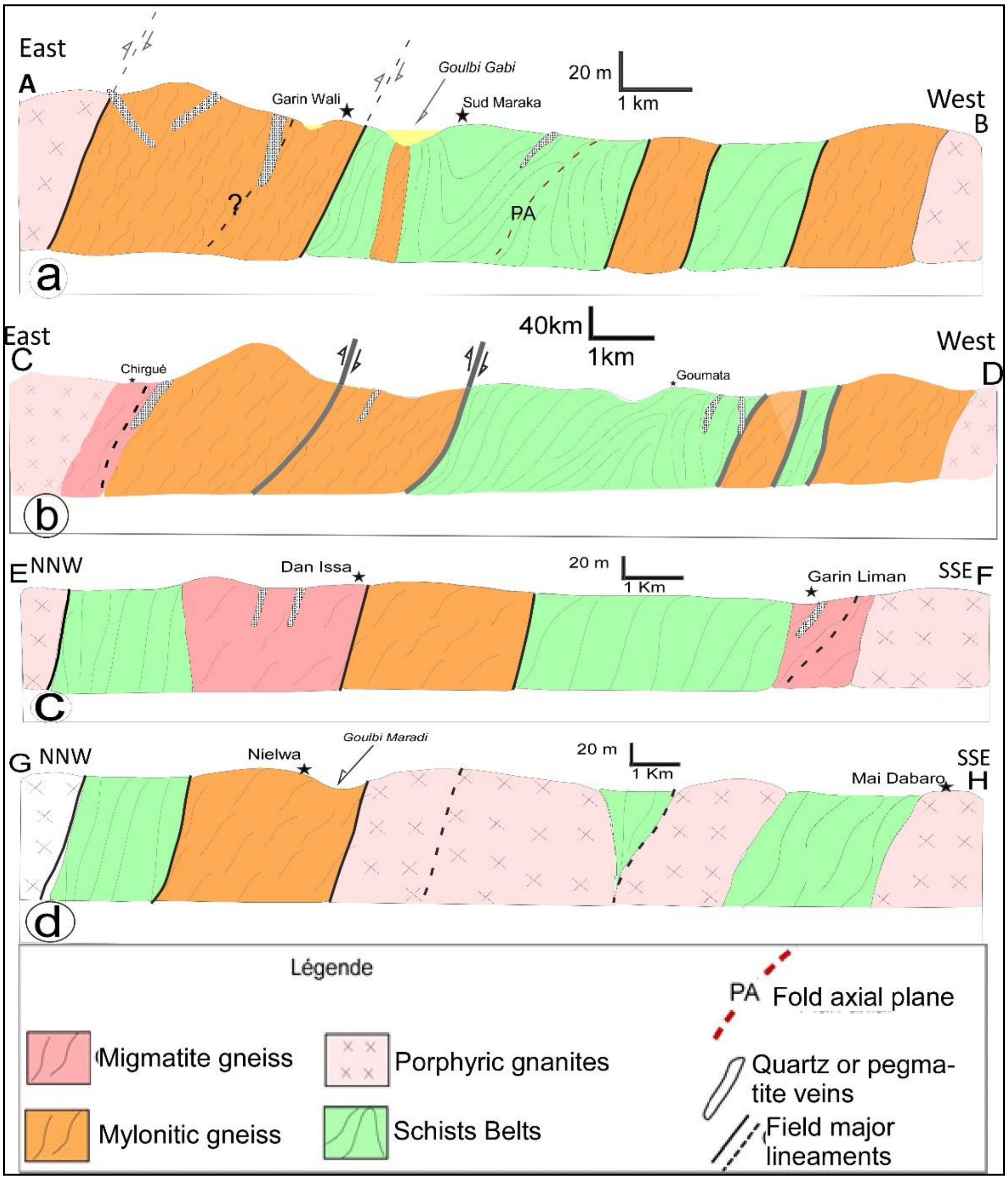

Figure 3. Different Cross-Sections Surveyed from Field Work: Cross-Sections A-B of Chirgué-Goumata, C-D of Garin-Wali-Maraka, E-F of the Dan Issa Gari Liman area and G-H of Nielwa-Maidaparo

3.3 Petro-structural Study of Mapped Outcrops

The different petrographic facies mapped during this study are: schist belt rocks, mylonitic gneiss, migmatitic gneiss and intrusive porphyry granites.

3.3.1 Migmatite Gneiss of South Maradi

In the South Maradi basement, the migmatites gneiss outcrop in a several petro-facies including (Fig. 4): paleosomes of porphyritic gneiss, neosomes of aplitic granites and melanosomes of biotitic restites. The presence of leucosomes and melanosomes indicates that metamorphism has reached higher degrees of amphibolite facies to granulite facies (Ferré et al., 2002).

In the Garin Liman migmatites, paleosomes are affected by anisopac folds with widely dispersed fold axes (Fig. 5a), showing a transition to anatexis granites (neosome). This petrofacies is pink to gray color (Fig. 5a). It consists of quartz, white centimetric crystals of feldspars and black beds of biotite, defining a disturbed foliation having several orientation varying from N30° to N50° (Fig. 5a). The Chirgué melanosomes (Fig. 2) correspond to biotite enclaves in the porphyritic gneiss parleosomes (Figs. 5b and 6). These enclaves correspond to assemblages of biotites, corresponding to a solid residue of partial melting (biotitic restites). The occurrence of large automorphous feldspar crystals in this solid residue (biotite melanosomes, Fig. 6-b) reveals the porphyritic nature of the initial magmatic rock.

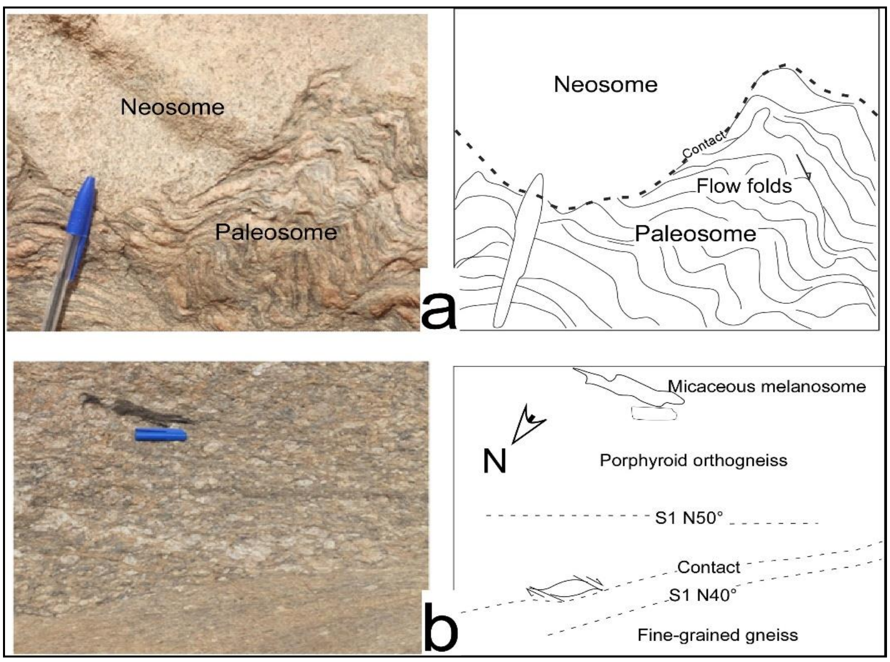

Figure 4. Outcrop Aspect of Garin Liman Migmatitite Gneiss (a) and Chirgué Migmatites (b)

Note. (a): Paleosome affected by anisopac folds, with strong dispersion of fold axes in contact with an undeformed neosome. The paleosome-neosome contact is concordant. (b): Porphyritic gneiss (diatextites) contain micaceous melanosomes of biotite.

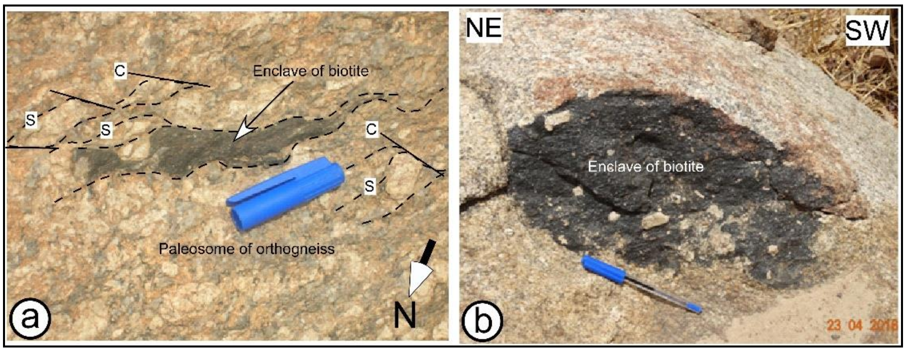

Figure 5. Enclaves of Chirgu ébiotite Enclaves in a NE-SW Shear Zone: S: Foliation Trajectory, C: Shear Plane

3.3.2 Schist Belt Rocks

In the South Maradi, the rocks of the schist belt outcrop in the directions varying from N40 ° to N50 ° (Fig. 7). These rocks are represented by sericite to chlorite schists and, rarely micaschists. These grey to green schists contain fined crystals of sericite and chlorite, quartz, K-feldspar as well as biotite and muscovite, defining a schistosity disturbed by synschistosity quartz veins (Fig. 7b). Some schist outcrops show the folded schistosity planes with vertical axial to subhorizontal axial plane of folds (Fig. 7c-d).

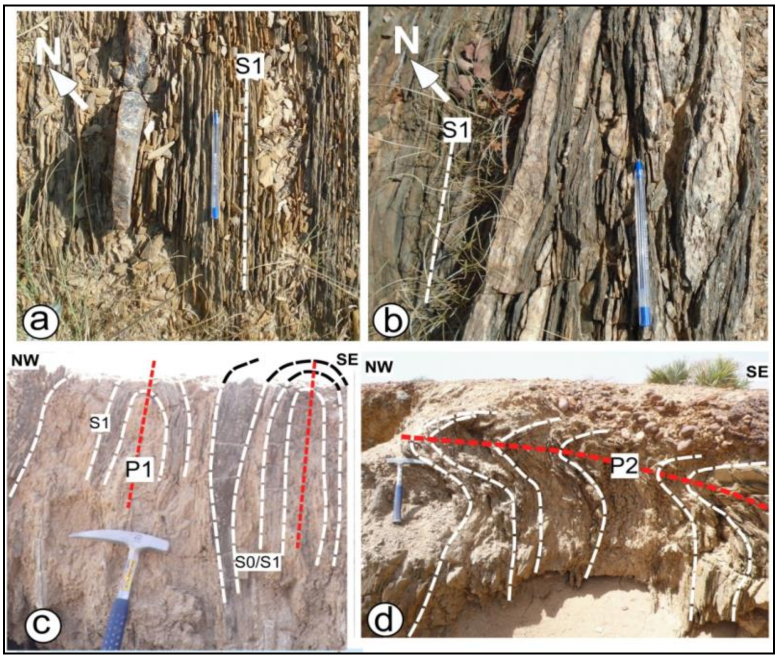

Figure 6. Outcrop Aspects of the Schists in the Maraka Schist Belt

Note. (a and b): Schistosity planes S1 N50 °. (c): P1: subvertical to vertical axial plane. (d): P2: subhorizontal axial plane of folds.

3.3.3 Shear Zones Rocks

Field observations show that in southern Maradi, the mylonitic gneiss outcrop according to the discontinuous bands outcropping mostly in the streambeds. Mylonitic gneiss were mostly observed in the Garin Wali-Fiawa and Dan Issa-Nielwa sectors (Figs. 8 and 9). Their outcrops form the N30 °shear zones more than 5 km wide (Figs. 3 and 4). These gneiss bands alternate with the “Schist belts” that prolongate in the contiguous province of North Nigerian (Fig. 4).

3.3.3.1 Mylonitic Gneiss Band of Garin Wali-Fiawa

The mylonitic gneiss of Garin Wali-Fiawa outcrop in a band with a mean N25 °direction (Fig. 8). They are marked by the presence of centimetric porphyroblastic crystals of K-feldspars. The presence of these porphyroblasts reveals that the protolith is an alkaline granite (orthogneiss). The sigmoid shape of feldspars highlights an episode of ductile mylonitization, marked:

- On the one hand, by the development of an S/C fabric (“**σ**-type structure”, **Passchier and Trouw 2005)**. This S/C fabric structure reveals a senestre rotation component, which is particularly described in the pegmatitic gneiss (Fig. 8a).
- Secondly, by a ductile boudinage of K-feldspars, associated with “**δ**-type structure” (**Passchier and Trouw 2005**, Fig. 8b). The spiral shape of the winding indicates also a senestre shear component.

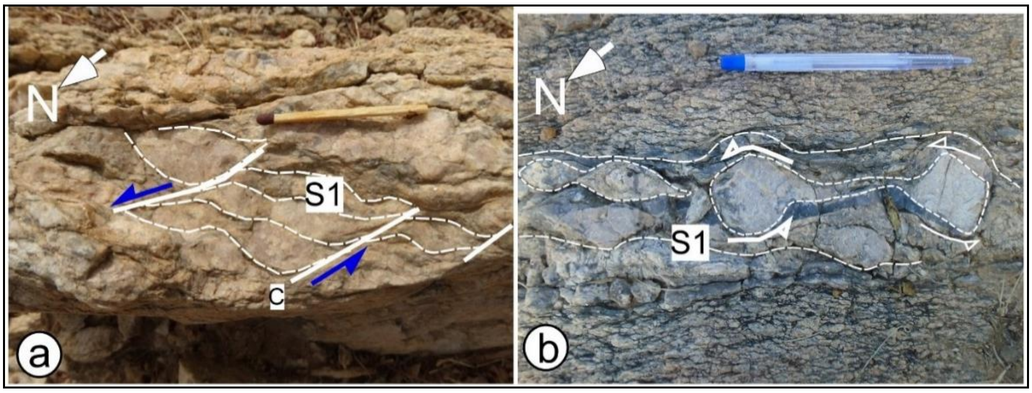

Figure 7. Mylonitic Gneiss from the Garin Wali and Fiawa Shear Zone Showing Different Types of Deformation Structures

Note. (a): K-feldspar porphyroblast gneiss with an S/C fabric senestre. (b): K-feldspar showing a “δ-type structure” senestre. C: N25 °shear plane, S: foliation trajectory.

3.3.3.2 Mylonitic Gneiss Band of Nielwa-Dan Issa

In this area, mylonitic gneiss outcrop in bands oriented mainly in N50° direction (Fig. 9). Macroscopically, the rocks are in gray-pink color, containing centimetric-porphyroclasts of K-feldspars and stretched crystals of quartz and biotite that define an S/C fabricated mylonitic foliation (Fig. 9).

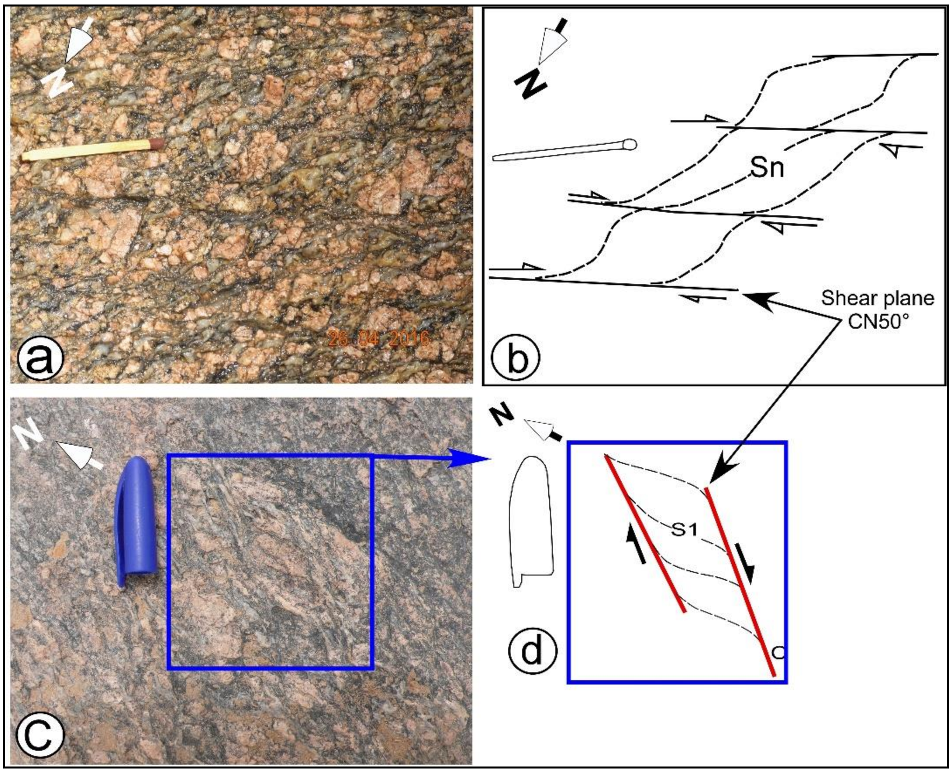

Figure 8. Dan Issa-Nielwa Mylonitic Orthogneisses Showing Dextral Shear Microshiear Zones. (b, d): respective interpretations of (a), (b) and (c). S: foliation trajectory, C: shear plane

3.3.4 Porphyric Granites

These types of granite outcrop in the Southwest of Chirgué and Rourouka villages (Fig. 10), in the form of discontinuous plurimetric plutons. They also occur in the Dan Issa and Kandamao areas. Generally, these granites appear in the pink color and have a porphyritic texture revealed by automorphious crystals of K-feldspar, quartz and biotite (Fig. 10). These granites are also known as "Pink pophyric granite" of Dan Issa and Kadamao villages.

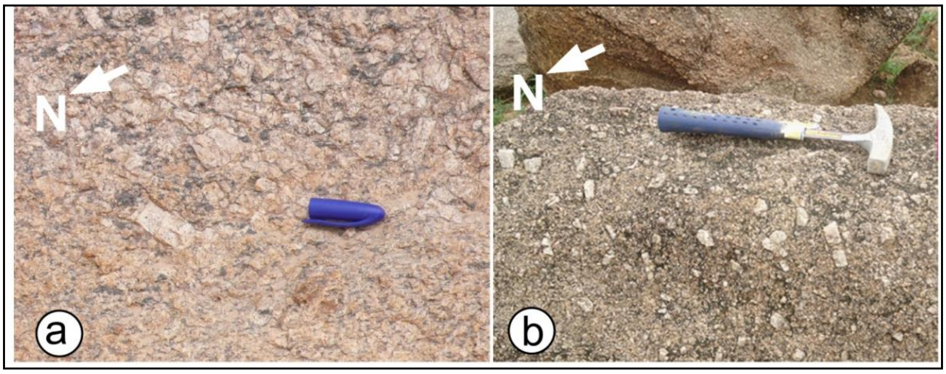

Figure 9. Porphyric Granites Outcrops of Nielwa (a) and Chirgué (b)

4. Discussion

The main structures and magnetic petro-facies described by aeromagnetic map (PRDSM, 2005) and lithological units described by summary geological map (Mignon, 1970) of southern Maradi were correlated with the field data. This correlation shows that there is relative geological continuity between the summary geological map (Mignon, 1970) and those deduced from aeromagnetic map (PRDSM, 2005). In addition, the aeromagnetic map revealed the ductile deformation structures represented by ductile and brittle shear zones. The ductile deformation structures trending NE-SW and N-S, not described on summary geological map of South Maradi (Mignon, 1970) were confirmed by field observations and the aeromagnetic map (PRDSM, 2005). Geological contours and structures were also corrected by using of aeromagnetic map and field data.

In addition, geological correlation with the contiguous Northern Nigeria Province has shown a lithological, structural and geochronological continuity between these two Pan-African provinces (Mignon, 1970; PRDSM, 2005; Caby, 1989; Talaat and Mohammed, 2010; Abubakar, 2012; Baraou et al., 2018). According to Ajibade and Wright (1989), these lithostructural assemblages were formed during the same process of crustal block accretion, corresponding to the Pan-African orogeny between 750-450 Ma.

5. Conclusion

The combined analysis of aeromagnetic and field data led to correct petrographic and structural gap existing since 1970, and to produce a new geological and structural map of the south Maradi Pan-African Province (PAP). Analysis of this new map shows that the spatial distribution of geological formations is characterized by the alternating schists and mylonitic gneiss bands associated with migmatites panels and granitoïd intrusions. Thus, the different petrographic facies mapped are represented by schists-micaschist, mylonitic gneiss, migmatitic gneiss and intrusive porphyry granites. Previous data revealed a petrographic and structural continuity between South Maradi Pan-African formations with those of contiguous North Nigeria Pan-African province. In the South Maradi, the greatest abundance of gold deposits is associated with the NE-SW and NW-SE trending shear systems. Thus, the petrographic facies mapped can be used as a proxy for the metamorphic origin of gold, associated with the late-orogenic events.

Acknowledgments

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