

Review Article

Mineralogical and Geochemical Characterization of the Zarnouski Felsic Suites, Anorogenic Damagaram-Mounio Province

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Abstract

The Zarnouski complex is located 80 km northeast of the Zinder pluton, in the province of Damagaram-Mounio, halfway between the more recent granites of the Aïr and those of Nigeria to the south. The aim of this study is to present the results of the mineralogical and geochemical characterisation of the Zarnouski felsic suites. It is a prime target for determining: (i) the nature of the rocks and (ii) tracing variations in the major elements controlling the mechanisms of magmatic differentiation. The methodological approach used is multidisciplinary, combining petrographic analysis, radiometric analysis and geochemistry of major elements. Two alkaline and hyperalkaline lineages are highlighted. The small elliptical Zarnouski pluton, consists of quartz-syenite [330 ± 3 Ma, $(^{87}\text{Sr}/^{86}\text{Sr})_0 = 0.7100$] cut by aegyrin-granite [302 ± 9 Ma, $(^{87}\text{Sr}/^{86}\text{Sr})_0 = 0.7157$]. The geochemical results obtained show that these rocks have high silica and alkalis contents. Indeed, using geochemical classification diagrams on rock typology coupled with calculated alkalinity indices, two magmatic lineages were highlighted. The first lineage comprises a petrographic sequence ranging from augite-syenite (K+Na: 0.30) to quartz-syenite (K+Na: 0.28) and biotite-granite, rhyolite (K+Na: 0.25), with an alkalinity index (AI) varying from 0.94 to 0.99. Hyperalkaline rocks are microsyenite (AI: 1.13; K+Na: 0.33) and riebeckite-granites (AI: 1.06 to 1.11; K+Na: 0.25-0.26). The relationship between alumina and alkalis, coupled with the decrease in CaO, FeO and MgO, has allowed us to propose a divergent differentiation from syenite, producing an alumina-deficient fraction (riebeckite-granite) and an aluminous fraction represented by biotite-granite. The presence of Fe²⁺-rich ferromagnesian minerals ($\text{Fe}^{2+}/\text{Fe}^{3+} > 1$) at the beginning and annite, Fe³⁺ [biotite-granite: ($\text{Fe}^{2+}/\text{Fe}^{3+}) < 1$] towards the end of crystallization indicates that magma influx was relatively reduced. This study suggests that the rocks studied were formed from magma that underwent significant differentiation/fractional crystallisation (DI: 81.75 to 94.76) and that alkali-rich mantle sources play a key role in their genesis. A divergent differentiation of syenite, producing an alumina-deficient fraction (riebeckite granite) and an alumina-rich fraction represented by biotite granites, is proposed for the Zarnouski rocks.

Keywords

Alkalinity Index, Aegyrin-rebeckite, Petrochemical Evolution, Damagaram-Mounio, Zarnouski

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1. Introduction

Alkaline and hyperalkaline rocks are types of magmatic rocks characterised by a high alkali content ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) and specific chemical compositions [1]. Indeed, the annular complexes of the Niger-Nigeria province are remarkable examples of intraplate epizonal magmatism in a continental domain. Numerous studies have highlighted a gradual southward shift of magmatic foci in the Niger-Nigeria superprovince [2, 3]. Several models, including the mantle plume model [3-5], the reactivated strike-slip fault system model [6, 7], and the complex interaction between the plume and ancient lineaments [2] have been proposed to explain the north-south alignment of this Niger-Nigeria province. Approximately 200 Ma after the Pan-African orogeny, the Damagaram-Mounio province (Figure 1) was affected by intraplate alkaline magmatism between 340 and 287 Ma. This purely anorogenic magmatism has been attributed as the type of magmatism for all the more recent granites of the Niger-Nigeria felsic province [8-10]. The Tchouni and Zarnouski ring complexes are located approximately 80 km

northeast of the Zinder granite pluton in the Damagaram-Mounio province. Known since the beginning of the century, this massif has been the subject of several petrographic [11-16] and radiometric studies based on the decay of the Rb/Sr pair: 330 ± 6 Ma [17]. The complex is characterised by varied intrusions composed of alkaline and hyperalkaline rocks where, in a tectonic setting of collapse (ring complex), volcanism and plutonism are closely linked [1, 11, 17]. Until recently, little information was available on the annular structure of Zarnouski. Provided a summary petrographic description as part of his cartographic work on Tchouni-Zarnouski [11]. This summary analysis of the complex reveals that several questions remain unanswered with regard to mineralogy, geochemistry and deformation. In this study, the complex is characterised in terms of geochemistry and mineralogy. Analytical techniques such as whole rock geochemistry (ICP-AES) and Rb-Sr radiometric analysis were performed to address the various questions.

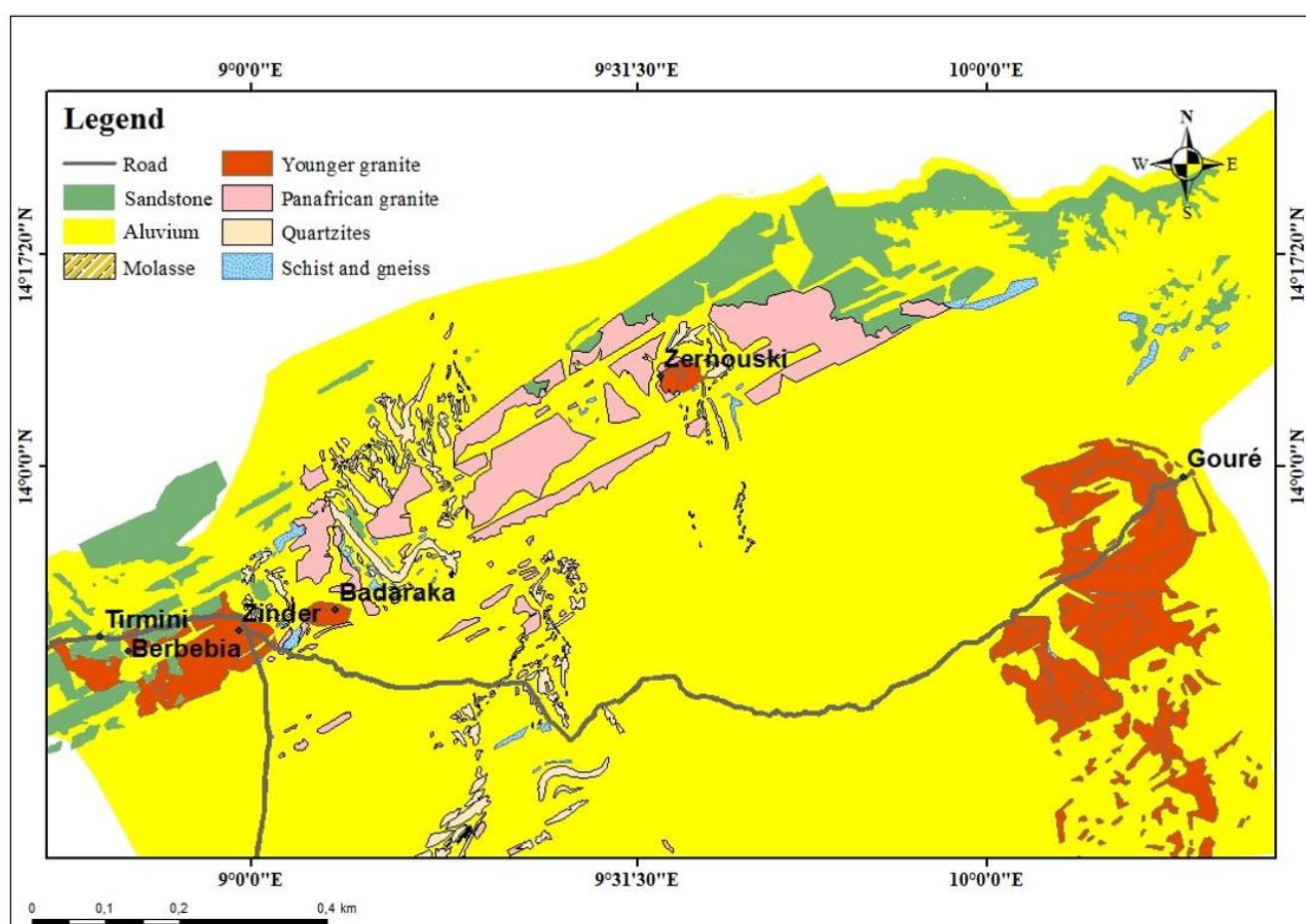


Figure 1. Geological map of Damagaram-Mounio province.

2. Geology of the Zarnouski Complex

The Chouni-Zarnouski complexes consist of two contiguous complexes composed of numerous plutonic, peri-plutonic and volcanic occurrences that cut a folded and faulted series of quartzites, gneisses and oriented porphyritic granite [11].

The Zarnouski complex, the subject of the present study, is entirely preserved and offers a beautiful oval-shaped ring-structure with a long axis of 7 km and a short axis of 5 km, oriented to the ENE.

Magmatic activity begins with a syenitic cycle. The play of a peripheral fault marked in the southeast by an explosion breccia (diatreme) leads to the emplacement of an augite-aegyrine syenite. Ring faults occur within this augite-syenite, producing successive intrusions of augite-syenite and quartz-syenite. These intrusions are crescent-shaped, which may be explained by the fact that the faults were stuck in the north during subsidence. The geometric arrangement of the intrusions would indicate a slight displacement of the magmatic focus towards the WSW, during the syenitic cycle. In the western part of the massif, augite-syenite intrudes along the augite-aegyrine syenite, augite microsyenite contact, and in the east, it obliquely cuts the fayalite-augite microsyenite and augite-aegyrine microsyenite ring dikes. Next, a granitic cycle begins with the emplacement of an incomplete ring-dyke of aegyrin-riebeckite microgranite along the peripheral fault in the northeast of the massif. Vein intrusions of riebeckite granite, followed by aegyrine microgranite, occur in the intensively faulted zone between Maora and Milori, and further west, in WNW-trending veins parallel to the ring fault that played a role during emplacement of the augite syenite. Activity then resumes in the center of the complex with the emplacement of a complete ring of riebeckite-biotite granite and aegyrin-biotite granite. Finally, the cycle ends with the intrusion of biotite granite forming the central core of the massif.

3. Petrographic Character of the Zarnouski Complex

In his research work, [11] highlighted a petrographic association of syenite, microsyenite, granite and microgranite at Zarnouski (Figure 2).

3.1. Syenite-microsyenite

The minerals present include:

- 1) Automorphous zoned feldspars, composed of a core of often dark-hued antiperthite and a periphery of white- to pink-colored layered perthite.
- 2) Interstitial quartz, which frequently forms vermiculations on the edges of the feldspars;
- 3) Colorless or slightly tinted augite and green or bluish hornblende, biotite and chlorite may be present, but in secondary quantities;
- 4) Perthitic feldspars (cryptoperthite, laminated perthite or

spotted perthite) in riebeckite-albite granites;

- 5) Phenocrysts of augite have been noted in a very fine-grained microsyenite;
- 6) Accessory minerals: magnetite, ilmenite-zircon, allanite, apatite and calcite.

3.2. Rhyolite-Granite-microgranite

Hornblende microsyenite and aegyrin-riebeckite microgranites form the hyperalkaline lineage at Zarnouski. Minerals include:

- 1) Perthitic feldspars, albite-oligoclase and biotite with a few flakes of white mica in the aegyrine-riebeckite microgranites;
- 2) Metasomatic albite in irregular patches that partially obliterate the lamellar structure of perthite;
- 3) Small, jagged crystals of macerated albite, entangled along the contacts between feldspar crystals;
- 4) Automorphic quartz in microgranites;
- 5) Dark-green aegyrine and bluish-tinted sodium amphibole with positive or negative elongation (riebeckite);
- 6) Structural relationships between ferromagnesian minerals that offer fine examples of Bowen's reaction series: pyroxene and olivine form residual cores surrounded by amphiboles and biotite, while pyroxene can be embedded in feldspars. Amphibole and biotite, on the other hand, are always interstitial;
- 7) Accessory minerals: abundant fluorite, zircon, apatite, allanite and iron oxides.

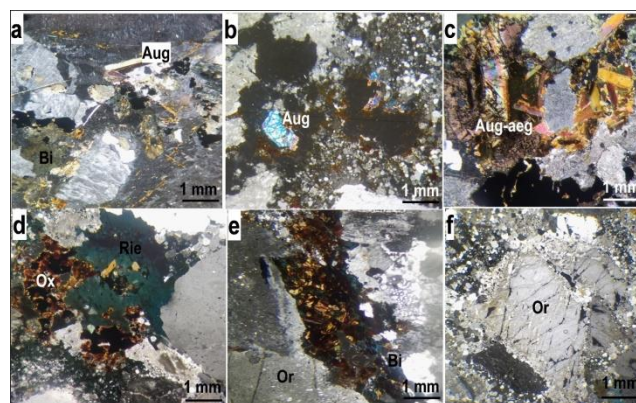


Figure 2. Microphotographs of the rock from Zarnouski ring complex. a: quartz-syenite; b: microsyenite; c: augite-syenite; d: riebeckite-granite; e: biotite-granite; f: biotite-granite. aug: augite; or: orthoclase; aeg: aegyrine; Bi: biotite; ox: oxides.

4. Methodological Approach

To achieve the objective of this study, several petrographic and geochemical analyses of the major elements were carried out. The purpose of the geochemical study is to chemically characterise the rocks of the Zarnouski complex. On the one hand, it allows us to situate them in relation to chemical variations and,

on the other hand, to identify the mechanisms of genesis and differentiation of these rocks. Geochemical studies were carried out on the different rocks and made it possible to decipher the physico-chemical conditions in which the rocks were formed. The choice of a sample for analysis is based on the physical state of the rock (intact or altered). Seven (07) samples were analysed (by Ms B. Martinet) using the ICP-AES method at the geochemical laboratory in Nancy, France. The results obtained were processed using the GCDKit version 2006 programme [18] and Grapher software. The GCDKit programme was used to determine the evolution of chemical elements and for petrographic characterisation, which consisted of correcting and validating macroscopic and microscopic descriptions. Canvas software, on the other hand, is a drawing program that was used to reproduce figures and process images of thin sections. The radiometric age was calculated by [17] using the Rb-Sr method. Mineralogical characterization was carried out on the basis of oxide-based mineral structural calculations. Calculated minerals are the key to determining felsic rocks. These alkaline minerals are feldspar,

pyroxene and amphibole.

5. Results

5.1. Mineralogical Characterization

5.1.1. Alkali Feldspars

Petrographic studies have shown that the feldspars contained in the Zarnouski rocks are represented by albite and orthoclase [11]. The structural formulas and polar components [Ab (Na)-An (Ca)- Or (K)] used in the feldspar classification diagram were calculated on the basis of eight (8) oxygens.

Plotting the calculated values in the Ab-Or-An diagram (Figure 3a) indicates that the feldspars in the Zarnouski rocks lie in the anorthoclase field. This is in agreement with the petrographic findings of [11], who pointed out that Zarnouski feldspars have a more sodic than potassic tendency.

Table 1. Mineral proportions (CIPW) in representative samples, Zarnouski ring complex, Damagaram, Niger. Symbols used: zsk1: augite-syenite, zsk2: microsyenite, zsk3 and zsk4: quartz syenite, zsk5 and zsk6: riebeckite-granite (hyperalkaline granite), zsk7: biotite-granite (alkaline granite).

	zsk1	zsk2	zsk3	zsk4	zsk 5	zsk6	zsk7
Qtz wt. %	-	7.29	9.28	16.14	23.82	22.14	28.62
Or	31.69	35.03	32.80	30.02	28.91	28.91	30.02
Al	49.25	42.97	46.63	44.01	35.63	38.25	37.20
Aeg	-	3.23	0.92	0.92	5.54	3.70	-
Mt	3.94	-	1.86	0.70	1.39	1.39	1.62
Il	1.82	1.52	1.06	0.30	1.06	1.06	0.30
Ap	0.67	0.51	0.34	-	-	-	-

Table 2. Bulk composition of representative samples, Zarnouski ring complex, Damagaram, Niger.

	zsk1	zsk2	zsk3	zsk4	zsk 5	zsk6	zsk7
SiO ₂ wt. %	60.25	62.30	66.60	68.85	70.70	71.15	74.50
Al ₂ O ₃	15.45	14.85	15.10	14.10	12.25	12.80	12.80
Fe ₂ O ₃	2.80	1.10	1.60	1.75	4.55	1.80	1.15
FeO	4.37	4.95	2.5	1.75	0.76	1.85	0.72
MnO	0.28	0.22	0.12	0.09	0.20	0.11	0.04
MgO	1.20	0.60	0.52	0.42	0.12	0.10	0.08
CaO	2.50	1.90	1.75	1.23	0.56	0.55	0.67
Na ₂ O	5.85	6.35	5.05	5.35	5.10	5.05	4.40
K ₂ O	5.35	5.95	5.55	5.05	4.90	4.90	5.10

	zsk1	zsk2	zsk3	zsk4	zsk 5	zsk6	zsk7
TiO ₂	0.95	0.80	0.12	0.35	0.55	0.20	0.15
P ₂ O ₅	0.36	0.21	0.50	0.14	0.06	0.03	0.04
Total	99.36	99.23	99.41	99.09	99.75	98.54	99.65
DI	81.75	86.61	85.82	89.42	94.69	94.76	93.41
A.I.	0.99	1.13	0.94	1.00	1.11	1.06	0.99

5.1.2. Sodium Amphibole

The structural formulas and poles $[Mg^{2+}/(Mg^{2+}+Fe^{2+})]$ and Si (c.u.p.f) used in amphibole classification diagrams were calculated on the basis of 23 oxygens. In [19] amphibole classification diagram $[Mg^{2+}/(Mg^{2+}+Fe^{2+})]$ and Si (c.u.p.f)] (Figure 3b), samples with parameters $(Na+K)_A < 0.50$ and $Na_B \geq 1.50$ underline that the amphibole types present are riebeckite and magnesio-riebeckite. This shows that the grade of Tirmini arfvedsonite granites [20, 21] is higher than that of

Zarnouski riebeckite granites.

5.1.3. Sodium Pyroxene

The structural formulas and axial components $[Na/(Na+Ca)]$ and $Al/(Al+Fe^{3+})]$ used in the binary diagrams employed in the pyroxene classification diagram, were calculated on the basis of six (6) oxygens. Plotting the calculated values in the Ab-Or-An binary diagram $[Na/(Na+Ca)]$ and $Al/(Al+Fe^{3+})]$ (Figure 3c) indicates that the pyroxenes present are aegyrin and augite-aegirine.

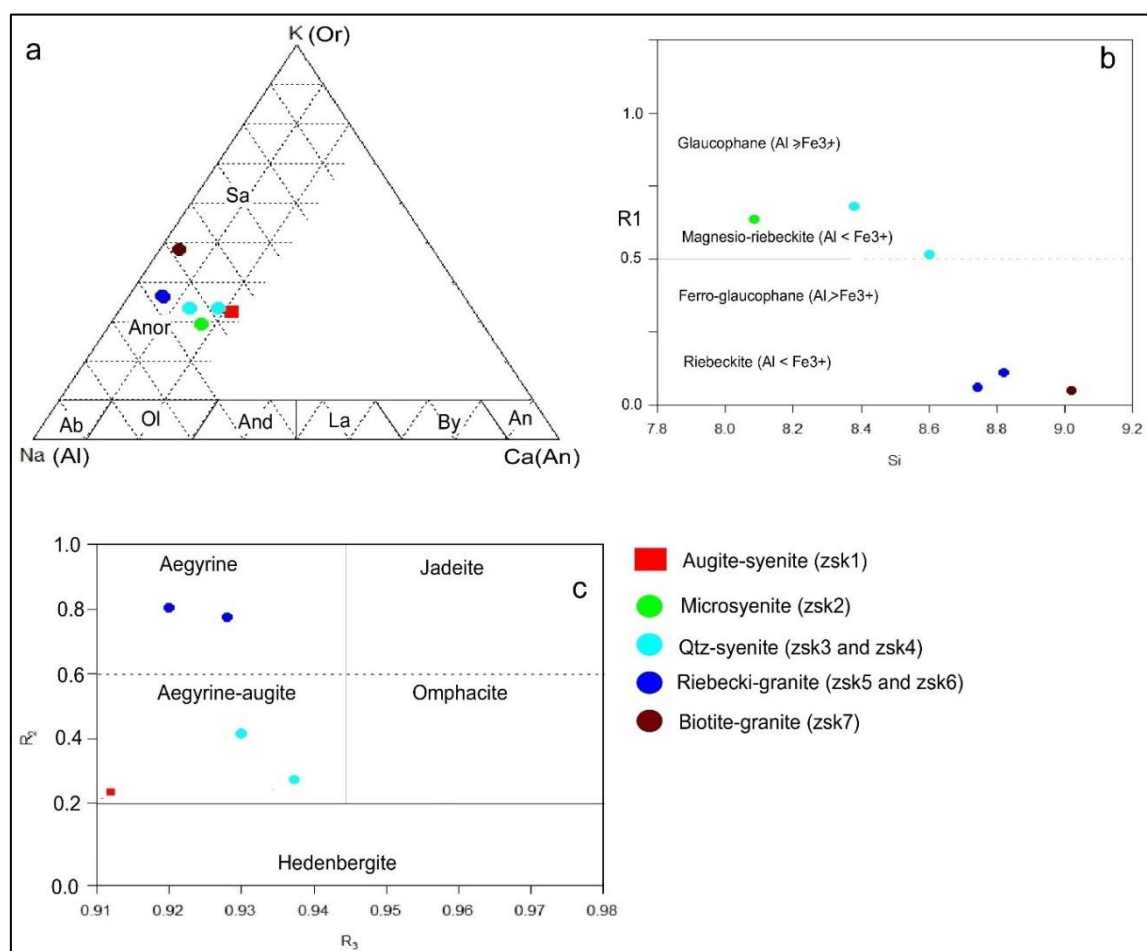


Figure 3. Mineral distribution diagrams. a) feldspar classification diagram (Ab-An-Or); b) [19] amphibole classification diagram $[Mg^{2+}/(Mg^{2+}+Fe^{2+})]$ and Si (c.u.p.f)] and c) pyroxene classification diagram. Ab: albite, Ol: oligoclase, And: andesine, La: labradorite, By: bytownite, An: anorthite.

5.2. Petrochemical Characteristics

The present study reveals two magmatic lineages: alkaline (augite-syenite: zsk1, quartz-syenite: zsk3 and zsk4 and biotite-granite: zsk7) and hyperalkaline (microsyenite: zsk2 and riebeckite-granite: zsk5 and zsk6).

5.2.1. Typology of Zarnouski Rocks

Geochemical analysis of the major elements shows that the SiO_2 composition of the Zarnouski complex ranges from 60.25 to 74.5 wt.% by weight. Na_2O and K_2O compositions range from 4.4 to 6.35 wt.% and 4.9 to 5.95 wt.% by weight respectively. These high SiO_2 , K_2O and Na_2O values underline the felsic character of the rocks of the Zarnouski complex. In order to remove the ambiguity between samples zsk5 and zsk6 initially described as microgranite and granite by [11], a chemical comparison was presented. The chemical results for these two samples are similar, with major element contents that are statistically equal. These results suggest that the two samples define the same rock (riebeckite-granite: hyperalkaline), despite the textural differences observed. In order to

provide a geochemical answer to the petrographic observations on the nature of the different facies of the Zarnouski complex, reference diagrams were used. Projection of the sample values in the [22] diagram (Figure 4a) positions the rocks in the syenite (zsk1), quartz syenite (zsk3 and 4) and alkaline granite (zsk5, zsk6 and zsk7) fields. Although they contain a high percentage of SiO_2 (> 65 wt.%: Table 2), samples zsk3 and zsk4 are positioned in the quartz syenite field. Sample zsk2 corresponds to the achaean microsyenite between the syenite and nepheline syenite fields. [23] diagram was used to give a more precise view of sample zsk2. The projection of Zarnouski's peri-plutonic and plutonic facies onto [23] TAS "Total Alkali Silica" diagram of $\text{Na}_2\text{O} + \text{K}_2\text{O}$ versus SiO_2 classification places the rocks in the syenite field (augite-syenite: zsk1 and microsyenite: zsk2), quartz-monzonite (zsk3 and zsk4) and in the granite field (riebeckite-granite: zsk5 and zsk6; and biotite-granite: zsk7) (Figure 4b), in good agreement with the results obtained on the diagram of [22].

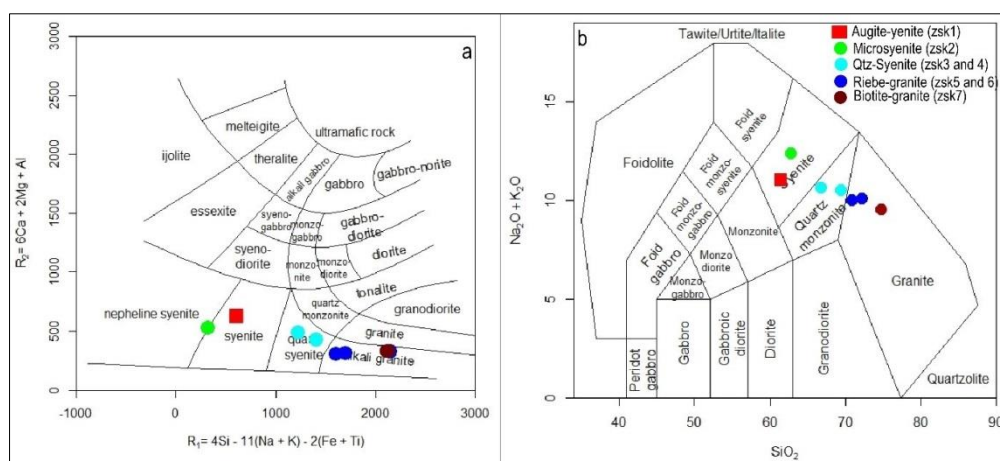


Figure 4. The composition of the felsic igneous rocks of the Zarnouski ring complex is shown in a plot of $[R_2: 6\text{Ca} + 2\text{Mg} + \text{Al}]$ versus $R_1: 4\text{Si} - 11(\text{Na} + \text{K}) - 2(\text{Fe} + \text{Ti})$: (a) [22]; in a plot of $\text{Na}_2\text{O} + \text{K}_2\text{O}$ versus SiO_2 TAS plot: [23] (b). The suite of relatively fresh igneous rocks consists of syenite or quartz-monzonite and one sample of granite.

Hyperalkaline rocks differ from alkaline rocks in particular in their higher Na_2O content (Table 2). This is accentuated by the presence of riebeckite and aegirine (sodium pyroxene) in these rock types, which are also depleted in aluminum (Table 2).

In order to discriminate between alkaline and hyperalkaline rocks, [24] alkalinity index $[\text{AI}: (\text{Na} + \text{K})/\text{Al}]$ is the best parameter for separating the alkaline rock group from the hyperalkaline rock group. This parameter was used by [24] to separate the rocks of the Adrar des Iforas in Mali. Alkaline rocks range from IA: 0.87 to 1; hyperalkaline rocks, on the other hand, have an alkalinity index >1. At Zarnouski, only microsyenite and riebeckite-granites have an alkalinity index >1 (Figure 5a). Alkalinity index values for augite-syenite,

quartz-syenite and biotite-granite demonstrate that these rocks are alkaline (Figure 5a).

The P_2O_5 and TiO_2 contents of Zarnouski Complex rocks are low compared with S-type rocks. Pronounced alkalinity due essentially to alumina deficiency; the alkali-alumina ratio is the criterion that determines mineralogical composition. Alumina deficiency compared with the alkalis produced by hyperalkaline rocks (aegirine and riebeckite). To discriminate between the aluminous and alkaline nature of Zarnouski rocks, [25] A/NK versus A/CNK diagram (Figure 5b) was used. In this diagram, microsyenite and riebeckite-granites lie within the hyperalkaline granite field, while alkaline facies (augite-syenite, quartz-syenite and biotite-granite) lie at the

boundary between the metaluminous and hyperalkaline granite fields (Figure 5b). Note that Figure 5b shows the balance

between alumina and alkalis from syenite to granitic facies.

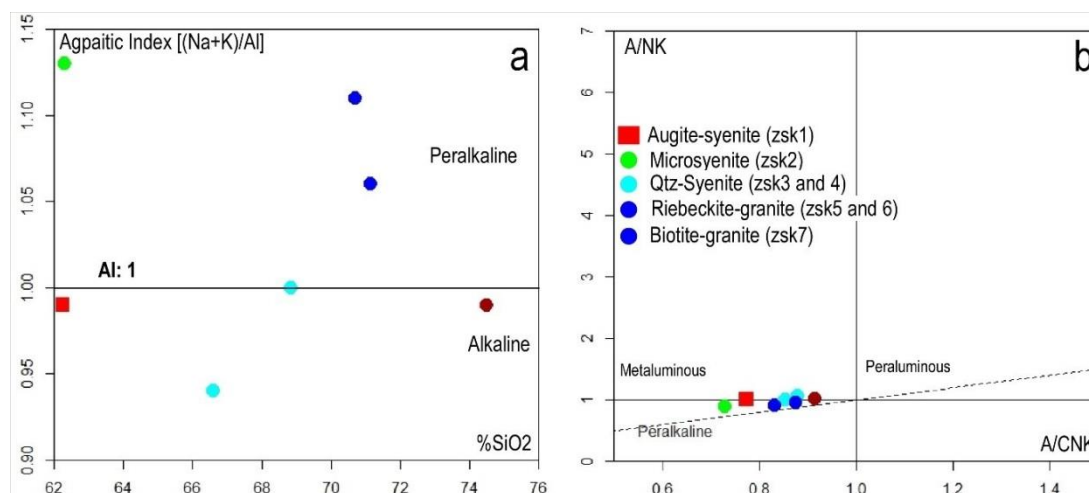


Figure 5. Major element variations of the different studied series. (a) SiO₂ vs agpaïtic index: peralkaline rocks have an agpaïtic index > 1 while other alkaline rocks are generally above 0.87 [24]; (b) Discrimination diagram of Zarnouski rocks [25].

5.2.2. Evolution of Major Elements

Chemical analysis in terms of major elements shows that SiO₂ and FeOt contents (Table 2) increase from syenite to granite. By contrast, Al₂O₃, CaO and MgO contents show the opposite trend (Table 2). These two observations underline the highly differentiated nature of the rocks in the Zarnouski complex. Although very rich in alumina (Al₂O₃: 15.45 wt.% by weight), sample zsk1 belonging to the augite syenite is distinguished from the others by its enrichment in FeO (4.37 wt.% by weight), MgO (1.20 wt.% by weight) and MnO (0.28 wt.% by weight), which can be explained by the enrichment in

colored minerals (augite, riebeckite and biotite). On the other hand, this zsk1 sample shows relatively less SiO₂ (60.25 wt.%). Contrary to SiO₂ behaviour, the evolution of alkaline oxide contents (K₂O+Na₂O) decreases from augite syenite (zsk1) to quartz syenite (zsk3 and zsk4) and biotite granite (zsk7). The same applies to microsyenites (zsk2) and hyperalkaline granites (zsk5 and zsk6): this explains why the emplacement chronology shows the evolution of a felsic magma justified by enrichment in silica (SiO₂) and alkalis (Na₂O + K₂O): this is magmatic differentiation [26] SiO₂ versus Oxides diagrams were used to determine chemical element mobilities and facies chronology (Figure 6).

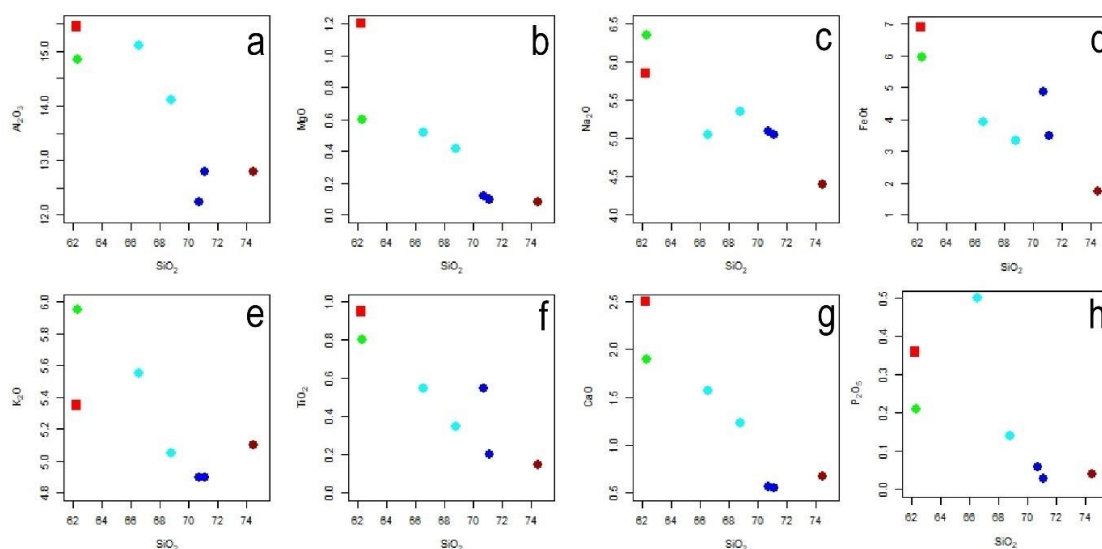


Figure 6. Variation of Zarnouski major element values as a function of silica content (SiO₂) in the [26] diagram.

These diagrams show a continuous, linear distribution of points representative of samples from the Zarnouski complex (Figure 6). This distribution indicates negative correlations between silica (SiO_2) and the other major elements. The negative correlations explain the important role played by fractional crystallization during magmatic differentiation. Negative correlations in MgO , TiO_2 and FeO (Figure 6b, d, f and h) reflect the decline in accessory minerals from syenites to granites. In the case of the Zarnouski rocks, this effect is accompanied by the early genesis of minerals such as monazite, apatite and ilmenite (Table 1). These negative correlations were interpreted by [26-28] as an effect of fractional crystallization processes from the very beginning of magma formation. As for the negative correlations observed in Al_2O_3 and K_2O (Figure 6a and e), they underline the fact that Zarnouski magmatic suites are progressively depleted in potassium feldspar and proportionally enriched in sodium. This sodium enrichment is justified by the presence of sodium minerals such as aegyrin and riebeckite. The presence of evolutionary trends (Figure 6) in the oxide-silica binary diagrams, coupled with chemical variations in major elements, militate in favor of a fractional crystallization process as the mechanism responsible for chemical variations within the rocks of the Zarnouski complex. It should also be noted that most of the formations were emplaced under reducing conditions, with a $\text{Fe}^{2+}/\text{Fe}^{3+}$ ratio greater than 1 ($\text{Fe}^{2+}/\text{Fe}^{3+}$: 1.13 to 5.23). Samples zsk5 and zsk7, corresponding to aegyrin granite and biotite granite respectively, show a ratio of less than 1 ($\text{Fe}^{2+}/\text{Fe}^{3+}$: 0.17 to 0.71), indicating emplacement under oxidizing conditions.

6. Discussion

All previous studies on the Zarnouski complex have been limited to petrographic, chemical and radiometric characterisation [11, 13, 17]. This study presents data on mineralogical characterisation and petrographic responses already made by [11]. The mechanism of magmatic differentiation of the felsic suites has been widely debated. Understanding the genesis of the rocks of the Zarnouski complex has required determination of the nature of the magmas, the mechanisms by which these felsic suites evolved, and the post-magmatic changes recorded. According to the work of [17] at Zarnouski, the age calculated by the Rb/Sr method gives an age of $302 \pm 9\text{Ma}$ and $330 \pm 3\text{Ma}$; corresponding to the Lower Carboniferous period. The results of geochemical analyses show that alkaline and hyperalkaline rocks from Zarnouski have high alkaline contents, with "Na + K" values ranging from 0.25 to 0.33. These results suggest that the rocks studied were formed from magma that underwent significant differentiation, and that alkali-rich mantle sources play a key role in their genesis. Figure 4b shows the equilibrium between alumina and alkalis, and the progressive decrease in CaO , FeO and MgO (Table 2), from syenites to granites. In Nigeria, [1] proposed a divergent differentiation hypothesis producing an alumina-deficient fraction represented by riebeckite-granites and an aluminous fraction represented by biotite granites. The

$\text{Fe}^{2+}/\text{Fe}^{3+}$ ratio >1 for most Zarnouski rocks supports this hypothesis. In such situations, [29] demonstrated for Kwadonkaya rocks (Nigeria) that the presence of Fe^{2+} -rich ferromagnesian minerals at the beginning and biotite (annite) towards the end of crystallization indicates that magma influx was relatively reduced (OFM buffer). These types of alkali-rich biotite granites may also have implications for the search for associated rare-earth mineralization [11, 29-31]. It seems that the genesis of riebeckite granites is due to an accentuation of anorthoclase fractionation compared to magnesite fractionation. The geochemical variations observed between the different rocks studied (Figure 6) can be attributed to magmatic differentiation processes, notably fractional crystallization. In general, the decrease in Fe_2O_3 as a function of the increase in SiO_2 also indicates the fractionation of opaque minerals such as magnetite and ilmenite [32-34]. In addition, the crystallization of riebeckite and biotite could also influence the fractionation of Fe_2O_3 . The negative correlation of MgO versus SiO_2 indicates pyroxene and amphibole fractionation. Such a hypothesis was adopted by [6] to explain the fractionation of aegyrin and arfvedsonite in the Daura rocks of Nigeria. According to [6], the high alkali content is compatible with rocks derived from mantle sources. On the other hand, the authors [35, 36] point out that alkaline rocks can also originate from a fenitized continental crust. Geochemical analysis of trace elements is necessary for the precise determination of the tectonic context of the Zarnouski complex.

7. Conclusion

This study presents the results of geochemical data from the Zarnouski complex. The rocks studied (aegyrin syenite, quartz syenite, biotite granite, microsyenite and riebeckite granite) have an alkalinity index (AI) between 0.94 and 1.13 and a magmatic differentiation index ranging from 81.75 to 94.76. A divergent differentiation of syenite, producing a fraction deficient in alumina (riebeckite granite) and an alumina-rich fraction represented by biotite granites, is proposed for the Zarnouski rocks. The calculated age of the beginning of emplacement is $[330 \pm 3\text{ Ma}]$, ($^{87}\text{Sr}/^{86}\text{Sr})_0 = 0.7100$; quartz-syenite). Emplacement ended around $[302 \pm 9\text{ Ma}]$, ($^{87}\text{Sr}/^{86}\text{Sr})_0 = 0.7157$; aegyrin-granite]. The $\text{Fe}^{2+}/\text{Fe}^{3+}$ ratio >1 reflects the fact that most of the rocks were emplaced under reducing conditions. The riebeckite granite (zsk5) and biotite granite (zsk7) show emplacement under oxidising conditions [$(\text{Fe}^{2+}/\text{Fe}^{3+}) < 1$].

Abbreviations

AI	Aigpaitic Index
DI	Magmatic Differentiation Index
A/NK	Aluminium/Sodium-Potassium
A/CNK	Aluminium/Calcium-Sodium-Potassium

Author Contributions

Lawali Idi Chamsi: Conceptualization, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing

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Conflicts of Interest

The authors declare no conflicts of interest.

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