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Petrographic Analysis of Rock Samples in Bui Division North West Region of Cameroon: Implications on Water Mineralization and Classification

Fondzenyuy Vitalis Fonfo[1], and Fondzenyuy Lionel Nyanchi[2]

1. University of Dschang, Faculty of Science, Department of Earth Sciences, P.O Box 67 Dschang
2. University of Bamenda, College of Technology

Abstract:
Percolation of water through rock samples is the main agent of the chemical weathering of most rocks. The rock- water interactions are identified as the main process responsible for water mineralization. The ionic content of any water source is dominantly expected to be as a consequence of these interactions. These assertions were verified in this work. In a bid to determine the possible ions in any water source and obtain its water type, a petrographic analysis of the rock samples within the water source vicinity and the geological set up of the entire zone is imperative. To put into evidence this inference, five water catchments, 29 boreholes. 16 Open wells, 16 rivers and 16 streams were studied in this work. Scrupulously sampling in accordance to the norms of the art was done and water samples taken immediately to the Laboratory for physico-chemical analysis. A petrographic analysis of the rock samples from Bui division was done using Dave's method in which thin section slides were prepared from the rocks for a microscopic identification of the minerals present. The rocks were basalts, trachytes, rhyolites, ignimbrites, phonolites and scoria characteristic of the dominant volcanic area, with granites in some plains. Water samples were analysed to deduce the relationship between the ions present and their origin from the dissolution of the rock minerals. Nonetheless, there is a likelihood of ions to be present in water sources from anthropogenic sources, but the aim of this article is to discern if the ions in water are dominantly from rock mineral dissolution or from other sources. The ions in the water samples were used to determine the main water type in Bui division. From the rock thin sections, the Modal composition of each rock type was also established. At the end of this research, it was emphatically revealed that rock-water interactions and the resultant mineral dissolution was the main mechanism responsible for mineralization of water sources in Bui division.

Keywords: Rock type, minerals, dissolution, petrography, water type

INTRODUCTION

The qualitative and quantitative importance of water sources remains of primordial concern in communities worldwide. An evaluation of water sources to determine their chemical compositions, the water types and their suitability for diverse purposes such as drinking, domestic and agriculture remain preoccupying. Water mineralization is due to the presence of ions derived from anthropogenic and natural sources such as water rock interactions involving dissolution of rock minerals. Application of chemical fertilizers remains one of the main anthropogenic sources of introducing some ions into water sources, but for this to be a dominant source; there must be a large-scale industrial application of fertilizer absent in Bui division. Based on this assertion the main objective of this work was to trace and put into evidence the fact that most water mineralization is as a consequence of dissolution of rock minerals. The ions determined will also be used to determine the water type. Rock samples representative of the entire division were collected and thin rock sections prepared according to the Dave's method. From these thin sections, microscopic observations were done to identify the minerals present in the rocks. The chemical compositions of the identified minerals were well determined with their relevant chemical formulae. With these known compositions relevant chemical equations were written that chemically expressed the mineral dissolutions to release into the water bodies the different ions. The ions present were revealed via a physicochemical analysis of the studied representative water samples (Dechao et al., 2020; Muhammed et al., 2020; Fondzenyuy and Kengni, 2021). This analysis in most communities has become increasingly important and has same implications in Bui division of the North West Region of Cameroon (WHO, 2017, 2018, 2019). In the same vein many works on water quality evaluation for suitability in diverse purposes through analysis of water mineralization has been done worldwide. Water related studies indicate that human activity and influence on physico-chemical variables can compromise water quality (Sajil et al., 2014; Tyagi et al., 2014; Njoyim et al., 2016 a; Inam et al., 2017; Germain et al., 2019). Population growth, economic activity and urbanization of most settlements, has an impact on the water sources.

The chemistry of most water sources done by (Ramesh and Elango, 2012; Akoachere et al., 2019; Frommen et al., 2019), highlight chemical reactions inherent with; soil- water interactions, dissolution of primary minerals, rock- water interactions and anthropogenic sources to be at the origin of ions in water bodies. This is further expressed in some detailed works on geochemical evolution of water (Edmunds and Smedley, 1996; Tanyileke et al., 1996; Deutsch, 1997; Appelo and Postma, 2005).

The objective of this study was to establish the mineralogy of the Bui rock samples and determine the ions present in the studied water samples. Specifically, thin rock sections revealed the minerals present while the physico- chemical results gave the ions in the water samples. The variables; Temperature (oC), and pH, EC, were obtained insitu, while Na+, K+, Ca2+, Mg2+, HCO3-, NO3-, Cl-, SO42-, SiO2 were obtained in the Laboratory using the Hanna Instrument HI83200 Multiparameter Photometer. This instrument is innovative, reliable and cost effective in its application as compared with the traditional titrimetric methods with many cumulative minor error margins.

LOCATION OF THE STUDY ZONE

Bui division has boundaries, with Donga Mantung to the North, Ngohketunjia to the South, Boyo to the West, and Noun division to the East. The location of Bui division and the Geology of the study site are presented in Fig.1, while a cross section of the rock outcrop in the study area is illustrated in Fig.2.

GEOLOGY (LITHOLOGY)

The Bamenda highland in which Bui division is part has a granitic basement covered by basalts and trachytes from tertiary volcanicity in the Cameroon Volcanic Line (Ngako et al., 2008). The division is part of the Bamenda highlands, a northward extension of the Bambouto Mountain part of the continental Cameroon Volcanic Line (C.V.L). The dominant geologic formations of Bui are basalts and trachytes similar to those of the Bamenda Mountain as reported by (kamgang, 2003). In these works, the Bambouto Mountain is reported to be of volcanic origin similar to its northern extension the Bamenda highlands in which Bui the study area is found. These results are in agreement with the field observations indicating that trachytes and basalts are the dominant rock types in Bui. To these rocks are often associated phonolites, rhyolites and ignimbrites. A summary of the minerals in the volcanic rocks of Bui division are presented in Table I.

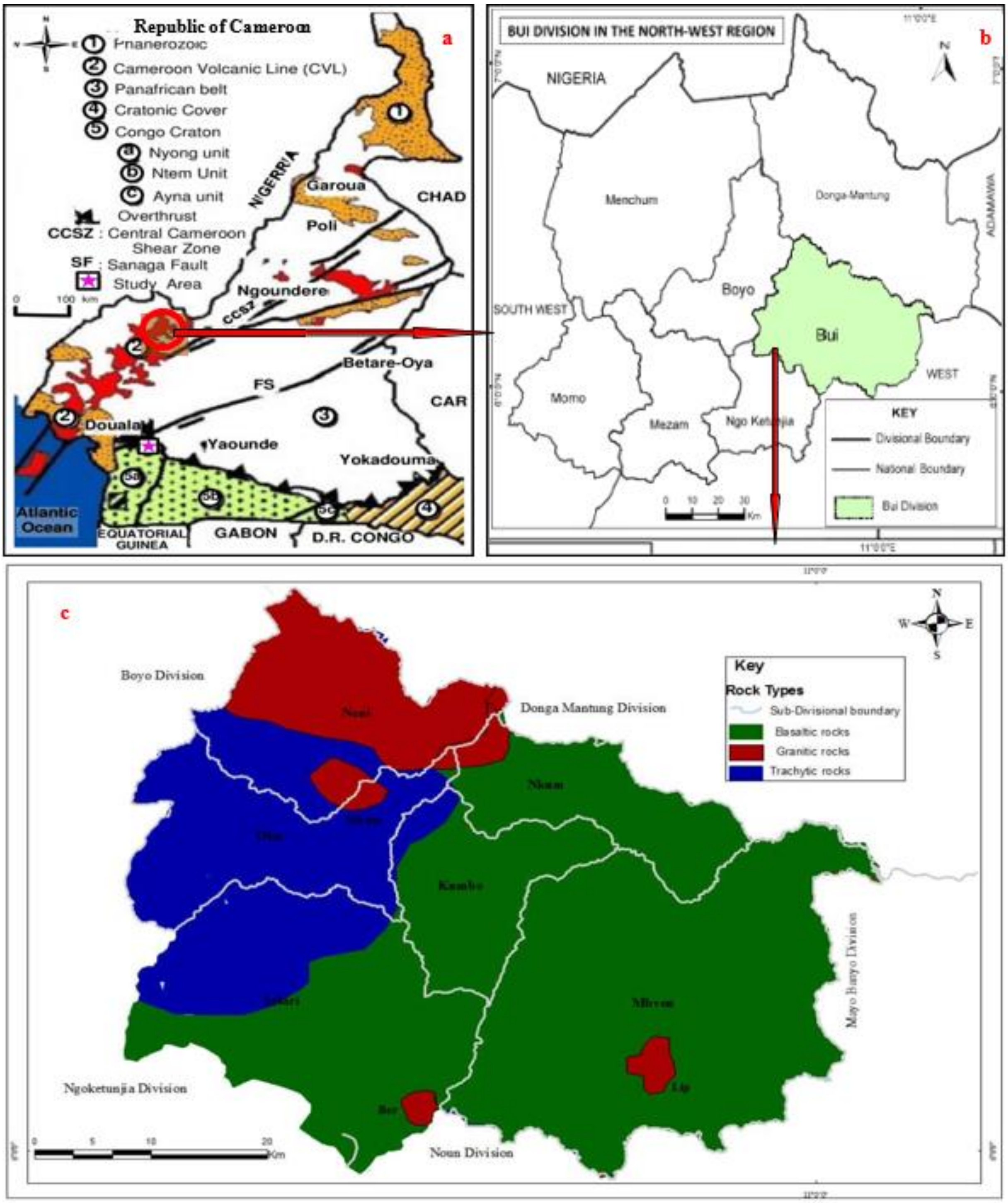


Fig. 1: (a)Site in Cameroon (b) Bui division (c)The geologic map of Bui Division

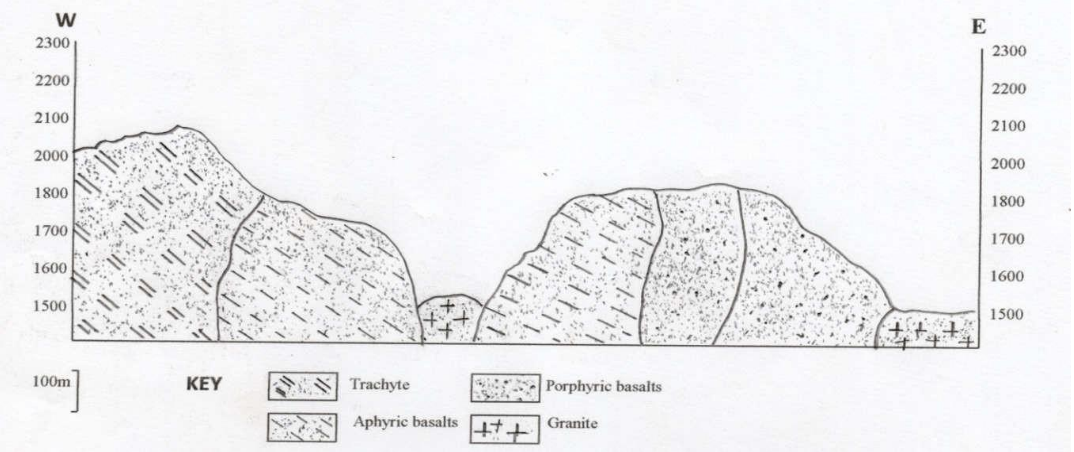


Fig. 2: Cross section of rock outcrop in the study area

Table I: Summary of the minerals in the volcanic rocks of Bui Division

Rock	Minerals
Basalt	Plagioclase Olivine, pyroxene
Trachyte	Plagioclase Alkaline feldspar, pyroxene, amphibole, biotite
Rhyolite	Plagioclase Alkaline feldspar, quartz, amphibole, biotite
Phonolite	Pyroxene
Ignimbrite	Plagioclase Quartz, biotite, alkaline, feldspar, pyroxene, rocky inclusions

The mineralogy of the rock samples of the study sites from the theoretical perception are presented in Table II.

Apart from the basalts and trachytes that are widespread in Bui Division, rhyolites, phonolites, ignimbrites and scoria also accompany these volcanic rocks. The mineralogy of the associated volcanic rocks was presented in Table III.

These mineralogic presentations were based on the understanding of the mineral constituents of the specific rock types and their known chemical compositions (Whitten and Brooks, 1978). These were confirmed in the petrographic studies done in this work.

Table II: Mineralogy of the rock samples from the study sites

SITES	Rock types	Minerals	Chemical composition
ELA	Trachytes	Alkaline feldspars Pyroxene(augite) Amphibole(hornblende) Biotite	$NaAlSi_3O_8$ $KAlSi_3O_8$ $(Ca, Mg, Fe, Al)_2(Al, Si)_2O_6$ $NaCa_2(Mg, Fe^{2+})_4(Al, Fe^{3+}) (SiAl)_8O_{22}(OH, F)_2$ $(K (Mg, Fe), (AlSi_2O_{10}) (OH)_2$
MBI	Basalts	Olivine Calcite Pyroxene (augite) Apatite	Mg_2SiO_4 Fe_2SiO_4 $CaCO_3$ $(Ca, Mg, Fe, Al)_2(Al, Si)_2O_6$ $Ca_2Cl_5(PO_4)_3$
BEL	Basalts	Olivine	Mg_2SiO_4 Fe_2SiO_4

		Calcite Pyroxene (augite) Apatite	$CaCO_3$ $(Ca, Mg, Fe, Al)_2(Al, Si)_2O_6$ $Ca_2Cl_5(PO_4)_3$
NKA	Basalts	Olivine Calcite Pyroxene (augite) Apatite	Mg_2SiO_4 Fe_2SiO_4 $CaCO_3$ $(Ca, Mg, Fe, Al)_2(Al, Si)_2O_6$ $Ca_2Cl_5(PO_4)_3$
YEH	Basalts	Olivine Calcite Pyroxene (augite) Apatite	Mg_2SiO_4 Fe_2SiO_4 $CaCO_3$ $(Ca, Mg, Fe, Al)_2(Al, Si)_2O_6$ $Ca_2Cl_5(PO_4)_3$

Source: (Whitten and Brooks, 1978).

Table III: Minerlogical composition of associated volcanic rocks

Rock type	Minerals	Chemical composition
Rhyolite	Quartz Pyroxene Alkaline feldspars	SiO_2 $(Ca, Mg, Fe, Al)_2(Al, Si)_2O_6$ $NaAlSi_3O_8$ –$KalSi_3O_8$
Ignimbrite	Quartz Biotite Pyroxene	SiO_2 $(K (Mg, Fe), (AlSi_2O_{10}) (OH)_2$ $(Ca, Mg, Fe, Al)_2(Al, Si)_2O_6$
Phonolite	Olivine Calcite Pyroxene (augite) Apatite	Mg_2SiO_4 Fe_2SiO_4 $CaCO_3$ $(Ca, Mg, Fe, Al)_2(Al, Si)_2O_6$ $Ca_2Cl_5(PO_4)_3$
Scoria	Plagioclase Pyroxene	$NaAlSi_3O_8$ $CaAl_2Si_2O_8$ $(Ca, Mg, Fe, Al)_2(Al, Si)_2O_6$

Source: (Whitten and Brooks, 1978).

The susceptibility of the various minerals in the rocks to weathering are generally in the order; glass > olivine > pyroxene > amphibole > plagioclase > k-feldspar (orthoclase) according to (Richard *et al*., 1987). From the weathering of these minerals the water samples were expectedto have the following ions in solution to be revealed in the laboratory analysis: $Si^{4+,}$ Na^+, K^+, Mg^{2+}, Ca^{2+}, Fe^{2+}, Fe^{3+}, Al^{3+}, Cl^-, HCO_3^-, CO_3^{2-}. Water samples were collected from open wells, boreholes, streams and rivers that have same geologic characteristics to the catchment areas except boreholes in GS Wasi ($BH4_a$), GS Tan ($BH4_b$), GS Kwanso, ($BH4_c$), GS Lip ($BH2_e$) and rivers in Kumbo RW5 within granitic environments with their characteristic minerals indicated below, (Whitten and Brooks, 1978).

Granites; Quartz (SiO_2), feldspars ($NaAlSi_3O_8$. $CaAl_2Si_2O_8$)
Amphiboles and hornblende ($NaCa_2$ $(Mg, Fe)_4(AlFe)$ (Si. Al) $_8O_{22}$ $(OH, F)_2$
Mica (biotite, K (MgFe), ($AlSi_3$) O_{10} $(OH, F)_2$ and
Muscovite, KAl_2 $(AlSi_3O_{10})$ $(OH, F)_2$.

MATERIALS AND METHODS

Materials

Aphyric and Porphyritic Basalts:

Aphryic basalts, dark in colour outcrop in Kumbo and Jakiri subdivisions Fig.3 a, b. In Mbven (MBI) and Nkum (BEL) Subdivisions, porphyritic basalts outcrop and are fairly dark in colour with olivine phenocryts Figs.3 c and d. The rock sample borders are highly oxidized producing reddish oxides, Fig .3 c and d.

Trachytes:

The trachyte outcrops in Elak and Tolon in Oku Subdivision Fig. 4 were light and greyishin colour with a vitreous lustre and aphyric in texture.

Ignimbrite:

They were made up of vesicles containing fiammes, quartz and other rock fragments as a result of ignimbritic dynamism (an acidic flow that becomes less viscous due to richness in gas). It was a variety of hardened tuff made up of glass shard (glass fragments) ground mass. Bamenda highlands Ignimbrites are greenish to whitish in colour resulting from the welding upof volcanic fragments; Fig .5.

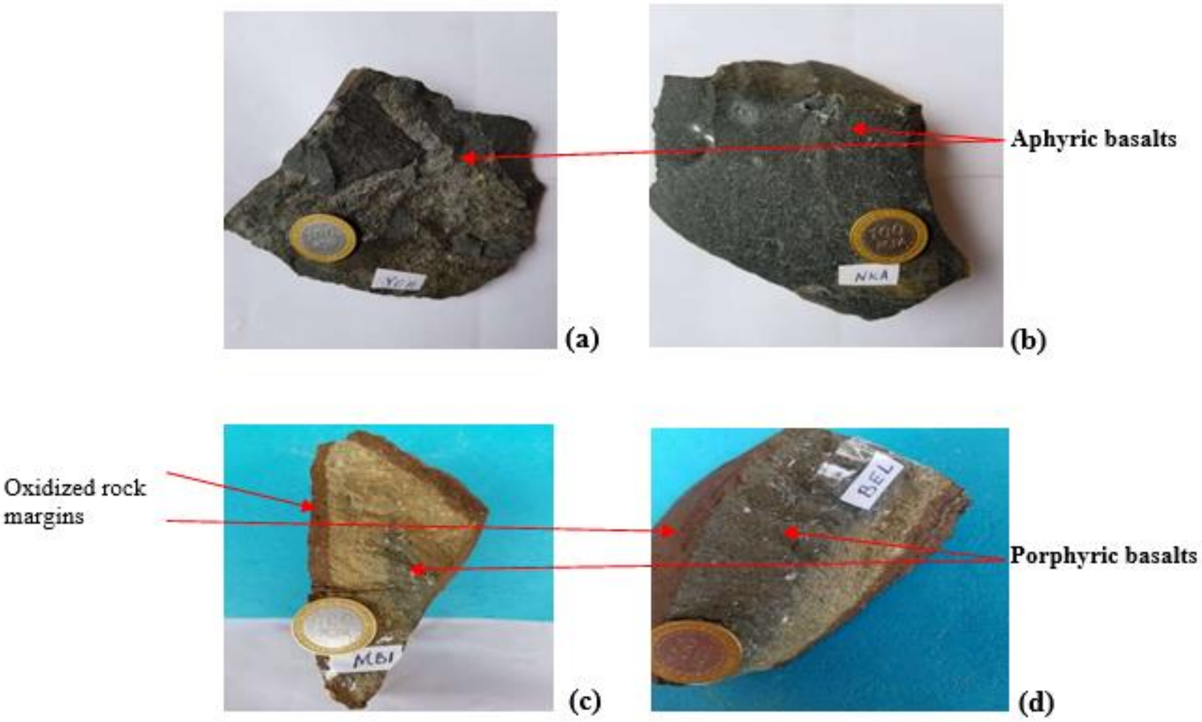


Fig .3: Aphyric basalts (a) Kumbo (b) Jakiri Subdivisions Porphyric basalts (c) Mbven (d) Nkum Subdivisions

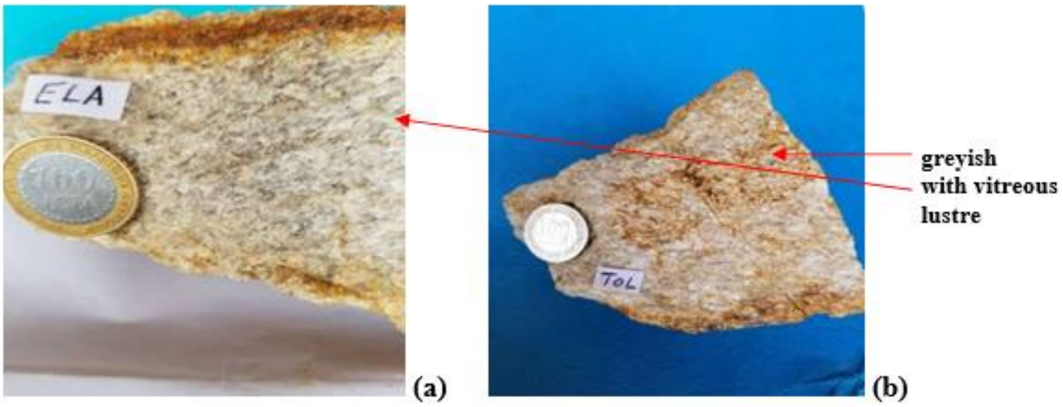


Fig .4: Trachytes from Oku Subdivision (a) Elak (b) Tolon

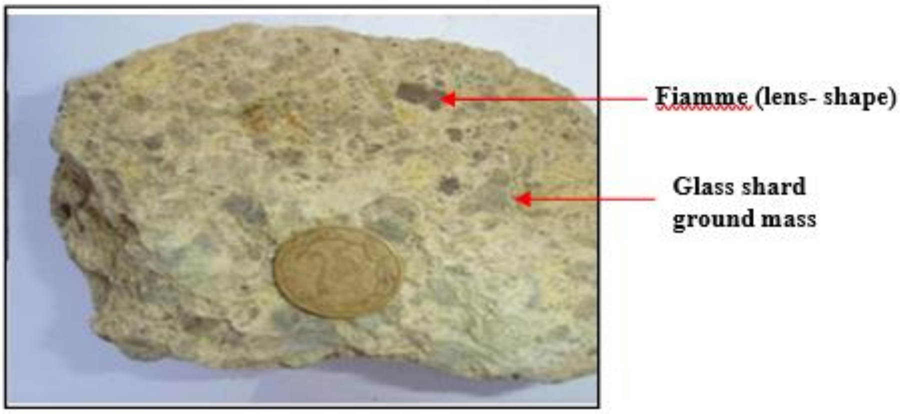


Fig .5: Ignimbrite rock sample

Rhyolite:

A common volcanic rock associated with basalts. They occured with dark to grey colours, with phenocrysts of quartz and alkali feldspars. Quartz in some ryholites was spheroidal indicating high temperatures of devitrification Fig .6.

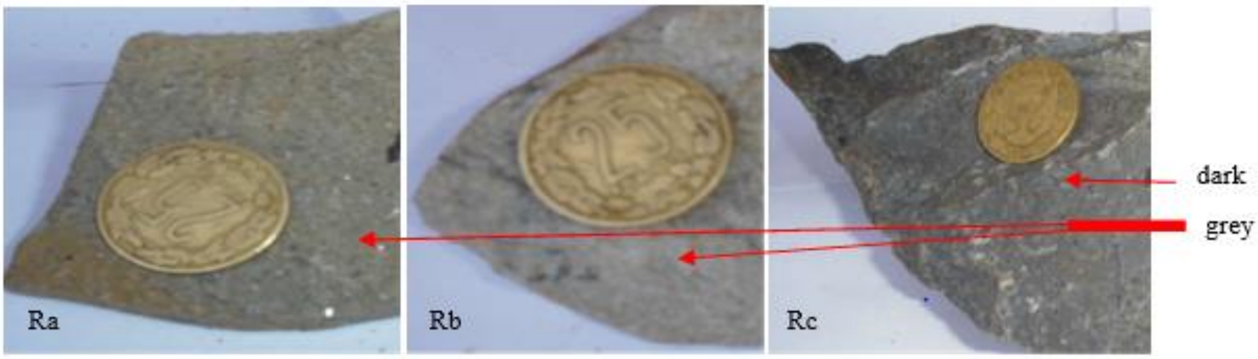


Fig .6: Rhyolite rock samples

Phonolite:

Phonolites had a white to grey colour, with an aphyric to porphyritic texture Fig .7.

Fig. 7: Phonolite rock sample

Scoria:

Identified within the Oku area associated to the volcanic activity responsible for the Oku massif.

It was an extrusive igneous rock of approximately 50% of silica having a vesiculartexture with a dark colour appearance having ellipsoidal vesicles (McPhie and Allen, 2005).

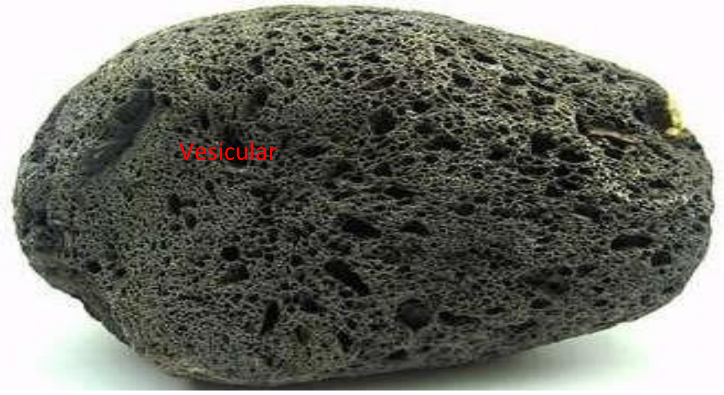


Fig .8: Scoria sample

Granites

Outcrops of the basement rocks occured within the locality of some water sources. Granites, Fig .9. constituted the basement complex on which the volcanic rocks overly, with outcrops at Ber, Mbam, Lip in Jakiri, Oku and Mbven subdivisions respectively. Also, there are outcrops along the banks of rivers that flow through Kumbo town. They were granular and phaneritic in texture with predominanlty whitish coloration, and often with pink to greyish colours depending on their mineralogy.

Fig .9: Granites sample Methods Laboratory analysis Petrographic analysis of the rock samples using Dave's method

Macroscopic appreciation of the rock samples was made. The basalts were from Kumbo, Nkum, Mbven, and Jakiri Subdivisions, with trachytes from Oku. The basalts were essentially porphyritic and aphyric in texture and covered approximately 80% of the study area with 4 out ofthe 5 samples being basaltic. Granites were sampled from Ber and Lip in Jakiri and Mbiame subdivisions respectively within the vicinity of boreholes studied. Seven thin rock section slides from basalts, trachytes, and granites from Bui were obtained. This was done in application of Dave's method on making thin sections (Hirsch, 2012). Thin sections of 0.03 mm (30 µm) thickness were prepared and attached on a glass slide with an epoxy and covered by another glass slide. Thin section slides of ignimbites, rhyolites, phonolites and scoria volcanic rocks commonly found associated with basalts and trachytes were used from Kamgang *et al*. (2008), at Bambui-Sabga area. A quantitative modal analysis was used to determine the volumetric proportions of the minerals that made up some of the rocks determined by areal analysis of a thinsection. Point counting is a technique Whitney and Evans (2010) used by petrographers to get an approximate modal composition of rock from its thin section slide. The following steps were involved in the thin section slides preparations:

Step 1: Had as objective, to prepare a thin section with a constant thickness. The face of a glass slide was placed parallel to the face of the grinding wheel. The glass slide was ground to flatten it and roughen the surface for the epoxy to bind well. This was called a frosted glass slide that was placed in a slide holder. The grinding wheel was cleaned with a sponge and water. Waterwas poured on the wheel and dried with a paper towel.

Step 2: The rock sample was marked, to decide where to cut the rock. Generally, the thin section was cut in a plane perpendicular to a planar fabric on the rock.

Step 3: Cutting a slab, using a slab saw. The slab was cut from the rock along the line marked in step 2. Two cuts were made in parallel directions to obtain a slab, which was cleaned and allowed to dry.

Step 4: Part of the slab to be cut was decided and cutting the chip, reduced the size of the slab to slightly smaller than a thin section using a trim saw. Using a glass slide the correct size of the chip was determined using a diamond blade. The side of the chip from where the thin section will be made was polished to remove marks from the saw blade.

Step 5: Glue the slide to the chip. The frosted side of the slide was attached to the side of the chip that was just grounded down. The binding was by an epoxy ensuring a constant thickness across the section.

- The chip was heated up by placing it on one of hot plates with the polished side up for it not to get any dirt. This allowed the epoxy to flow easily and cure faster. Once the epoxy was well mixed, few drops were spread across the top (polished side) of the warmed chip. The epoxy was spread and waited until it soaked in 5 minutes, then more epoxy was spread. This was repeated until no more epoxy soaked into the chip.
- Sit to cure and check periodically for the first 5 to 10 minutes to be sure the slide has not slid off the chip. The epoxy cured in about 20 to 30 minutes (donot take the next step before that)

Step 6: Cutting off the chip from the slide was done as the rock chip was epoxied to the glass slide;

- This cutting off was done very slowly for it can break the slide.
- Once the chip was cut off the slide, the slide was rinsed to remove any particles.

Step 7: Grind the slide to correct thickness by grinding away rock remains but not all of it. This was the step in which most thin sections go bad. The key was to go slowly, especially near the end.

- The grinding wheel must be used carefully back and forth to evenly clean off the chip from the slide.
- Remove the slide and see if you can identify any minerals in the section. This was done and the process continued slowly until these minerals achieve the correct maximum

interference colour, for example quartz is pale yellow. We proceeded slowly especially when close to the correct thickness, for it was quite easy to go from slightly too thick to slightly too thin or ground completely away. In this study, a chemical analysis on the minerals was expected as such the section needed to be polished

- Caution was taken not to grind too fast for this could lead to cracking the minerals, the edges of the slide becoming thin and thick at the center. This was because these analysis tools require a flat, smooth surface at the micrometer scale.

Step 8: Place the slide-frosted side of a second glass section on the epoxy, and this serves as a cover slide. It is best to put one side down then let the other side fall to avoid trapping bubbles.

- Move the slide around with your finger or a pencil eraser. This squeezed out extra epoxy to achieve a constant thickness. The cover slide protects the section from damage

Step 9, required a cleaning up of the place where the thin slide preparation was carried out.

RESULTS

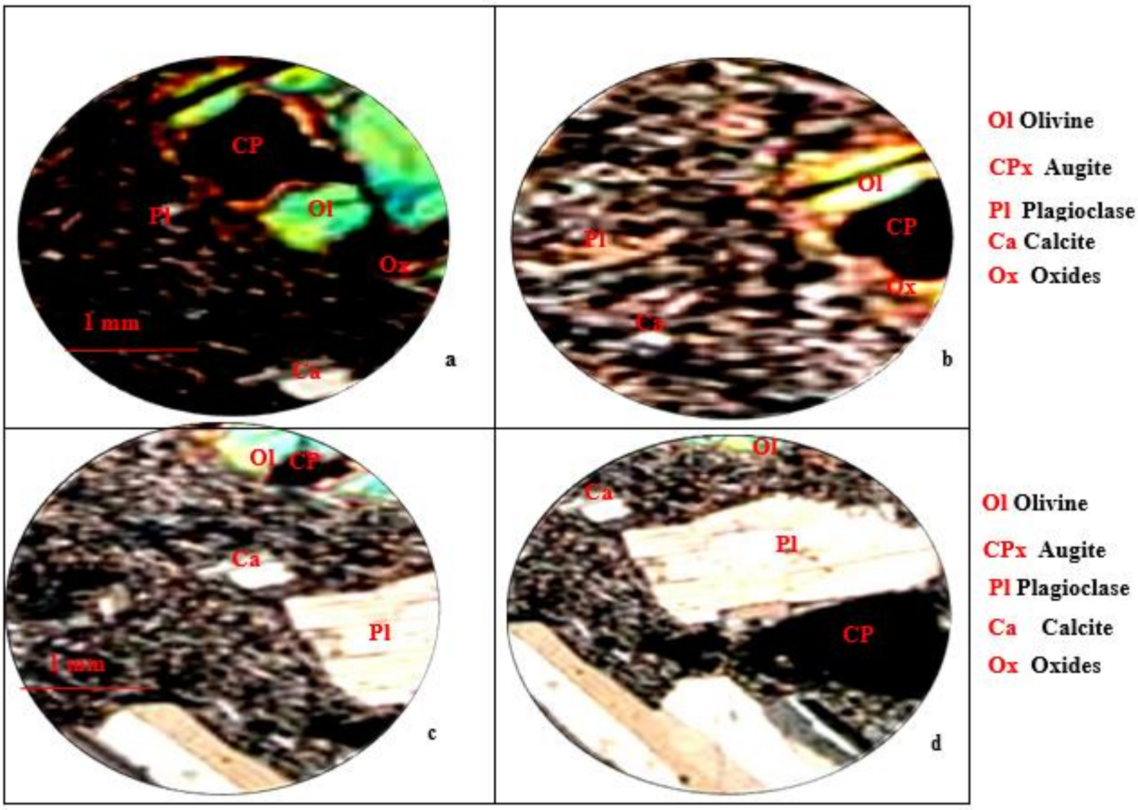
Thin Section Slides Observation of Porphyritic Basalts

This showed the presence of plagioclase, olivine, pyroxene and oxides of oxidized minerals in the groundmass. Plagioclase occupied about 70% of the total volume, with olivine, pyroxene and oxides making up the remaining 30% in the order: olivine > oxides > pyroxene;Fig .16(b). Table IV shows the modal (quantitative mineralogical) analysis of Bui basalts done inaccordance with (Chayes, 1967).

Table IV: Modal analysis of basalts

Basalt	**Minerals**	**MBI**	**BEL**	**NKA**	**YEH**
Phenocryst	Olivine	10	11	18	17
	Augite	1	1	9	10
	Plagioclase	2	2	--	--
	Total	13	14	27	27
Groundmass	Olivine	31	30	40	41
	Pyroxene	3	3	20	20
	Plagioclase	40	40	10	10
	Oxides	10	10	1	1
	Total	84	83	71	72
Total		97	97	98	99

Thin sections of the basalt observed under the Polarised Light Microscope (PLM); Fig.10revealed a preponderance of calcic plagioclase feldspars, pyroxene (augite) and olivine (forsterite). Calcite was also identified in the Bui basalts. Accessory minerals present were magnetite and ilmenite. The magnetite was present as phenocrysts in a groundmass of fine- grained feldspars. Both basalts (aphyric and porphyritic) were made of plagioclase microlites, microcrystals of oxides, olivine and clinopyroxenes scattered within the groundmass. Basalts overly most of the areas in Bui.



(a and b) Aphyric Basalt thin section (c and d) Porphyric Basalt thin section
Fig .10: Basalt thin sections (Under PLM)

Trachyte

The modal analysis of Bui trachytes met mainly in Oku Subdivision within the locality ofthe water catchment at Elak and the sampled river at Tolon were presented in Table V.

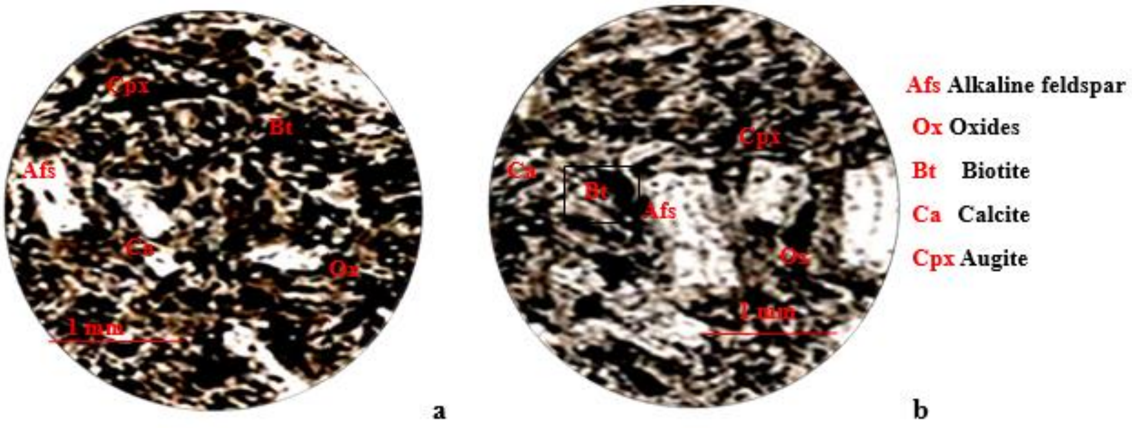
Table V: Modal analysis of trachyte

Trachyte	Mineral	ELA (Elak)	TOL (Tolon)
Phenocryst	Alkaline feldspar	22	20
	Oxides	15	15
	Calcite	18	19
	Biotite	5	5
	Total	60	59
Groundmass	Alkaline feldspar	15	15
	Oxides	06	05
	Calcite	12	13
	Biotite	4	5
	Total	37	38
Total		97	97

Thin Section Slide Observation of Trachyte

Thin section slide from trachyte; Fig .11 had as dominant mineral alkaline feldspars having large well shaped porphyritic crystals, and laths that form fine crystalline ground mass. They had elongated crystals of plagioclase with sanidine crystals, and clinopyroxenes mostly in the groundmass. The alkali feldspar was constituted of minerals that range from albite through sanidine to orthoclase. Sanidine made up about 80% of the rock. Biotite, oxides and calcite constituted 20 % in the order; oxides > calcite > biotite. In addition to the dominantly clear

minerals, mafic minerals such as biotite, amphiboles (hornblende) and augite were identified. The mineral crystal sizes range from microcrystals to phenocrysts (0.25 ×0.5mm to 1.5 × 2.5mm). This agrees with works by (Flett, 1911).



(a)Trachyte thin section (Elak)   (b) Trachyte thin section (Tolon)

Fig .11: Trachyte thin sections (Under PLM)

In addition to the basalts and trachytes which are dominant other associated volcanic rocks include: ignimbrites, rhyolites, phonolites and scoria whose study was done at Sabga in the Bamenda highlands by (Kamgang, 2003).

Thin Section Slide Observation of Ignimbrite

Vitroclastic texture with feldspar, quartz, plagioclase, pyroxene, oxides in Fig.12.

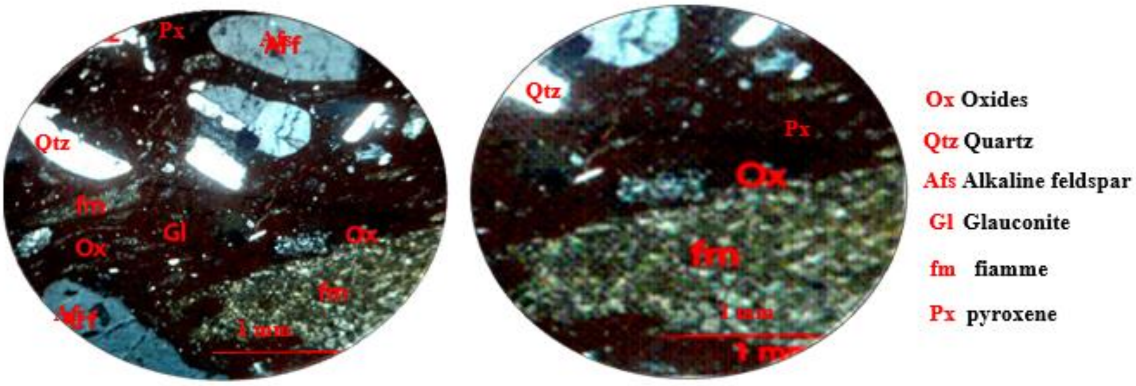


Fig .12: Thin section slides of ignimbrite from the Bambui-Sabga area.

Rhyolite

Modal analysis of rhyolites was presented in table VI. The minerals were in order quartz > sanidine > clinopyroxene. Rhyolite samples were presented in Fig .13.

Table VI: Modal analysis of rhyolite

Rhyolite	**Minerals**	**Ra**	**Rb**	**Rc**
Phenocrysts	Quartz	34	34	33
	Sanidine	16	17	15
	Clinopyroxene	03	02	03
	Plagioclase	05	06	09
	Oxides	02	01	03
	Total	60	60	63
	Quartz	25	25	20
Matrix	Sanidine	10	9	10
	Oxides	02	02	03
	Total	37	36	33
Total		100	100	

Thin Section Slide Observation of Rhyolites

The minerals present in rhyolite were mostly orthoclase (feldspars) with a ground mass composed of quartz, pyroxene, with the minerals occuring as isolated grains Fig .13. Quartz was most abundant and minerals were in order quartz (present as a phenocryst) > alkali feldspar > opaque oxides as inclusions in quatrz. Carlsbad twining was evident in sanidine crystals.

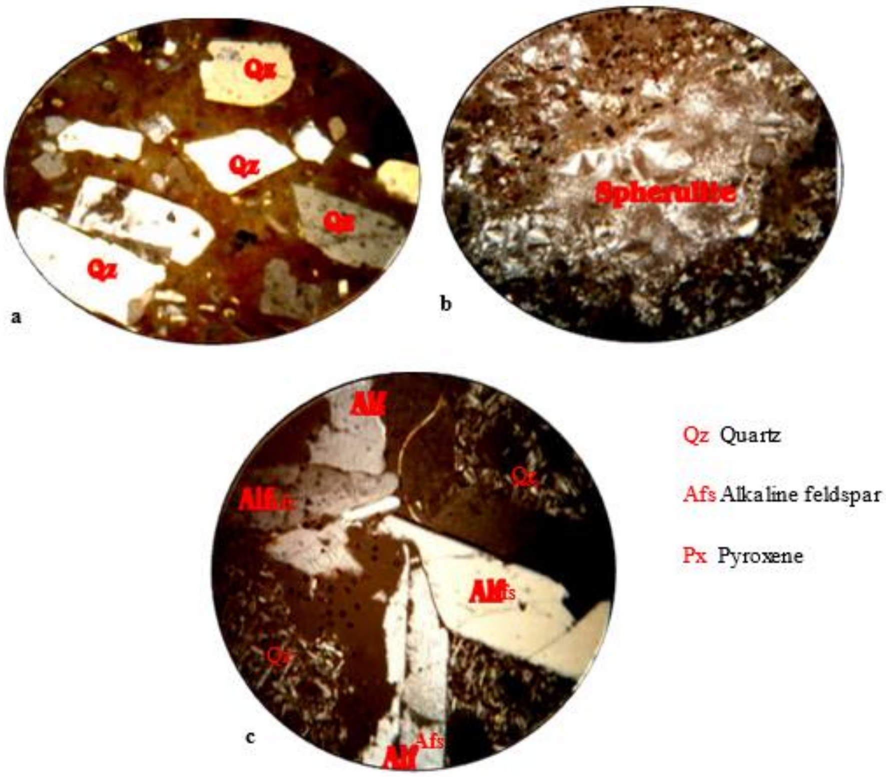


Fig .13: Thin section slide of Rhyolite from the Bambui-Sabga area; (a) Automorphic crystals of quartz, (b) Devitrification, (c) Sanidine showing twining.

Thin Section Slide Observation of Phonolite

The feldpathoids, alkaline feldspars and pyroxene were observed in order; feldspathoids (nepheline) > alkaline feldspars (sanidine) > pyroxene. Thin sections were presented in Fig .14.

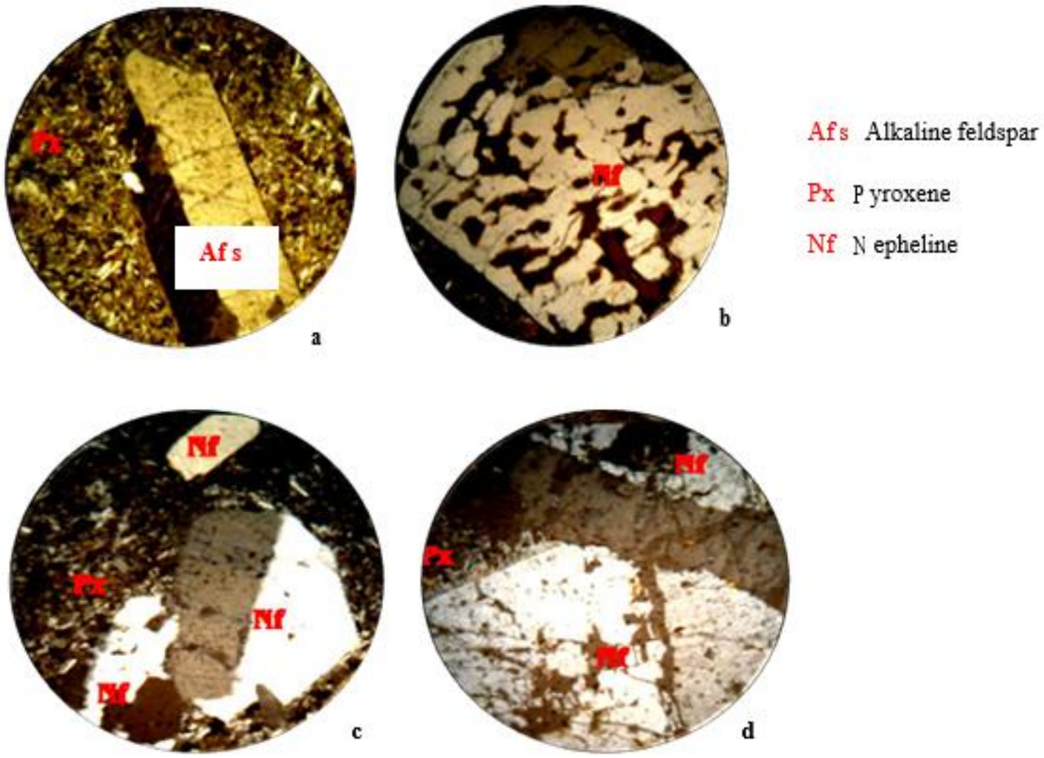


Fig .14: Phonolite thin section slides from the Bambui-Sabga area. (a) Sanidine phenocrysts, (b) Nepheline skeleton, (c and d) Nephelinecrystals.

Thin Section Slide Observation of Scoria

Thin section studies revealed scoria to be mainly hyalopilitic- porphyritic in textureassociated with a vitrophyric-porphyritic texture. Thin section slide in Fig .14 indicated sample was composed of phenocrystals of plagioclase. The major minerals were plagioclase and pyroxene. Minor minerals included apatite, biotite, haematite, hornblende, and magnetite.

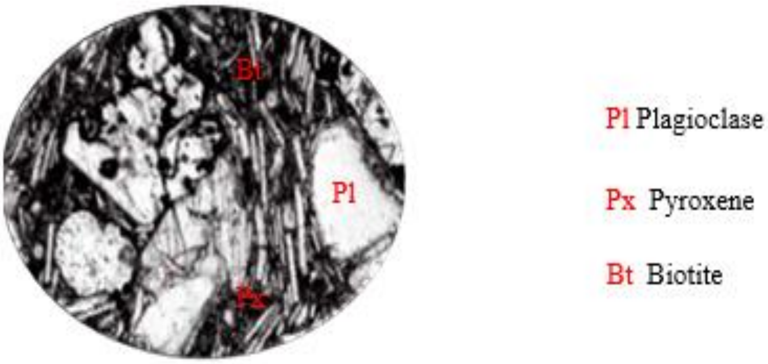


Fig .14 : Scoria thin section slide (PLM)

Granites

Thin Section Slide Observation:

The main minerals in thin section Fig.15 were quartz and alkali feldspars (orthoclase) with micas (biotite) and amphiboles as minor minerals. The alkali felspars constituted about 65 to 90 % of the total feldspar content in granites. On weathering most minerals undergo hydrolysis to form clay, and iron rich minerals oxidise to form the oxides. Micas (Muscovite)and quartz remain residual as they were resistant to weathering.

Fig .15: Granites sample thin section slide

The symbols of the minerals in the thin section slides were given in abbreviation form, (Whitney and Evans, 2010).

RESULTS OF THE PHYSICO-CHEMICAL PARAMETERS

The results of the physico- chemical parameters from the studied water samples in BuiDivision collected in 2016 and 2018 are presented in Table VII (a to f).

Table VII (a): Physico-chemical results of ground and surface water (n = 60) in Bui water catchments (February, May, August, November) in 2016; n = 40, and March/ September 2017; n = 20 (n = number of samples)

Catchment	ID	Alt	T	pH	EC	TDS	Na$^+$	K$^+$	Mg^{2+}	Ca^{2+}	Cl	HCO$_3^-$	SiO$_2$	SO $^{2-}$	NO$_3^-$	NH$_4^+$
		(m)	(° C)		µs/m		mg/l									
ELA 2016	ELA$_1$	2254	10.4	7.0	0.15	96.00	0.11	0.76	9.80	34.20	0.02	30.50	32.08	13.2	10.1	0.00
	ELA$_2$	2254	15.5	6.9	0.13	83.00	0.09	0.73	9.70	33.50	0.01	30.30	31.29	13.5	10.9	0.00
	ELA$_3$	2254	15.3	6.8	0.11	70.40	0.08	0.71	8.90	33.00	0.01	29.91	31.00	13.2	10.0	0.00
	ELA$_4$	2254	15.0	6.9	0.14	89.60	0.10	0.75	8.95	33.45	0.02	30.00	31.06	13.1	11.8	0.00
ELA 2017	ELA $_1$	2254	14.8	6.8	0.13	83.20	0.12	0.75	9.80	33.40	0.01	30.40	32.00	13.3	12.0	0.00
	ELA $_2$	2254	15.4	6.7	0.10	64.00	0.08	0.70	8.89	33.00	0.01	29.90	31.00	13.5	11.0	0.00
MBI 2016	MBI $_1$	2111	19.9	6.7	0.19	121.6	0.13	0.69	8.70	31.60	0.02	33.70	31.82	13.0	12.5	0.00
	MBI $_2$	2111	20.2	6.7	0.16	102.4	0.11	0.51	7.60	31.00	0.02	33.68	30.00	14.1	11.9	0.00
	MBI $_3$	2111	20.0	6.6	0.14	89.60	0.08	0.53	8.00	30.00	0.01	33.21	31.02	13.9	10.9	0.00
	MBI $_4$	2111	21.0	6.8	0.17	108.8	0.10	0.61	8.52	31.20	0.01	33.40	31.36	12.9	09.2	0.00
MBI 2017	MBI $_1$	2111	19.8	6.6	0.18	115.2	0.12	0.68	8.60	31.50	0.01	33.67	33.70	13.3	10.4	0.00
	MBI $_2$	2111	20.0	6.7	0.14	89.60	0.08	0.52	7.90	29.90	0.01	33.20	31.00	13.7	10.8	0.00
BEL 2016	BEL$_1$	2185	21.8	6.7	0.19	121.6	0.13	0.73	7.70	32.00	0.02	34.00	31.36	13.2	11.5	0.39
	BEL $_2$	2185	21.7	6.6	0.17	108.8	0.12	0.71	7.62	30.90	0.01	33.80	30.36	13.8	11.0	0.37
	BEL $_3$	2185	22.0	6.4	0.15	96.00	0.01	0.62	7.00	30.00	0.01	32.31	30.50	14.0	15.0	0.35
	BEL $_4$	2185	22.5	6.7	0.17	108.8	0.11	0.69	7.64	31.00	0.01	33.00	30.91	13.6	15.6	0.34
BEL 2017	BEL $_1$	2185	21.7	6.6	0.18	115.2	0.12	0.72	7.69	31.90	0.01	33.82	31.20	13.3	16.3	0.30
	BEL$_2$	2185	21.9	6.7	0.15	96.00	0.01	0.61	7.00	30.01	0.01	32.30	30.00	13.5	14.0	0.32
NKA 2016	NKA $_1$	1746	20.0	7.0	0.31	198.4	0.12	0.68	9.53	30.90	0.02	32.52	31.39	14.0	11.5	0.03
	NKA $_2$	1746	18.9	6.9	0.28	179.2	0.12	0.65	9.00	30.00	0.00	32.52	31.21	13.8	09.0	0.02
	NKA $_3$	1746	19.8	6.8	0.20	128.0	0.08	0.45	8.76	30.00	0.00	31.20	31.00	13.4	08.0	0.02
	NKA $_4$	1746	22.8	6.9	0.29	185.6	0.11	0.57	9.21	30.60	0.00	31.58	31.23	13.3	10.2	0.02
NKA 2017	NKA $_1$	1746	18.8	6.8	0.27	123.1	0.11	0.65	9.50	30.80	0.01	32.50	31.20	13.0	09.4	0.02
	NKA $_2$	1746	22.7	6.9	0.28	179.2	0.07	0.44	8.74	30.00	0.00	31.00	31.00	13.1	08.1	0.01
YEH	YEH $_1$	1895	21.0	7.1	0.30	192.0	0.14	0.13	9.21	40.20	0.02	33.60	31.82	14.0	10.0	0.00

2016	YEH $_2$	1895	20.5	7.0	0.22	140.8	0.13	1.00	9.00	39.90	0.01	33.54	31.03	13.9	10.8	0.00
	YEH $_3$	1895	20.6	6.7	0.20	128.0	0.11	0.08	8.52	37.82	0.01	31.50	31.00	13.2	10.1	0.00
	YEH $_4$	1895	22.9	6.8	0.28	179.2	0.12	0.09	8.80	38.54	0.01	32.30	31.40	13.6	10.0	0.00
YEH 2017	YEH $_1$	1895	20.4	6.7	0.21	134.4	0.10	0.07	8.50	37.80	0.01	31.40	31.00	13.7	10.7	0.00
	YEH $_2$	1895	22.7	6.7	0.20	128.0	0.10	0.07	8.51	37.81	0.01	31.42	31.00	13.5	11.0	0.00
BEL 2016	BEL$_1$	2185	21.8	6.7	0.19	121.6	0.13	0.73	7.70	32.00	0.02	34.00	31.36	13.2	11.5	0.39
	BEL$_2$	2185	21.7	6.6	0.17	108.8	0.12	0.71	7.62	30.90	0.01	33.80	30.36	13.8	11.0	0.37
	BEL$_3$	2185	22.0	6.4	0.15	96.00	0.01	0.62	7.00	30.00	0.01	32.31	30.50	14.0	15.0	0.35
	BEL$_4$	2185	22.5	6.7	0.17	108.8	0.11	0.69	7.64	31.00	0.01	33.00	30.91	13.6	15.6	0.34
BEL 2017	BEL$_1$	2185	21.7	6.6	0.18	115.2	0.12	0.72	7.69	31.90	0.01	33.82	31.20	13.3	16.3	0.30
	BEL$_2$	2185	21.9	6.7	0.15	96.00	0.01	0.61	7.00	30.01	0.01	32.30	30.00	13.5	14.0	0.32
NKA 2016	NKA$_1$	1746	20.0	7.0	0.31	198.4	0.12	0.68	9.53	30.90	0.02	32.52	31.39	14.0	11.5	0.03
	NKA$_2$	1746	18.9	6.9	0.28	179.2	0.12	0.65	9.00	30.00	0.00	32.52	31.21	13.8	09.0	0.02
	NKA$_3$	1746	19.8	6.8	0.20	128.0	0.08	0.45	8.76	30.00	0.00	31.20	31.00	13.4	08.0	0.02
	NKA$_4$	1746	22.8	6.9	0.29	185.6	0.11	0.57	9.21	30.60	0.00	31.58	31.23	13.3	10.2	0.02
NKA 2017	NKA$_1$	1746	18.8	6.8	0.27	123.1	0.11	0.65	9.50	30.80	0.01	32.50	31.20	13.0	09.4	0.02
	NKA$_2$	1746	22.7	6.9	0.28	179.2	0.07	0.44	8.74	30.00	0.00	31.00	31.00	13.1	08.1	0.01
YEH 2016	YEH$_1$	1895	21.0	7.1	0.30	192.0	0.14	0.13	9.21	40.20	0.02	33.60	31.82	14.0	10.0	0.00
	YEH$_2$	1895	20.5	7.0	0.22	140.8	0.13	1.00	9.00	39.90	0.01	33.54	31.03	13.9	10.8	0.00
	YEH$_3$	1895	20.6	6.7	0.20	128.0	0.11	0.08	8.52	37.82	0.01	31.50	31.00	13.2	10.1	0.00
	YEH$_4$	1895	22.9	6.8	0.28	179.2	0.12	0.09	8.80	38.54	0.01	32.30	31.40	13.6	10.0	0.00
YEH 2017	YEH$_1$	1895	20.4	6.7	0.21	134.4	0.10	0.07	8.50	37.80	0.01	31.40	31.00	13.7	10.7	0.00
	YEH$_2$	1895	22.7	6.7	0.20	128.0	0.10	0.07	8.51	37.81	0.01	31.42	31.00	13.5	11.0	0.00

Table VII (b): Physico-chemical results of groundwater and surface water (n = 13) in Oku subdivision (1) (April/May 2018)

ID	Alt	Site	Depth	T	PH	EC	Na$^+$	K$^+$	Ca^{2+}	Mg^{2+}	HCO$_3^-$	NO$_3^-$	Cl$^-$	SO$_4^{2-}$	SiO$_2$
	M	(Name)	M	°C		µs/cm	← mg/l →								
BH1$_a$	1388	GS Ibal	46	21.8	6.9	0.17	0.09	0.07	31.90	8.58	31.16	10.29	0.02	13.0	32.01
BH1$_b$	1808	CBC Jikijem	27	20.1	6.5	0.18	0.11	0.06	32.00	8.56	31.09	10.59	0.02	13.6	33.45
BH1$_c$	1837	GS Ichim	46	20,3	6.7	0.21	0.12	0.04	32.18	8.19	31.58	10.00	0.01	13.3	33.64
BH1$_d$	1347	GS Itoh Doh	46	20.9	6.8	0.15	0.09	0.05	33.00	8.50	33.69	10.09	0.01	13.7	32.18
BH1$_e$	1973	GS Ngashie	56	21.0	6.6	0.16	0.08	0.05	34.00	7.89	34.02	10.02	0.01	13.4	31.17
BH1$_f$	2048	CBC Ngvenkei	54	20.5	6.7	0.15	0.11	0.04	33.50	8.43	33.50	10.28	0.00	14.0	31.59
ST1$_a$	1764	Jikijem- Oku	---	20.8	6.9	0.18	0.13	0.05	33.61	8.57	32.58	11.45	0.00	14.0	33.00
ST1$_b$	1645	Ikal	---	20.3	6.8	0.17	0.15	0.08	32.91	9.00	31.90	11.08	0.02	14.1	32.50
ST1$_c$	1975	Elak	---	20.4	6.9	0.21	0.20	0.07	33.61	9.13	32.09	10.97	0.01	12.9	33.16
RW1$_a$	1632	Tolon	---	21.9	7.0	0.22	0.09	0.06	33.04	8.33	32.67	11.50	0.00	13.1	32.94
RW1$_b$	2050	Ngwenkie	---	21.7	6.7	0.21	0.08	0.07	32.95	8.56	31.88	11.08	0.00	13.9	32.93
OW1$_a$	1985	Catholic mission	23	21.4	6.6	0.17	0.13	0.06	32.82	8.48	31.78	10.62	0.01	13.7	32.19
OW1$_b$	1670	Oku Palace	20	21.1	6.7	0.20	0.14	0.05	32.79	8.50	32.00	11.10	0.01	14.0	32.00

OW: Open well. BH: Borehole. ST: Stream water. RW: River water. EC: Electrical conductivity. GS: Government school CBC: Cameroon Baptist Convention. CS: Catholic school. ID = Identity

Table VII (c): Physico-chemical parameters of groundwater and surface water (n = 9) in Mbven subdivision (2) (April/May 2018)

ID	Alt	Site	Depth	T	Ph	EC	Na$^+$	K$^+$	Ca^{2+}	Mg^{2+}	HCO$_3^-$	NO$_3^-$	Cl$^-$	SO$_4^{2-}$	SiO$_2$
	M	(Name)	M	°C		µs/cm	← mg/l →								
BH2a	1927	PS Rifem	65	22.2	6.9	0.18	0.10	0.06	31.99	8.72	32.92	10.00	0.01	13.0	33.25
BH2b	1919	GS Rifem	45	23.0	7.0	0.16	0.11	0.04	31.98	7.97	33.52	10.20	0.02	13.8	33.58
BH2c	1904	CS Rifem	55	22.8	6.6	0.15	0.09	0.05	32.00	8.88	33.55	11.06	0.01	13.4	33.43
BH2d	1740	GS Sang	80	23.3	6.8	0.17	0.12	0.08	32.51	8.92	34.01	11.04	0.00	13.1	32.91
BH2e	785	GS Lip	45	24.5	6.9	0.20	0.13	0.06	32.08	8.31	33.95	10.09	0.01	13.7	32.01
ST2	1940	Kitang	---	23.1	6.7	0.15	0.08	0.08	33.00	8.00	31.90	10.50	0.01	12.9	32.82
RW2	1960	Mbven	---	23.0	6.5	0.14	0.14	0.07	32.91	7.98	31.00	10.34	0.01	14.1	32.19
OW2a	1936	Mbiame market	10	23.7	6.8	0.22	0.13	0.05	34.00	8.54	32.74	10.19	0.00	13.5	33.70
OW2b	1938	Mbiame market	12	23.6	6.9	0.23	0.11	0.06	33.81	8.96	32.19	11.00	0.00	13.9	33.52

PS: Presbyterian School ID: Identity

Table VII (d): Physico-chemical parameters of groundwater and surface water (n =12) in Nkum subdivision (3) (April/May 2018)

ID	Alt	Site	Depth	T	Ph	EC	Na$^+$	K$^+$	Ca^{2+}	Mg^{2+}	HCO$_3^-$	NO$_3^-$	Cl$^-$	SO$_4^{2-}$	SiO$_2$
	M	(Name)	M	°C		µs/cm	← mg/l →								
BH3a	2027	GS Tatum	42	21-9	6.5	0.16	0.10	0.06	32.97	8	31.98	10.18	0.02	13.9	31.92
BH3b	2060	IPS Tatum	36	21.7	6.6	0.13	0.14	0.08	33.01	7.89	32.29	10.37	0.00	14.0	31.58
BH3c	2048	CS Tatum	34	21.6	6.8	0.18	0.12	0.04	33.26	8.79	32.38	10.45	0.00	14.1	31.69
BH3d	2185	PS Mah	32	21.8	7.0	0.15	0.08	0.07	32.15	8.19	32.18	11.50	0.01	13.1	31.00
BH3e	2182	IPS Takijah	30	21.9	6.7	0.15	0.11	0.05	32.13	8.11	33.69	10.85	0.02	13.8	32.93
BH3f	2158	CS Dzeng	28	21.8	6.5	0.16	0.12	0.06	31.99	8.13	33.00	10.64	0.00	13.5	33.00
ST3a	1888	Memfu	---	22.0	6.9	0.17	0.11	0.07	32.06	8.56	34.02	11.19	0.00	13.3	33.60
ST3b	1891	Memfu	---	22.1	6.8	0.16	0.12	0.06	32.18	8.33	34.00	11.05	0.00	12.9	33.65
RW3	1892	Mbi-im	---	22.3	6.9	0.20	0.08	0.08	33.98	7.94	33.17	10.50	0.02	13.0	32.96
OW3a	2028	Hill top hotel	24	21.0	7.0	0.21	0.13	0.07	34.01	8.00	33.39	10.00	0.01	13.7	31.99
OW3b	2005	Tatum market	19	21.2	6.6	0.19	0.09	0.06	34.00	8.03	33.79	10.02	0.02	13.7	31.90
ST3c	1991	Memfu road	---	22.4	6.7	0.16	0.10	0.05	34.11	8.14	33.68	11.11	0.02	13.2	31.16

Table VII (e): Physico-chemical parameters of groundwater and surface water (n =15) in Jakiri subdivision (4) (April/May2018)

ID	Alt	Site	Depth	T	Ph	EC	Na$^+$	K$^+$	Ca^{2+}	Mg^{2+}	HCO$_3^-$	NO$_3^-$	Cl$^-$	SO$_4^{2-}$	SiO$_2$
	M	(Name)	M	°C		µs/cm	← mg/l →								
BH4$_a$	1201	GS Wasi	48	24.0	6.6	0.16	0.11	0.06	33.21	7.95	31.20	10.10	0.00	12.9	31.00
BH4$_b$	1552	GS Tan	55	23.6	6.8	0.18	0.13	0.08	32.32	8.25	31.00	10.50	0.01	13.1	32.01
BH4$_c$	1424	GS Kwanso	50	23.4	6.5	0.20	0.09	0.04	32.10	8.33	31.24	11.00	0.01	13.4	33.50
BH4$_e$	1695	CS Jakiri	65	24.1	6.7	0.13	0.12	0.06	33.01	8.41	31.15	11.12	0.02	13.2	33.61
BH4$_f$	2071	IPS Fakuiy	30	22.6	6.6	0.14	0.13	0.07	33.24	7.99	31.99	11.05	0.01	14.0	33.24
BH4$_g$	2051	GS Vekovi	59	23.8	6.9	0.19	0.08	0.05	32.91	7.69	32.00	10.98	0.00	13.9	31.50
ST4$_a$	1670	Wahrin	----	21.0	6.4	0.21	0.07	0.07	32.80	8.36	32.01	10.00	0.01	14.1	31.14
ST4$_b$	1671	Vet school	----	20.9	6.8	0.15	0.10	0.06	32.80	8.00	33.40	10.20	0.01	13.2	33.50
ST4$_c$	1673	Nsulong	----	20.1	6.8	0.16	0.12	0.04	34.00	8.12	33.12	11.11	0.02	13.7	33.19
RW4$_a$	1748	Sop (Kiree)	----	21.9	6.7	0.14	0.11	0.08	34.01	8.15	31.99	11.45	0.00	13.3	33.70
RW4$_b$	1629	Mensai	----	22.5	6.6	0.22	0.13	0.05	33.03	8.98	32.16	10.50	0.00	13.1	32.50
RW4$_c$	1674	Tsemkan upper	----	22.3	70	0.21	0.14	0.06	32.91	8.00	33.43	10.45	0.01	14.0	32.51
RW4$_d$	1636	Tsemkan lower	----	22.9	69	0.16	0.12	0.04	32.08	8.57	33.17	10.51	0.02	14.0	33.00
OW4$_a$	1600	Abakwa	----	22.3	68	0.15	0.13	0.04	32.63	8.60	33.24	10.00	0.02	13.1	32.59
OW4$_b$	1612	St Jude’s Clinic	----	22.1	67	0.17	0.11	0.05	33.34	8.17	32.18	10.61	0.01	13.8	32.19

Table VII (f): Physico-chemical parameters of groundwater and surface water (n =28) in Kumbo subdivision (5) of Bui (April/May2018)

ID	Alt	Site	Depth	T	pH	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	NO_3^-	Cl^-	SO_4^{2-}	SiO_2
	M	(Name)	m	ºC		µs/cm	mg/l								
OW5$_a$	1613	Komban street	1.0	21.0	5.9	0.21	0.10	0.09	34.20	8.50	31.42	11.0	0.02	12.9	32.00
OW5$_b$	1654	Tobin Mosque	46	19.9	6.5	0.19	0.13	0.06	33.96	8.62	32.00	10.9	0.01	13.0	31.00
OW5$_c$	1721	CS Tobin	48	20.9	6.8	0.23	0.11	0.08	33.92	8.91	33.21	10.6	0.01	13.3	32.90
OW5$_d$	1734	Catholic Univ	50	20.0	6.7	0.18	0.11	0.06	34.00	7.90	33.00	11.2	0.01	13.1	31.36
OW5$_e$	1845	SAC	36	19.8	6.5	0.24	0.10	0.07	32.91	8.02	31.19	11.3	0.02	13.8	33.70
OW5$_f$	1916	Bamkikaiy	4	20.2	6.0	0.22	0.14	0.10	32.98	8.52	31.00	11.2	0.00	13.6	32.10
OW5$_g$	1946	LAP Centrek'bo	15	21.2	5.9	0.20	0.12	0.09	34.00	8.53	31.20	10.8	0.01	13.9	32.00
OW5$_h$	1922	Pig farm Bamkikaiy	19	21.1	6.8	0.17	0.13	0.09	34.03	8.51	31.00	10.3	0.01	14.0	33.00
ST5$_a$	1695	Meluf upper	----	20.0	6.7	0.19	0.11	0.08	34.11	8.50	32.00	11.0	0.01	14.4	32.10
ST5$_b$	1671	Meluf lower	----	21.0	6.8	0.18	0.10	0.09	33.97	7.92	33.21	10.9	0.01	13.2	31.90
ST5$_c$	1665	Roh Bui upper	----	19.7	6.7	0.20	0.12	0.08	33.06	8.25	30.21	11.4	0.02	13.5	31.87
ST5$_d$	1646	Roh Bui lower	----	19.9	6.5	0.22	0.14	0.06	33.08	8.50	32.11	11.2	0.01	12.9	32.00
ST5$_e$	1874	Roh Kimbo up	----	20.0	6.6	0.16	0.11	0.07	32.91	8.51	33.40	10.8	0.01	13.1	32.01
ST5$_f$	1633	Roh Kimbo low	----	21.1	6.9	0.18	0.10	0.08	31.90	8.53	33.20	10.5	0.01	13.0	32.03
RW5$_a$	1687	Meluf	----	19.9	6.5	0.21	0.13	0.08	34.11	8.10	31.00	10.1	0.00	13.0	32.82
RW5$_b$	1620	Roh Bui	----	19.8	6.7	0.20	0.10	0.09	34.00	8.23	33.40	10.0	0.02	13.7	31.00
RW5$_c$	1615	Meluf/ Bui	----	20.0	6.6	0.22	0.13	0.08	34.30	8.25	32.00	10.2	0.02	12.9	31.57
RW5$_d$	1610	Roh Kimbo	----	21.0	6.8	0.19	0.14	0.07	33.90	8.51	31.19	11.5	0.02	13.4	32.50
RW5$_e$	1604	Bui/Roh Kimbo	----	21.0	6.7	0.17	0.11	0.09	32.98	8.50	31.20	11.2	0.01	13.9	31.92
RW5$_f$	1900	Romajaiy	----	21.2	6.6	0.23	0.10	0.10	33.21	8.52	32.00	10.9	0.01	14.0	30.90
RW5$_g$	1876	Nji-iy	----	20.0	6.5	0.20	0.13	0.07	34.00	8.51	32.18	10.0	0.02	12.9	31.80
RW5$_h$	1860	Kinsaan	----	19.9	6.8	0.21	0.14	0.08	34.12	8.00	31.16	10.5	0.02	13.3	31.70
BH5$_a$	1906	GS Bamkikaiy	31	21.2	6.8	0.24	0.12	0.06	33.91	8.60	31.40	10.9	0.00	13.1	33.40
BH5$_b$	2020	CBC Kishiy	35	22.3	6.6	0.22	0.11	0.08	33.70	7.98	30.92	11.2	0.02	13.9	32.98
BH5$_c$	1763	GS Kiyan	50	22.0	6.7	0.20	0.10	0.05	32.91	8.51	31.20	11.0	0.01	12.9	31.82
BH5$_d$	2037	GS Tadu	55	21.9	6.5	0.24	0.14	0.07	33.00	8.20	29.90	11.4	0.02	13.0	32.60
BH5$_e$	1968	GS Kai	45	22.2	6.7	0.20	0.11	0.06	33.10	8.25	30.00	10.6	0.02	14.0	31.90
BH5$_f$	1742	GS Njavnyuy	65	23.0	6.6	0.18	0.13	0.08	33.69	7.99	31.25	10.8	0.01	13.5	32.00

GS= Government school. CS= Catholic school. LAP= Life abundant programme. SAC= Saint Augustine's Colle

DISCUSSION AND INTERPRETATION

Dissolution of Minerals from Rock Samples

The dissolution of the minerals can be presented in form of chemical equations. The ions in water were responsible for the various analysis to depict suitability for different purposes as well as classify water from the sources. Many authors have published works that support the dissolution of rock minerals as the basis of controlling water quality (Gibb's, 1970; Tardy, 1971; Sarin *et al.*, 1989; Schott *et al.*, 1989; Schweda, 1989; Njilah, 1991; Frogner and Schweda, 1998; Srinivasamoorthy *et al.*, 2008; Xiang *et al.*, 2008; Yuce *et al.*, 2009; Kengni *et al.*, 2011; Temgoua 2011; Tay, 2012; Mengnjo *et al.*, 2013). Based on the mineralogy of the rock samples viewed in thin sections the following equations are written;

$$CaCO_3\ (s) + H^+\ (aq) + HCO_3^-\ (aq) \longrightarrow Ca^{2+}\ (aq) + 2HCO_3^-\ (aq) \ldots\ldots\ldots\ldots (1)$$

Calcite

$$Fe_2SiO_4(s) + 4H_2CO_3\ (aq) \longrightarrow 2Fe^{2+}\ (aq) + 4HCO_3^-\ (aq) + H_4SiO_4\ (aq) \ldots\ldots\ldots\ldots (2)$$

Olivine

In the presence of oxygen, the dissolved iron is quickly converted to haematite with a perception of iron oxides in the slides.

$$2Fe^{2+}\ (aq) + 4HCO_3^-\ (aq) + 1/2O_2\ (g) + 2H_2O\ (l) \qquad Fe_2O_3(s) + 4H_2CO_3\ (aq) \ldots\ldots\ldots\ldots (3)$$

Pyroxenes, amphiboles and olivines are most susceptible to oxidation because of their high iron content. Iron contained in the minerals combines with oxygen and water to form hydrated iron oxides.

$$4Fe^{2+}\ (aq) + 3O_2\ (g) + 6H_2O\ (l) \qquad 2(Fe_2O_3 .\ 3H_2O)\ (s) \ldots\ldots\ldots\ldots (4)$$

Anorthite and albite end members of the plagioclase minerals present in the rock minerals.

$$3CaAl_3Si_5O_{16} + 8CO_2 + 9H_2O \longrightarrow 3Ca^{2+} + 6HCO_3^- + 4SiO_2 + 3AlSi_2(OH)_4 + 2CO_2 \ldots\ldots (5)$$

Anorthite

(Anorthite - Albite). Reactions that characterize hydrochemical evolution of groundwater in plagioclase dominated rocks.

$$2NaCaAl_3Si_5O_{16} + 8CO_2 + 9H_2O \longrightarrow 2Ca^{2+} + Na^+ + 6HCO_3^- + 4SiO_2 + 3AlSi_2(OH)_4 + CO_2 \ldots\ldots\ldots (6)$$

$$2KFe_3AlSi_2O_{10}(OH)_2 + 13H^+ + CO_2 + 2H_2O \rightarrow Al_2SiO_5(OH)_4 + 4H_4SiO_4 + 2K^+ + 6Fe^{3+} + HCO_3^- \ldots\ldots\ldots\ldots (7)$$

Biotite

The variations observed in the water samples from the different water bodies were greatlydue to the rocktypes of the environments and to a limited extent human activity within the vicinity of the water bodies.

The Hydrochemical Facies

The concentrations of major ion analysis from all sampling sites revealed the $Ca^{2+,}$ Mg^{2+} and HCO_3^- as the dominant species. The lower concentration of K^+ in the water samples was due to its low geochemical mobility (Hem, 1989; Srinivasamoorthy *et al.*, 2008). These variations in concentrations of major ions were represented with Bar charts in Fig. 56 for each water catchments in 2016. Fig. 57 illustrated a graphical representation for other water sources during the different expeditions in 2018.

In all data, the ions had the highest concentrations in the dry season and the lowest concentrations in the rainy season within the water catchments. The high concentrations were found in the heart of the dry season in February, while low concentrations were observed in August at the peak of the rainy season. This could be because during the rainy season, much rain results in the dilution of the ions, unlike the dry season with no dilution. This agrees with the factthat the climatic conditions could influence the water chemistry of the water samples (Kiming *et al.*, 2020a, 2020b).

The high prevalence of the nitrate ion was observed at the Belem catchment (BEL) where animal rearing was done within the open unprotected plain of the catchment and at ELA due to animal rearing at the summit of Oku Mountain that would result in the infiltration of urine and faecal desposits. A high prevalence of nitrates and sulphate ions was observed within the rivers that flow through Kumbo because of farming within the flood plains of these rivers with regular application of some fertilizer. Equally, runoff of wastes from homes, garages, slaughter houses and a prison could also enhance the prevalence. The major ions relevant to the Piper diagram presented in Table VIII, were used to determine the hydrochemical facies (water type) of the Bui water catchments studied, OW, BH, ST and RW in this work.

Table VIII: Percentages of cations and anions for classification (Piper, 1994)

Sites	**Na^++ K^+**	**Ca^{2+}**	**Mg^{2+}**	**HCO $^-$**	**SO $^{2-}$**	**Cl^-**
ELA	1.90	75.70	21.40	68.50	30.20	0.04
MBI	1.70	77.60	20.70	71.20	28.70	0.03
BEL	1.90	76.60	19.00	73.90	29.20	0.04
NKA	1.80	75.60	22.70	73.80	26.10	0.04
YEH	1.00	80.60	18.30	70.20	29.90	0.07
OW	0.50	79.40	20.20	72.90	27.10	0.01
BH	0.40	79.50	20.10	70.30	29.70	0.02
ST	0.50	79.20	20.30	70.40	29.80	0.02
RW	0.40	79.30	20.20	70.30	29.50	0.02

Variations in mg/l for major ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, HCO_3^-, NO_3^-, SiO_2) in the water catchments were illustrated in a Bar chart in Fig. 16.

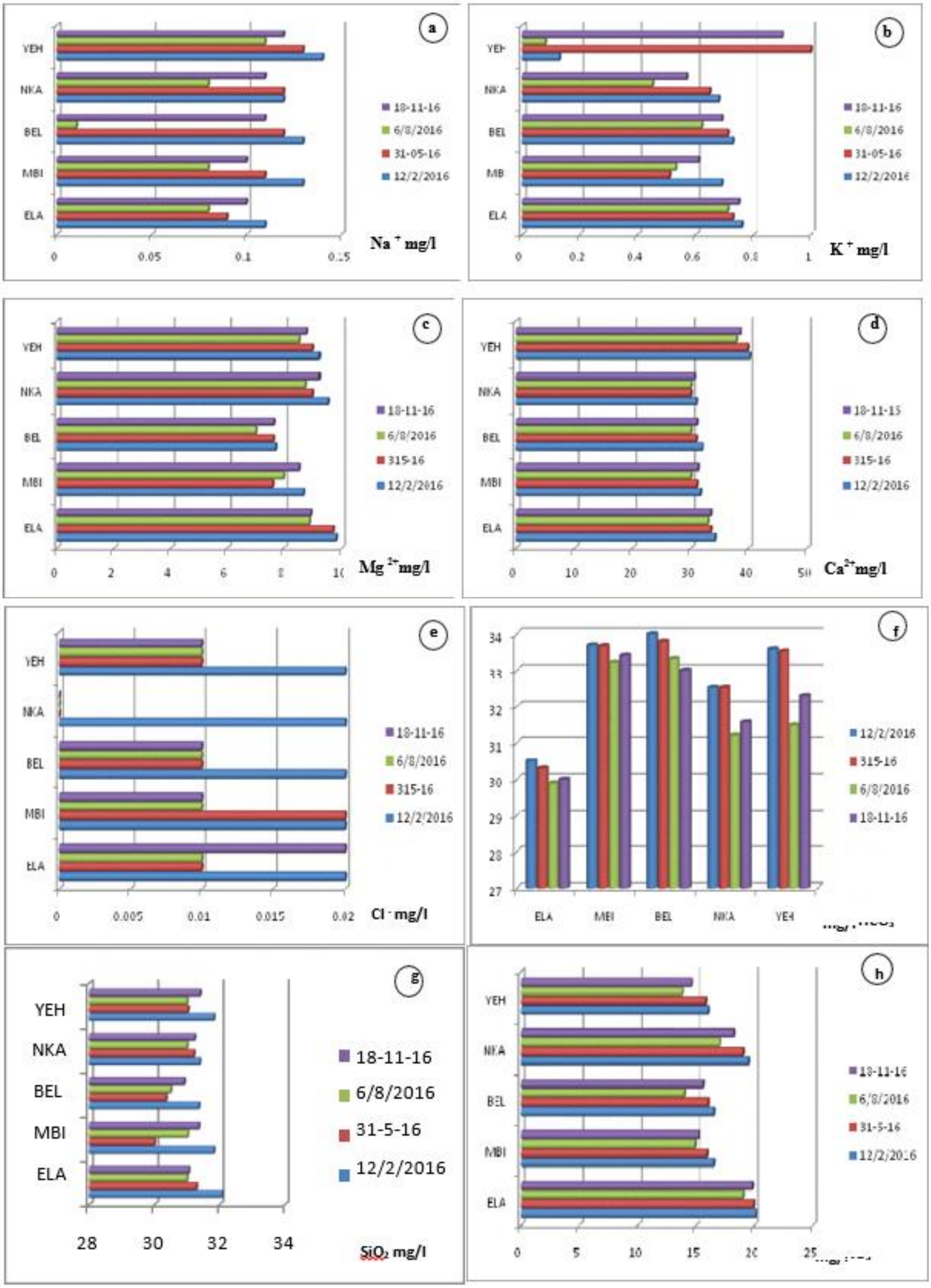


Fig. 16: Variations of the major ion concentrations in the Bui water catchments in 2016

In open wells, boreholes, streams and rivers the dominance of Ca^{2+} and HCO_3^- over all the other ions was evident with a significant contribution in boreholes. The variations in concentrations of these ions determined in 2018, presented in Fig. 17; again, confirmed the dominance of Ca^{2+} and HCO_3^-. mg/l

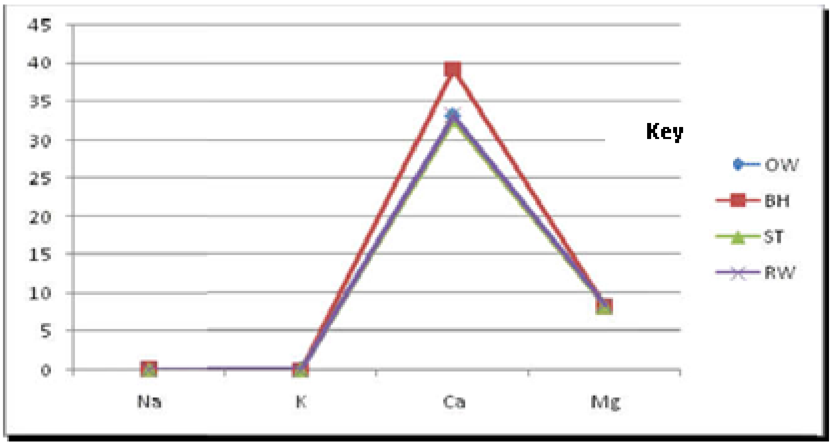


Fig.17: Variations of the major ion concentrations in OW, BH, ST and RW

Water Classification Piper Diagram

The water classification enabled the water types of the study area to be obtained.The Piper diagram; Fig. 18 determine the water type, wherein most samples plotted in the alkalineearth metals and bicarbonate domains. This indicated the dominance of alkaline earth metals in the aquifer systems. From the percentages calculated and presented in Table VIII, a general chemical nature of the water was observed by plotting major cation and anion concentrations ona Piper tri-linear diagram, (Piper, 1944). The Bui water catchments and OW, BH, ST and RW were dominantly the calcium bicarbonate water types; Ca $(HCO_3)_2$.

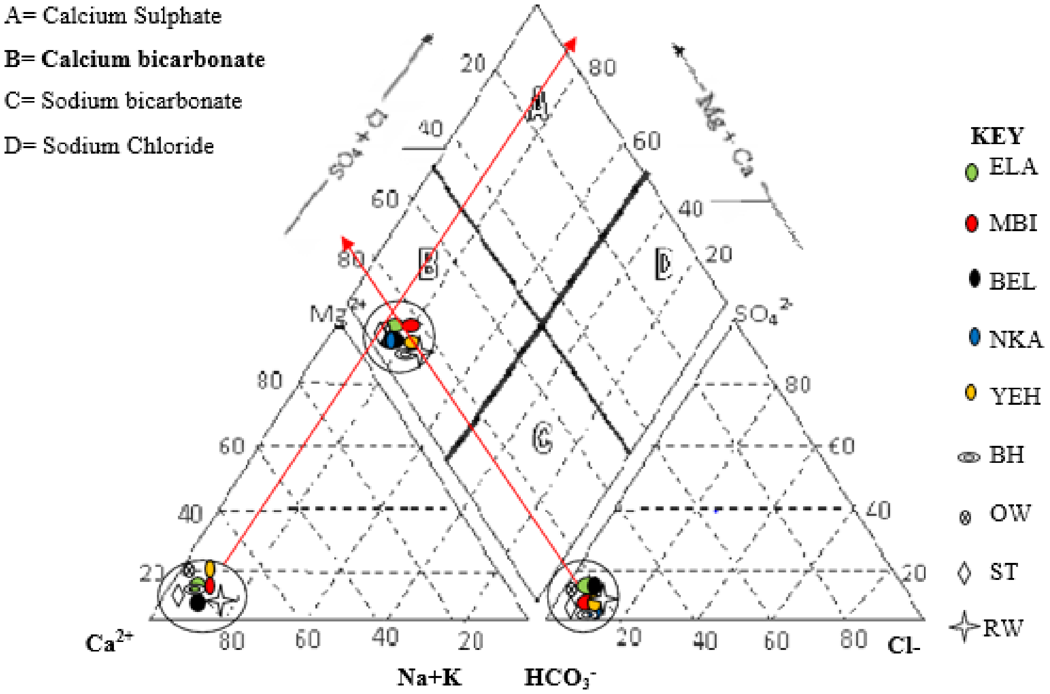


Fig.18: Water types and hydrochemical facies (Piper,1994)

The percentage of HCO3- was very high compared to other anions, while Ca2+ was the dominant cation. The observation prevailed in all the water sources during the different expeditions.

GENERAL CONCLUSION

In all water sources in our study sites same as elsewhere, the mineralization of the water sources has both anthropogenic and natural sources. In this research it is clearly expressed that; despite the two main sources of water mineralization, the dissolution of primary minerals from the rock samples is the dominant process responsible for mineralization. This is further supported by the dissolution of the different silicate minerals into the water sources as evident in the different chemical reactions for the dissolution of these minerals. Nonetheless, influence of chemical fertilizers in water mineralization could be possible in areas with large scale uses that could be verified in Bui division within the vicinities of commercial gardening. a perspective set for verification.

Perspectives

The water mineralization of water sources is dominantly a natural process governed by the dissolution of rock minerals. Agricultural practices within the vicinity of some water sources particularly in some neighborhoods with commercial gardening could have a high prevalence of NO3-, K+, SO42- and PO43- due to a considerable application of Nitrates, potassium, sulphate and phosphate fertilizers. This perception could be verified in areas having commercial gardening activities prevalent to discern the influence of fertilizers in the ions derived from application of specific chemical fertlizers

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Conflict of Interest

No conflict of interests was witnessed in the execution of this research in which the authors had absolute collaboration and support from the Earth science department of the University of Dschang and the College of Technology of the university of Bamenda

Data Availability

A totality of the data used in the development of this article that includes the physico- chemical and petrographic data are available in this article.

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