Original Research Article

Petrographic characterisation of the Mounio "Younger Granites" province, central portion of the Pan-African mobile chain at Gouré, south-east Niger

ABSTRACT

The petrography of the Mounio province, the subject of this study, is poorly understood, as very few geological studies have been undertaken. This province is an integral part of the Pan-African mobile zone located to the east of the West African craton, between the Tuareg and the Benino-Nigerian Shields. In the study area, the Pan-African formations were intruded by anorogenic magmatism, resulting in the emplacement of the Younger granites. Most of the petrographic data in this area of the Niger basement come from geological correlations. The aim of this study is to update the geological map of the Mounio province through a petrographic analysis of the various lithological formations in the study area. The methodology used consisted of a macroscopic description of outcrops in the field. In the laboratory, thin sections of rock were processed and interpreted. The results of this work enabled us to distinguish three types of geological formations. (i) Pan-African formations made up of metasediments (schists and volcanosclastites) and “ancient granites”. The cardinal minerals in these granites are quartz (30%), potassium feldspar (40%), plagioclase (10%) and biotite (20%). (ii) Younger granites have intruded ancient formations and form three groups: (a) A volcanic group, comprising several occurrences: pyroclastites, alkaline and hyperalkaline rhyolites and trachytes. Alkaline rhyolites contain green hornblende-type amphibole, which differentiates them from hyperalkaline rhyolites, characterized by the presence of riébeckite-type amphibole and ægyrine-type pyroxene. (b) A hypovolcanic group represented by alkaline and hyperalkaline microgranites. Alkaline microgranites are characterized by the presence of amphibole, represented by hornblende, while hyperalkaline microgranites specifically contain ribeckite-type amphibole, aegyrine-type pyroxene and sanidine phenocrysts. (c) A plutonic group made up of alkaline and hyperalkaline granites and quartzite syenites. The alkaline granite is characterized by clinopyroxene pyroxene and hornblende amphibole, while the hyperalkaline granite is characterized by aegyrine pyroxene. (iii) A sedimentary cover composed of sandstone and alluvium, overlies ancient formations throughout the study area.

Keywords: *Petrographic characterisation, Metasediments,* "Older Granites"*, "Younger granites", Pan-African mobile chain*, *Mounio Province, Gouré, Niger.*

1. INTRODUCTION

The Mounio basement is an integral part of the Pan-African Chain, which extends from the Hoggar in the north to the Gulf of Benin in the south (Figure 1). This chain, also known as the

Trans-Saharan Range, is considered to be the result of the convergence of the West African, Sao Francisco and Congo cratons and the Saharan Metacraton (Caby, 2003; Abdel-Salam et al., 2002; Ferré et al., 2002). This tectonic phenomenon is thought to underlie the formation of the Gondwana Supercontinent (Koner et al., 2005; Castaing et al., 1993; Ajibade & Wright, 1989; Caby, 1989). Subsequently, Gondwana began to break up, which led, from the Palaeozoic onwards, to the emplacement of anorogenic alkaline granite complexes known as "Younger Granites" and the development of Meso-Cenozoic rifts (Castaing et al., 1993; Black et al., 1991; Ba et al., 1985). Magmatism in these so-called "Younger Granite" complexes continued until the Quaternary, following a meridional alignment and southward migration (Ngako et al., 2006; Black et al., 1985; Karche et Vachette, 1978; Bowden et al., 1976) (Figure 1). The petrographic characteristics of this zone, remobilised during the Pan-African orogeny, are the subject of much debate. In the Mounio province, very few studies have been carried out on the petrographic characteristics. These include the work of Mignon (1970) and Black (1963), who showed that the Mounio Province is made up of "Younger granites" that intruded ancient formations consisting of granites and metasediments virtually covered by a sedimentary blanket comprising Hamadian Continental sandstones and eolian sand. However, these results are still controversial. The aim of the present study is to carry out a detailed petrographic characterisation of the study area to remove any ambiguity. A petrographic description of the various facies in the field and in the laboratory (thin sections) was used to produce a detailed geological map of the Mounio Province.

2. GENERAL GEOLOGICAL SETTING

2.1. General Geodynamic Context

The Mounio province, which is the subject of this report, is closely linked to the Damagaram province, forming the Damagaram-Mounio geological province. This province occupies the central part of the Pan-African Mobile Belt, between the Tuareg Shield and the Benin-Nigeria Shield (Figure 1). The Pan-African Mobile Belt consists of a Palaeo-Neoproterozoic basement, which was strongly remobilised during the Pan-African orogeny (750 to 450 Ma) (Van Breemen et al., 1977; Caby, 1989; Ajibade and Wright, 1989; Castaing et al., 1993; Ferré et al., 1996; Kröner and Stern, 2005; Abdelsalam et al., 2002). In the Damagaram-Mounio region, the crust was built up as a result of an orogenic process involving tangential tectonics with metamorphism, migmatisation and granitisation, relayed to a greater or lesser extent by transcurrent tectonics (context of oblique convergence) (Castaing et al., 1988; Ferré et al., 2002; Badamassi, 2021). From a general point of view, the Pan-African chain is one of many Neoproterozoic orogenic chains that may have participated in the accretion of various cratonic blocks, forming the Gondwana Supercontinent between 750 and 500 Ma. Gondwana then began to break up, leading, from the Palaeozoic onwards, to the emplacement of anorogenic alkaline "Younger Granites" and the development of Meso-Cenozoic rifts (Castaing et al., 1993; Black et Liégeois, 1991; Ba et al., 1985; Sanda & Konaté, 2021). Magmatism linked to the installation of the "Younger Granites" continued until the Quaternary, following a meridional alignment and southward migration (Bowden and Kinnaird, 1984; Karche and Vachette, 1978).

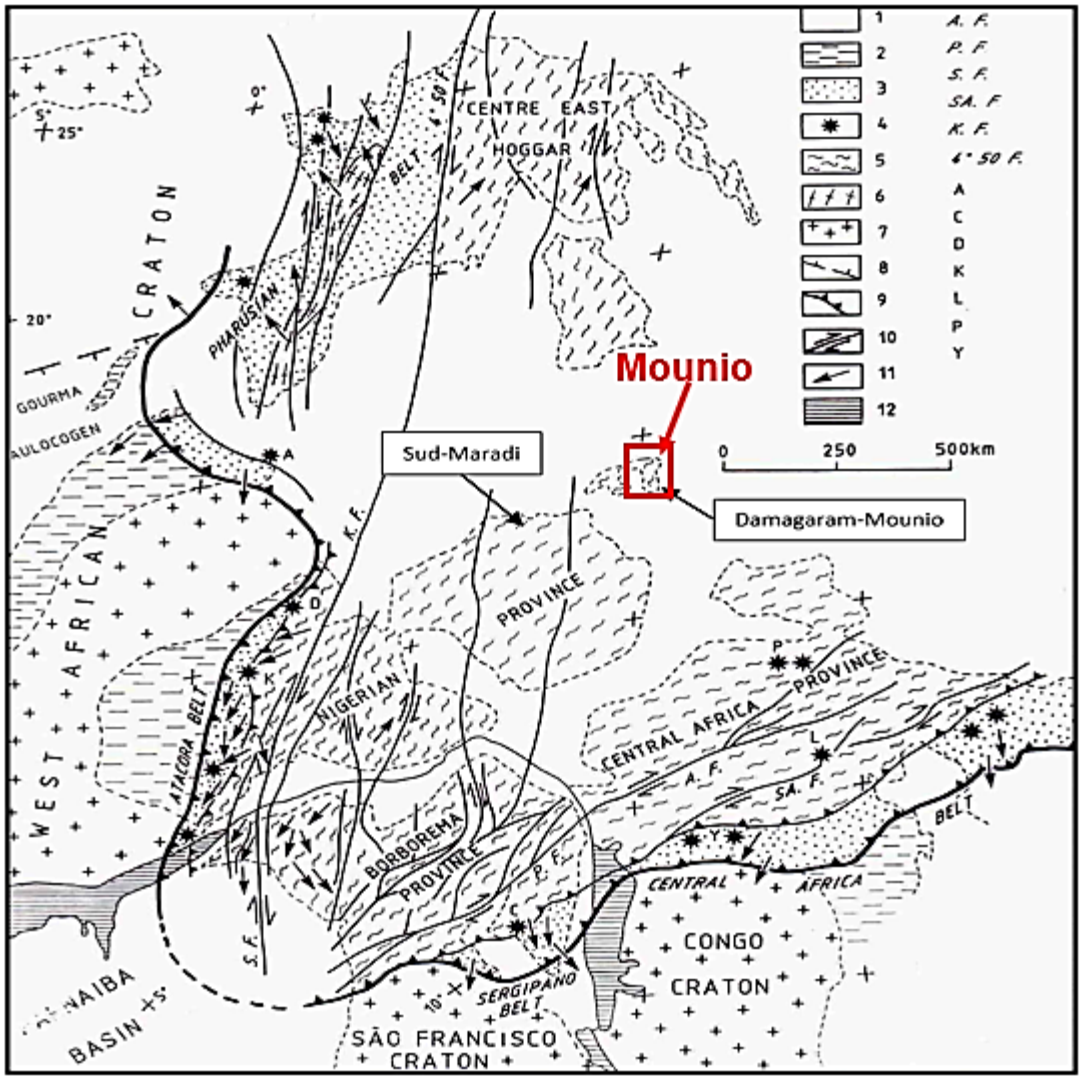

Fig. 1. Location of the Mounio geological province in its pan-African geodynamic setting within the Trans-Saharan mobile chain (Castaing et al., 1993)

1: Phanerozoic cover; 2: Proterozoic cover; 3: Pan-African volcano-sedimentary belts; 4: Main basic and ultrabasic massifs underlining the suture zone; 5: Gneisses, metasediments, migmatites and mono- or polycyclic undifferentiated granites; 6: Ouzzal and Iforas Eburnian granulites; 7: 2 Ga Cratons; 8: Gourma Aulacogen; 9: Major external thrusts; 10: Main shear zones; 11: Direction of tectonic transport of nappes; 12: Sea; AF -Anaga-Adamaoua Fault; PF - Pernambouco Fault; SF - Sobral Fault; SAF - Sanaga Fault; K.F. - Kandi fault; A, C, D, K, L, P, Y. - Metabasic complexes of Amalaoulaou, Canindé, Dérouvarou, Kabyé, Lom, Poli, Yaoundé.

From a geological point of view, the pan-African province of Damagaram-Mounio is made up of three main lithological units (Black et al., 1967; Mignon, 1970; Ousmane, 1988; Badamassi and Konaté, 2021; Badamassi, 2021), more or less covered by the formations of the Hamadian Continental and Quaternary deposits (Mignon, 1970; Ousmane, 1988). (1) Ortho- and para-derivative formations: an ortho-derivative metamorphic series outcrops in the north-east of the Damagaram-Mounio province. This series consists of migmatites, calcic gneisses, banded gneisses, mylonitic gneisses, leptynites, amphibolites and metagabbros (Mignon, 1970;

Badamassi and Konaté, 2021; Badamassi, 2021). This ortho-derivative formation is particularly accompanied by platelet quartzites in the Birnin Kazoé sector (Mignon, 1970). The paraderivative formations constitute a metamorphic sequence comprising the chrono-stratigraphic succession, from base to summit: meta-conglomerates, calc-silicate gneisses, several varieties of quartzites and phyllades (Mignon, 1970; PRDSM, 2013; Badamassi & Konaté, 2021; Badamassi, 2021). This sequence, affected in its entirety by metamorphism evolving from "green schist" facies to "amphibolite" facies, is characterised by the presence of muscovite-biotite-staurotide-grenate-disthenes (Mignon, 1970). (2) Pan-African "Older Granites": these granitoids form the bulk of the formations in the north-western Damagaram-Mounio. They are intruded by metasediments. These are calc-alkaline granites, often covered by sandy formations, but which must make up the majority of the region. Rb-Sr dating has given these rocks an average age of 575 Ma (Black & Liégeois, 1991), indicating that they were emplaced during the Pan-African orogeny. These granitoids show syn-, late- to post-teconic characteristics (Mignon, 1970; PRDSM, 2013; Badamassi, 2021). They are made up of four units: biotite granites, two-mica granites, porphyry granites and alkaline granites (Badamassi, 2021).

- Biotite granites outcrop in slabs or in the form of balls throughout the Damagaram-Mounio sector.
- Two-mica granites outcrop in the Bourbourwa and Dakoussa sectors. These are fine- to medium-grained granites with a blackish colour and a composition of homogeneous mineralogy. Two-mica granites outcrop in the form of granite chaos.
- Porphyritic granites outcrop in the form of balls throughout the study area. They are pinkish in colour and have a gritty porphyry structure.
- Alkaline granites outcrop throughout the study area. They are characterised by their pinkish colour. In the Gafati sector, they are in the form of a dome multi-decametric (Badamassi, 2021).

(3) Younger granites: these correspond to the Zinder, Badaraka, Zarnouski and Gouré massifs. These are anorogenic alkaline and hyperalkaline granites, forming annular structures (Mignon, 1970). They form part of the alkaline "Younger Granites" super-province of Niger-Nigeria (Bowden et al., 1987). These ring complexes of Late Carboniferous to Permian age (Karche and Vachette, 1978; Bowden et al., 1987; Chékaraou and Konaté, 2021) are made up of volcanic rocks (rhyolites, ignimbrites, tuffs, breccias), hypovolcanic rocks (microgranites and microsyenites) and plutonic rocks (granites and syenites) (Mignon, 1970; Lawali et al., 2022).

2.2. Local geology

Classically, the geological formations of the Mounio province (Figure 2) consist mainly of ancient formations (Palaeo- to Neoproterozoic in age) and "Younger Granites" of Late Carboniferous to Permian age (Bowden et al., 1976; Karche and Vachette, 1978; Sanda & Konaté, 2021). (1) The ancient formations of the Mounio province are characterised by metasediments and granites of Palaeo- to Neoproterozoic age (Mignon, 1970; Bertrand & Caby, 1978; PRDSM, 2013). They outcrop in isolation in the north-eastern part of the Mounio. The metasediments are the result of greenschist to amphibolite facies metamorphism (Black and Liégeois, 1991). Granites intrude the metasediments (Mignon, 1970; PRDSM, 2013). Rb-Sr dating has given these ancient formations a mean age of 575 ± 12 Ma (Black and Liégeois, 1991), showing that they were emplaced during the Pan-African orogeny. (2) The post-Pan-African Youngers Granites of the Mounio geological province are of late Carboniferous age (Karche and Vachette, 1978; Bowden et al., 1976). These formations appear as sporadic or continuous domes to the south of Mounio, while to the north, in the Gouré sector, they form a "ring-complex". The Mounio complex is part of the Nigeria-Niger "Young Granites" Superprovince (Bowden et al., 1987). From the outside to the centre, this ring-shaped complex is made up of volcanic, hypovolcanic and plutonic rocks (Black and Morosoff, 1960; Black,

1963; Mignon, 1970; PRDSM, 2013; Vincent et al., 2022): (i) Volcanic rocks: rhyolitic volcanic rocks are particularly abundant in the Mounio province, accounting for around 60% of outcrops (Mignon, 1970). They comprise intrusive and effusive facies (Black and Morosoff, 1960; Black, 1963). (ii) Hypovolcanic rocks: hypovolcanic facies are characterised by microgranites. They are the most common facies after rhyolites. At the Gouré "ring complex" (north of Mounio), microgranites form the second ring of the annular structure (Black & Morosoff, 1960; Black, 1963; Mignon, 1970). (iii) Plutonic rocks: the plutonic assemblage consists of granites and syenites (Black & Morosoff, 1960; Black, 1963; PRDSM, 2013). This assemblage outcrops sporadically in the Mounio province, at the base of volcanic and hypovolcanic assemblages (Mignon, 1970). To the north of Mounio, it occupies the heart of the Gouré annular structure. This complex is characterised by a coarse-grained texture. This facies marks the end of the last magmatic event that marked the Gouré ring complex (Mignon, 1970). In the Mounio province, the metasediments and Pan-African granitoids (ancient formations) have been affected by deformation characteristic of soft tectonics. This ductile deformation is marked by folds of variable ductility, ranging from tight to open style (Mignon, 1970). Subsequently, a network of fractures of varying directions (N20°-30°, N50°-60°, N90°-100° and N150°) affected these ancient formations (Mignon, 1970). Boubacar and Konaté, 2020). All these deformations occurred in a compressive context (Mignon, 1970). From the Palaeozoic onwards, an extensive tectonic regime was established, which favoured the development of curved faults that gave rise to an anorogenic granitic complex (Castaing et al., 1993; Black and Liégeois, 1991; Ba et al., 1985) known as the "Younger Granites" (Falconer and Raeburn, 1923).

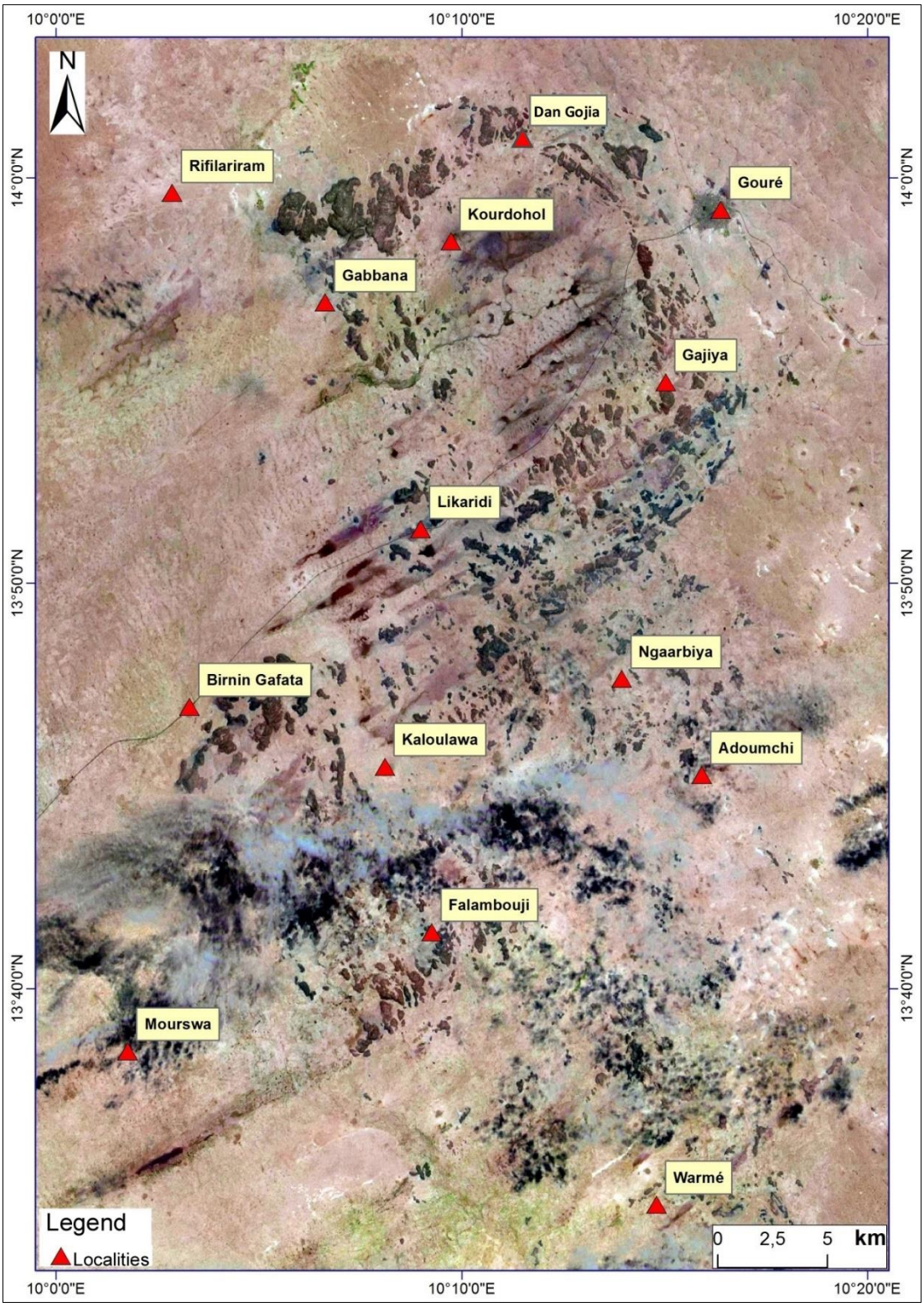

Fig. 2. Location of the Mounio geological province on the sentinel-2 satellite image

3. METHODOLOGY

The methodology used in this study combines field excursions and laboratory work. The fieldwork consisted of petrographic descriptions of the outcrops. The most representative of these outcrops were methodically sampled, preserved and sent to the laboratory. Thin sections of rock were performed at the geology laboratories of the Centre de Recherche Géologique et Minière (CRGM) of the Niger Ministry of Mines and the Ecole des Mines, de l'Industrie et de la Géologie (EMIG). Microscopic/Petrographic observations have been done at the Laboratoire Eaux souterraines et Géoressources at the Université Abdou Moumouni (UAM) in Niamey. In the microphotographs of the thin sections presented, the conventional mineral abbreviations according to Kretz (1983) have been used.

4. RESULTS

Strategic field investigations revealed six (6) lithological units: (i) the sedimentary cover, (ii) the Pan-African granites (ancient granites), (iii) the metasediments, (iv) the volcanic unit, (v) the hypovolcanic unit and (vi) the plutonic unit.

4.1. Sedimentary cover

The sedimentary formation of the Hamadian Continental (CH) and the Quaternary dune sands overlie the ancient formations (Pan-African granites and metasediments) throughout the study area (Figure 3a). On a regional scale, the sandy dune ridges trend NW-SE. Deposits of the Hamadian Continental outcrop mainly to the north of the Gouré ring complex, forming plateaux and mounds (Figure 3b).

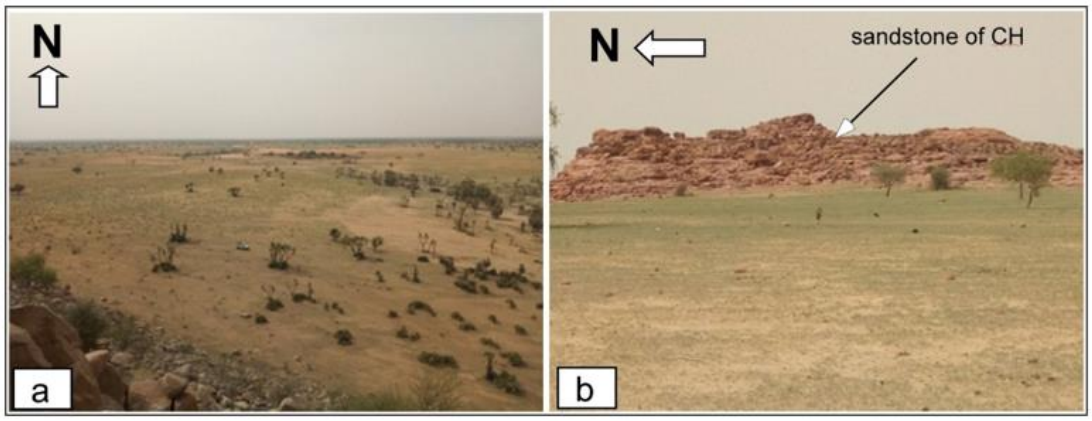

Fig. 3. Sedimentary cover. (a) Clay alluvium and sand dunes. (b) Hamadian Continental Sandstone (CH).

4.2. Pan-African granites

The observation of ancient granites in the Mounio province is fastidious given t h e scarcity of outcrops. However, injections of pegmatite veinlets, made up of quartz and potassium feldspar, have been observed in muscovite schists. Water drilling in the study area also revealed the presence of Pan-African granites. Three of these boreholes reached the Pan-African granitic basement between 43m and 114m (Figure 4). As an indication, the Pan-African basement rocks are encountered from a depth of 43m in the Dan Gojia borehole (Figure 4). In all three boreholes, the granites described are either weathered or sound. The

healthy parts show that they are biotite granites (Figure 4), consisting of quartz (35%), potassium feldspar (40%), plagioclase (10%), biotite (20%) and, secondarily, ferromagnesian minerals that are difficult to identify in the cuttings.

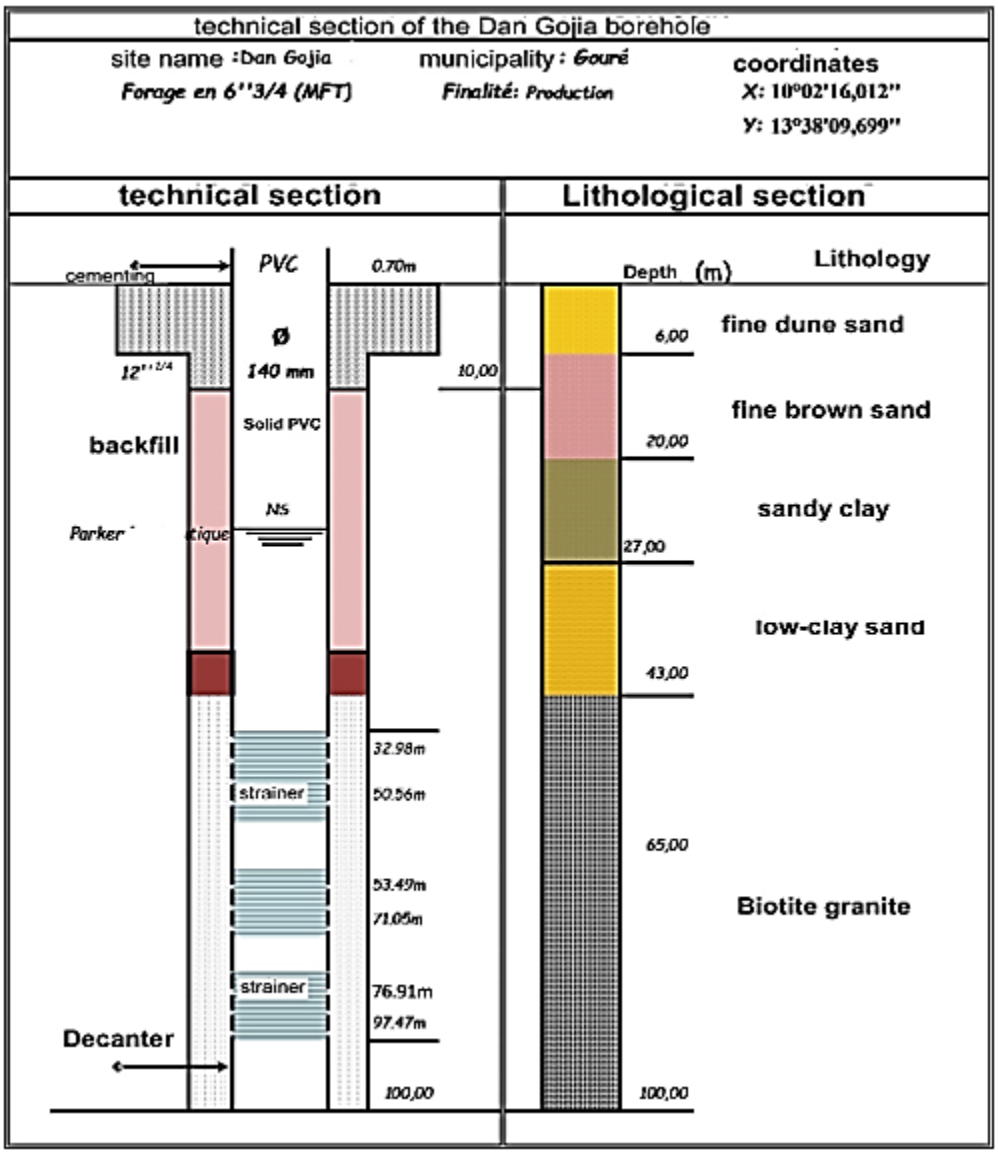

Fig. 4. Technical section of the Dan Gojia borehole

4.3. Metasedimentary set

The metasedimentary assemblage consists of metavolcaoclastites and micaschists with sericite. Both facies outcrop to the north-east of the town of Gouré. (i) The metamorphosed volcanoclastites of the Mounio province are in contact with the "Younger Granites" of the ring complex. These metavolcanosediments contain quartz and feldspar pebbles, rhyolitic lapilli and a tuffaceous framework affected by N110° schistosity-foliation (Figures 5a and 5d). Microscopic study of the metavolcanoclastites shows that they consist of a slightly vacuolated

mesostasis, with a tuffaceous appearance of quartz and feldspar (Figures 5c and 5d). Traces of the circulation of oxidised fluids resulting from hydrothermal alteration can be seen both in outcrop and in thin sections in the fractured zones (Figure 5c). Polarising microscopy shows clear foliation, very often highlighted by chalcedony (Figures 5c and 5d). (ii) The epimetamorphic schists have an average direction of schistosity of N10° to N30° (Figure 5b). These schists show sericitisation in places, resulting in the formation of sericite platelets (Figure 5b). The fractures in these sericite schists mean that intensive tectonic activity has affected the rock after it has been formed.

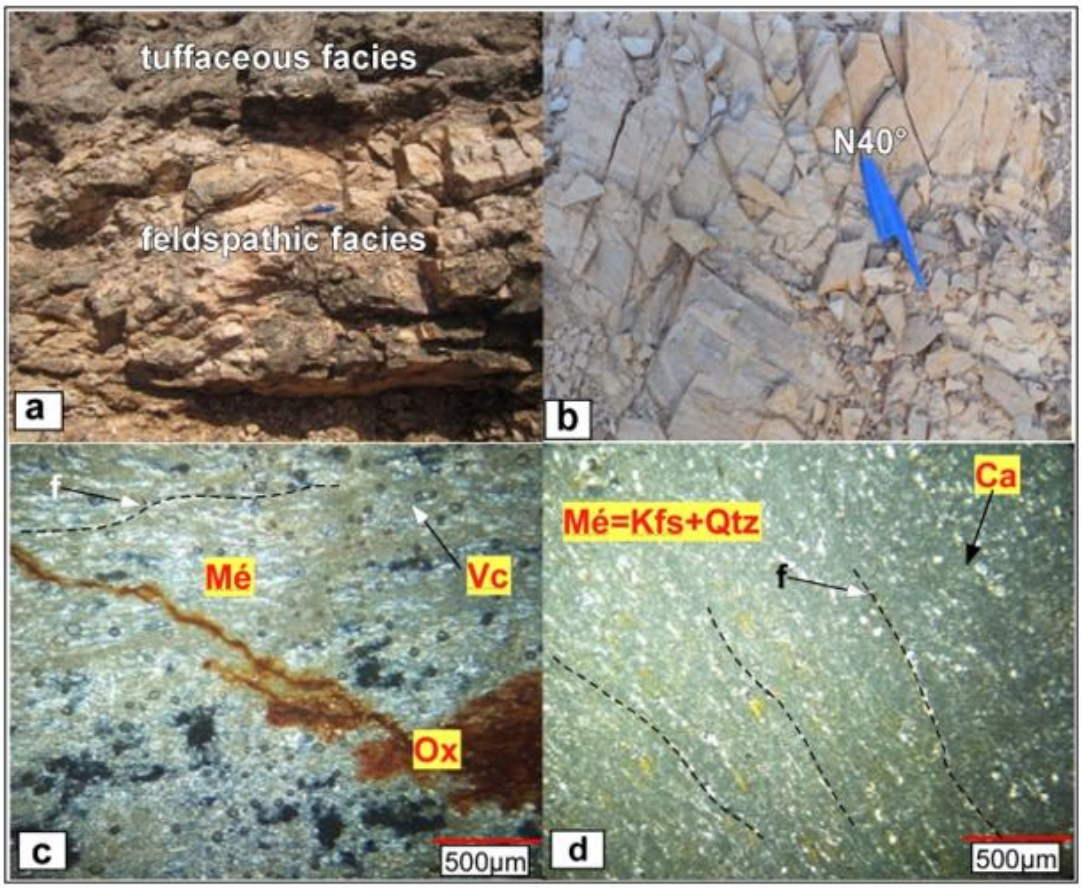

Fig. 5. Aspects of the Mounio metasediments.
(a) Metavolcanoclastite with tuffaceous and feldspathic layers; (b) Cataclastic sericite schist; (c and d) Polarised and Analysed Light microphotograph of the Gouré metavolcanoclastite. (b) Cataclastic sericite schist. (c and d) Polarised and analysed light microphotograph of Gouré metavolcanoclastites. [Mé: mesostasis. Qtz: Quartz. Ox: Oxide. Vc: Gas exhaust vacuole. Kfs: Potassium feldspar. Ca: Chalcedony. f: foliation].

4.4. Volcanic complex

The Mounio volcanic complex comprises alkaline and hyperalkaline rhyolites, pyroclastites and trachytes.

4.4.1. Alkaline and hyperalkaline rhyolites

The Mounio rhyolites outcrop at the edge of the Gouré ring structure (north of the Mounio) and in several places to the south of the study area (Figure 2). The alkaline rhyolites consist of a very abundant quartz and feldspar mesostasis, often with a few phenocrysts of potassium feldspar or automorphous quartz. Some outcrops of the alkaline rhyolites of the Mounio are characterised by dissolution figures (Figure 6b) and a mineral lineation highlighted by the orientation of the fine orthoclase crystals. Hyperalkaline rhyolites are not easily distinguished from alkaline rhyolites on outcrop. In general, hyperalkaline rhyolites are pinkish to greyish in colour; their texture is porphyritic microlitic or microgritty. In places, these rhyolites appear fluid (Figure 6a). They have sparse mesostasis and chalcedony stringers (Figure 6a). Microscopic analysis shows that the rhyolites from the Mounio province have either a vitreous or porphyritic microlitic texture (Figures 6c and 6d). These rhyolites consist of a mesostasis in which crystals of potassic feldspar, quartz and plagioclase are embedded (Figures 6c, 6d). The quartz is automorphic or with "corrosion gulfs". It has mineral inclusions (feldspars and quartz microcrystals) and frequent fractures (Figures 6c and 6d). Plagioclase is automorphic to subautomorphic (Figure 6c). The mesostasis is either cryptocrystalline (Figure 6c) or fibro-radial and contains quartz and potassium feldspars. Patches of oxides (blackish in LPA) and ferromagnesian patches (reddish in LPA) are regularly embedded in this mesostasis (Figure 6d). Alkaline rhyolites incidentally contain green hornblende-type amphibole, which differentiates them from hyperalkaline rhyolites, which are characterised by the presence of riébeckite-type amphibole and ægyrine-type pyroxene (Figure 6d). Locally, narsarsukite associated with aegirine is observed in the mesostasis in the form of very small whitish crystals, slightly tinted (yellowish).

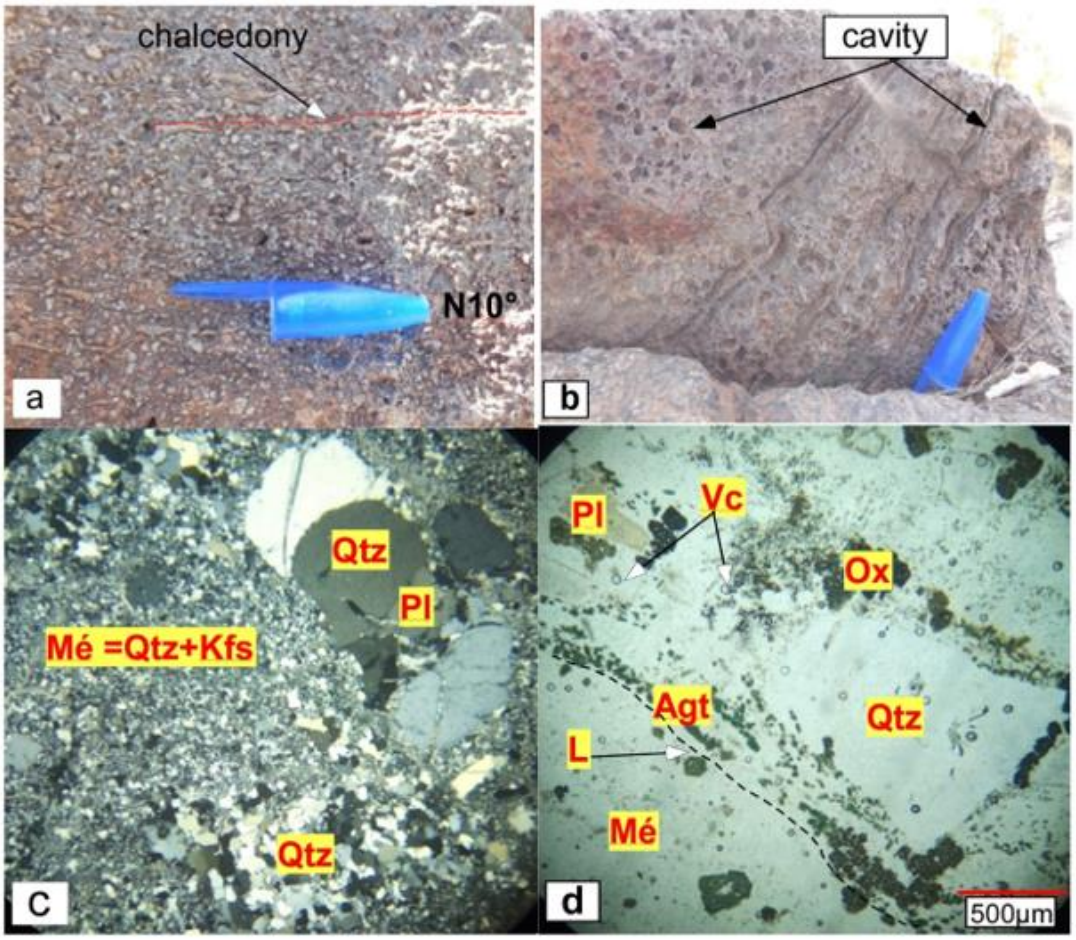

Fig. 6. Macroscopic and microscopic aspects of the Mounio rhyolites.
(a) Hyperalkaline rhyolite with chalcedony injections and gas escape vacuoles. (b) Fluid-textured Gouré alkaline rhyolite showing dissolution figures and gas escape cavities. (c) Mounio rhyolite showing quartz phenocrysts in Polarised Analyzed Light. (d) Mounio rhyolite seen in Polarised Unanalysed Light (LPNA) showing quartz phenocrysts with numerous quartz-feldspar inclusions; a magmatic bedding highlighted by aegyrin is also observed. [Kfs: Potassium feldspar, Qtz: Quartz, Mé: Mesostase, Pl: Plagioclase, Agt: Aegirine, Ox: Oxide, L: Magmatic bedding, Vc: Degassing vacuole].

4.4.2. Pyroclastites

The pyroclastic outcrops are tuffaceous, brecciated or ignimbritic (Figures 7a, 7b and 7d). Pyroclastites are found at the top of rhyolite outcrops. Tuffs and breccias sometimes form continuous patches that are difficult to distinguish. They have a vitreous to microcrystalline mesostasis, locally vitroclastic (Figure 7c). This pyroclastic facies contains numerous crystals and lapilli of micrometric to centimetric size, of various types (quartzite, feldspathic and/or rhyolitic) (Figures 7b and 7c). Microscopic examination of the Mounio pyroclastics shows a porphyritic microlitic texture (Figure 7c). The mesostasis is strewn with rhyolitic lapillis, centimetric crystals of quartz and potassic feldspars, and chalcedony (Figures 7c and 7d). In some localities (Kaloulawa), these pyroclastites show an ignimbritic aspect, highlighted by the presence of "fiammes" (Figure 7d).

Fig. 7. Macroscopic and microscopic aspects of the Mounio pyroclastites.
(a) Kaloulawa pyroclastites with a banded appearance. (b) Gouré rhyolitic breccia. (c) Gajiya pyroclastite showing a potassic feldspar phenocrystal in Polarised and Analysed Light. (d) Kaloulawa pyroclastite with ignimbritic appearance in Polarised Unanalysed Light. [Ca: chalcedony. Kfs: potassium feldspar. Me: mesostasis. fm: fiamme].

4.4.3. Trachytes

The Mounio ring structure contains isolated extrusions of trachytes in rhyolites. The rock is brownish to blackish in colour. It has a fluid microlitic texture (Figure 8a). In thin sections, the Mounio trachyte is composed of automorphic potassic feldspars and a feldspathic mesostasis, interspersed with ferromagnesian minerals and opaques (Figure 8b).

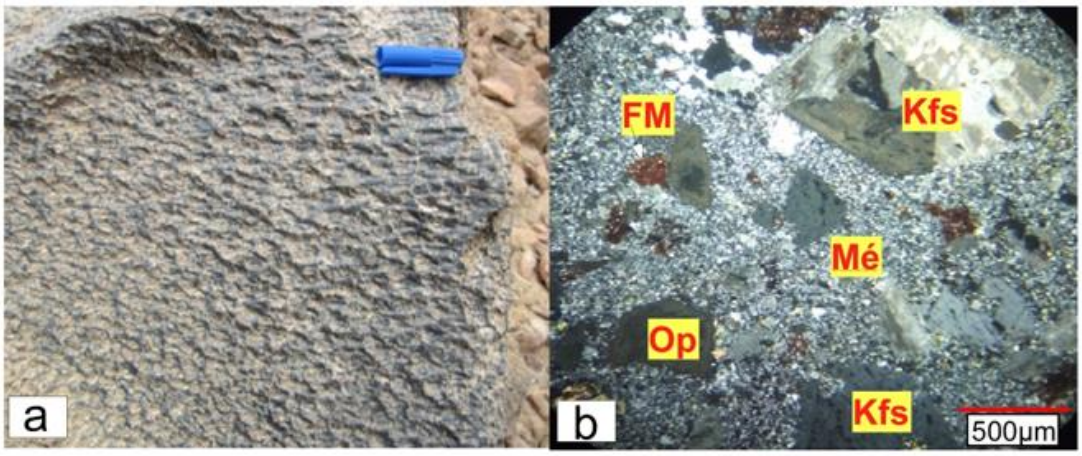

Fig. 8. Aspects of the Mounio trachytes.
(a) Outcrop aspect of the trachyte; (b) Microphotograph of the trachyte under a polarising microscope using Polarised and Analysed Light [Kfs: Potassium feldspar, Mé: Mesostasis, FM: Ferromagnesian minerals, Op: Opaque].

4.5. Hypovolcanic set

This group consists of alkaline and hyperalkaline microgranites (Figure 9a). Microgranites are the second most common facies in the study area after rhyolites. They are always in contact with rhyolite outcrops. Under binocular magnifying glass (Figure 9b), the rock consists of smoky quartz, automorphic to subautomorphic (20%), with a vitreous lustre (Figure 9b). Muscovite is observed in the form of brilliant sheets (5%) (Figure 9b). Orthose (50%) is pinkish, crumbly and automorphic (Figure 9b). Plagioclase (10%), whitish in colour, is subautomorphic (Figure 9b). The mesostasis consists of quartz and feldspar. Hyperalkaline microgranites differ from alkaline microgranites in the presence of sanidine and riébeckite. Under polarising microscopy, the microgranites have a porphyritic microgritty texture (Figures 9c and 9d). It contains potassic feldspars, quartz, plagioclase, amphibole and biotite (Figures 9c and 9d). The quartz is globular, subautomorphic, with rolling extinction, mineral inclusions and microfractures (Figures 9c and 9d). Plagioclase has a grey polarisation hue of 1st order (Figure 9d). In thin sections, alkaline microgranites are characterised by the presence of amphibole, represented by brown or pale green hornblende (beginning of chloritisation) with poecilitic mineral inclusions (Figure 9c). Hyperalkaline microgranites specifically contain ribeckite-type amphibole and green aegyrine-type phenocrysts of sanidine and pyroxene with numerous feldspathic inclusions (Figure 9d). Riebeckite is dark blue in PL and dark green in XPL (Figure 9d). The aegyrin shows automorphic, squat and rectangular sections (Figure 9d).

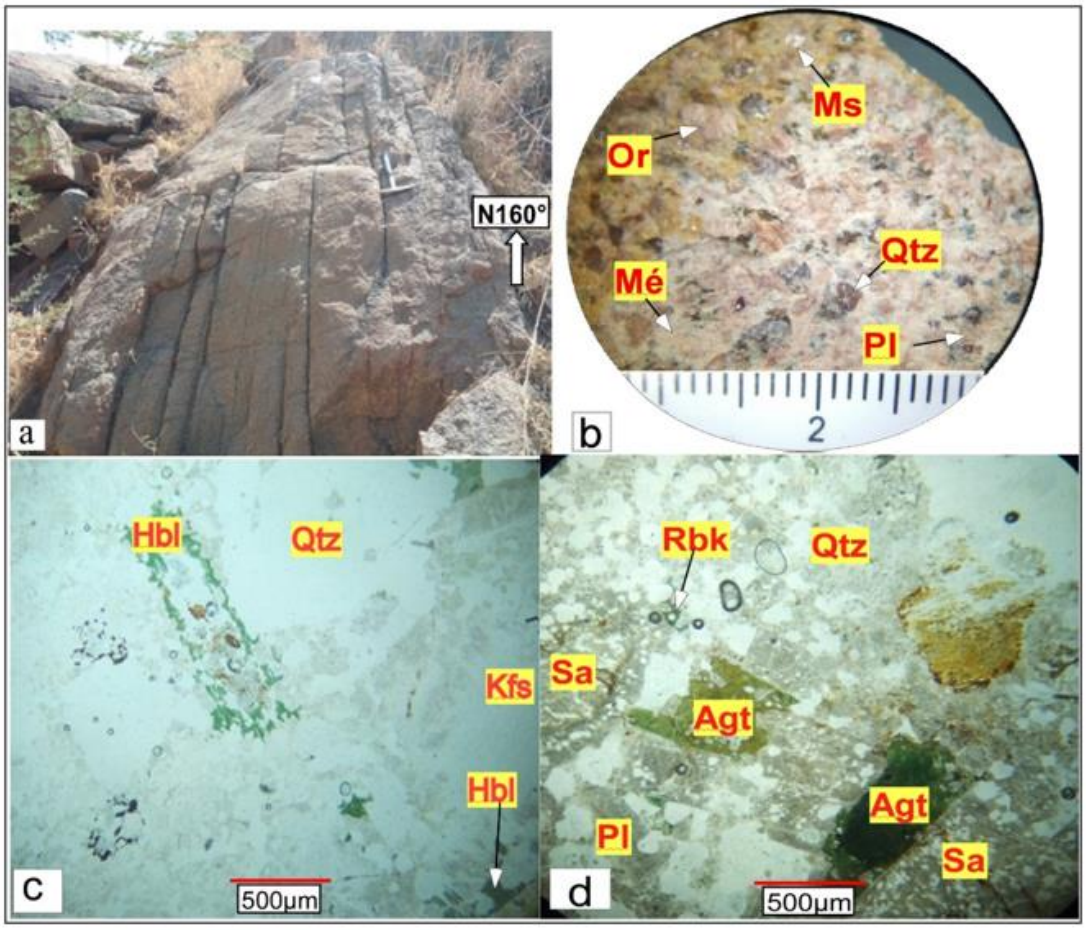

Fig. 9. Macroscopic and microscopic aspects of the microgranites of the Mounio province.
(a) Outcrop of the Gajiya hyperalkaline microgranite, affected by fracture schistosity. (b) Binocular magnifying glass view of the Adoumchi microgranite. (c) Microphotograph of the Mounio alkaline microgranite using polarised light (PL) without analysis. (d) Microphotograph of the Mounio hyperalkaline microgranite using cross polarised light (XPL). Analysed. [Qtz: Quartz, Or: Orthose, Pl: Plagioclase, Ms: Muscovite, Hbl: Hornblende, Kfs: Potassium feldspar, Mé: Mesostase, Bt: Biotite, Sa: Sanidine, Rbk: Riébeckite, Ox: Oxides, Agt: Ægyrine].

4.6. Plutonic set

The plutonic ensemble is made up of alkaline and hyperalkaline granites and syenites.

4.6.1. Alkaline and hyperalkaline granites

Alkaline and hyperalkaline granites outcrop in the form of small hills of granitic chaos in the central and outer part (south Mounio) of the Mounio ring complex (Figure 10a). Macroscopically, these granites are pegmatitic in appearance, sometimes aplitic (Figure 10b), and consist of smoky quartz, plagioclase, potassium feldspar and pyroxene. In the cataclase zone, outcrops are characterised by fillings of ferruginous oxides and barite (Figure 10b). Its mineralogical composition is characterised by potassic feldspar, quartz, pyroxene, plagioclase, amphibole and, secondarily, biotite (Figures 10c and 10d). Quartz is abundant

and xenomorphic, showing rolling extinction (Figures 10c and 10d). Potassium feldspars, which are very abundant, are represented by orthoclase and microcline. Microcline is distinguished by its "tartan cloth" macle (Figure 10c). Albite-type plagioclase is less abundant (Figure 10c). Alkaline granite is characterised by clinopyroxene pyroxene, automorphic with a squat rectangular cross-section (Figure 10d) and incidentally hornblende amphibole, whereas hyperalkaline granite is characterised by aegyrine pyroxene.

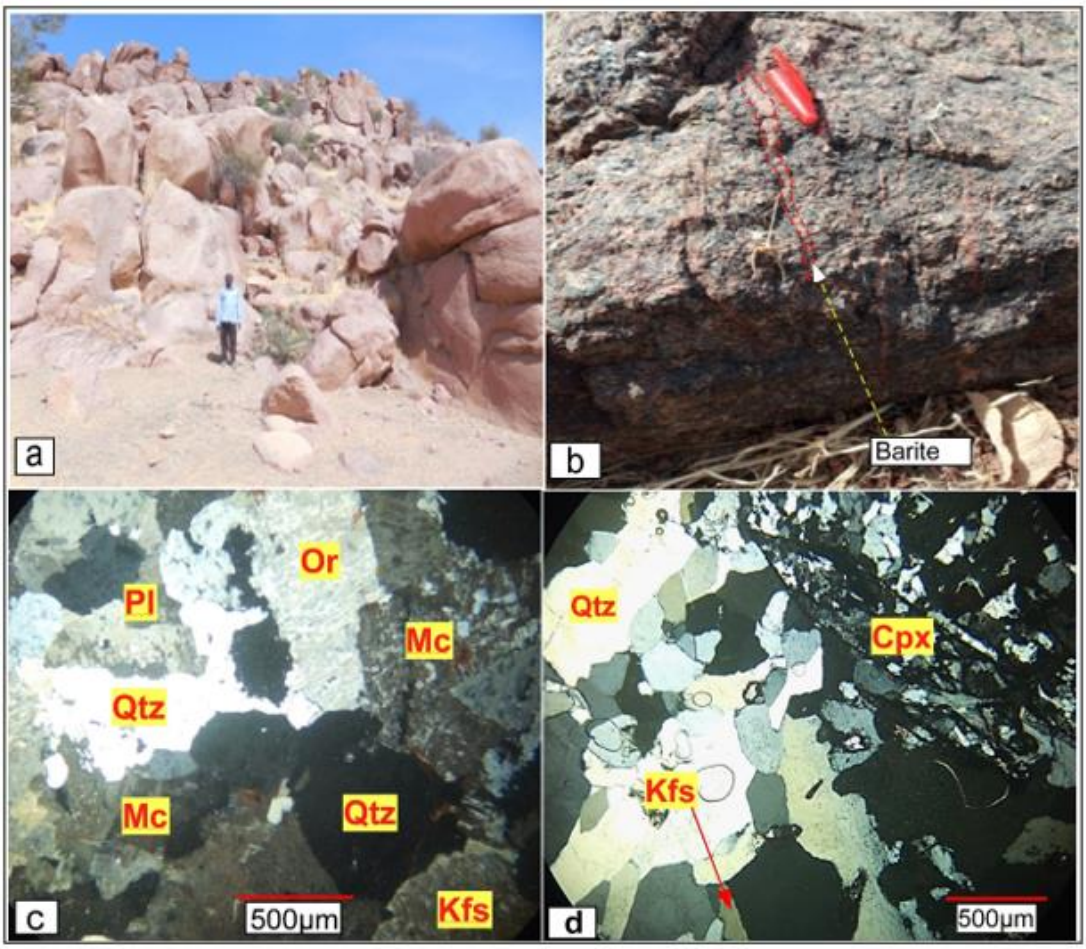

Fig. 10. Macroscopic and microscopic aspects of the Mounio granites.
(a) Panoramic view of the outcrop of hyperalkaline granite in the Likaridi-Gabbana sector. (b) Alkaline granite injected with barite veinlets. Microphotographs of alkaline granite (c) and hyperalkaline granite (d) using Polarised Analyzed Light. [Qtz: Quartz, Pl: plagioclase, Or: Orthose, Mc: Microcline, Cpx: Clinopyroxene, Kfs: Potassium feldspar].

4.6.2. Quartzite syenites

The pinkish syenites, quartzite in nature (Figures 11a and 11b), outcrop at the heart of the Gouré ring structure and in a very isolated fashion in certain places in the study area (Figure 11a). Macroscopically, the Mounio syenites consist of abundant potassium feldspar and quartz. In thin sections, the syenites are characterised by a grainy texture and the development of myrmekite (Figures 11c and 11d). They consist of quartz, potassium feldspars, biotite and plagioclase (Figures 11c and 11d). The millimetre-sized xenomorphic quartz developed in the potassic feldspars (Figures 11c and 11d). The potassic feldspars are

represented by orthoclase and microcline. Microcline is the most abundant, mainly in the form of phenocrysts. It can be recognised by its "tartan cloth" macle (Figure 11d). Microcline often shows the beginnings of myrmekitisation, highlighted by phenocrysts dotted with quartz crystals (Figure 11c). The reddish-brown biotite (magnesian) is xenomorphic and pleochroic in PL (Figure 11d). Plagioclase, which is xenomorphic, is uncommon (Figure 11c).

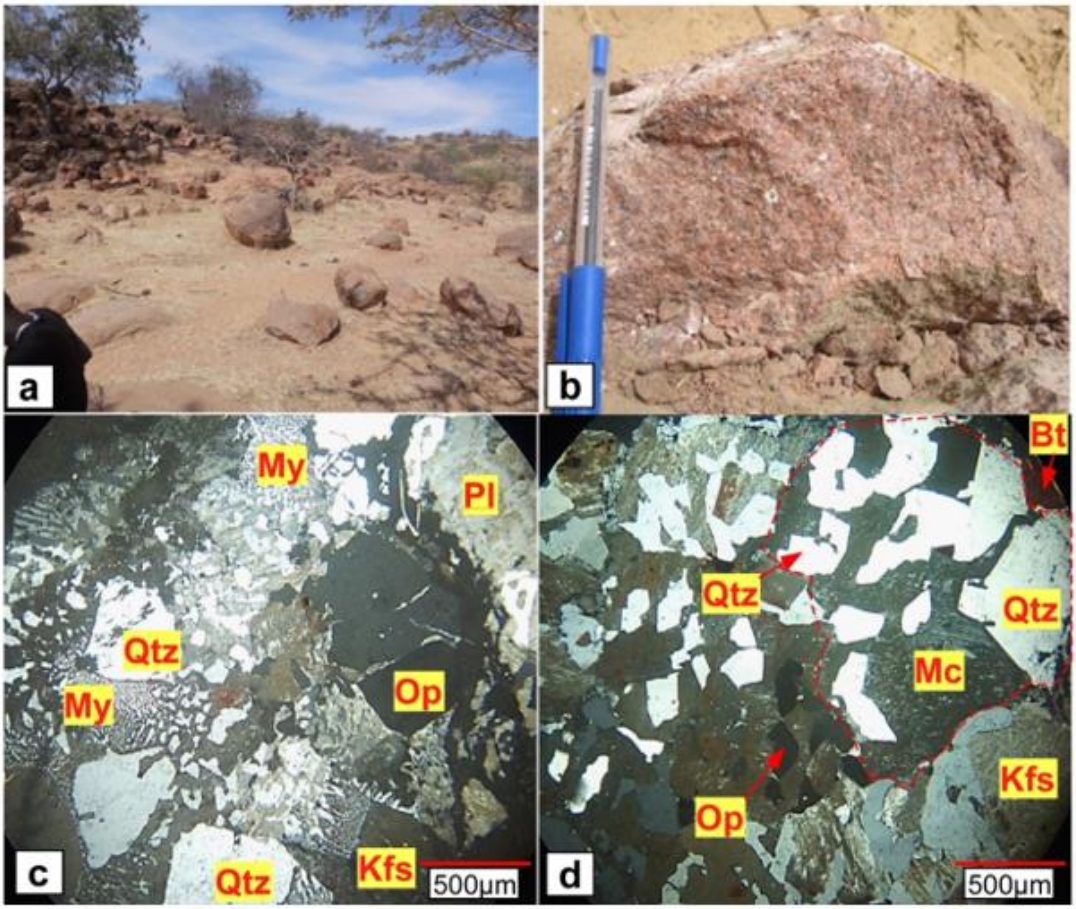

Fig. 11. Mounio quartzite syenites.
(a and b) Outcrop view of quartz syenites. (c and d) Polarized Light microphotographs of the Mounio syenites [Qtz: Quartz, Kfs: Potassium feldspar, Mc: Microcline, Bt: Biotite, Pl: Plagioclase, My: Myrmekite, Op: Opaque (sulfide)].

5. DISCUSSION

The petrographic study of the Mounio province identified three (3) types of terranes: (i) a sedimentary cover of Quaternary age (Tidjani, 2008) consisting of eolian sand and sandstones, (ii) ancient formations of Palaeo- to Neoproterozoic age (Mignon, 1970; Bertrand & Caby, 1978; Black & Liégeois, 1991) consisting of calc-alkaline granites and metasediments, (iii) and the Permian-age "Younger Granites" (Sanda & Konaté, 2021) consisting of volcanic, hypovolcanic and plutonic facies. This study confirmed the existence of ancient formations (metasediments and granites) in the Mounio province. Indeed, authors (Black, 1960 and 1963; Mignon, 1970) have mentioned the presence of metasediments and granites of Pan-African age in the Gouré area, on the basis of geological correlations. The abundance of sericite and

muscovite in the micaschists and metavolcanoclastites (Figure 5b) is compatible with greenschist facies metamorphism (Black and Liégeois, 1991). In addition, the petrographic descriptions (paragraph 4.2) carried out during this study confirm the calc-alkaline character of the ancient Mounio granites (Black, 1960 and 1963; Mignon, 1970). The present study has made it possible to characterise the "Younger granites" of the Mounio province. The alkaline and hyperalkaline characteristics of the lithological facies (rhyolites, microgranites and granites) were highlighted, which is in line with previous work carried out in the study area (Black and Morosoff, 1960; Black, 1963; Mignon, 1970; PRDSM, 2013). Also, the present work shows that hyperalkaline granites have a two-stage crystallisation appearance (gritty and aplitic texture). Also, older granites and younger granites can be distinguished on the basis of their mineralogical composition and textures. Older granites are calc-alkaline with a grainy to porphyritic texture, while Younger granites are alkaline to hyperalkaline with a texture varying between microlitic, micrograined and grainy. In addition, new geological data on this studied zone in Niger are available. The Mounio ring-structure complex is made up of volcanic (alkaline and hyperalkaline rhyolites, pyroclastites and trachytes), hypovolcanic (alkaline and hyperalkaline microgranites) and plutonic (alkaline and hyperalkaline granites and syenites) units, from the outside to the centre. These results were used to update the geological map (Figure 12) of the Mounio province.

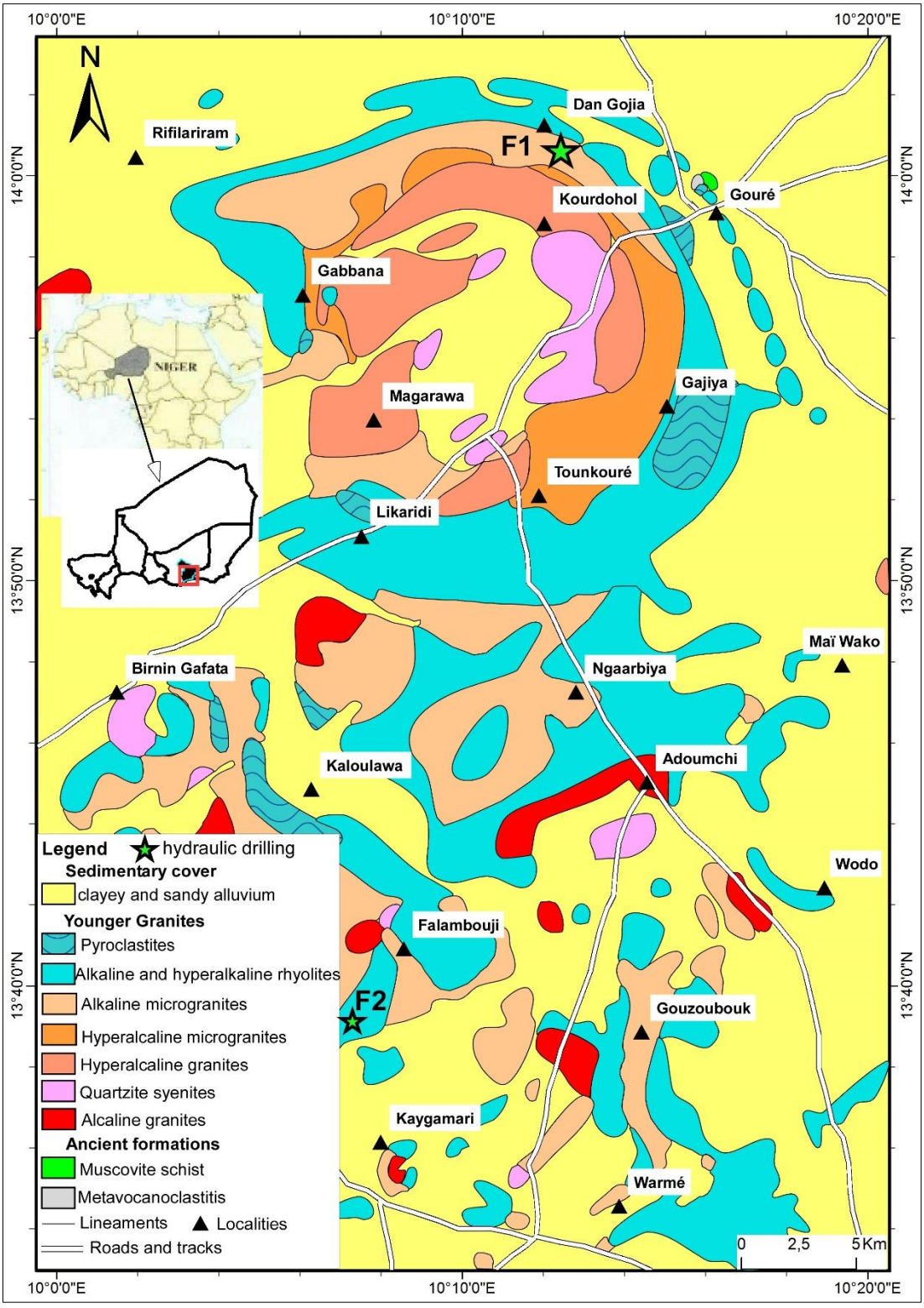

Fig. 12. Geological map of the Mounio province

6. CONCLUSION

A petrographic study of the geological formations in the Mounio province has identified 3 types of geological terrain: (i) Pan-African basement formations made up of metasediments and "Older Granites", (ii) "Younger Granites", (iii) the sedimentary cover made up of dune alluvium, clay deposits and Hamadian Continental sandstones. The metasedimentary assemblage consists of metavolcaoclastites and micaschists while the older granite is consisting of quartz, potassium feldspar, plagioclase, biotite. The "Younger Granites" form three groups. (a) A volcanic group, comprising several occurrences: pyroclastites, alkaline rhyolites and hyperalkaline granites and trachytes. Alkaline rhyolites incidentally contain green hornblende-type amphibole, which differentiates them from hyperalkaline rhyolites, which are characterised by the presence of riébeckite-type amphibole and ægyrine-type pyroxene. (b) A hypovolcanic group represented by alkaline and hyperalkaline microgranites. Alkaline microgranites are characterised by the presence of amphibole, represented by hornblende while hyperalkaline microgranites specifically contain ribeckite-type amphibole, green aegyrine-type and phenocrysts of sanidine. (c) A plutonic group made up of alkaline and hyperalkaline granites and quartzite syenites. Alkaline granite is characterised by clinopyroxene pyroxene, and incidentally hornblende amphibole, whereas hyperalkaline granite is characterised by aegyrine pyroxene. The "Younger Granites" form a circular, concentric structure known as the Mounio Ring Complex.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

REFERENCES

1. Caby, R. (2003). Terrane assembly and geodynamic evolution of Central-Western Hoggar: a synthesis. Journal of AfricanEarth Sciences. 37, 133-159.
2. Abdelsalam, M. G., Liegeois, J. P., & Stern, R. J. (2002). "The Saharan Metacraton", Journal of African Earth Sciences, vol. 34, no. 3-4, pp. 119-136.
3. Ferré, E. C., Gleizes, G., & Caby, R. (2002). Obliquely convergent tectonics and granite emplacement in the Trans-Saharan belt of Eastern Nigeria: a synthesis. Precambrian research, 114 199 - 219 p.
4. Koner, A., & Stern, R. J. (2005). Pan Africanorogeny. In: Selley, R.C., Cocks, L.R.M., Plimer, R.I. (Eds.), Encycl. Geol. 1, 2005:1-12.
5. Castaing, C., Triboulet, C., Feybesse, J. L., & Chèvremont, P. (1993). Tectonometamorphic evolution Ghana, Togo and Benin in the light of Pan-African /Bresikiano orogeny. Tectnophysis, 218: 323-342.
6. Ajibade, A. C., & Wright, J. B. (1989). The Togo-Benin-Nigeria Shield: evidence of crustal aggregation in the Pan-African belt. Tectonophysics, 165 (1989) 125-129.
7. Caby, R. (1989). Precambrian terranes of Benin-Nigeria and Northeast Brazil and the Late Proterozoic South Atlantic fit. Geological Society of America Special Paper, 230, 145-158.
8. Black, R., & Liegeois, J. P. (1991). Pan-African plutonism of the Damagaram inlier, Niger Republic. Journal of African Earth Science, Vol. 13. No.3/4, 471-482 pp.
9. Ba, H., Black, R., Benziane, B., Diombana, D., Hascoet-Fender, J., Bonin, B., Fabre, J., & Liegeois, J. P. (1985). The province of the susaturated alkaline annular complexes of the Iforas adrar, Mali. Journal of African Earth Sciences, Vol. 3, No. 1/2, pp. 123-142.

10. Ngako, V., Njonfang, E., Aka, F.T., Affaton, P. & Nnange, J. M. (2006). The North-South Paleozoic to Quaternary trend of alkaline magmatism from Niger-Nigeria to Cameroon: Complex interaction between hotspots and Precambrian faults. Journal of African Earth Sciences 45 (2006) 241-256.
11. Black, R., Lameyre, J. & Bonin, B. (1985). The structural sitting of alkaline complexes. Journal of African Earth Sciences. Vol, 3, No. 1/2, pp. 5-16, 1985.
12. Karche, J. P., & Vachette, M. (1978). Age and migration of magmatic activity in the Paleozoic complexes of Niger, consequences. Bull. Soc. Géol. Fr. 20: 941-953.
13. Bowden, P., Van Breemen, D., Hutchinson, J., & Turner, D. C. (1976). Paleozoic and Mesozoic ages trends for some ring complexes in Niger and Nigeria. Nature, 259, no. 5541: 297-299.
14. Mignon, R., (1970). Geological study and prospecting of Damagaram-Mounio and South Maradi. BRGM report, 269p.

15. Lawali, I.C., Ahmed, Y., Mallam, M.H., Badamassi, K.M.M., Chékaraou, S.M.M., Attourabi, A.S., And Gambo, R. N. 2022. Petrographic Characterization Of The Badaraka Alkaline Ring Complex (Damagaram, South-East Niger). IJSRM, vol. 22, no. 1, pp. 94-105, 2022.

16. Black, R., (1963). Note on the annular complexes of Tchouni-Zarnouski and Gouré, Bull. B.R.G.M. Fr, N°1.
17. Van Breemen, O., Pidgeon, R. T., & Bowden, P. (1977). Age and isotopic studies of some Pan-African granites from north-central Nigeria. Precambrian Res. 4: 307--319.
18. Ferré, E. C., Deleris, J., Bouchez, J. -L., Lar, A. U., & Peucat, J. -J. (1996). The Pan-African reactivation of Eburnean and Archaean provinces in Nigeria: structural and isotopic data. Journal of the Geological Society of London 153, 719-728.
19. Castaing, C., Aregba, A., Assih-Edeou, P., Chèvremont, P., Godonou, K. S., & Sylvain J. P. (1988). Gneissic units and the great crustal shear of the Benino-Togolese plain. Journal of African Earth Sciences, 7(5): 859-866.

20. Badamassi, K. M. M. (2021). Petrostructural and geochemical characterization of the Pan-African formations of the Damagaram province (Southeastern Niger). PhD thesis from the Université Abdou Moumouni de Niamey (Niger), 157 p.

21. Sanda, C. M. M., & Konaté M. (2021). Permian ages of Younger Granites from Mounio province (Gouré area, Southeastern Niger). European Journal of Environment and Earth Sciences.
22. Bowden, P., & Kinnaird, J. A. (1984). geology and mineralization of the Nigerian anorogenic ring complexes: with a geological map at the scale of 1:500000. Geologischesjahrb (hannover) b vol. 56: 365.

23. Black, R., Jaujou, M., & Pellaton, C. (1967). Explanatory note on the geological map of Aïr, at a scale of 1/500,000. Directorate of Mines and Geology, Republic of Niger. BRGM Editions: 57p.

24. Ousmane, B. (1988). Geochemical and isotopic study of the basement aquifers of the Sahelian belt of Niger (Liptako, South Maradi and East Zinder), PhD thesis, University of Niamey. 175 p.

25. Badamassi, K.M.M., & Konaté, M. (2021). Characterization of the Damagaram Province Pan - African basement Deformation (South - East, Niger). International Journal of Science and Research. 10. 9. pp. 1421-1431.

26. Program for Strengthening and Diversification of the Mining Sector in Niger (PRDSM). (2013). Notice of the Damagaram-Mounio geological map (Scales 1/100,000 and 1/200,000), technical assistance in the geoscientific field (SOFRECO), 2nd edition, 62p.

27. Bowden, P., Black, R., Martin, R. F., Iké, E., Kinnaird, J. A., & Batchelor, R. A. (1987). Niger-Nigerian alkaline ring-complexes: a classic example of African Panerozoic anorogenic mid-plate magmatism. In Fitton, J. G., & Upton, B. J. G., (eds) Alkaline Igneous Rocks. Geological Society, London, Special Publication, 30, 357-380.

28. Bertrand, J. M. L., & Caby, R. (1978). Geodynamic evolution of the Pan-African Orogenic Belt: A new interpretation of the Hoggar Shield (Algerian Sahara). Geol. Rundschau, 67, (2), 357-388.

29. Black, R. & Morosoff, W. (1960). Interim report on the younger granites of the Zinder-Gouré region. B.R.G.M. Dakar.

30. Vincent, I., Wang, L., Zhu, Y., And Kamaunji, V.D. 2022. Onset Of The Anorogenic Alkaline Magmatism In The Nigerian Younger Granite Province: Constraints From The Daura And Dutse Complexes. Afrique Earth Sci., p. 27, 2022

31. Boubacar, F., & Konaté M. (2020). Use of remote sensing and GIS for mapping gold mineralized zones in the Pan-African province of South-East Niger (South Maradi and Damagaram-Mounio). Rev. ivoir. sci. technol. 36 (2020) 230 - 252.

32. Falconer, J. D., & Raeburn, C. (1923). The Northern Tinfields of Bauchi Province, with notes by A. D. N. Bain and W. Russ. Geol. Survey of Nigeria, Bulletin No. 4, pp. 67 with 10 plates and 2 colored maps. Published by the Nigerian Government (1923). Geological Magazine, 60(10), 476. doi:10.1017/s0016756800088373.

33. Kretz, R. (1983). Symbols of rock-forming minerals. American Mineralogist, Vol. 68, pages 277-279.

34. Tidjani, A. D. (2008). Wind erosion in East Damagaram (South-East Niger): Parameterization, quantification and means of control. PhD thesis, Catholic University of Louvain.