

Petrology and Geochemistry Study of the Basaltic Rocks of Tchaga South East of Fitri Lake-Chad: Metallogenic Implication

Tekoum Leontine^{1,2*}, Mady Esaie^{1,2}, Klamadji Moussa Ngarena³,
Jean Claude Doumnang Mbaigane^{1,2}, Rochette Pierre⁴

¹Laboratory of Geology, Geomorphology, and Remote Sensing, Faculty of Exact and Applied Sciences, University of N'Djamena, N'Djamena, Chad

²Laboratory of Hydro-Geoscience and Reservoir, Department of Geology, Faculty of Exact and Applied Sciences, University of N'Djamena, N'Djamena, Chad

³Department of Mining and Geology Engineering, Faculty of Earth and Life Sciences, University of Pala, Pala, Chad

⁴National Centre for Scientific Research, Research Institute for Development, National Research Institute for Agriculture, Food and the Environment, Aix-Marseille University, Aix-en-Provence, France

Email: *leontinetekoum@yahoo.fr, madyesaie@gmail.com, doumnag@gmail.com

How to cite this paper: Leontine, T., Esaie, M., Ngarena, K.M., Mbaigane, J.C.D. and Pierre, R. (2026) Petrology and Geochemistry Study of the Basaltic Rocks of Tchaga South East of Fitri Lake-Chad: Metallogenic Implication. *International Journal of Geosciences*, 17, 14-37.

<https://doi.org/10.4236/ijg.2026.171002>

Received: December 25, 2024

Accepted: January 11, 2026

Published: January 14, 2026

Copyright © 2026 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

In this paper, we present the new data from the study area. Located in the Southeast of Fitri Lake, at the center of the Republic of Chad in the Batha region, our study sector is an excellent metallogenic province, characterized by the presence of meta-volcano-sedimentary rocks. Based on petrography and geochemistry findings, these meta-volcano-sedimentary rocks are: the metavolcanites (metabasalt, metadacite) and the metasediments (metaconglomerates, and marbles), covered by quaternary sedimentary formations (clay and sandstone). These rocks are crosscut by quartz-veins and a vein network hosting pyrite, chalcopyrite and gold mineralization. In the TAS classification we identify two lithological rocks of basaltic and dacitic composition. In the AFM ternary diagram, some rocks plot into the tholeiitic field and others in the calco-alkaline domain, but have higher tholeiitic tendency suggesting that the rocks have been crystallized from a similar parent magma. The high loss on ignition (LOI) values from 2.26 to 11.65 wt. % suggesting probably the contribution of secondary hydrated and carbonate phases. The variable contents of MgO, Mg# (36.09 - 67) and transition elements (Sc, Cr, Co, Ni) of the meta-volcanic rocks studied suggest that a certain degree of fractional crystallization occurred during the emplacement of meta-volcanic rocks. The Harker diagram shows a trend of negative evolution with the exception of the Al_2O_3 vs SiO_2 diagram which shows a positive trend. The high enrichment of Th, Rb, Cs, K

and Y, Zr, Hf, Sr shows a negative anomaly and subduction tectonic setting. Based on Chondrite and primitive mantle spider diagrams, LREE have been enriched to HREE in this area. The Th/Yb VS Nb/Yb diagram shows that, these rocks are original MORB of the oceanic arcs which have been enriched to the Metadacites of the continental arcs.

Keywords

Meta-Volcano-Sedimentary Rocks, Meta-Andesite, Metallogeny, Tchaga, Fitri Lake, Chad

1. Introduction

The Batha region is one of the largest regions in Chad, accounting for more than 22% of the country's total land area. In this region, previous studies are much more oriented towards the search for water for which several exploratory boreholes have been drilled. [1] [2] studied tertiary and quaternary formations for the preparation of a soil map for the recognition of Bokoro. [3] published a synthesis on the geophysical work carried out by the Office of Scientific and Technical Research of Overseas (ORSTOM), this work revealed a very important positive anomaly.

It extends in a general direction SW-NE from the east of Massenya to Ounianga Kébir in the north and even beyond to the Erdis Basin passing through the whole eastern half of the Chad Basin; [4] carried out the work of geochemical prospecting as part of the activities of the project to strengthen the Direction of Geological and Minières (DRGM), for the purpose of verifying the gold indices of the Precambrian metamorphic base and in the intrusive granites was reported.

In and around Chaga, the work of [5] as part of the project strengthening the DRGM showed some formations such as quartzites, granites, granodiorites, laterites and Metaconglomerates. These formations are similar to those of Mayo kebbi where many economic deposits are found along the southern margin: gold, uranium, copper, chromium, and nickel. The exposed part of this terrane is made up of metavolcanics and metasedimentary intruded by late-to post-tectonic granites and diorites most of which have different radiometric ages [6]-[8]. The Batha igneous formation is poorly surveyed, particularly with regard to petrographic, geochemical and geochronological studies.

Despite this work carried out in the area, as far as geology is concerned, the Batha region remains little known today, it is nowadays the covetousness of mining companies since the last gold rush of 2016 without any real knowledge of the geology, these formations mentioned above would show an economic interest and that could be explored and of course exploited to boost the economy of the region in particular and of Chad in general. In the present study, the field observations, petrography, geochemical and metallogeny data of the igneous rocks in the Batha region are presented. The approach of this study is therefore entirely suitable for providing new data on the of metavolcanics rocks and to discuss the geodynamic

context in the Pan-African orogens.

Location of the Study Area, Hydrology and Geological Setting

The Batha Region, located in the center of the Republic of Chad between 12° 12' 50" North and 18° 20' 10" East, named after the Batha River, is one of the largest regions of Chad with a population of 527,031 inhabitants in 2009 with a density of 5.9 hab/km [9]. The Region includes six administrative departments including the department of Fitri where our study area is located, in the permits of the GMIA Minerals group near the village of Tchaga, 75 km northwest of the large city of Bokoro, connected to the capital Ndjamená by an asphalt road located approximately 300 Km. There is an airstrip at Ati 80 km to the North-East, the nearest port is 1470 km away in Douala in Cameroon as shown in **Figure 1**.

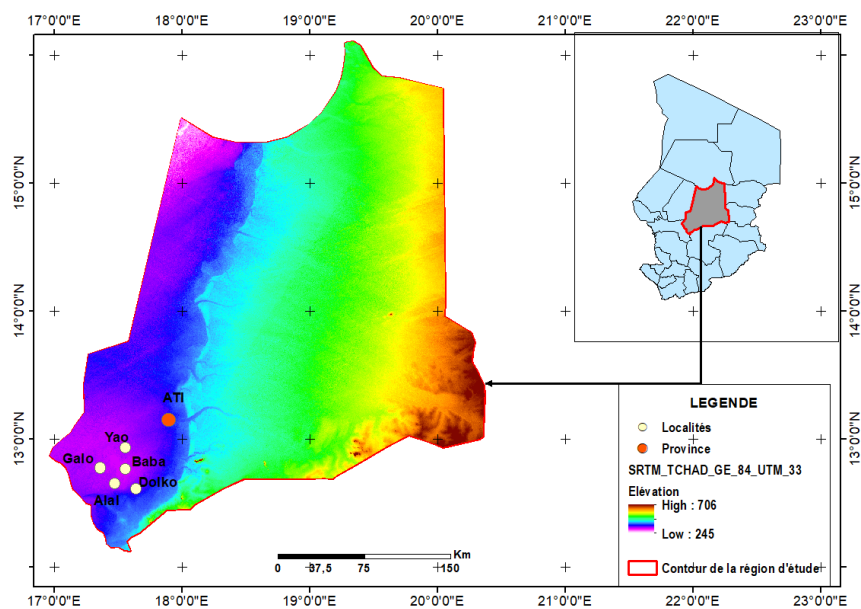


Figure 1. Map of the study area.

Hydrographic Network Made up of a set of intermittent oadis, the most important of which are the ridjil Djaya which takes its source about twenty kilometers north of Bitkine, Barh Zerzer to the north Gueria and Barh Zila to the South East of Ati Ardebé and the big watercourse, the Batha which runs along the town of Ati has its source in Sudan [5]. All these watercourses are temporary and all flow into Lake Fitri constituting a perennial waterbank as shown in **Figure 2**.

Chad is located in the middle of a vast domain called the “Pan-African Mobile Zone” between the West African Craton in the South-West and the Nilotic Craton in the North-East [10]. The African Orogenic Belt that recorded both Paleoproterozoic and Neoproterozoic juvenile accretion to the west. From recent investigations, it has been argued that the Mayo Kebbi massif was formed during the Neoproterozoic in response to the closure of an ocean involving juvenile accretion related to an active margin tectonic setting [7] [11].

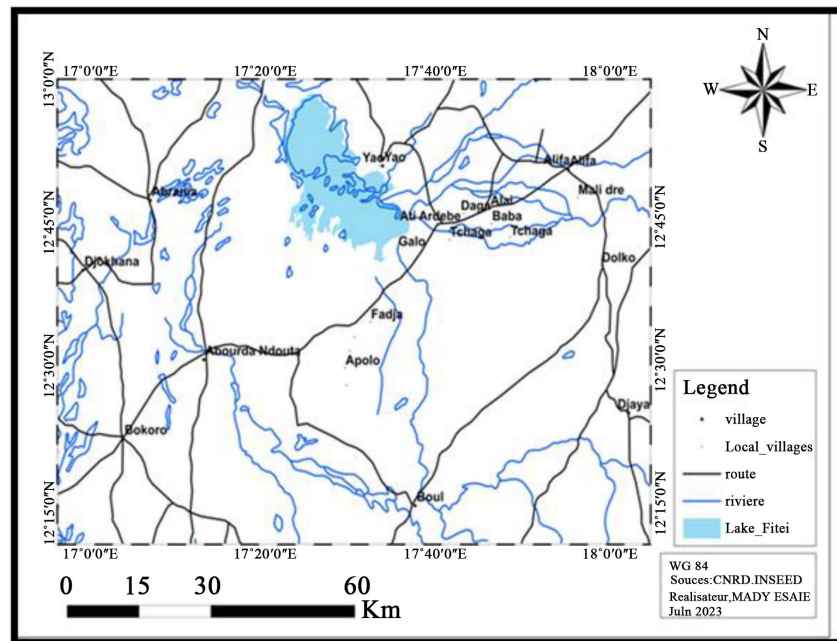


Figure 2. Hydrographic map of the study area.

The pan-African tectono-thermal event represents the last active orogeny on Chadian territory and the rocks formed or influenced by this event constitute the bulk of the crystalline massifs (Tibesti Ouaddaï, massif central, Mayo kebbi and Yadé). Now Chad is part of a stable block. Its geological history since the beginning of the Paleozoic is marked by the deposition of sedimentary platform formations over most of the territory. Paleozoic sediments accumulate in the north and east of the country following the latest pan-African tectonic shift. The posterior tectonics and the surrection of Tibesti and Ouaddaï limit sedimentation in the Erdis and Djado basin, which occupy northern Chad and adjacent regions [12]-[15]. The crystallophyllian rocks and Precambrian granitoids of Tibesti in the north, Ouaddai in the east, Guera in the center, Mayo-Kebbi in the southwest, and Mbaibokoum in the south correspond to the basement [16].

According to the regional geology in Batha, there are three stratigraphic units, namely, the gneiss-migmatite complex, the shale belt, and the pan-African granitoids as shown in **Figure 3**.

The migmatite gneiss complex reflects the ages between the Archean and early Proterozoic isotopic ages [17].

The rocks have undergone metamorphism under amphibolite facial conditions [18]. Complex structural units are evident in this stratigraphic unit and have in turn been invaded by the granitoid plutons of Pan-African magmatism [17]. Shale belts are of late Proterozoic Age and were deposited and metamorphosed with the base migmatite gneiss complex during pan-African orogenesis.

Shale belts are associated with a complex geological structure and tend to be N-S and NNE-SSO and contain assemblages of igneous rocks, polytictic sediment, and ribbed iron formations. They were further deformed and underwent a shale-green

metamorphism.

Granitoids are tectonic late pan-African intrusions of granites, granodiorites, and diorites with gabbros and syenites. They occur mainly under the small subcircular [19]. The regional geological structure is either of a very tense area, or the mother rocks are highly deformed, laminated and affected by ductile and brittle shear zones [17]. According to local geology, specifically the Tchaga area, from field observations we identified meta-volcanic rocks covered by quaternary sediments with an average thickness of 1m, with poorly sorted and polymeric well-rounded sediments, and angular quartz fragments derived from quartz veins. This formation is in turn covered with dark gray clay soil ranging from 0 to 100cm, and recent gravel sometimes covers the clay soil as shown in **Figure 3**. Metavolcanic rocks are exposed in some places and are traversed by many quartz veins, as well as a conglomerate strip, which is traversed by quartz veins. The conglomerates have a dip varying between 15° and 20° and an azimuth of 120°. They are composed of well-packed, polymeric and poorly sorted clasts ranging from stones to rocks; the matrix is basaltic of greenish gray color. They are sporadically flush according to an orientation as a function of the nesting. This is attributed to a 500 m fault in the geological structure or a 50m fault to the East that re-exposes the sediments [20]. The flush quartz veins have a thickness ranging from 15 cm to 2 m with an azimuth of about 205° on average and a dip of 45° subvertically. These quartz veins are post-volcanic and their Age remains to be determined [20].

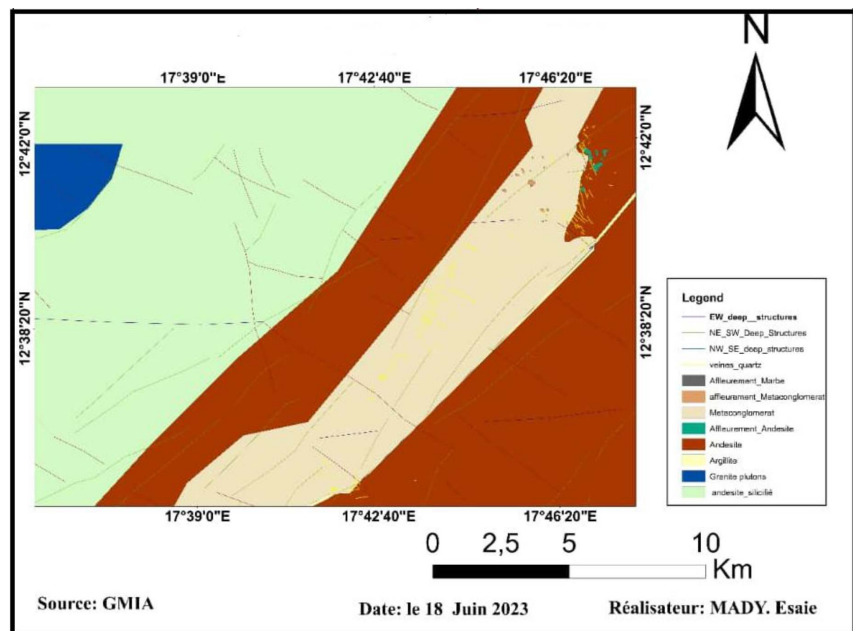


Figure 3. Geological map of the study area.

2. Material and Methods

2.1. Material

A total of thirty-four (34) fresh and representative metavolcanic samples were se-

lected based on their health and degree of alteration for petrographic and geochemical studies. The sample was carefully cleaned and then sawn into two rock sugar cubes. Ten (10) rock cubes were ground (pretreatment) at the laboratory of GMIA MINERALS group while ensuring that there is no contamination by applying the QAQC Chad and then sent to the ALS laboratory (South Africa) for geochemical analyses. The other ten (10) were sent to the thin-section at the Geosciences and Environment Laboratory (LaGE) of the University of Joseph Kizerbo (UJKZ) in Ouagadougou, Burkina Faso. Twenty-six (26) samples were analyzed at the SGS laboratory to specifically determine the gold content by FAE (fire assay analysis).

2.2. Methods

For geochemical analysis, the analytical uncertainties vary from 0.1% to 0.04% for major elements; from 0.1% to 0.5% for trace elements; and from 0.01 to 0.5 ppm for rare earths. The remaining trace elements were analyzed by ICP-MME.

Loss on ignition or LOI (Loss on ignition) for ICP-MS and ICP-AES (Inductively Coupled Plasma Atomic Emission Spectrometry) analyses is also known as calcination. Its determination is done by heating the powders to the point that they release all their water bound to the particles. Once in solution, the samples were analyzed by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). The prepared samples were mixed with the $\text{LiBO}_2/\text{Li}_2\text{B}_4\text{O}_7$ flow. The samples were dissolved under a Teflon bomb pressure, using a 1:1 mixture of HF and HClO_4 at 180°C , and then taken up in an HNO_3 solution with an international In-Re standard. After dissolution in HF- HClO_4 , the samples were taken into a mixture of HNO_3 , HCl and HF and diluted. These solutions were measured within 24 hours of dilution to prevent HFSE absorption. For major elements, a comprehensive major element analysis was performed by combining several methods in a single package. This package combines the entire whole-rock analysis package (ME-ICP06) in addition to carbon and sulfur, which are analyzed using a combustion furnace (ME-IR08). The elements SiO_2 , Al_2O_3 , Fe_2O_3 , CaO, MgO, Na_2O , K_2O , Cr_2O_3 , TiO_2 , MnO, P_2O_5 , SrO, and BaO were analyzed by ICP-AES. Twenty-six (26) samples were analyzed at the SGS laboratory to specifically determine the gold content by FAE (fire assay analysis) which consists of melting the sample at a temperature of more than 1000°C and separating the silicates from the metals by settling and then determining the percentage of gold.

3. Results

3.1. Petrography

A total of thirty-four (34) samples were taken according to their lithology at various sites, in Tchaga Base, Tchaga Est, Ndjarai and Iteim and around Tchaga village in the exploration licenses of the GMIA Mineral group where the exploration work has been carried out for more than four years for the search for gold and many other metals. The petrography of the Tchaga area shows a low diversity of rocks dominated

by meta-volcanic and meta-sedimentary formations: specifically meta-basalts, meta-dacites, marbles and meta-conglomerates and a few vein rocks such as quartz veins.

3.1.1. Metavolcanic Rocks

The Meta Basalts

The Metabasalts are flush in the form of a pointing direction NW-SE (**Figure 4**).

Macroscopically, these rocks have a greenish to gray color, with a microlithic texture cut in some places by veinules made of white minerals or quartz veins. Minerals such as biotite, amphiboles and plagioclases are observed.

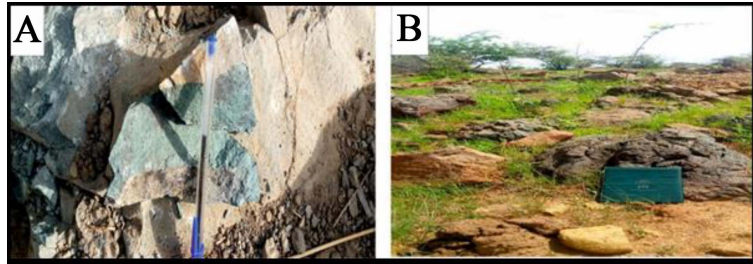


Figure 4. (A) and (B) showing the outcrop of the Meta basalts.

Microscopically, minerals such as olivine, amphibole-altered pyroxenes, and relics of phenocrysts of plagioclases, quartz, and micas are observed. Also chlorites, epidote and carbonates, quartz grains and oxides that would come from the alteration of ferromagnesian minerals (olivine, Amphiboles; Pyroxenes). The presence of opaque elements is also noted as shown in **Figure 5**, an alteration was noted which affected almost all rocks showing extensive destabilization of minerals on microscopy and fissures filled either with carbonates or hydrothermal fluids showing hydrothermal activity in the area.

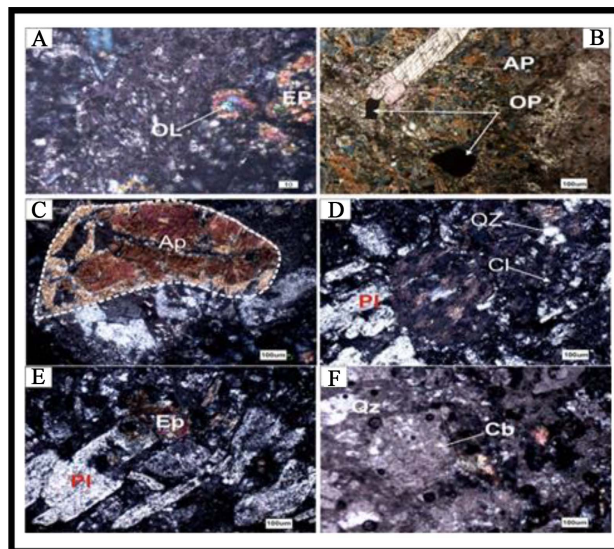


Figure 5. Microphotography of Metabasalts: Amp: amphibole; Pl: plagioclase; Qz: quartz; Ep: epidote; Cl: chlorite; Cb: carbonate; Op: opaque; Ol: olivine.

- Relics

Amphiboles (15%); they are large automorphs with cleavages forming angles of about 120° . Olivines (5%); they are more or less altered and difficult to distinguish from the average size. Plagioclases (65%); they are large automorphs partially or completely destabilized with fine sometimes kinked twins showing small-scale deformities. Newly formed minerals include: epidote (5%): formed by altered plagioclases; quartz (4%): which are recrystallized quartz; carbonates (2%) also formed by alteration of plagioclases, opaque (1%) resulting from the alteration of olivines, chlorite (1%) derived from biotite. Quartz (2%): constituting the xenomorphic matrix of small size.

3.1.2. Metadacites

On macroscopy, the samples with cracks have a green color with a microlitic structure. Minerals are rarely visible as shown in **Figure 6**.

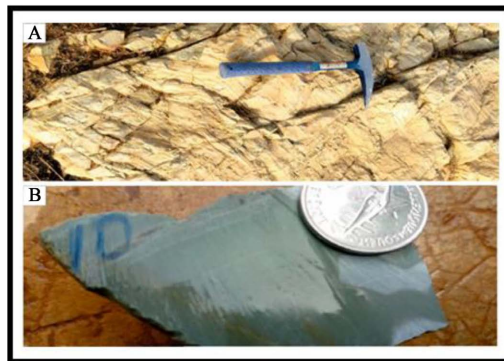


Figure 6. Metadacite Flush and hand specimen.

Microscopically, grains of quartz recrystallized in the subgrain, and plagioclases in mesostas are observed, followed by amphiboles, epidote, and a shearing quartz venule as shown in **Figure 7**. Relics are: amphiboles (15%), which have a mean cleaved size. Plagioclases (48%) were predominant in the medium sample size but a large proportion of the fine grains were in the matrix.

The newly formed minerals are: quartz (25%) forming the matrix with fine grains, carbonates (8%), which are the matrix of the rock and the opaque sulfides (4%), which are rarely automorphic.

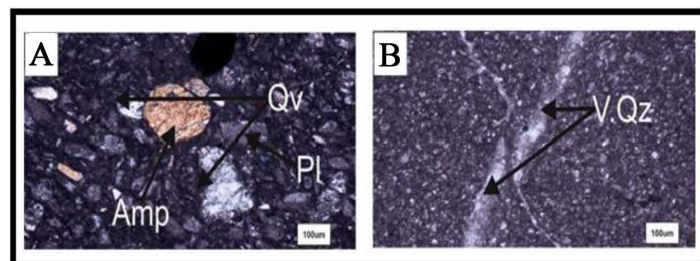


Figure 7. Microphotography of metadacites with a ruptured vein VQZ: quartz vein; Bt: biotite; Qz: quartz.

Metasedimentary Rocks

Metaconglomerates

For this purpose, two samples were taken to make the thin slides; one was cut, just from the matrix, and the other was all the rock that was cut. When observed macroscopically, these metaconglomerates are formed of polygenic medium-sized pebbles embedded in a green matrix as shown in **Figure 8**.

The Meta conglomerates are located in the eastern part of the Chaga village, more than 4 km wide and more than 30 km long. The conglomerates have dips varying between 15° and 20° and an azimuth of 120°. These conglomerates are composed of clasts of granite, basalt, quartzite, flint and rarely quartz of millimeter to centimeter size. Our observations on the ground have allowed us to say that, given the size of the granite pebbles, which are generally smooth and rounded, testify to the power of the transport agent and the distance traveled which is important, and this makes us think of the mega lake whose bank is located not far from gueria and Zoubou at the origin of these important deposits.

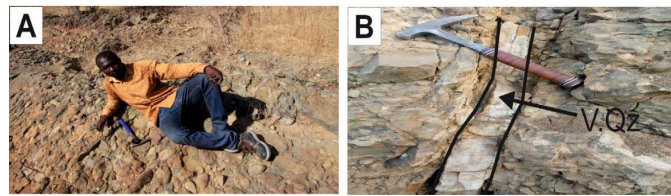


Figure 8. (A) Pebble in a conglomerate; (B) Conglomerate pass through a Quartz vein.

Microscopic observation of the matrix showed small quartz crystals, an abundance of carbonates and white micas that would likely have come from the alteration of plagioclases (**Figure 9(C)**), and some black minerals that could have been sulfides (**Figure 9**).

Under the microscope, the second sample, *i.e.* the entire rock, primary minerals, relics of plagioclases and white micas phenocrystals of small epidotes are observed, which are thought to have originated from the alteration of the plagioclases constituting the secondary minerals. The absence of ferro-magnesian would explain their fragility in the face of alteration.

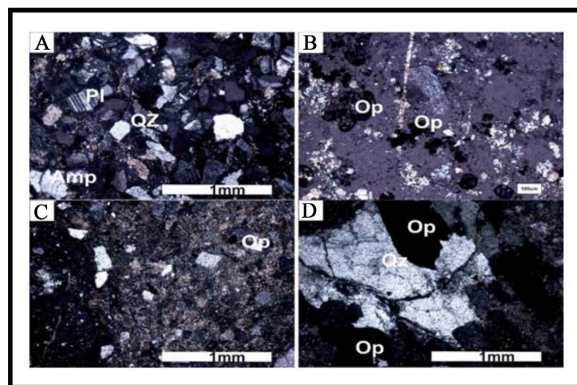


Figure 9. Conglomerate microphotography: Qz:quartz; Pl:plagioclase; Op:opaque.

Marbles

When observed macroscopically, the sample called marble, is yellowish gray in color with venules of impurities and some visible black crystals and quartz. Flush to the south in a ball with smooth faces and small holes that could be burrows, or are due to the dissolution of calcite in contact with acid from rainwater.

Structurally the geological formations are subjected to stresses that result in deformations that may not be visible. Field observations have enabled us to identify and measure various structures, including veins, diaclasses and shears.

The veins observed in the study area are mainly quartz veins 15 cm to 3 m wide and generally over 50 m long, dipping from 45° to subvertical with a major N30° E orientation observed in the meta-andesites and meta-conglomerates (**Figure 10(B)** and **Figure 10(C)**). Diaclasses are observed in almost all the Tchaga formations, especially the Meta basalts, Meta conglomerates and Meta dacites. (**Figure 10(A)**). In the Meta basalts, two main directions are observed, one at N45° E and the other at N60° E. In the Meta conglomerates, the directions are more or less uniform, mostly around N50° E. Shears are observed specifically on quartz veins with horizontal movements whose striations are observed on the faces of quartz veins showing horizontal movement in the same direction as the quartz veins (**Figure 10(D)**). These movements are responsible for the brecciation of the quartz veins, which are carried away by erosion and deposited at the foot of the veins, forming gold-bearing sediments.

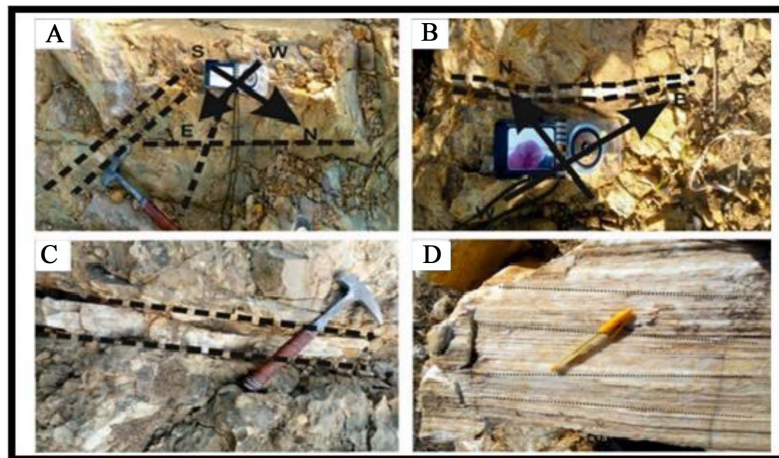


Figure 10. The outcrop showing the deformations that the rocks have undergone, (A) shearing on the Metabasalts, (B) and (C) quartz vein and (D) shearing.

3.2. Geochemical

Geochemical Characterization

Ten (10) samples were analyzed at the ALS Chimex South Africa (pty) Ltd. laboratory in Johannesburg, South Africa, for major, trace and rare earth elements.

The major elements summarized in **Table 1** as a function of the different lithologies show high silica contents in the Meta-dacites which vary between 66.4% - 69.1%, in the Meta-basalts the silica values vary between 48% - 51.6%. The loss on

ignition of the samples is very high, ranging between 2.73% - 11.65%. We also note higher alkali values in the Meta-dacites compared to alkalis in the Meta-basalts. High iron values are observed in all lithologies varying between 5.1% and 14% while the MgO content is very low 1.6% - 9.47% apart from the elements SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO, the elements CrO₃, TiO₂, MnO, P₂O₅, SrO, BaO have very low contents (**Table 1**).

In the SiO₂-K₂O diagram of [21], the metavolcanics rocks are transitional between the tholeiitic and subalkaline domains. Three (3) rocks (Metadacite) have a high potassium character, in medium they belong to the calc-alkaline domain (**Figure 11(A)**), other rocks (metabasalts) belong to the domain of the tholeiitic series with low potassium contents. In the Na₂O + K₂O versus SiO₂ diagram [22] all samples are subalkaline (**Figure 11(B)**). On the ternary diagram of [23], used to discriminate the tholeiitic and calc-alkaline suites, some samples plot in tholeiitic domain (**Figure 11(C)**) suggesting that, the mafic rocks were crystallized from similar parent magma.

Analytical results plotted in the TAS classification diagram [24], have enabled us to identify two lithological units of basaltic and dacitic composition.

In addition, the lower Na₂O + K₂O ranging from 0.52 to 3.05% and the Na₂O content are higher than K₂O indicating that Na is also more enriched than K in the basalt. The low alkali contents are typical of the tholeiitic domain [25] [26].

The first geochemical studies carried out in this area demonstrated the oceanic provenance of the tchaga metabasites rock.

The major chemical analyses show a linear correlation between Al₂O₃, Na₂O and MgO, due to plagioclase fractionation. At the same time, the linear correlation between FeO, MnO and MgO suggests that both ortho- and clinopyroxene are the main ferro-magnesian phases that fractionated during the differentiation processes. The chemical pattern might be the result of a fractional crystallization process, which mainly involves pyroxene and plagioclase.

On the other hand, the variation in the refractory element (Ti, Cr, v) contents is consistent with the fractionation of ferro magnesian phase of orth- and clinopyroxene, hornblende and also with the accumulation of the pyroxene.

Moreover, Eu anomaly is negative in the accumulation phase and slightly positive in others facies. This shows the importance of plagioclase fractionation in the metabasic rocks.

The geochemical results show that the loss on ignition of the samples is very high, ranging between 2.73% - 11.65%, and is due to the effects of the metamorphic and hydrothermal phenomena affecting these formations. Altered rocks will contain variable proportions of Zr and Ti, caused by mass gains and losses, but the Zr/Ti ratio will remain constant as these elements are immobile in volcanic rocks [27] [28]. Potassium-poor rocks (K₂O < 1% by weight) tend, before metamorphism, to incorporate this element into mafic phases such as biotite. Note in this regard that our petrographic study leads us to believe that some of the samples may contain accessory quantities of primary biotite [29].

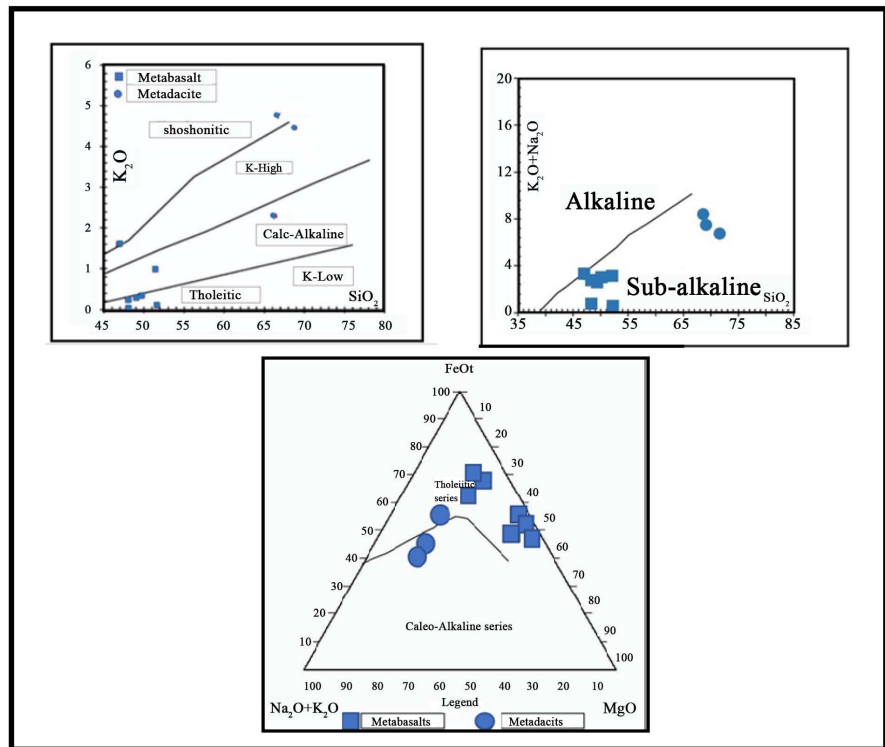


Figure 11. (A) (Peccerillo and Taylor 1976); (B) $\text{SiO}_2\text{-(K}_2\text{O+Na}_2\text{O)}$; Irvine and Baragar 1971 (C) Alk-FeO-MgO applied to Tchaga meta-volcanic formation.

Table 1. Modal mass results of major and trace elements of Metabasalts, Metadacites.

Elements	23TCH 038	23TCH 01	23TCH 02A	23TCH 02B	23TCH 05A	23TCH 08A	23TCH 021A	23TCH 010	23TCH 011	23TCH 037
SiO ₂	48	46.9	48	51.6	49	51.4	49.7	66.4	69.1	66.9
Al ₂ O ₃	13.75	16.9	13.15	15.9	12.95	15.75	9.04	15.65	12.65	13.9
Fe ₂ O ₃	9.15	8.32	13.3	9.79	14	8.54	13.15	5.4	5.43	5.1
CaO	12.85	9.87	6.35	6.65	6.2	9.57	10.6	1.33	0.13	2.94
MgO	9.3	2.82	4.44	8.37	3.97	7.32	9.47	1.66	1.94	1.9
Na ₂ O	0.46	1.44	2.49	0.41	2.1	1.9	2.42	5.37	1.71	2.08
K ₂ O	0.23	1.61	0.03	0.11	0.28	0.99	0.34	2.29	4.44	4.75
Cr ₂ O ₃	0.088	0.011	0.002	0.045	0.004	0.049	0.151	0.005	0.004	0.012
TiO ₂	0.39	0.48	1.75	0.46	1.88	0.44	0.45	0.59	0.36	0.59
MnO	0.19	0.2	0.13	0.14	0.19	0.17	0.44	0.11	0.05	0.11
P ₂ O ₅	0.14	0.2	0.19	0.15	0.19	0.21	0.15	0.15	0.02	0.15
SrO	0.02	0.05	0.01	0.05	0.01	0.07	0.02	0.02	<0.01	0.04
BaO	0.02	0.06	<0.01	0.01	0.01	0.04	0.07	0.06	0.09	0.09
LOI	4.63	11.65	10.3	7.67	9.94	4.4	3.09	2.26	5.08	2.73
Total	99.22	100.51	100.14	101.36	100.72	100.85	99.09	101.3	101	101.29
Na ₂ O+K ₂ O	0.69	3.05	2.52	0.52	2.38	2.89	2.76	7.66	6.15	6.83
Ba	846	148.5	489	17.2	97.3	83.3	396	533	777	662
Ce	48.3	13.8	16	16.6	12.4	17.2	18.6	28.5	264	9.3
Cr	90	666	78	14	322	29	365	37	27	1170
Cs	5.4	0.08	0.89	0.06	0.16	0.29	0.3	0.39	0.97	0.02
Dy	4.64	1.98	2.36	5.16	1.98	5.79	2.45	4.2	25.1	2.16

Continued

Er	2.73	1.14	1.4	3.2	1.22	3.41	1.51	2.52	15.25	1.24
Eu	1.09	0.66	0.78	1.39	0.68	1.54	0.85	1.3	3.95	0.64
Ga	20.3	15.8	16.4	22.9	16.7	20.5	17.2	18.7	43.7	8.5
Gd	5.01	2.21	2.46	5.05	2.15	5.34	2.53	4.42	22.6	2.25
Hf	5.03	0.74	1.13	2.98	0.79	3.25	1.16	3.83	31.3	0.72
Ho	0.92	0.43	0.47	1.08	0.41	1.14	0.5	0.88	5.33	0.44
La	23.2	7	8.1	6.6	6.5	6.6	9.6	13	138.5	4.1
Lu	0.39	0.19	0.21	0.44	0.2	0.46	0.25	0.38	1.9	0.18
Nb	10.05	1.03	2.55	5.23	1.1	5.33	2.4	6.82	243	1
Nd	25.1	8.3	10	13.3	7.8	14	11.2	17.4	118.5	7.6
Pr	6.11	1.8	2.18	2.63	1.76	2.79	2.44	3.98	30.5	1.46
Rb	191.5	3.3	41.3	0.8	2.6	5	24.4	35.7	305	7.7
Sm	5.43	2.12	2.32	4.06	2.01	4.26	2.62	4.5	23.8	2.26
Sn	2.2	<0.5	<0.5	0.6	<0.5	0.7	<0.5	0.8	10	<0.5
Sr	334	156	411	68.9	411	110	551	170.5	26.6	132.5
Ta	0.9	1.9	0.1	0.3	0.1	0.3	0.1	0.5	14.6	<0.1
Tb	0.82	0.31	0.4	0.89	0.35	0.94	0.43	0.72	4.12	0.39
Th	9.25	1.21	1.22	0.48	1.06	0.48	1.42	2.63	26	0.54
Tm	0.39	0.18	0.22	0.44	0.19	0.45	0.21	0.36	2.05	0.18
U	3.04	0.37	0.44	0.42	0.32	0.27	0.48	0.71	5.84	0.05
V	95	255	223	373	256	387	220	86	8	199
W	9.3	<0.5	1.7	4.4	10.9	1.7	<0.5	10.5	15.2	10.4
Y	26.9	11.2	13.7	29.8	11.7	30.7	14.3	23.1	141	12.5
Yb	2.68	1.17	1.42	3.1	1.27	3.09	1.52	2.54	13.9	1.25
Zr	166	27	39	107	27	112	41	135	1240	26

The Hacker diagram of major elements as a function of SiO₂ shows two groups of rocks, the metabasalt and the metadacite. The whole diagram shows a negative trend except for the Al₂O₃ Vs SiO₂ diagram as shown in **Figure 12**. The decrease of these oxides in the magma is due mainly to the fractionation of plagioclases.

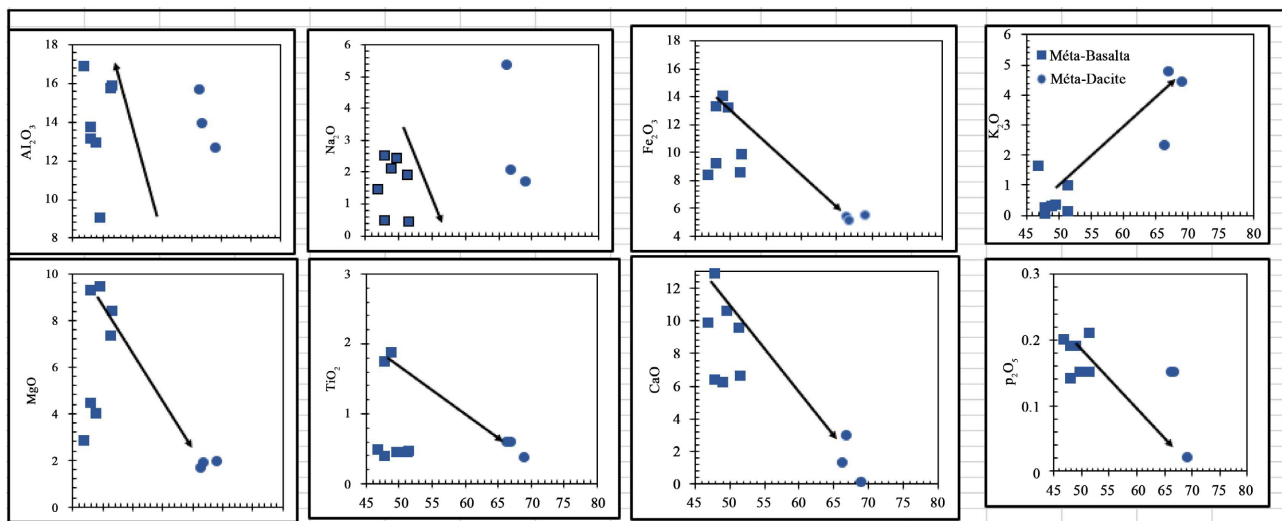


Figure 12. Hacker diagram showing the evolution of the major elements as a function of SiO₂ of the metabasalt, and metadacite of the study area.

Rare Earth Spectrum

In the Chondrite-normalised REE patterns for metavolcanics rocks from Study Area (Chondrite Normalized values are from Boynton 1984) we note the strong negative Nb, Ce, Eu, Sr and Zr anomaly in the metabasalt and metadacite, these samples have a rare earth spectrum marked by a slight negative anomaly in Eu with (δEu ranges from 0.85 to 1.39) and negative anomaly in Nd, having a more or less constant negative appearance at the level of the light rare earths (LREE) and a progressive depletion in heavy rare earth (HREE) as shown in **Figure 13(A)**. Metadacite has a very pronounced negative anomaly in Eu, with (δEu ranges from 0.6 to 3.95) due to the plagioclase fractionation and a very significant depletion of the heavy rare earths from Y to Lu (**Figure 13(B)**).

The high content of Cr and Ni indicated by the parental magma had been derived through partial melting of the peridotite mantle source, and suggested the presence of olivine and clinopyroxene fractions in the tchaga rocks [30] [31]. The concentration of Sr and Zr, in the tchaga rock sample study had relatively high contents. The Sr ranged between 26.6 to 551 ppm with an average of 289 ppm, Zr content between 26 to 1240 ppm with average of 635 ppm (**Table 1**). Vanadium concentration ranges between 8 and 387 with an average of 200 ppm. Vanadium and Titanium have a comparable behaviour in melting and crystallization processes; these elements provide a useful signal for the fractionation of Fe-Ti oxides (such as ilmenite) [32].

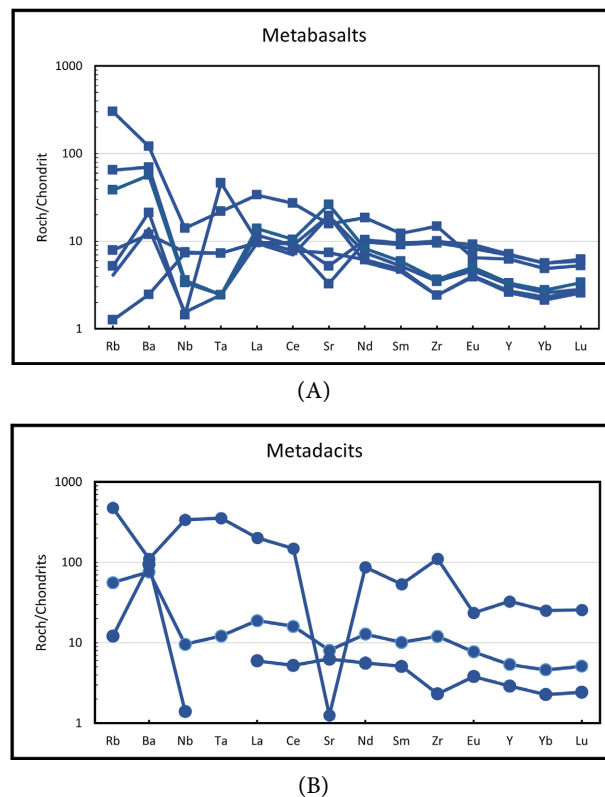


Figure 13. (A) and (B): Chondrite-normalised REE patterns for metavolcanics rocks from Study Area (Chondrite Normalized values are from Boynton 1984) Note the strong negative Nb, Eu, Sr and Zr anomaly in the metabasalt and metadacite.

In the Multielement variation patterns for the various rocks normalized to primitive mantle values of [33], we note the strong negative Nb, K₂O, Sr, Zr and Ti, P₂O₅, Y anomaly and positive en K₂O, Rb, Ta, anomaly in the metabasalt and metadacite as shown in **Figure 14**. Normalization of multielement to primitive mantle indicates losses of Ba, Ti and Cs which can be caused by the fractionation of plagioclase, apatite and ilmenite. The Ba anomaly is also controlled by the presence of K-feldspar and mica. The observed Ti anomalies are due to the fractionation of magnetite indicating a subduction environment (or remelting of a source from a subduction environment). Positive anomaly of Rb may have happened due to contamination of magma with crustal (due to the high concentration of these elements in the continental crust). In the primitive mantle normalized (**Figure 14**) enrichment from LREE and HREE was observed in all samples. Enrichment of LREE elements is higher than HREE and the negative gradient of the graph indicates the higher amount of LREE than HREE that conforms with the overall pattern of spider diagrams subduction zones.

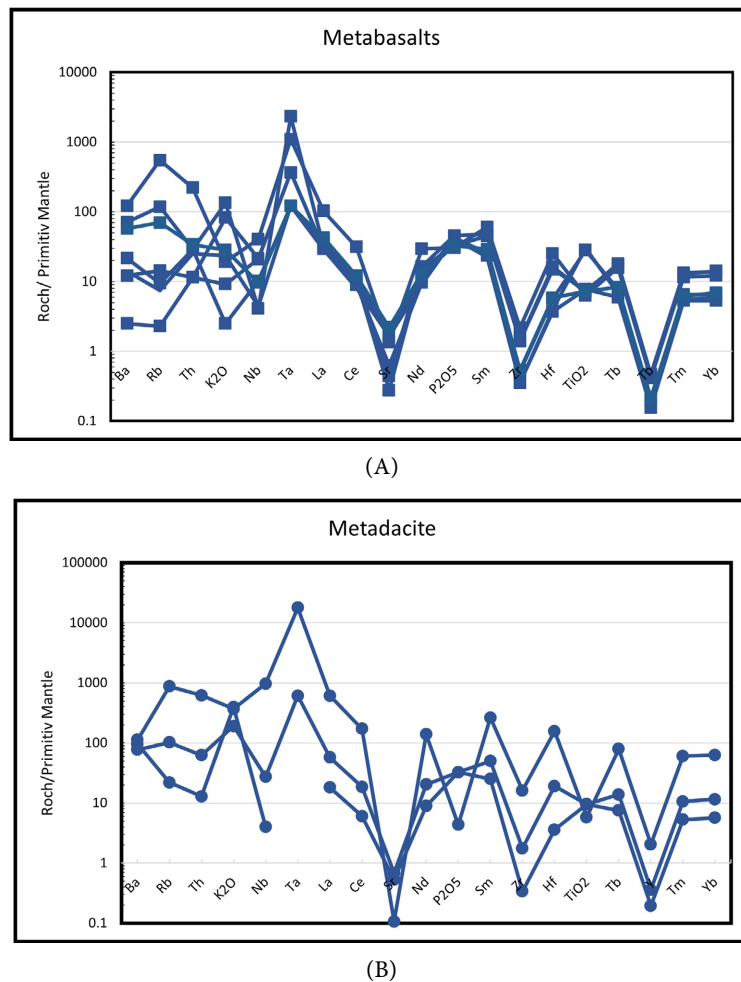


Figure 14. (A) (B) Multielement variation patterns for the various rocks normalized to primitive mantle values of [33], we note the strong negative Nb, K₂O, Sr, Zr and Ti, P₂O₅, Y anomaly and positive en K₂O, Rb, Ta, anomaly in the metabasalt and metadacite.

Geodynamic context

The geodynamic context of the Tchaga region is debated, the geochemical analysis shows that, in the [19] diagram, all samples are subalkaline, in the ternary diagram, some samples plot in the tholeiitic domain, characteristic of oceanic dorsal or oceanic arc. The other samples plot in the calc alkaline field, the high loss on ignon of the sample suggests their origin on the oceanic arc. The Tchaga area from which the petrographic and geochemical studies are conducted has several deformation structures with quartz veins oriented mostly N30E whose geophysical studies have also revealed three main directions NW-SE, NE-SW and E-W.

The analysis of the field stratigraphic data showed that the volcanic Meta facies would have been first put in place after which the deposition of the conglomerates occurred, since these conglomerates consist mainly of basalt clasts, granite and quartz veins cross the basalts and the conglomerates, which would show that these veins are late in relation to the surrounding rocks.

On the Th/Yb versus Nb/Yb variation diagram of [34], used to distinguish the conservative and nonconservative behaviour of Ti, Th, the mafic lava invariably displays a higher Th/Yb ratio than MORB confirming the status of Th as a non-conservative element. We note that, the mafic lava has a spread of ratios comparable to that of MORB indicating that the mantle source of volcanic arc basalt may be enriched and depleted with respect to an average N-MORB source. The igneous rocks plot in the field of the oceanic arcs and continental arc show that these samples are MORBs of oceanic arc in origin that have enriched to the Meta Dacite of continental arcs as shown in **Figure 15**.

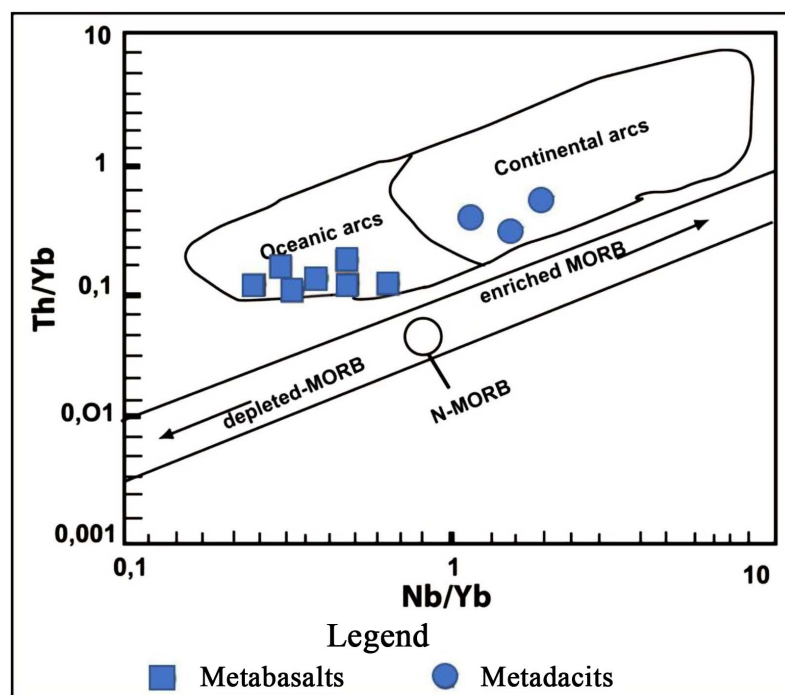


Figure 15. Pearce and Peate (1995); MORB: Medium oceanic wrinkle basalts; E-MORB: Medium oceanic wrinkle basalts enriched.

Metallogenic of gold forming mineralisation metallic deposit

Fieldwork, the geological environment of the study area and geochemical analyses of the samples revealed some evidence of mineralization. Gold is native in quartz veins as shown in **Figure 16(A)** and nuggets in eluvium deposited around vein fields as shown in **Figure 16(B)**. Mineralization in this zone occurs as pyrites, chalcopyrite as shown in **Figure 16(C)** and **Figure 16(D)** and arsenopyrite, which are often combined with carbonates. A macroscopic observation of some nuggets found by artisanal gold miners in this area, given the angular and rough shapes, gives information on the origin and distance traveled. These nuggets would probably have originated from the quartz veins located nearby. As a result of the erosion phenomenon, gold is released and deposited just at the foot of the veins. Five (5) thin plates were metallized to allow observation and identification of metals as shown in **Figure 17(A)** and **Figure 17(B)**.

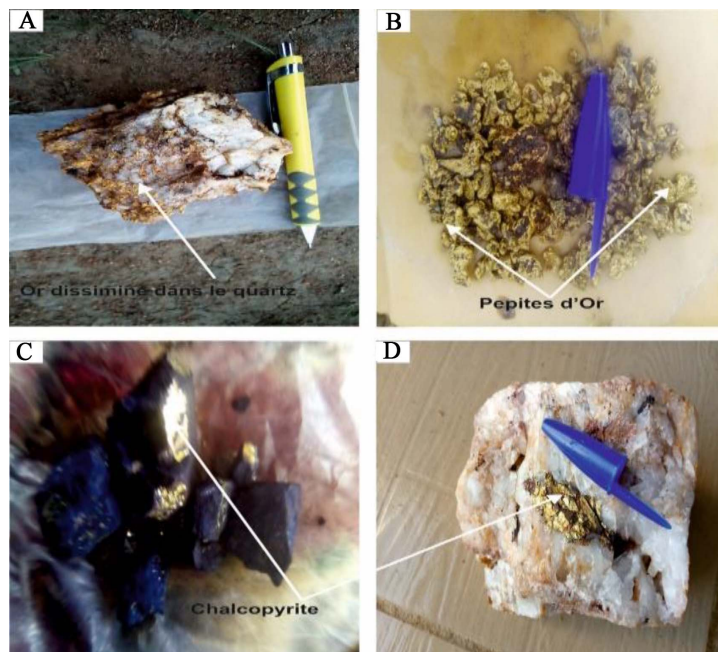


Figure 16. Photography of gold and pyrite in quartz and gold nuggets.

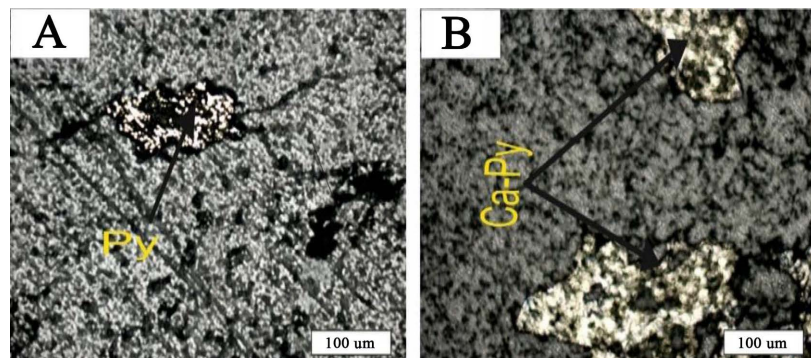


Figure 17. Microphotograph of a conglomerate in natural light. Py: Pyrite, Ca-Py: Chalcopyrite.

In metallogeny, a metal deposit is a geological formation in which the chemical element being exploited is at a much higher content than Clarke's of that element. The Clarke value is the average concentration of a chemical element in the earth's crust.

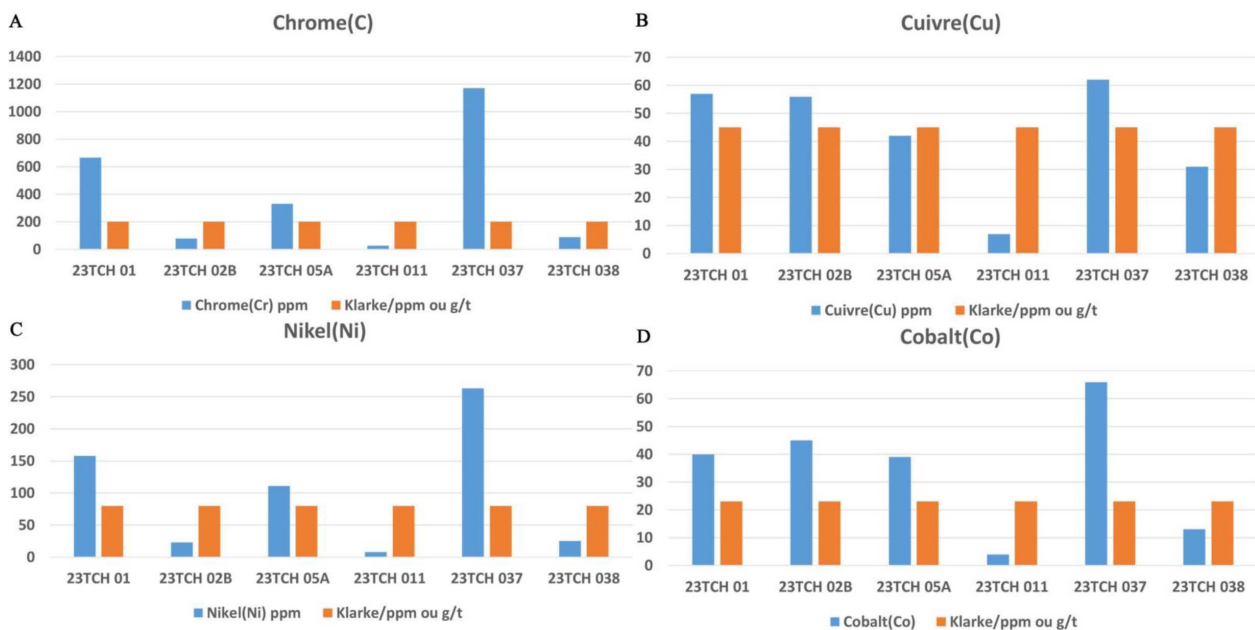
The studied elements compared with Clarke show higher levels than Clarke in some rock samples, for example uranium in Metadacite and Metasalts.

According to the analysis result our deposits belong to the deposit of ferrous and non-ferrous metals.

- Ferrous metals: The chromium in the basalt has a higher content than Clarke and the usable content is (0.02%) as shown in **Figure 18(A)**.

- Non-ferrous metals Copper has a content exceeding Clarke, and an exploitable value of 0.0045%. as shown in **Figure 18(B)**. Nickel has a value far greater than Clarke content; the exploitable content is 0.008 as shown in **Figure 18(C)**. The Cobalt content is higher than Clarke with a value of 0.0023% as shown in **Figure 18(D)**. Vanadium has a higher content than Clarke with a usable value of 0.011% as shown in **Figure 18(E)**. Zirconium has a very high value compared to Clarke with a value of 0,016% as shown in **Figure 18(F)**.

Twenty-six (26) samples were analyzed for gold content. 80% have a content varying between 1 and 9 ppb showing very low content and especially in rocks such as meta conglomerates and meta basalts, the remaining 20% have contents varying from 45 to 351 ppb, the highest content is that of quartz samples followed by conglomerate. The usable content of gold is 103. ppb. It is the artisanal mined metal in the Batha area today. Since the 2016 gold rush, the operation uses metal detectors to detect nuggets ranging from 0.5 g to 25 g in eluvium. Briefly, the few deposit indices represented by these metals described above in the rocks analyzed show positive anomalies; these metals are potentially exploitable subject to advanced studies for the evaluation of their tonnage to really prove the reserve.



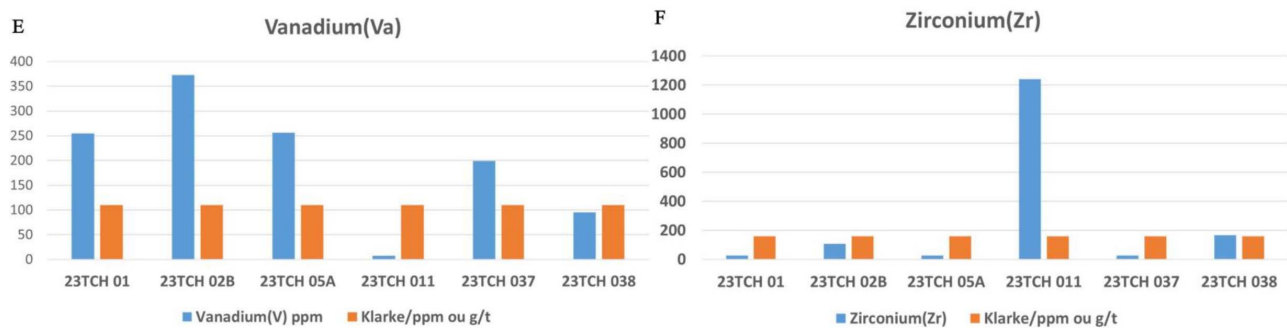


Figure 18. Histogram of sample analysis results showing chromium, nickel, vanadium, copper, cobalt and zirconium abnormalities compared to the Clarke value of each element.

4. Discussion

In this section we will try to discuss the different study results in order to characterize the geological formations of the northwest periphery of the central massif for the first time.

For a petrographical study we have identified meta-volcano-sedimentary rocks (Metabasalts, Metadacites, Metaconglomerates and marbles). The geological environment shows that the study area is located in the Paleo-basin of mega-Lake Chad, the accumulation of sediments of which would therefore be responsible for the formation of these sedimentary rocks, in this case the conglomerates and carbonates which have later undergone metamorphism.

The presence of newly formed minerals such as chlorites, calcite, and epidotes indicates alteration and metamorphism. These newly formed minerals are characteristic of low temperature, low pressure metamorphic conditions of green shale metamorphism.

The presence of feldspar in the rock samples is well matched with a positive Eu anomaly in the REE pattern [8]. These results are similar to the results of [5] [8] in the other region in Chad. Compared to the primitive magmas of the mantle, the very variable contents of MgO, Mg# (36.09 - 67) and transition elements (Sc, Cr, Co, Ni) of the metavolcanosedimentary rocks studied suggest that a certain degree of fractional crystallization occurred during the emplacement of mafic metavolcanic rocks [35]. The negative Nb anomaly, specific to subduction zone magmas, unrelated to that of Zr, suggests crustal contamination of a mantle basaltic magma in a context far from the influence of a subduction zone [36]. In the subduction area, fluid released from the upper part of the subducted lithosphere which is rich in LILE and poor in Nb is added to the mantle wedge [37]. Positive anomaly of Rb may have happened due to contamination of magma with crustal material (due to the high concentration of these elements in the continental crust). Meanwhile, negative anomalies of Ti element in lava can be formed on one hand to participate in the partial melting of lithospheric mantle linked to metasomatization and on the other hand crustal contamination resulting from digestion is attributed to zirconium [38]. This Nb signature is due to an oceanic-oceanic subduction magmatic residue or a contamination from a MORB-like source.

The TAS [21], SiO₂ Vs K₂O [19] and Alk-FeO-MgO diagrams distinguished the calco-alkaline series rocks with high potassium characters on the one hand and the rocks belonging to the tholeiitic series on the other. A dorsal cord is the site of frequent magmatism. Dorsal volcanism is generally basaltic, with tholeiitic geochemistry. The fusion of the peridotitic material that takes place at the ridge is the origin of the material constituting the oceanic lithosphere [39].

Normalization of multielement to MORBs indicates losses of Ba, Ti and Cs which can be caused by the fractionation of plagioclase, apatite and ilmenite. The Ba anomaly is also controlled by the presence of K-feldspar and mica. The observed Ti anomalies are due to the fractionation of magnetite indicating a subduction environment (or remelting of a source from a subduction environment)

The characteristic of the calco-alkaline rocks described above corroborates the results of studies carried out in the Mayo-Kebbi zone showing a geodynamic environment of transition between subduction and collision [6] [11]. A tholeiitic basalt has as its source the “oceanic” upper mantle, often depleted at the base, a larger partial fusion (10 to 25%) and little evolution after the formation of the magma. Calc-alkali basalt is also influenced by its source, close to a subduction zone, bringing alkalis and water which can promote the incorporation of CaO in the liquid. The rocks studied geochemically had intermediate to hypersilicic silica contents. Correlations observed between major elements with silica would show a fractionation of plagioclases during magmatic differentiation processes as shown in **Figure 15**.

The rare earth spectra of LREE enrichment relative to HREE are also similar to the work of [40] on volcanic rocks of El Aouana, NE Algerian. Negative correlations between major elements and silica in the Harker diagram show a significant fractionation of plagioclases. The diagram of [34] shows that the samples are MORBs of oceanic and continental arcs, which is consistent with the studies conducted by [8] in the Mayo-Kebbi region. These rocks have loss on ignition (LOI) values ranging from 2.26 to 11.65 wt%. % (**Table 1**), suggesting the contribution of secondary hydrated and carbonate phases. The few positive anomalies in Cr, Ni, Cu, Co, V; Zr reported are consistent with the results of geochemical studies conducted by [3] in the Batha area. From the metallogeny study, some samples have a higher chemical element content than Clarke’s value.

The Chaga geological formations in the Batha region which have been the subject of petrographic and geochemical studies, with obtained results and the work carried out by [6] [8] in the Mayo-Kebbi region show similarities in these facies which would probably be the extension to the South country.

5. Conclusions

The study of petrology, the geochemistry of geological formations southeast of Fitri Lake with metallogenic involvement, has allowed us to better understand the petrography of the Chaga area defined by volcano-meta-sedimentary formations specifically metabasalt, metadacite, marbles, meta conglomerates and quartz

veins.

The geochemical analysis shows intermediate to hypersiliceous silica contents. Correlations observed between major elements with silica showed fractionation of plagioclases during magmatic differentiation processes. The Enrichment from LREE and HREE was observed in all samples. Enrichment of LREE elements is higher than HREE and the negative gradient of the graph indicates the higher amount of LREE than HREE which conforms with the overall pattern of spider diagrams in subduction zones.

These basaltic rocks are MORBs of oceanic arcs enriched to meta-dacite of continental arcs.

The deposit indices represented by some metals in the analyzed rocks show positive anomalies; these metals are potentially exploitable, subject to further studies to evaluate their tonnage to really prove the reserve.

Normalization of multielement to MORBs indicates losses of Ba, Ti and Cs which can be caused by the fractionation of plagioclase, apatite and ilmenite. The Ba anomaly is also controlled by the presence of K-feldspar and mica. The observed Ti anomalies are due to the fractionation of magnetite. Also, the presence of negative anomaly in P, Nb, Ta and Ti elements could indicate the formation of rocks in a subduction environment (or remelting of a source from a subduction environment)

Acknowledge

The authors are grateful to GMIA Minearls for supporting the field and laboratory financial and to the anonymous reviewers.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Schneider, J.L. (2001) Géologie, archéologie, hydrogéologie de la République du Tchad, tome 1 et 2, carte de valorisation des ressources en eau souterraines. UE-STABEX.
- [2] Pias, J. (1970) La végétation du Tchad. Ses rapports avec les sols. Variations paléobotaniques au Quaternaire. Travaux et Documents de l'ORSTOM N° 6, 49 p.
- [3] Pierre, L. (1970) Contribution géophysique à la connaissance géologique du bassin du lac Tchad. ORSTOM, 312 p.
- [4] Barbarin, B.D. (1996) Genesis of the Two Main Types of Peraluminous Granitoids. *Geology*, **24**, 295-298.
- [5] Abba kaka, A. and Petit, Ch. (1993) Projet CHD/91/007 Renforcement de la DRGM. Géologie et géochimie du secteur de lélé-dolko.
- [6] Doumnang, J.C. (2006) Géologie des formations Néoprotérozoïque du Mayo-Kebbi (Sud-ouest du Tchad): Apports de la pétrologie et de la géochimie, implications sur la Géodynamique au Panafricain. Master's Thesis, Université d'Orléans.
- [7] Penaye, J., Kröner, A., Toteu, S.F., Van Schmus, W.R. and Doumnang, J. (2006) Evo-

- lution of the Mayo Kebbi Region as Revealed by Zircon Dating: An Early (ca. 740ma) Pan-African Magmatic Arc in Southwestern Chad. *Journal of African Earth Sciences*, **44**, 530-542. <https://doi.org/10.1016/j.jafrearsci.2005.11.018>
- [8] Tekoum, L., Doumnang Mbaigane, J.C., Kadjangaba, E., Qian, Y., Guang, D.W. and Sun, F.Y. (2023) Petrology, Geochemistry and Tectonic Environment of Igneous Complex in the Neoproterozoic Mayo Kebbi Basin, Chad. *International Journal of Current Research*, **15**, 23253-23260.
- [9] INSEED (2009) Recensement général de la population et de l'habitation (RGPH). Institut National de la Statistique et de la Démographie, Bureau de la statistique et de la démographie, N'Djamena, TCHAD.
- [10] Bessoles, B. and Trompette, R. (1980) Géologie de l'Afrique. La chaîne panafricaine "zone mobile d'Afrique centrale", (partie sud) et zone soudanaise. *Mémoire BRGM, Orléans*, **92**, 394.
- [11] Pouclet, A., Vidal, M., Doumnang, J., Vicat, J. and Tchameni, R. (2006) Neoproterozoic Crustal Evolution in Southern Chad: Pan-African Ocean Basin Closing, Arc Accretion and Late- to Post-Orogenic Granitic Intrusion. *Journal of African Earth Sciences*, **44**, 543-560. <https://doi.org/10.1016/j.jafrearsci.2005.11.019>
- [12] Pouclet, A. and Durand, A. (1983) Structures cassantes cénozoïques d'après les phénomènes volcaniques et néotectoniques au nord-ouest du lac Tchad (Niger oriental). *Annales de la Société Géologique du Nord*, No. 103-104, 143-153.
- [13] Vincent, P.M. (1952) Rapport de Mission géologique Du Borkou Ennedi Tibesti. B.R.G.M.
- [14] Vincent, P.M. (1963) Les volcans tertiaires et quaternaires du Tibesti occidental et central (Sahara du Tchad). *Mémoire du BRGM* 23, 307 p.
- [15] Durand, A. (1993) Enregistrement sédimentaire de la dynamique climatique au Quaternaire supérieur dans le Sahel central (Niger et Tchad). Master's Thesis, Université de Bourgogne.
- [16] Kusnir, I. and Moutaye, H.A. (1997) Ressources minérales du Tchad: Une revue. *Journal of African Earth Sciences*, **24**, 549-562. [https://doi.org/10.1016/s0899-5362\(97\)00080-8](https://doi.org/10.1016/s0899-5362(97)00080-8)
- [17] Ramadan (2010) Géologie régionale du Batha (Rapport).
- [18] Fitches, W.R., Ajibade, A.C., Egbuniwe, I.G., Holt, R.W. and Wright, J.B. (1985) Late Proterozoic Schist Belts and Plutonism in NW Nigeria. *Journal of the Geological Society*, **142**, 319-337. <https://doi.org/10.1144/gsjgs.142.2.0319>
- [19] Wright, J.B., Hastings, D.A., Jones, W.B. and Williams, H.R. (1985) *Geology and Mineral Resources of West Africa*. Springer, 187 p.
- [20] Aubrey and Mvokwe, N. (2008) Rapport annuel de la société GMIA Minerals.
- [21] Peccerillo, A. and Taylor, S.R. (1976) Geochemistry of Eocene Calc-Alkaline Volcanic Rocks from the Kastamonu Area, Northern Turkey. *Contributions to Mineralogy and Petrology*, **58**, 63-81. <https://doi.org/10.1007/bf00384745>
- [22] Le Maitre, R.W., Bateman, P., Dudek, A.G., *et al.* (1989) Download scientific diagram/Diagramme SiO₂ vs Na₂O + K₂O appliqué aux roches magmatiques du Group de Ouarzazate (NP3sW).
- [23] Irvine, T.N. and Baragar, W.R.A. (1971) A Guide to the Chemical Classification of the Common Volcanic Rocks. *Canadian Journal of Earth Sciences*, **8**, 523-548. <https://doi.org/10.1139/e71-055>
- [24] Bas, M.J.L., Maitre, R.W.L., Streckeisen, A. and Zanettin, B. (1986) A Chemical Clas-

- sification of Volcanic Rocks Based on the Total Alkali-Silica Diagram. *Journal of Petrology*, **27**, 745-750. <https://doi.org/10.1093/petrology/27.3.745>
- [25] Schilling, J.G., Zajac, M., Evans, R., Johnston, T., White, W., Devine, J.D., *et al.* (1983) Petrologic and Geochemical Variations along the Mid-Atlantic Ridge from 29 Degrees N to 73 Degrees N. *American Journal of Science*, **283**, 510-586. <https://doi.org/10.2475/ajs.283.6.510>
- [26] Sun, S. and McDonough, W.F. (1989) Chemical and Isotopic Systematics of Oceanic Basalts: Implications for Mantle Composition and Processes. *Geological Society, London, Special Publications*, **42**, 313-345. <https://doi.org/10.1144/gsl.sp.1989.042.01.19>
- [27] MacLean, W.H. and Kranidiotis, P. (1987) Immobile Elements as Monitors of Mass Transfer in Hydrothermal Alteration; Phelps Dodge Massive Sulfide Deposit, Matagami, Quebec. *Economic Geology*, **82**, 951-962. <https://doi.org/10.2113/gsecongeo.82.4.951>
- [28] Barrett, T.J., Cattalani, S. and MacLean, W.H. (1993) Volcanic Lithochemistry and Alteration at the Delbridge Massive Sulfide Deposit, Noranda, Quebec. *Journal of Geochemical Exploration*, **48**, 135-173. [https://doi.org/10.1016/0375-6742\(93\)90003-5](https://doi.org/10.1016/0375-6742(93)90003-5)
- [29] Rudnick, R.L., McLennan, S.M. and Taylor, S.R. (1985) Large Ion Lithophile Elements in Rocks from High-Pressure Granulite Facies Terrains. *Geochimica et Cosmochimica Acta*, **49**, 1645-1655. [https://doi.org/10.1016/0016-7037\(85\)90268-6](https://doi.org/10.1016/0016-7037(85)90268-6)
- [30] Winter, J.D. (2014) Principles of Igneous and Metamorphic Petrology: Pearson New International Edition (2e). Pearson Education, 738 p.
- [31] Al-Fugha, H. and Bany Yaseen, I.A.A. (2019) Petrography, Geochemistry and Petrogenesis of Pleistocene Basaltic Flow from Northwest Atarous Area, Central Jordan. *International Journal of Geosciences*, **10**, 613-631. <https://doi.org/10.4236/ijg.2019.106035>
- [32] Brian, M. and Carleton, B.M. (1982) Principles of Geochemistry. 4th Edition, John Wiley & Sons, 350 p.
- [33] Thompson, R.N. (1982) Magmatism of the British Tertiary Volcanic Province. *Scottish Journal of Geology*, **18**, 49-107. <https://doi.org/10.1144/sjg18010049>
- [34] Pearce, J.A. and Peate, D.W. (1995) Tectonic Implications of the Composition of Volcanic ARC Magmas. *Annual Review of Earth and Planetary Sciences*, **23**, 251-285. <https://doi.org/10.1146/annurev.earth.23.050195.001343>
- [35] Frey, F.A., Green, D.H. and Roy, S.D. (1978) Integrated Models of Basalt Petrogenesis: A Study of Quartz Tholeiites to Olivine Melilitites from South Eastern Australia Utilizing Geochemical and Experimental Petrological Data. *Journal of Petrology*, **19**, 463-513. <https://doi.org/10.1093/petrology/19.3.463>
- [36] Nlomngan, J.P.S., Penaye, J., Tchameni, R., Owona, S., Ibohn, A.P.M., Nsifa, E.N., *et al.* (2019) Geochemical Characterization of Boula Ibi Granitoids and Implications in Geodynamic Evolution. *Journal of Geography and Geology*, **11**, 13-28. <https://doi.org/10.5539/ijgg.v11n4p13>
- [37] Borg, G. and Shackleton, R.M. (1997) The Tanzania and NE Zaire Cratons. In: de Wit, M.J. and Ashwal, L.D., Eds., *Greenstone Belts*, Clarendon Press, 608-619.
- [38] McDonough, W.F. and Sun, S. (1995) The Composition of the Earth. *Chemical Geology*, **120**, 223-253. [https://doi.org/10.1016/0009-2541\(94\)00140-4](https://doi.org/10.1016/0009-2541(94)00140-4)
- [39] Sauter, D., Cannat, M., Rouméjon, S., Andreani, M., Birot, D., Bronner, A., *et al.* (2013) Continuous Exhumation of Mantle-Derived Rocks at the Southwest Indian Ridge for 11 Million Years. *Nature Geoscience*, **6**, 314-320.

<https://doi.org/10.1038/ngeo1771>

- [40] Hamlaoui, H., Laouar, R., Bouhlel, S. and Boyce, A.J. (2020) Caractéristiques pétrologiques et géochimiques des roches magmatiques d'El Aouana, NE algérien. *Estudios Geológicos*, **76**, e124. <https://doi.org/10.3989/egeol.43391.510>