UDC: 552.3 **ISSN 1609-0691**
DOI: https://doi.org/10.17308/geology/1609-0691/2023/1/65–79
Received: 01.09.2023
Accepted: 02.03.2023
Published online: 31.03.2023

Dolerite sills in the sandstone of Bangui, Central African Republic: geochemistry and petrology

©2023 H. F. A. Mapoka[1]✉, J. Biandja[2], K. A. Savko[3], S. M. N'gbatouka[2], N. S. Bazikov[3]

[1]Geosciences Laboratory, Department of Earth Sciences, University of Bangui, B. P: 908, Bangui, Central African Republic
[2]Georesources Laboratory, Department of the Mines and Geology, Higher Institute of Technology, B. P: 892, Bangui, Central African Republic
[3]Voronezh State University, Universitetskaya sq., 1, Voronezh, 394018, Voronezh, Russian Federation

Abstract

The geology of the Bangui region is not very known, although sufficient data exist. However, the lithostratigraphic synthesis remains limited. The presence of certain rock types such as dolerite sills in sandstones can be observed as a consequence of extensional tectonics in the region. The dolerites of the Bangui-Mbaiki-Boali series correspond in composition to ferruginous subalkaline basalts of the tholeiite affinity. They are enriched in LILE, HFSE and LREE with low concentrations of Ni and Cr, and have experienced fractional crystallization with fractionation of olivine and pyroxene. Parental magmas were formed in shallow conditions of garnet instability. They are characterized by a high degree of oxidation and an increased content of fluid. The source for the dolerites could be enriched protoliths from the subcontinental lithospheric mantle. The Bangui dolerites were formed in an intraplate setting.

Keywords: lithostratigraphic synthesis, dolerite sills, sandstone, tangential tectonics, lithological succession, mylonitisation, breccia, tholeiitic affinity

For citation: Mapoka H. F. A., Bianda J., Savko K. A., N'gbatouka S. M., Bazikov N. S. Dolerite sills in the sandstone of Bangui, Central African Republic: geochemistry and petrology // *Vestnik Voronezhskogo gosudarstvennogo universiteta. Seriya: Geologiya –Proceedings of Voronezh State University. Series: Geology*, 2023, no. 1, pp. 65–79. DOI: https://doi.org/10.17308/geology/1609-0691/2023/1/65–79

Introduction

The formations of the Bangui-Mbaiki-Boda-Boali series were described by [1–6]. In Bangui, they are presented as an ensemble which is slightly or not folded, mylonitised, and cut through by various intrusions. It is made up of the Yangana-Pama-Boda series of sericite, black sandstone-quartzite, black Bimbo conglomerate, Fatima limestone, and grey sandstone-quartzite with shale layers from bottom to top (Fig. 1).

New observations in the Daouba Kassai hill located in the north-eastern periphery of Bangui in Central African Republic (CAR), with dominating in the Boy-Rabe, the north-eastern district of Bangui, in the base of National Guard and Ngaragba district, have revealed outcrops of previously undescribed weakly deformed doleritic sills in metamorphosed sandstone-quartzites of the Bangui series. Similar sills have been described in this series elsewhere at the Boali (north-west of Bangui), the Palambo (south-east of Bangui) and Mbaiki-Bagandou (south-west).

These sills are metric to decametric, occur over the Boy-Rabe breccias and intercalated in mylonitic schists. These dolerites are located between 4°19'N and 4°31'N, and between longitude of 18°58079'E and 18°58090'E.

The dolerites described in this study are five massifs, which occur in point form. The petrographic and chemical composition of these dolerites and their geotectonic environment indicate that they were emplaced during the pre-Pan-African extensional phase.

✉ Mapoka Hubert François – d'Assise, e-mail: mpkman2003@yahoo.fr / mpkmarie4@gmail.com

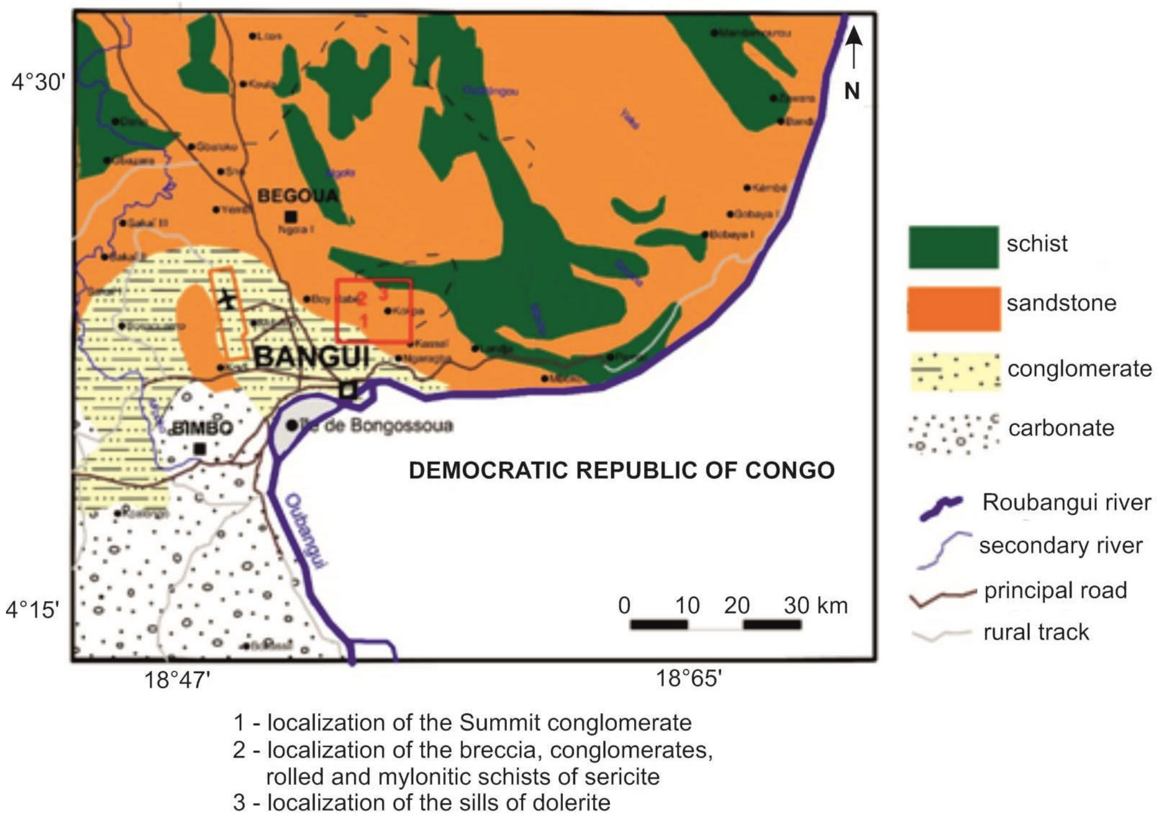

Fig. 1. Geological sketch of Bangui and surroundings.
[Рис. 1. Схематическая геологическая карта Банги и окрестностей.]

Geological context

The Oubangui River flows through quartzites that outcrop on both sides of the river, from upstream to the confluence with the Kotto. These formations, from the Possel region upstream of Palambo to the region of Moungoumba, not far from the border with Congo-Brazzaville, are related to the Bangui-Mbaiki-Boali formation, which is a schistose sandstone dominated formation of the Middle to Upper Proterozoic that occupies almost the entire southern part of the Central African Republic from the confluence of the Kotto River with the Oubangui River to the town of Moungoumba on the border with Congo-Brazzaville. It extends on either side of the Central African – Congo Democratic Republic border. These formations cover the strongly metamorphosed formations of the Paleoproterozoic and Archean with major unconformity. They are intruded in places by granite, granodiorite, diorite and especially dolerite. They are essentially made up from top to bottom of a sandstone-quartzite block intercalated with shales known as the Bangui formation, a carbonate formation known as the Fatima-Bobassa-Damara-Possel series and sericite shales known as the Yangana-Pama-Yadji series. These deposits are intruded in places by granite, granodiorite, diorite and especially dolerite.

Structural geology and geochronology

According to many authors [1–3, 6–8] the Precambrian basement in the territory of CAR underwent several episodes of the Pan-African orogeny (ca. 550 Ma). A. Doyemet [6] states that the Yangana Yadji Pama Boda series which underlies the Bangui-Mbaiki-Boali formation in the broadest sense is affected by the first phase of the Eburnian I orogeny. The Bangui Mbaiki Boda Boali series, consisting of quartzites and schists, is affected by weak metamorphism. It would be undergone by the Eburnian II or Transamazonian orogeny.

The post-Eburnian II sandstone-carbonate cover (Bimbo Series with limestone, arkose sandstone and black conglomerate) is thought to have been affected by the Kibaran tectono-magmatic event, which is responsible for the setting up of an overthrust by a shortening of medium equatorial orientation marked by submeridian structures [6] (Fig. 2).

All previous authors point out the complexity of the geology of the area due to the Cenozoic deposits that mask the formations in the depressions. The tectonic structures of the Bangui geological formations have been studied by the authors mentioned above. However, the actual geometry of the structures and formations remains to be clarified if not defined. The most marked geological structures in the Bangui area are faults, often overlapping towards the west, and small isoclinal folds in the sandstone-quartzites and tight folds in the pelitic layers, notably in the Panthères hill, Daouba Kassai and the Ouango and Loko quarry. In the Bangui plain, all the relationships between the formations and structures are largely masked by laterites.

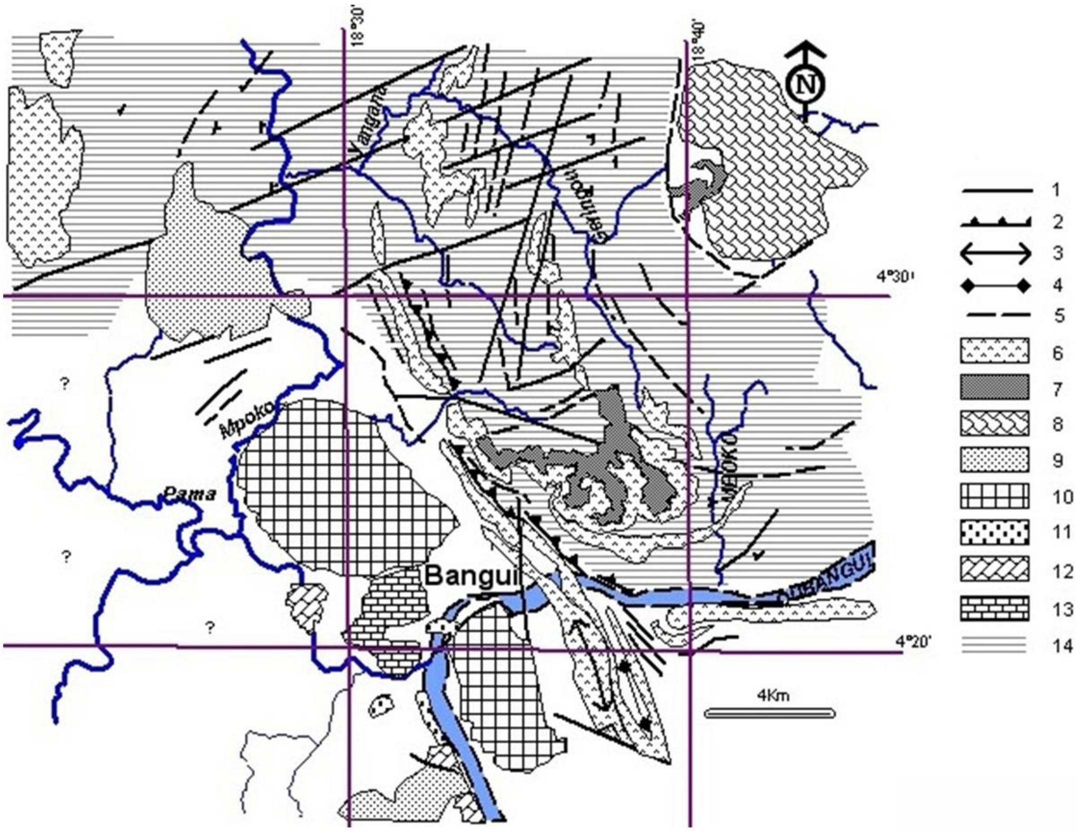

Fig. 2. Location of major geological units (after [1] reproduced by [6]). Legends: *(1)* – direction of schistosity; *(2)* – overlap; *(3)* – anticline axis; *(4)* – syncline axis; *(5)* – fractures and faults; *(6)* – quartzite; *(7)* – cuirasse; *(8)* – amphibolite and micaschist; *(9)* – quartzite, sandstone; *(10)* – karstic morphology; *(11)* – conglomerate; *(12)* – chert and limestone; *(13)* – limestone recognised by sounding; *(14)* – chlorite and sericite schists (YPB).

[Рис. 2. Расположение основных геологических единиц (по [1] воспроизведено по [6]). Условные обозначения: *1* – направление сланцеватости; *2* – перекрытие; *3* – ось антиклинали; *4* – ось синклинали; *5* – трещины и разломы; *6* – кварцит; *7* – кираса; *8* – амфиболит и слюдяной сланец; *9* – кварцит, песчаник; *10* – карстовая морфология; *11* – конгломерат; *12* – кремнистый сланец и известняк; *13* – известняк, выделенный зондированием; *14* – хлоритовые и серицитовые сланцы (ХСЛ).]

In the hypothesis of the structuring of the Bangui series, A. Doyemet [6] purposes that the quartzites which overlie the limestones are in an abnormal position and are therefore overlapping. These quartzites of the Bangui series would then belong to a higher unit whose root would be located in the Panthères hill and to which quartzite of the right bank of the M'poko could belong. In this hypothesis, there would be at least two overlapping units: the lower unit and the unit higher than the detached Bangui unit, which would have a much greater extent than the lower one; the overlapping of this unit would be mainly identifiable in the western sector. Doyemet [6] then notes that the submeridian structures are not only intersected but offset by the shearing and conjugate faults, respectively senestrial and dextral, which would then be posterior (or late) to the thrust. This would be a major structural feature of the Bangui series, which probably distorted the major orientations of the folds and the meridional schistosity. Field work and some interpretation of the available borehole and geophysical data carried out for better understanding of the tectonic events and fault network of the Bangui series revealed that the faulted system is divided into three families (N10-N30, N130-N150 and N60-N80) (Fig. 3, 4).

The first family would correspond to the overthrust and would be prior to the other two, conjugated, which are shearing and are associated with subequatorial constraints. The other two families would affect the Gbayas nappe. They would then probably have been reused in the Pan-African orogeny.

As the Kibaran convergence affected the whole Bangui series, the quartzite of Bangui and the formations of Bimbo would predate the Kibaran. The Bangui series could therefore have been metamorphosed during the emplacement of granitoids (Mbi granite). It would therefore be affected by the Eburnian II, thus modifying the stratigraphic succession proposed by J. L. Poidevin [2]. The contact between the Fatima limestones to the east and the sandstones of the Bimbo series is thought to be submeridian overall. The carbonates overlap the quartzites of the Bangui series. The Fatima series is said to be duplicated. This redoubling, linked to folded structures diverted towards the west, is analogous to those found associated with tectonic ramp structures (anticlines and synclines).

We will not discuss the above as our study focuses only on the Boy-Rabe area where a south-western thrust is caused by a north-western shear fault. This caused the intrusion of a dolerite sill and created a scaling.

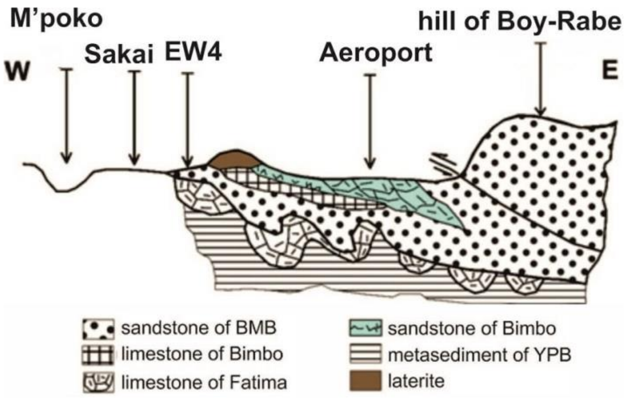

Fig. 3. Schematic section illustrating the hypothetical geometry of the geological formations of the Bangui sector in the first hypothesis (redrawn after [6]).
[Рис. 3. Схематический разрез, иллюстрирующий гипотетическую геометрию геологических образований сектора Банги в первой гипотезе (перерисован по [6]).]

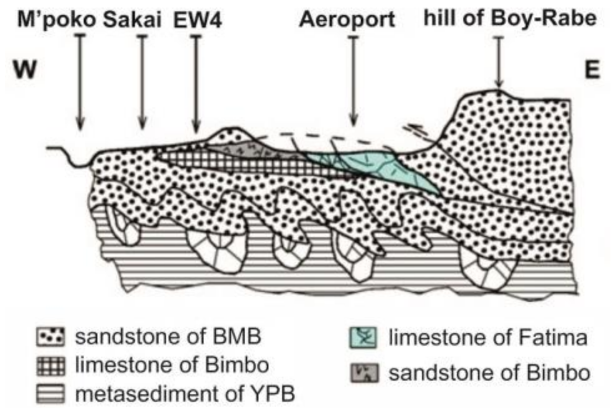

Fig. 4. Schematic section illustrating the possible geometry of the geological formations of the Bangui area in the second hypothesis (redrawn after [6]).
[Рис. 4. Схематический разрез, иллюстрирующий возможную геометрию геологических образований района Банги во второй гипотезе (перерисован по [6]).]

Lithology

The lithological succession of the Bangui series is very complex, and has been the subject of several interpretations by previous authors [1–4, 6].

According to the lithostratigraphy of Bangui, it is characterised by schists and quartzites to the north and north-east that belong to the Bangui and Yangana series. Their degree of metamorphism is low. Limestones, dolomites and quartzites in decreasing succession in the south-west constitute the Fatima series. The superficial formations are represented by alluvium, sand, clay and laterite (Fig. 5).

The upper part of this series is made up of a quartzite-pelite alternation of unknown thickness and poorly studied, but rather with relatively coarse elements at the base and more pelitic at the top. In the present study, we propose to complete this lithological succession in its summit part with a conglomerate and to highlight the Boy-Rabe dolerite sill at the base of the quartzites in the shear fault, which is the origin of mylonitic schist layers and breccias with quartzite fragments and very laminated coarse pebbles (Fig. 6).

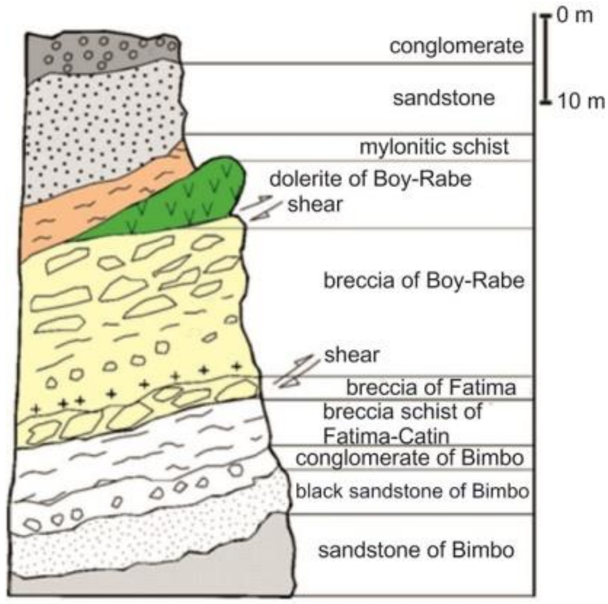

Fig. 5. Lithostratigraphic synthesis.
[Рис. 5. Литостратиграфический синтез.]

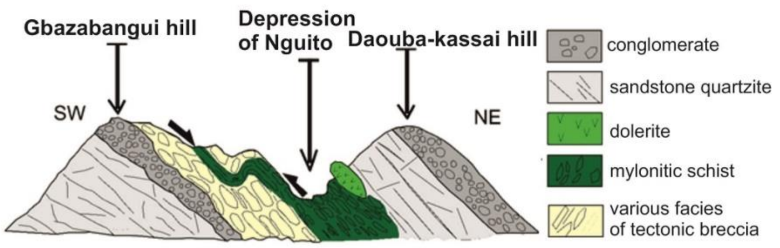

Fig. 6. New schematic synthesis of the litho-stratigraphic succession of Bangui (SW-NE section).
[Рис. 6. Новый схематический синтез литостратиграфической последовательности Банги (разрез ЮЗ-СВ).]

Petrographic description

The Bangui-Mbaiki-Boali Formation has been the subject of many previous works. The present study will only focus on the description of the upper conglomerate, the dolerite, the mylonitic schists and the breccia met at Boy-Rabe and never described before.

The upper conglomerate (Fig. 7 a, b), within the frame of the section shown in Fig. 5, is at the base of each layer.

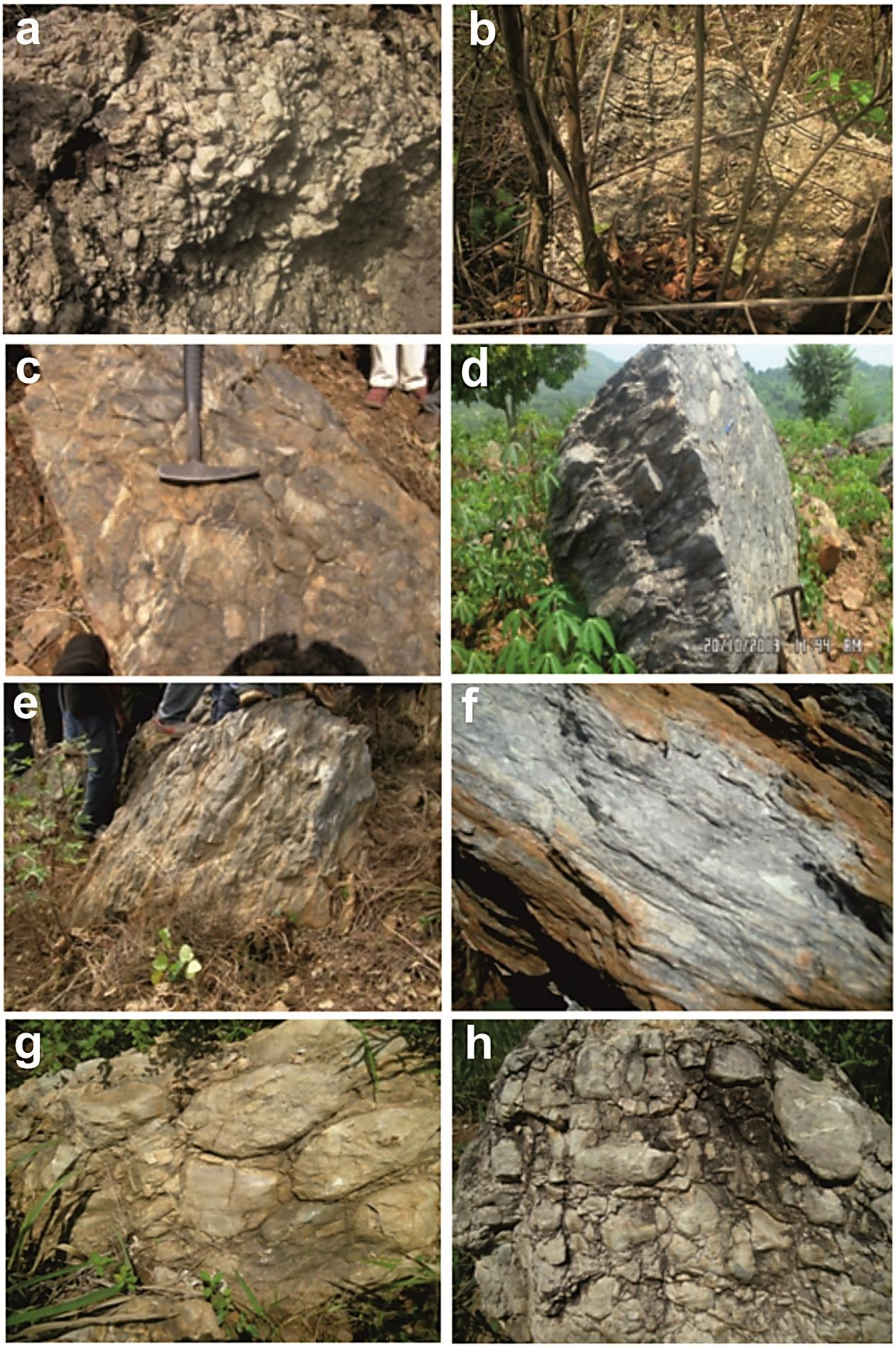

Fig. 7. Outcrop pictures: *(a, b)* – upper conglomerates with rounded *(a)* and flattened *(b)* pebbles; *(c, d)* – various facies of tectonic breccia; *(e, f)* – breccia overlying the laminated conglomerate *(e)* and mylonitic schists to sericite shale *(f)*; *(g, h)* – breccia with coarse fragments, Boy Rabe.

[Рис. 7. Картины обнажения: *a, b* – верхние конгломераты с окатанной *(a)* и уплощенной *(b)* галькой; *c, d* – различные фации тектонической брекчии; *e, f* – брекчии, залегающие на слоистых конгломератах *(e)* и милонитовых сланцах до серицитовых сланцев *(f)*; *g, h* – брекчия с крупными обломками, Бой-Рабе.]

It is a very coarse, non-metamorphosed conglomerate, with centimetric to decimetric pebbles, poorly consolidated, and with clay cement. It is found at the top of the hill overlooking the base of national guard and the road to Ngaragba district. The pebbles are composed of quartz and various well rolled rocks. This layer, towards Ngaragba, is more than twenty meters thick. It does not have visible bedding and covers the quartz sandstone. At the top of the hill overlooking the camp de Roux (military base), the conglomerate indicates the beginning of a shearing orientation. The pebbles are flattened. This conglomerate covers the previous conglomerate.

The breccia of Boy-Rabe (Fig. 7 c, d). Behind the National Assembly this conglomerate is entirely sheared. The pebbles are decimetric, oblong, recrystallised, laminated, fractured and clogged with mylonitic cement. They are mixed with quartzite fragments having undergone the same deformations. The fractures are filled with dissolution quartz giving tension slot figures. These breccias are above the conglomerate described above.

The breccia overlying the laminated conglomerate (Fig. 7 e, f). This level consists of centimetric to decimetric quartzite fragments also highly laminated, recrystallized, fractured and cemented by recrystallized quartz or mylonitic clay schists.

The mylonitic schists (Fig. 8). This breccia is overlain by a lustrous sericite schist with millimetre to centimetre fragments of quartzite showing pressure queues typical of shear zones. The shale is covered by a coarse breccia layer with slightly elongated, fractured and little or not recrystallised decametric fragments whose cracks are not sealed but cemented together by clay resulting from crushing. This breccia is overlain by finer mylonitic shale with millimetric quartzite fragments. It has a thickness exceeding the hundred meters and also includes intercalations of sandstone. It is directly surmounted by the sandstone with which it has a normal contact.

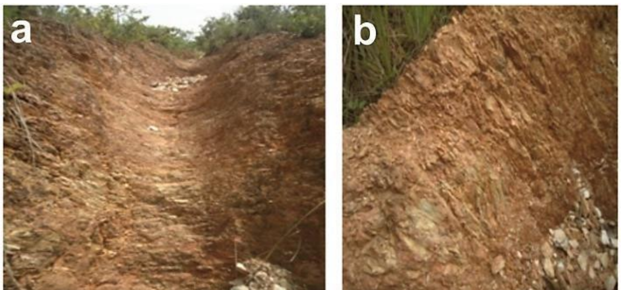

Fig. 8. Fine-grained mylonitic shale with millimetric sandstone fragments of Boy-Rabe.

[Рис. 8. Мелкозернистый милонитовый сланец с миллиметровыми обломками песчаника Бой-Рабе.]

Dolerites. Dolerite is intruded into the mylonitics schist. Its color is green with a characteristic dolerite texture and sometimes with hornfels at the contact. The mineralogy consists of olivine, pyroxene, plagioclase, chlorite, and sometimes garnets and sulfides (Fig. 9).

The rock is 40 to 50 m thick with a lateral extension at an outcrop of about 100 m. It exhibits flow schistosity. The cleavage fracture is probably caused by late thrusting movements sin- or post-thrust fractures affecting the series of Bangui.

Fig. 9. Outcrop pictures: *(1)* – dolerite sill consistent with the schistosity of the mylonitic schists; *(2)* – outcrop of dolerite showing a roughly east-west fracture; *(3)* – ball-shaped cutting of the dolerite.

[Рис. 9. Картины обнажений: *1* – долеритовый силл, соответствующий сланцеватости милонитовых сланцев; *2* – обнажение долеритов с разломом примерно с востока на запад; *3* – шаровидная огранка долерита.]

Petrography and mineralogy

Among the studied rocks, four magmatic rock samples of the Bangui-Mbaiki-Boali series (RU4, Palambo; RU5, Bagandou; RU6, Bangui and RU7, Boali of CAR) and one metamorphic rock from Bangassou (RU3, CAR) were selected. These rocks intrude the Bangui-Mbaiki-Boali series at various locations. The aim of the present work is to characterise their magmatic features, which we suspect to be post-kinematically orogenic but of the same tectonic event.

They are slightly oriented massive basalts. Hornblende is the main mineral, garnet is omnipresent, plagioclase occurs in rods and myrmekites, and clinopyroxenes are present in the interstices. The amphibolite with garnet has a fabric marked by elongated dark green amphiboles, rare plagioclase, quartz, garnet and titanite. The amphibolite is intruded by granite or gabbro-dolerite.

Amphibolite with garnet of Bangassou Grenat (RU3)

This amphibolite was collected at Bangassou in the south-east of CAR. It has a granoblastic oriented texture and bears the imprint of a deformation characterised by banding. It is a rock with often elongated crystals. The mineralogy consists of amphibole, quartz, titanite, rare plagioclase, fractured and elongated garnet. The fractures are always fulfilled by iron oxides (Fig. 10).

The thin sections show that the texture is mainly lepidogranoblastic, marked by deformation highlighted in the amphibolite by amphiboles associated with quartz crystals, and also deformed garnet (Fig 10 h, i). The amphibole in this rock is essentially green hornblende with strong pleochroism. Quartz is either small (0.08 to 0.36 mm) or elongated and amoeboid (Fig. 10 a, b). Plagioclase is rare in this amphibolite and shows an altered dirty patch, often with secondary epidote grains. Rare titanite (Fig. 10 i) is idiomorphic, strongly pleochroic with a characteristic shape. Garnet is observed not often. It is deformed and elongated, probably due to a stress.

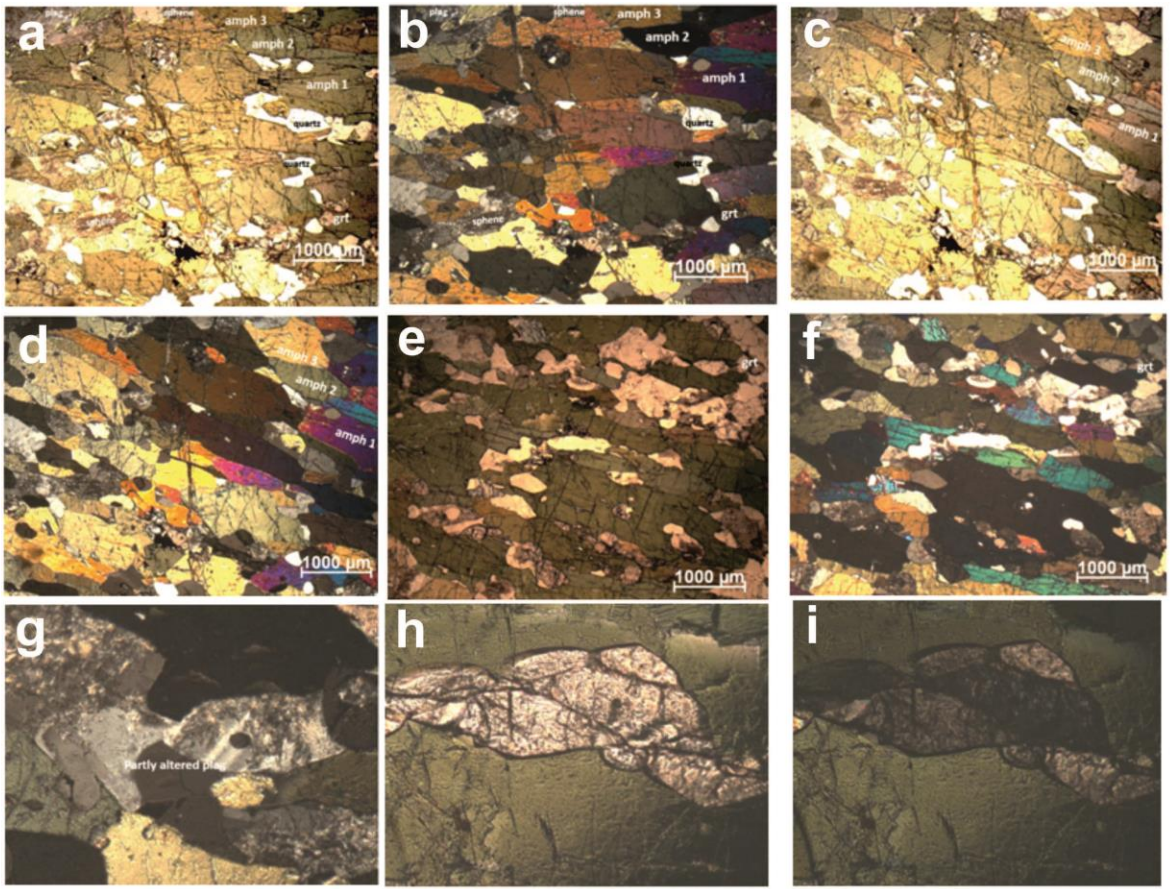

Fig. 10. Microstructure of the garnet-bearing amphibolite, Bangassou, (RU3).
[Рис. 10. Микроструктура гранатсодержащего амфиболита, Бангасу, (RU3).]

Daouba Kassai dolerites

Dolerite with quartz (RU4) is shown in Fig. 11 a–h.

Quartz dolerite (RU7) (Fig. 11 i). These dolerites are found in the foothills, where residual pockets of extensive weathering are observed. They are intruded into the mylonitic schists.

Alterated dolerite with quartz (RU6) (Fig. 12). This rock shows significant alteration with also the presence of myrmekites showing its position in a low part of the hill environment. Intense alteration of the feldspars, up to their albitisation, is observed. In addition, the granophyric intergrowths (quartz-feldspar) (Fig. 12 f), are the characteristic for the metamorphic minerals.

Both types of dolerite have undergone a high degree of alteration showing strong oxidation of the ferromagnesian minerals. The first type (RU4 and RU7) shows less altered rocks, while the second type (RU6) is totally altered. Plagioclase and pyroxene are replaced by epidote and actinolite, respectively. The primary oxide grains occupy the interstices between the plagioclase crystals. They can also appear at the expense of ferromagnesian minerals. Pyroxenes are augite, often altered to amphibole, with relics observable. Plagioclase, pyroxene and amphibole are intersertal and ophitic in texture. Plagioclase is often replaced by epidote and occurs in two forms: tabular phenocrysts (RU4) and prismatic crystals and their intergrowths. Their edges are studded with granular epidote. Some albitic plagioclases are covered with a felting of the sericite small flakes which is the evidence of the alteration. Pseudomorphoses of actinolite are developed after xenomorphic augite in the form of rosettes (RU4 and RU6), or augite forms phenocrysts embedded in plagioclase. Opaque minerals, which are quite rare, are sometimes included in the pyroxene and plagioclase. Epidote is the alteration product of plagioclase. Myrmekites (RU6) are buds of potassium feldspar containing quartz vermicules which develop in it. Thus, they result from the replacement of K in the potassium feldspar by Ca-Na (plagioclase) with the release of silica.

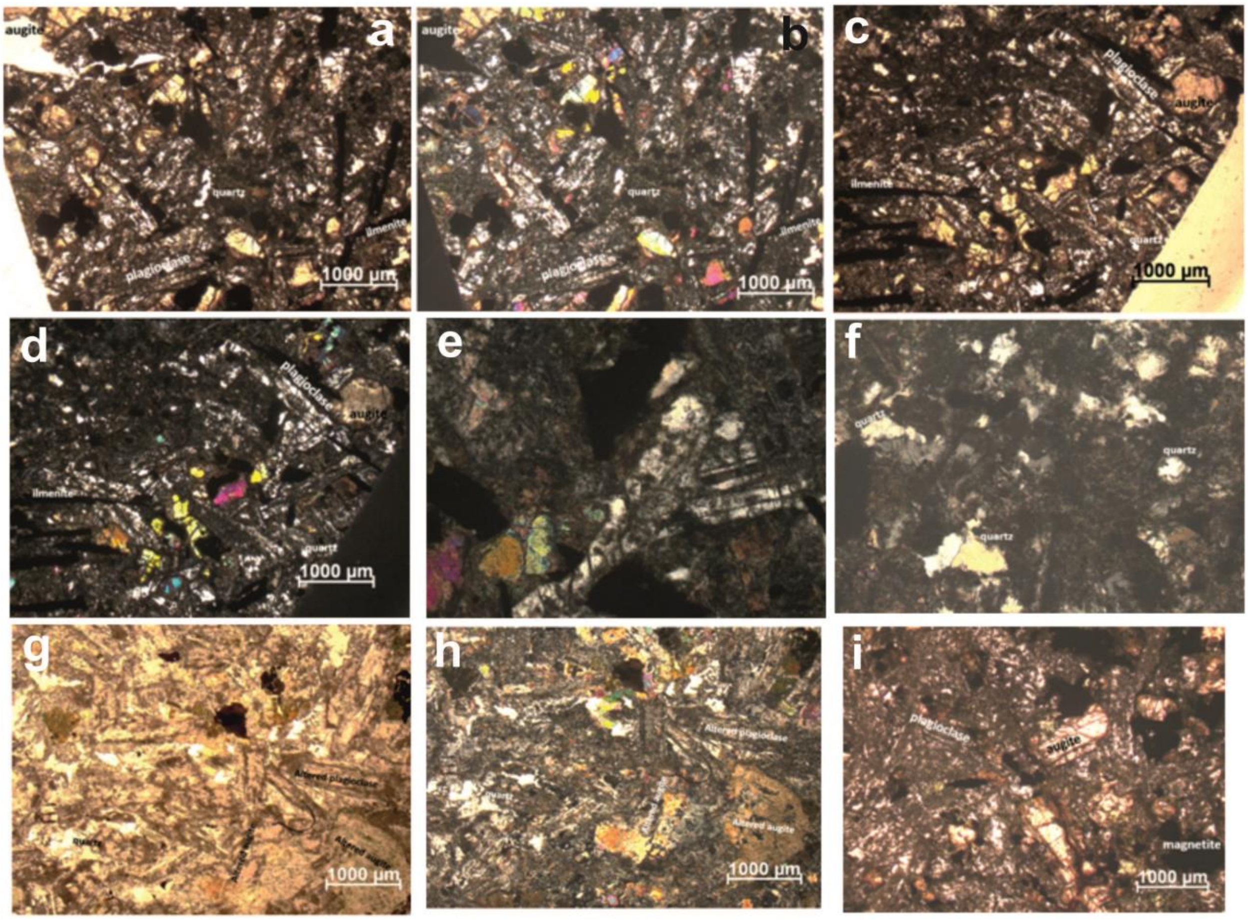

Fig. 11. Microstructure of dolerite with quartz, Daouba Kassai: (*a–h* – sample RU4; *i* – sample RU7).
[Рис. 11. Микроструктура долерита с кварцем, Дауба Кассаи: (*a–h* – обр. РУ4; *i* – обр. РУ7).]

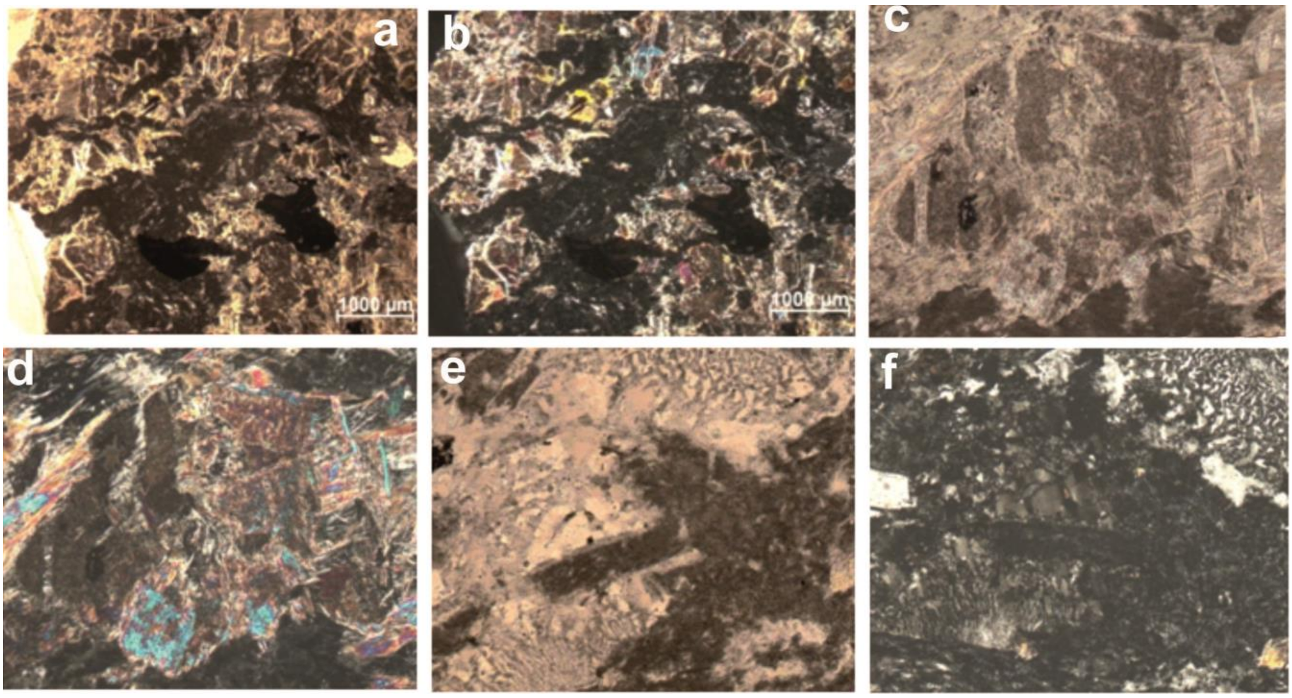

Fig. 12. Microstructure of alterated dolerite with quartz, Bangui, (RU6).
[Рис. 12. Микроструктура измененного долерита с кварцем, Банги, (RU6).]

Geochemistry

Major element analysis was obtained for 4 dolerites (RU4, Palambo; RU5, Bagandou; RU6, Bangui and RU7, Boali of CAR) and one Bangassou amphibolite (RU3, CAR) as an additional sample for comparison (Table 1). In the Bangassou area, the amphibolite is generally garnet-bearing, which is cut by poorly oriented granite and gabbro-dolerite intrusions. This amphibolite may be the result of these basic rocks metamorphism, so it may have the same origin. The concentration of trace elements for these rocks is also shown in Table 1.

Dolerites have compositional similarity with amphibolites and will be considered together further. SiO_2 varies from 45.6 to 50.2 wt. % (Table 1). Mafic rocks are enriched with Fe_2O_{3tot} (14.8–19.9 wt. %; Mg# = 0.17–0.31), TiO_2 (1.43–4.41 wt. %) and P_2O_5 (0.15–0.63 wt. %). Alkali contents ($Na_2O + K_2O$) vary from 2.39 to 4.19 wt. %, with Na_2O dominating over K_2O. In the SiO_2 – (Na_2O + K_2O) classification diagram, the rock composition points are located in the fields of basalt (Fig. 13 a).

The oxides show a good correlation in the diagrams with SiO_2 on the x-axis, although they are taken from rather distant points. One point, the amphibolite, is outside this correlation. Alkalis, alumina and at certain extent calcium show a positive correlation with silica while iron, titanium, magnesium, manganese and phosphorus have a negative correlation (Fig. 14).

The distribution of trace elements shows depletion in the "mantle" elements such as Ni (49–97 ppm) and Cr (52–198 ppm), but a pronounced enrichment of V (287–487 ppm) and Cu (202–419 ppm). Dolerites are enriched in LILE (large ion lithophile elements), namely Rb (5–32 ppm, av. 23 ppm), Sr (154–367 ppm, av. 252 ppm), Ba (30–303 ppm, av. 137 ppm), HFSE (high field strength elements) such as Nb (6–29 ppm, av. 16 ppm), Zr (83–325 ppm), Y (20–56 ppm, av. 38 ppm) and LREE (light rare earths elements).

Table 1. Geochemical analyses of dolerites and amphibolite
[**Табл. 1.** Геохимический анализ долеритов и амфиболитов]

wt. %	RU4	RU6	RU5	RU7	RU3
SiO_2	45.64	50.2	48.36	46.98	47.5
TiO_2	4.41	2.25	1.51	3.99	1.43
Al_2O_3	12.09	14.13	11.78	12.67	11.73
Fe_2O_{3tot}	19.88	14.84	16.51	18.74	17.94
MnO	0.26	0.19	0.25	0.22	0.23
MgO	4.47	4.51	7.29	3.84	6.48
CaO	9.47	9.09	11.61	9.34	11.72
Na_2O	2.17	3.08	2.3	2.5	2.07
K_2O	0.74	1.11	0.09	0.9	0.59
P_2O_5	0.63	0.36	0.15	0.59	0.14
$K_2O+ Na_2O$	3.91	4.19	2.39	3.4	2.66
Mg#	0.18	0.23	0.31	0.17	0.27
ppm					
S	246	396	201	334	150
V	487	324	287	441	395
Cr	84	56	198	52	121
Co	72	64	56	60	91
Ni	63	50	97	49	85
Cu	334	202	237	419	224
Zn	157	121	123	152	112
Rb	23	32	< 5	32	23
Sr	180	367	356	201	154
Y	54	39	20	56	22
Zr	306	235	106	325	83
Nb	19	29	6	21	6
Ba	81	303	< 30	145	127
La	34	38	< 8	31	< 8
Ce	171	123	67	157	45
Nd	39	34	12	42	12
Pb	7	12	9	8	7
Ti/Y	490	346	453	428	390
Zr/Y	5.6	6.0	5.3	5.8	3.8
Nb/Y_{PM}	11.9	8.6	4.4	12.3	4.8

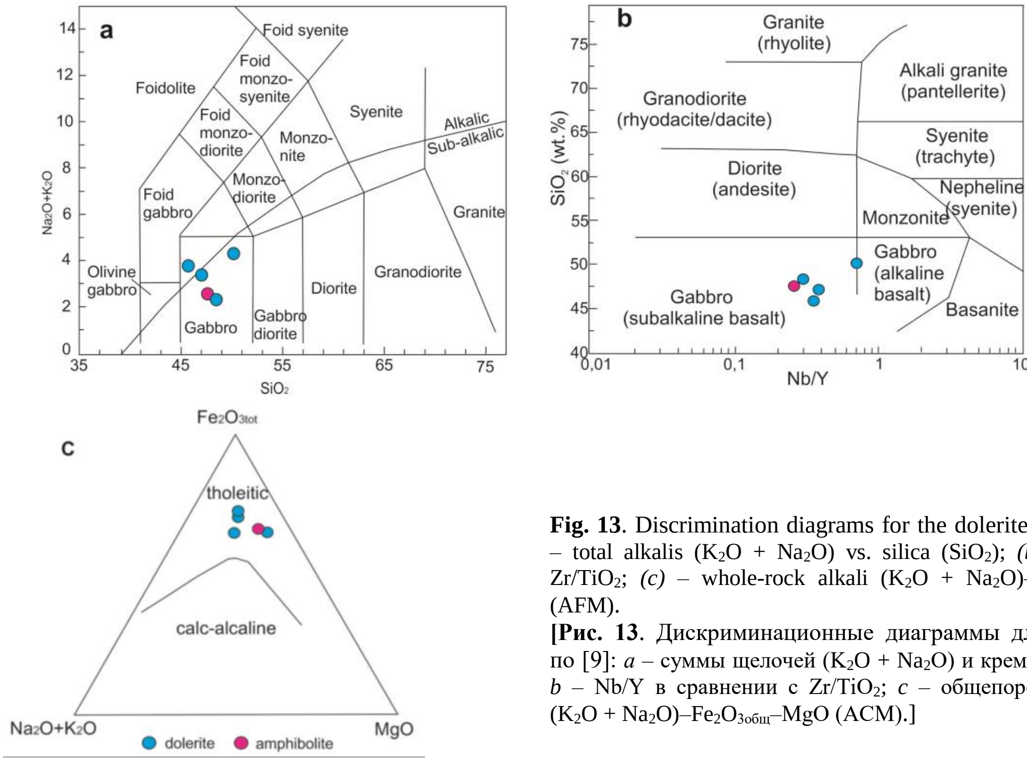

Fig. 13. Discrimination diagrams for the dolerites after [9]: *(a)* – total alkalis ($K_2O + Na_2O$) vs. silica (SiO_2); *(b)* – Nb/Y vs. Zr/TiO_2; *(c)* – whole-rock alkali ($K_2O + Na_2O$)–Fe_2O_{3tot}–MgO (AFM).

[Рис. 13. Дискриминационные диаграммы для долеритов по [9]: *a* – суммы щелочей ($K_2O + Na_2O$) и кремнезема (SiO_2); *b* – Nb/Y в сравнении с Zr/TiO_2; *c* – общепородная щелочь ($K_2O + Na_2O$)–$Fe_2O_{3общ}$–MgO (АСМ).]

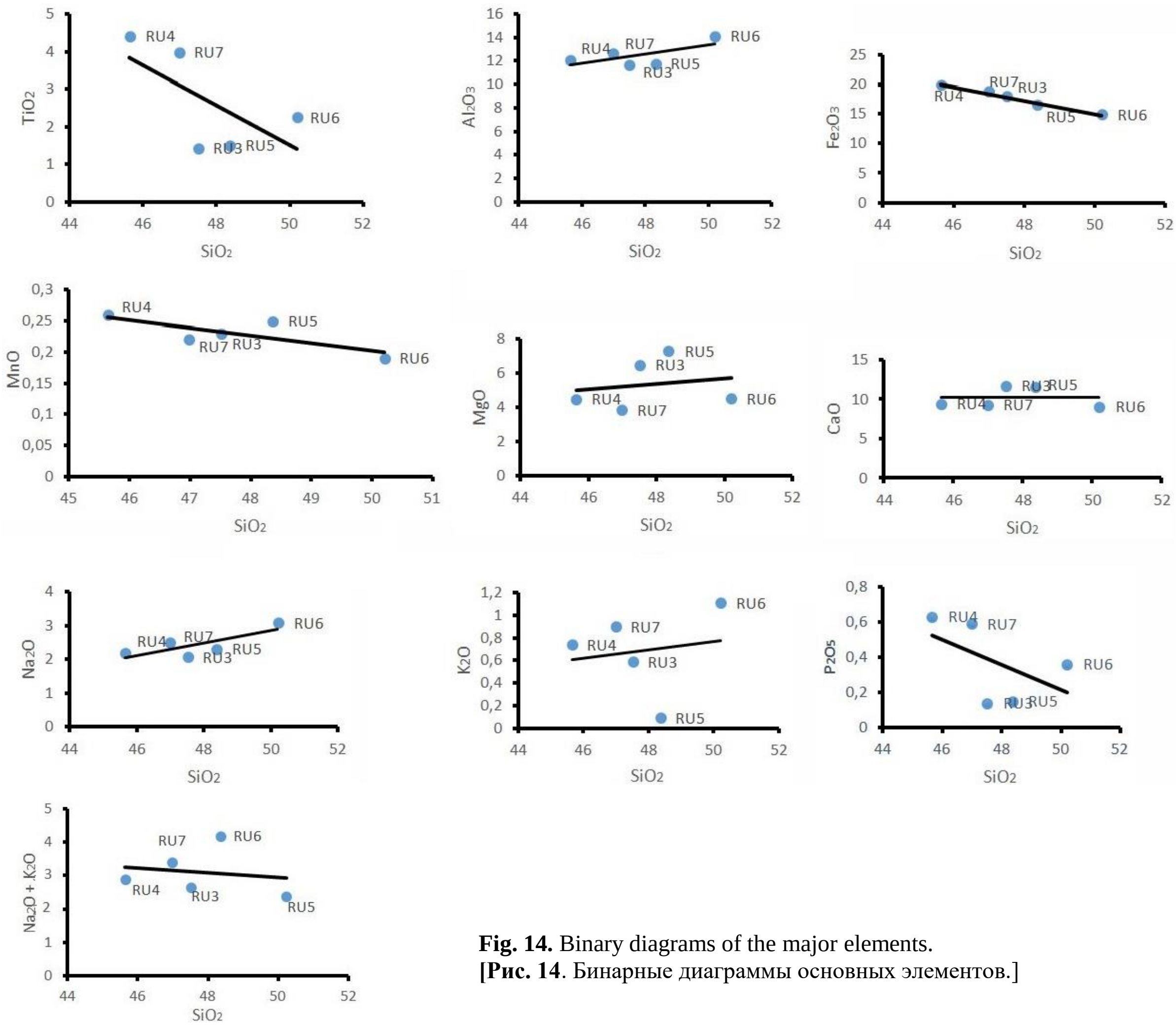

Fig. 14. Binary diagrams of the major elements.

[Рис. 14. Бинарные диаграммы основных элементов.]

Discussion

In Bangui, as in Palambo to the east and Mbaiki to the west, tangential tectonics towards the south-west have been confirmed, creating a cuesta landscape in Bangui and causing, as in Palambo and Mbaiki, the emplacement of dolerite sills. This thrusting has given beds each composed of a fractured recrystallised flattened pebble breccia, breccia with quartzite fragments having undergone the same deformations as the flattened pebble breccia, mylonitic sericite schists and finally mylonitic shales in normal contact with the overlying quartzites, quartz sandstone, sandstone with clayey cement and conglomerates that are not very or not at all consolidated. The Bangui Formation is terminated by unconsolidated or weakly consolidated conglomerate with rolled fragments. The shales described by previous authors in Bangui from Ngaragba to Boy-Rabe are actually mylonits resulting from a thrust.

Dyke swarms have previously been studied in the Central African subregion [10]. Dolerite dyke swarms in the Lopo (Nola) in the southeast of the CAR are composed of continental tholeiites and belong to the pre-Pan-African phase of extension, which occurred about 1 Ga. The dolerites of the Precambrian Sembe-Ouesso Basin (RC) were emplaced during crustal distension and are characterized by two types of dolerites: quartz-alkaline dolerites and olivine dolerites of tholeiitic affinity. In the regions of Mayo, Ulo-Lere and Baburi-Figil (northern Cameroon), two types of basic magmatism (tholeiitic and alkaline) were identified in the continental extension zone and veins of olivine dolerites (continental tholeiites) associated with basalts and microgabbro were characterized by [11]. At the same time, dykes of continental dolerites of the tholeiitic series were identified in the Alkaline Province of Cameroon [12]. The geochemical characteristics of the basite dykes of the Mayombe chain in the southwest Congo with a transitional tholeiite affinity in extension zones are given in [13].

Our results on geochemistry do not contradict the above data on basalts from the Central African subregion. The dolerites of the Bangui-Mbaiki-Boali series correspond in composition to subalkaline basalts of the tholeiite affinity (Fig. 13 b, c). High iron content and low concentrations of compatible elements such as Ni and Cr indicate the evolutionary nature of dolerite melts due to the fractional crystallization of parental magmas, and a high degree of olivine and pyroxenes fractionation. The values of the Ti/Y ratio < 500 indicate a shallow garnetless source of magma generation.

High contents of Cu and V suggest a strong differentiation of mafic magma with an increased content of the fluid component. Another reason could be the high oxygen fugacity in the basite melt [14]. Although V and Cu are compatible elements, under relatively oxidizing conditions the high valence of V^{5+} and Cu^{2+} (and even Cu^{3+}) does not allow them to be in the composition of rock-forming minerals. Therefore, they accumulate in the residual melt. In the Cu/Zr in primary magma versus Zr (ppm) diagram, dolerite composition points fall into a region with high fO_2 values, sufficiently above the QFM buffer (Fig. 15).

The geochemical signatures of the Bangui-Mbaiki-Boali dolerites as high iron rocks, enriched with P_2O_5, LILE, HFSE, LREE are characteristic of within-plate basalts (Fig. 16). On the tectonic discriminant diagrams, the composition points fall into the fields of within-plate basalts. As can be seen in the Zr/Y – Nb/Y diagram (Fig. 17), enrichment in incompatible elements suggests their source as enriched melts from the lithospheric subcontinental mantle, possibly contaminated with continental crust material.

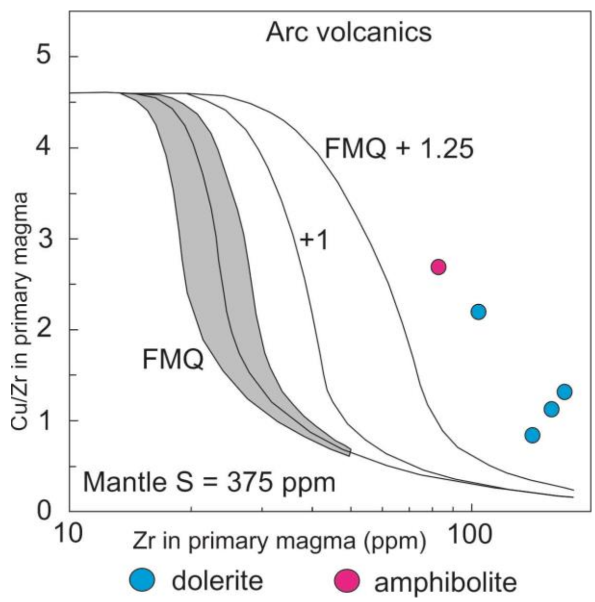

Fig. 15. Estimated mantle oxygen fugacities after [14]. Quantitative estimation on mantle redox states beneath arc with varied mantle sulfur contents using Cu/Zr vs. Zr variations for primary arc magmas. The black dashed lines show the mantle melting models with different mantle sulfur contents at fO_2 = FMQ.

[**Рис. 15**. Оценки фугитивности мантийного кислорода по [14]. Количественная оценка окислительно-восстановительного состояния мантии под дугой с различным содержанием серы в мантии с использованием вариаций Cu / Zr по сравнению с Zr для первичных дуговых магм. Черными пунктирными линиями показаны модели плавления мантии с разным содержанием серы в мантии при fO2 = FMQ.]

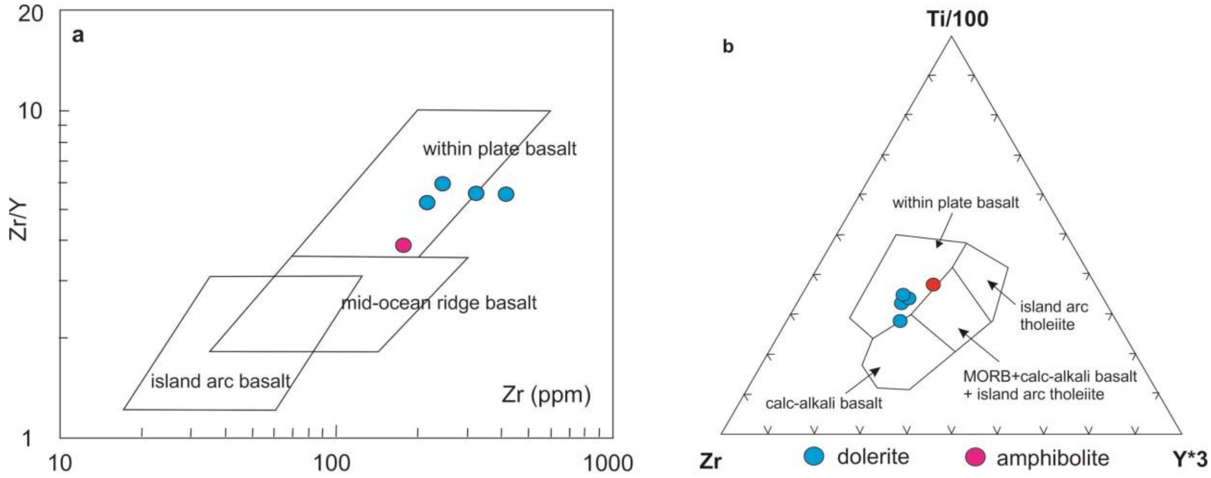

Fig. 16. Tectonic discrimination plots after [15]: *(a)* – the Zr-Zr/Y diagram; *(b)* – the Ti/100-Zr-Y*3 diagram.
[Рис. 16. Графики тектонической дискриминации по [15]: *а* – диаграмма Zr-Zr/Y; *б* – диаграмма Ti/100-Zr-Y*3.]

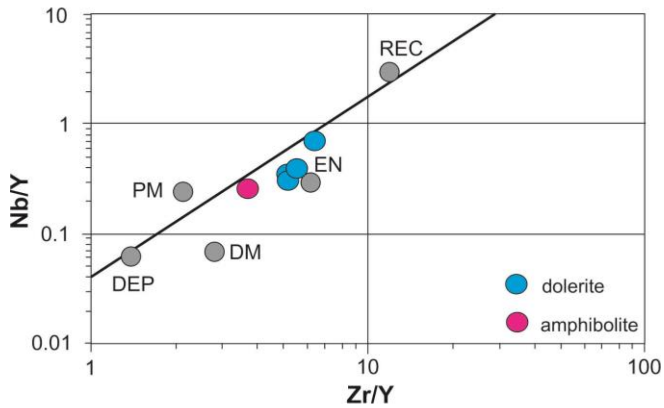

Fig. 17. The Zr/Y – Nb/Y diagram aftrer [16, 17]: *DEP* – deep depleted mantle; *EN* – enriched component; *REC* – recycled component; *PM* – primitive mantle; *DM* – shallow depleted mantle.
[Рис. 17. Диаграмма Zr/Y – Nb/Y по [16, 17]: *DEP* – глубоко деплетированная мантия; *EN* – обогащенный компонент; *REC* – переработанный компонент; *PM* – примитивная мантия; *DM* – неглубокая деплетированная мантия.]

Conclusion

1. The dolerites of the Bangui-Mbaiki-Boali series are ferruginous subalkaline basites of the tholeiitic affinity, enriched in LILE, HFSE and LREE with low concentrations of Ni and Cr, and have experienced fractional crystallization with fractionation of olivine and pyroxene.

2. Parental magmas were formed in shallow conditions of garnet instability. They are characterized by a high degree of oxidation and an increased content of fluid.

3. The source for the dolerites could be enriched protoliths from the subcontinental lithospheric mantle. The Bangui dolerites were formed in an intraplate setting.

Acknowledgements. The authors are grateful to Doctorants Poukesserandji Josey Stéphane and Elokoua Yadjenga Hermann Ray of the Department of Sciences of the Earth of the University of Bangui – Central African Republic, which helped us in the data-gatherings and the realization of the charts and other diagrams.

Conflict of interest. The authors declare the absence of obvious and potential conflicts of interest related to the publication of this article.

REFERENCES

1. Cornacchia M., Giorgi L. Precambrian series of sedimentary and volcanogenic origin of the Central African Republic. *Ann. Mus. Roy. Afr. Central, Tervuren, Belgium, Geological Sciences*, 1986, ser. in-8, 93. 51 p.
2. Poidevin J.L. Trainings of the Precambrian superior of the area of Bangui (R.C.A.). *Bul. Soc. Géol*., 1976, 7, XVIII, 4, pp. 999–1003.
3. Poidevin J.L. Formations Proterozoic superior of the East and the North of the Central African Republic. Towards a global approach to the Upper Precambrian of the Central African Republic. Series of covers of the west and the center of the Central African Republic. *Ann. Mus. Roy. Central Afr. Tervuren, Belgium, Geological Sciences,* 1985, ser. in-8, 91.
4. Biandja J. Metallogenic approach of Green stone belt of Bogoin (R.C.A). Its mineralisation in Gold. Thesis of Doctor-Engineer, Académie de Paris VI, 1988. 318 p.
5. Moloto G.R. Evolution paleoproterozoic geotectonics with neoproterozoic of the cover of the archaean craton of Congo to the borders of Congo, Cameroun and Central Africa. Doct. thesis, Orléans University, 2002. 264 p.
6. Doyemet A. Le système aquifère de la région de Bangui (République Centrafricaine), conséquences des caractéristiques géologiques du socle sur la dynamique, les modalités de recharge et la qualité des eaux souterraines. Thesis (PhD), USTL University of Lille, France, 2006.
7. Alvarez P. Evidence for a Neoproterozoic carbonate ramp on the northern of the central African craton: relations with

Late Neoproterozoic intracratonic troughs. *Geol. Rundschau*, 1995, vol. 84, pp. 636–648.
8. Rolin P. New tectonic data on the Precambrian base in Central Africa: geodynamic implication. *Ed. collect. Géocam, Presse Univ, Yaoundé 1*, 1998, no. 1, pp. 249–224.
9. Le Maitre R.W., Streckeisen A., Zanettin B., et al. Igneous Rocks: A Classification and Glossary of Terms, Recommendations of the International Union of Geological Sciences, Subcommission of the Systematics of Igneous Rocks, Cambridge: University Press, 2002. 236 p. DOI: 10.1017/CBO9780511535581
10. Vicat J.P., Pouclet A., Nsifa E. Les Dolérites du Groupe du Ntem (Sud Cameroun) et des Régions Voisines (Centrafrique, Gabon, Congo, Bas Zaïre): Caractéristiques Géochimiques et Place dans L'évolution du Craton Centrafricaine), Tém tal Part of the Cameroon Volcanic du Congo au Protérozoïque. *Géologie et Environnements au Cameroun, Eds. Vicat J.P. and Bilong P.* Collection GEOCAM, 1998, pp. 305–324.
11. Ngounouno I., Deruelle B., Guiraud R., Vicat J.-P. Les dykes des bassins crétacés de Mayo-Oulo-Léré et de Babouri-Figuil (Nord du Cameroun-Sud du Tchad). *12e Conférence Internationale de la Société Géologique d'Afrique. Yaoundé. Volume: J. Geosci. Soc. Cameroon, 1, n 1A, Special Abstract Issue, GSA 12th Inter. Conf. "Geo-Environmental Catastrophes in Africa"*, 2001. p. 90.
12. Vicat J.P., Ngounouno I., Pouclet A. Existence of old doleritic dykes of continental tholeiite composition, in the Cameroon Line alkaline province. Implication to the geodynamical context. *Comptes Rendus de l Académie des Sciences - Series IIA - Earth and Planetary Science*, 2001, vol. 332, no. 4, pp. 243–249. DOI: 10.1016/S1251-8050(01)01526-9
13. Mpemba-Boni J., Vellutini P-J. Characterisation geochimique des dykes basiques du Massif de les Saras (Mayombe Congolais, Afrique Centrale): consequences geodynamiques. *J. Afr. Earth Sci.*, 1992, vol. 14, no. 2, pp. 209–215. DOI: 10.1016/0899-5362(92)90098-W
14. Zhao S.-Y., Yang A.Y., Langmuir C.H., Zhao T.-P. Oxidized primary arc magmas: Constraints from Cu/Zr systematics in global arc volcanics. *Sci. Adv.*, 2022, vol. 8, no. 12, eabk0718. DOI: 10.1126/sciadv.abk071
15. Pearce, J.A., Norry, M.J. Petrogenetic implications of Ti, Zr, Y, and Nb variations in volcanic rocks. *Contrib. Mineral. Petrol.*, 1979, vol. 69, pp. 33–47. DOI: 10.1007/BF00375192
16. Fitton J.G., Saunders A.D., Norry M.J. et al. Thermal and chemical structure of the Iceland plume. *Earth Planet. Sci. Lett.*, 1997, vol. 153, pp. 197–208. DOI: 10.1016/S0012-821X(97)00170-2
17. Condie K.C. High field strength element ratios in Archean basalts: a window to evolving sources of mantle plumes? *Lithos*, 2005, vol. 79, pp. 491–504. DOI: 10.1016/j.lithos.2004.09.014

УДК 552.3 **ISSN 1609-0691**
DOI: https://doi.org/10.17308/geology/1609-0691/2023/1/65–79
Поступила в редакцию: 01.09.2023
Принята к публикации: 02.03.2023
Опубликована онлайн: 31.03.2023

Долеритовые силлы в песчаниках Банги, Центральноафриканская Республика: геохимия и петрология

©2023 Х. Ф. А. Мапока[1]✉, Дж. Биандза[2], К. А. Савко[3], С. М. Н'Гбатука[2], Н. С. Базиков[3]

[1]Лаборатория геонаук, факультет наук о Земле, Университет Банги, B. P: 908, Банги, Центральноафриканская Республика
[2] Лаборатория георесурсов, департамент горного дела и геологии, Высший технологический институт, B. P: 892, Банги, Центральноафриканская Республика
[3] Воронежский государственный университет, Университетская пл., 1, Воронеж, 394018, Воронеж, Российская Федерация

Аннотация
Геология региона Банги слабо изучена, хотя уже появилось достаточно новых данных. Однако литостратиграфических обобщений еще очень немного. Присутствие некоторых типов пород, таких как долеритовые силлы в песчаниках, может быть следствием тектоники растяжения в регионе. Долериты серии Банги-Мбаики-Боали отвечают субщелочным базальтам толеитовой серии. Они обогащены LILE, HFSE и LREE, имеют низкие концентрации Ni и Cr и подверглись фракционной кристаллизации с фракционированием оливина и пироксена. Родительские магмы формировались в малоглубинных условиях, в поле неустойчивости граната. Они характеризуются высокой степенью окисления и повышенным содержанием флюида. Источником долеритов могли быть обогащенные протолиты из субконтинентальной литосферной мантии. Долериты Банги были сформированы во внутриплитной обстановке.
Ключевые слова: долеритовые силлы, песчаники, тангенциальная тектоника, литологическая последовательность, милонитизация, брекчия, толеитовая серия.

Для цитирования: Мапока Х. Ф. А., Биандза Дж., Савко К. А., Н'Гбатука С. М., Базиков Н. С. Долеритовые силлы в песчаниках Банги, Центральноафриканская Республика: геохимия и петрология// *Вестник Воронежского государственного университета. Серия: Геология*. 2023. № 1. С. 65–79. DOI: https://doi.org/10.17308/geology/1609-0691/2023/1/65–79

Конфликт интересов: Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

ЛИТЕРАТУРА

1. Cornacchia M., Giorgi L. Precambrian series of sedimentary and volcanogenic origin of the Central African Republic. *Ann. Mus. Roy. Afr. Central, Tervuren, Belgium, Geological Sciences*.1986. ser. in-8, 93. 51 p.
2. Poidevin J.L. Trainings of the Precambrian superior of the area of Bangui (R.C.A.).*Bul. Soc. Géol*. 1976. 7. XVIII. 4.P. 999–1003.
3. Poidevin J.L. Formations Proterozoic superior of the East and the North of the Central African Republic. Towards a global approach to the Upper Precambrian of the Central African Republic.Series of covers of the west and the center of the Central African Republic.*Ann. Mus. Roy. Central Afr. Tervuren, Belgium, Geological Sciences.* 1985. ser. in-8. 91.
4. Biandja J. Metallogenic approach of Green stone belt of Bogoin (R.C.A). Its mineralisation in Gold.Thesis of Doctor-Engineer, Académie de Paris VI, 1988.318 p.
5. Moloto G.R. Evolution paleoproterozoicgeotectonics with neoproterozoic of the cover of the archaean craton of Congo to the borders of Congo, Cameroun and Central Africa. Doct.thesis, Orléans University, 2002. 264 p.
6. Doyemet A. Le systèmeaquifère de la région de Bangui (RépubliqueCentrafricaine), conséquences des caractéristiquesgéologiques du socle sur la dynamique, les modalités de recharge et la qualité des eauxsouterraines. Thesis (PhD), USTL University of Lille, France, 2006.

✉ Мапока Юбер Франсуа – д'Ассиз, e-mail: mpkman2003@yahoo.fr / mpkmarie4@gmail.com

7. Alvarez P. Evidence for a Neoproterozoic carbonate ramp on the northern of the central African craton: relations with Late Neoproterozoic intracratonic troughs. *Geol. Rundschau.* 1995.Vol. 84.P. 636–648.
8. Rolin P. New tectonic data on the Precambrian base in Central Africa: geodynamic implication. *Ed. collect. Géocam, PresseUniv, Yaoundé 1*.1998.No. 1.P. 249–224.
9. Le Maitre R.W., Streckeisen A., Zanettin B., et al. Igneous Rocks: A Classification and Glossary of Terms, Recommendations of the International Union of Geological Sciences, Subcommission of the Systematics of Igneous Rocks, Cambridge: University Press, 2002. 236 p. DOI: 10.1017/CBO9780511535581
10. Vicat J.P., Pouclet A., Nsifa E. Les Dolérites du Groupe du Ntem (Sud Cameroun) et des RégionsVoisines (Centrafrique, Gabon, Congo, Bas Zaïre): CaractéristiquesGéochimiques et Place dansL'évolution du Craton Centrafricaine), Témtal Part of the Cameroon Volcanic du Congo au Protérozoïque. *Géologiee-tEnvironnements au Cameroun, Eds.Vicat J.P. and Bilong P.* Collection GEOCAM. 1998.P. 305–324.
11. Ngounouno I., Deruelle B., Guiraud R., Vicat J.-P. Les dykes des bassinscrétacés de Mayo-Oulo-Léréet de Babouri-Figuil (Nord du Cameroun-Sud du Tchad). *12e ConférenceInternationale de la SociétéGéologiqued'Afrique.Yaoundé. Volume: J. Geosci. Soc. Cameroon, 1, n 1A, Special Abstract Issue, GSA 12th Inter. Conf. "Geo-Environmental Catastrophes in Africa"*. 2001. 90p.
12. Vicat J.P., Ngounouno I., Pouclet A. Existence of old doleritic dykes of continental tholeiite composition, in the Cameroon Line alkaline province. Implication to the geodynamical context.*ComptesRendus de l Académie des Sciences - Series IIA - Earth and Planetary Science.* 2001.Vol. 332.No. 4.P. 243–249. DOI: 10.1016/S1251-8050(01)01526-9
13. Mpemba-Boni J., Vellutini P-J. Characterisationgeochimique des dykes basiques du Massif de les Saras (MayombeCongolais, Afrique Centrale): consequences geodynamiques. *J. Afr. Earth Sci.*. 1992.Vol. 14.No. 2.P. 209–215. DOI: 10.1016/0899-5362(92)90098-W
14. Zhao S.-Y., Yang A.Y., Langmuir C.H., Zhao T.-P. Oxidized primary arc magmas: Constraints from Cu/Zr systematics in global arc volcanics. *Sci. Adv.*. 2022.Vol. 8.No. 12. eabk0718. DOI: 10.1126/sciadv.abk071
15. Pearce, J.A., Norry, M.J. Petrogenetic implications of Ti, Zr, Y, and Nb variations in volcanic rocks. *Contrib. Mineral. Petrol.*. 1979.Vol. 69.P. 33–47. DOI: 10.1007/BF00375192
16. Fitton J.G., Saunders A.D., Norry M.J. et al. Thermal and chemical structure of the Iceland plume.*Earth Planet. Sci. Lett.*. 1997.Vol. 153.P. 197–208. DOI: 10.1016/S0012-821X(97)00170-2
17. Condie K.C. High field strength element ratios in Archean basalts: a window to evolving sources of mantle plumes? *Lithos.*. 2005.Vol. 79.P. 491–504. DOI: 10.1016/j.lithos.2004.09.014

Mapoka Hubert François – d'Assise, Assistant in Geology, Director of the Geosciences Laboratory, Department of Earth Sciences, University of Bangui, Central African Republic; e-mail: mpkman2003@yahoo.fr; ORCID 0009-0007-5538-3124

Biandja Jean, Professor, Director of the Georesources Laboratory, Department of the Mines and Geology, Higher Institute of Technology, Bangui, Central African Republic; e-mail: biandja@hotmail.com; ORCID 0009-0004-2911-2513

Savko Konstantin A., Dr.habil. in Geology and Mineralogy, Professor, Head of the Department of Mineral Resources and Mineral Management Studies, Voronezh State University, Voronezh, Russian Federation; e-mail: ksavko@geol.vsu.ru; ORCID 0000-0002-7291-7024

N'gbatouka Sylvain Marius, Assistant in Geology, Membre of the Georesources Laboratory, Department of the Mines and Geology, Higher Institute of Technology, Bangui, Central African Republic; e-mail: ngbatouk@yahoo.fr; ORCID 0009-0005-0592-8814

Bazikov Nikolay S., PhD in Geology and Mineralogy, associate professor, Department of Mineral Resources and Mineral Management Studies, Voronezh State University, Voronezh, Russian Federation; e-mail: nickolasss@yandex.ru; ORCID 0000-0002-0847-6498

Authors have read and approved the final manuscript.

Мапока Юбер Франсуа–д'Ассиз – ассистент по геологии, директор лаборатории геонаук, факультет наук о Земле, Университет Банги, B. P: 908, Банги, Центральноафриканская Республика; e-mail: mpkman2003@yahoo.fr; ORCID 0009-0007-5538-3124

Джейн Биандза – профессор, директор лаборатории георесурсов, департамент горного дела и геологии, Высший технологический институт B. P: 892, Банги, Центральноафриканская Республика; e-mail: biandja@hotmail.com; ORCID 0009-0004-2911-2513

Савко Константин Аркадьевич – д.г.-м.н., профессор, заведующий кафедрой полезных ископаемых и недропользования, Воронежский государственный университет, Воронеж; e-mail: ksavko@geol.vsu.ru; ORCID 0000-0002-7291-7024

Сильвен Мариус Н'Гбатука – ассистент по геологии, сотрудник лаборатории георесурсов департамента горного дела и геологии Высшего технологического института B. P: 892, Банги, Центральноафриканская Республика; e-mail: ngbatouk@yahoo.fr , ORCID 0009-0005-0592-8814

Базиков Николай Сергеевич – к.г.-м.н., доцент кафедры полезных ископаемых и недропользования Воронежского государственного университета, Воронеж, Российская Федерация; e-mail: nickolasss@yandex.ru; ORCID 0000-0002-0847-6498

Авторы прочитали и одобрили окончательный вариант рукописи.