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PETROGRAPHIC CHARACTERIZATION OF THE VOLCANIC ROCKS OF THE NORTHERN PART OF TOUMODI (CENTRAL CÔTE D'IVOIRE)

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ABSTRACT

The study area is located north of Toumodi, in central Côte d'Ivoire, specifically in the southern part of the Birimian Toumodi–Fètêkro greenstone belt. The aim of this work is the petrographic characterization of the volcanic rocks. This study made it possible to identify volcanic lavas (basalts, andesites, dacites, rhyodacites and rhyolites). The basalts and andesites frequently display pillow structures. To these are added volcaniclastic rocks consisting of breccias, lapilli tuffs, cinerites and ignimbrites. All these lithologies have been affected by alteration and greenschist-facies metamorphism, which have deeply transformed the original nature of the parent rocks. This has led to silicification, carbonation, chloritization, epidotization, sericitization and albitization. These lithologies are crosscut by quartzo-feldspathic veins and veinlets, sometimes associated with crystals of chlorite, epidote, and iron oxides and hydroxides. The study area was affected by effusive, submarine effusive and explosive volcanism.

Keywords: Côte d'Ivoire; Northern Toumodi; Birimian; Volcanism; Volcanic Rocks

1 INTRODUCTION

Archean terrains are mostly composed of granite–gneiss areas coexisting with greenstone belts within the Man Shield (West African Craton). Côte d'Ivoire contains numerous greenstone belts both in the Archean and in the Paleoproterozoic. Knowledge of these belts remains an important goal in the study of the evolution of the Earth's history. Birimian greenstone belts form elongated sequences of volcano-sedimentary and volcanic rocks, with tholeiitic to calc-alkaline affinities ranging from basalts to rhyolites [2, 18, 29]. The Toumodi volcano-sedimentary belt has been the subject of several petrographic and structural studies [7-8, 24, 27]. According to these works, the Toumodi region consists of volcano-sedimentary, plutonic and volcanic formations, together with detrital sediments. It shows great potential in mineral resources, mainly gold. Indeed, the study area belongs to the southern part of the Toumodi–Fètêkro belt, which hosts the Agbahou, Bonikro and Dougbafla-Bandama deposits and many promising prospects such as the Blaffo Gueto prospect [17, 27-28]. However, these studies cover large areas and may not provide certain information

with certainty. This is why it is necessary to target well-defined areas of modest extent in order to contribute to the understanding of the geology of Toumodi. It is in this context that this work was initiated, to contribute to improving the petrographic knowledge of the volcanic rocks of northern Toumodi.

2 GEOLOGICAL SETTING

Côte d'Ivoire belongs to the West African Craton and particularly to the Man Shield [3] **(figure 1).** Its geology is essentially characterized by a Precambrian basement occupying 97.5% of the territory, and a more recent sedimentary cover (Secondary to present) occupying 2.5% of the territory [32] **(figure 2).**

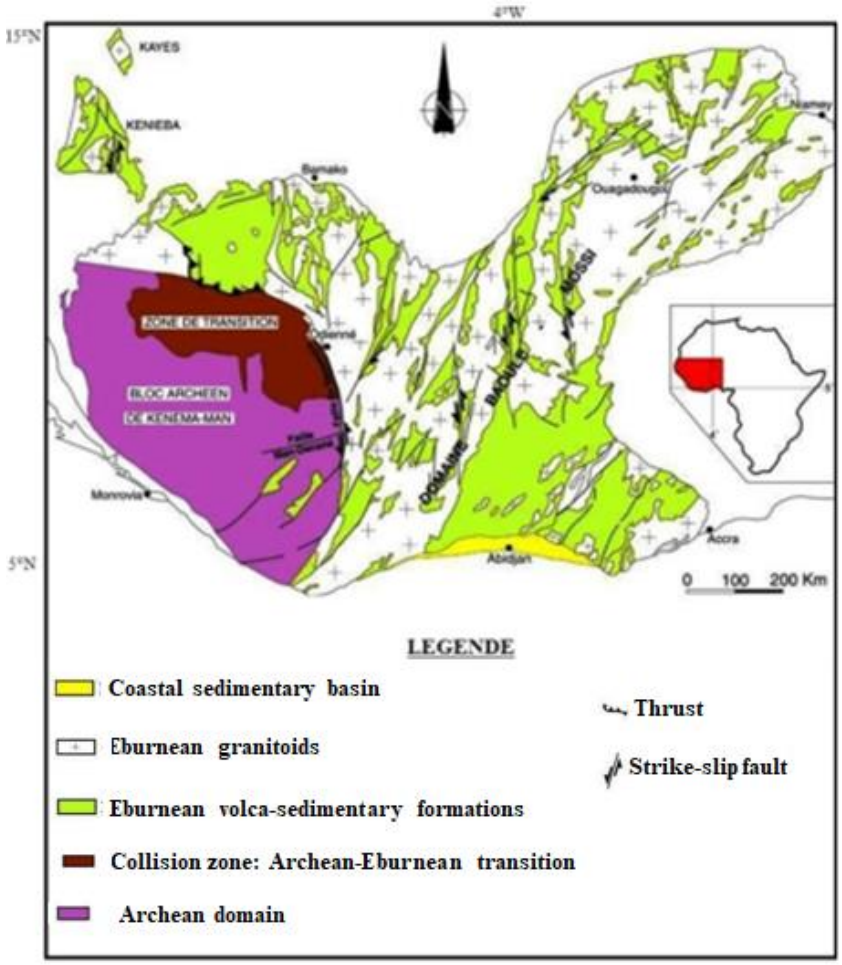


Figure 1: Structural organization of the Man Shield [23].

The basement is divided into two main domains by the Sassandra Fault [3]: the Archean and the Proterozoic. The Paleoproterozoic domain is characterized by the presence of greenstone belts, generally trending NNE to NE and interbedded with a granite–gneiss unit containing granitoid batholiths. The works of [19-20], indicate the existence of a transition zone in the Paleoproterozoic between the Sassandra Fault and longitude 6°W. This zone is thought to be characterized by the contamination of juvenile Birimian formations by the Archean crust (intermediate Nd model ages and inherited zircons). It is notably characterized by the existence of Archean relics within the Paleoproterozoic domain. The geology of the study area is part of that of the Toumodi–Fètêkro belt, located in the Ivorian Paleoproterozoic domain **(figure 3).** The geology of the belt is known through the works of [8, 21-22, 24, 35-36]. As with all formations of the Birimian belts, volcano-plutonic rocks (gabbros, basalts, andesites, rhyodacites), volcano-sediments (basaltic to rhyodacitic pyroclastites and epiclastites) and detrital sandy-pelitic sediments are encountered. The belt is bordered and intruded by granitoids; according to [36], the Birimian formations consist of schists and quartzites, among which appear large lenses of volcano-sedimentary rocks, some of which may be in synclinal or anticlinal positions. Figure 3 illustrates the geology of our study area.

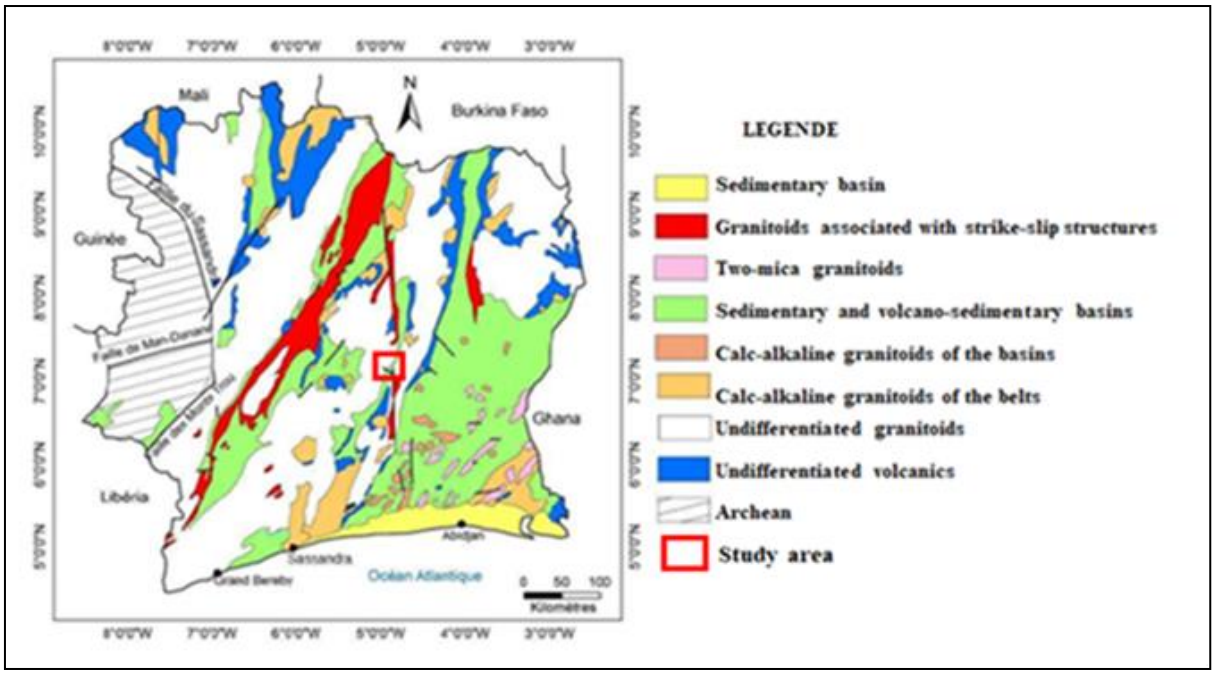


Figure 2: Simplified geological map of Côte d'Ivoire [19]; modified by [32].

3 METHODOLOGY

The methodology used combined documentary review, field work and a laboratory phase. The field phase consisted of macroscopic observations. Subsequently, careful sampling was carried out for laboratory analyses. Thin sections were prepared in order to refine and complete the macroscopic petrography. The microscopic observations were carried out at the Laboratory of Geology, Mineral and Energy Resources of the UFR STRM of Université Félix HOUPHOUET-BOIGNY of Abidjan.

4 RESULTS

4.1 Volcani lavas

These lavas comprise mafic and intermediate volcanic rocks (basalts and andesites) and felsic volcanic rocks (dacites, rhyolites and rhyodacites).

4.1.1 Mafic and intermediate volcanic rocks

The formations encountered are basalts, porphyritic basalts and pillow basalts.

4.1.1.1 Basalts s.s.

These rocks are massive, melanocratic, slightly to strongly deformed, and crop out as blocks with a sub-rounded shape at Lomo Nord, Djangoménou, Koffi Djékro, Tokoréyaokro and Akakro N'Zikpri **(figure 4A).** Under the microscope, they display a microlitic texture **(figure 4B).** The observed minerals are pyroxene and amphibole. These amphiboles generally result from the destabilization of pyroxenes. The groundmass consists of carbonates, feldspars, amphiboles progressively altered into chlorite, and epidote. Quartz veinlets and a few opaque minerals are observed.

4.1.1.2 Porphyritic basalts

The porphyritic basalts are located at Koffi Djékro and Akakro N'Zikpri. At the outcrop, these rocks are massive, deformed and show pyroxene and amphibole phenocrysts generally altered into epidote and/or chlorite **(figure 4C).** These porphyries have variable shapes and reach sizes of 1.5 to 2 cm. Parallel and truncated laminations are also observed in places in the field. Under the microscope, pyroxene phenocrysts are observed, often altered and transformed into amphibole, epidote and chlorite **(figure 4D).** These amphiboles derive from the destabilization of pyroxenes. Plagioclase phenocrysts, generally altered into carbonates, are also present. These phenocrysts are set in a groundmass composed of carbonates, feldspars, amphibole, chlorite and epidote.

4.1.1.3 Pillow basalts

These rocks are located at Koffi Djékro and Akakro N'Zikpri. At the outcrop, pyroxene and/or amphibole phenocrysts are observed in a fine matrix. In places, pillows with a mean diameter of 50 cm are observed **(figure 4E).** The vesicles within the pillows are often filled with quartz or calcite. These pillows contain pyroxene and/or amphibole phenocrysts. Under the microscope, a porphyritic microlitic texture is observed **(figure 4F).** The observed phenocrysts are generally pyroxene (sometimes augite) and actinote, set in a matrix of amphibole, chlorite, epidote, carbonates and fine plagioclase laths. Carbonate veinlets, most often associated with chlorite, epidote and oxides, are also observed.

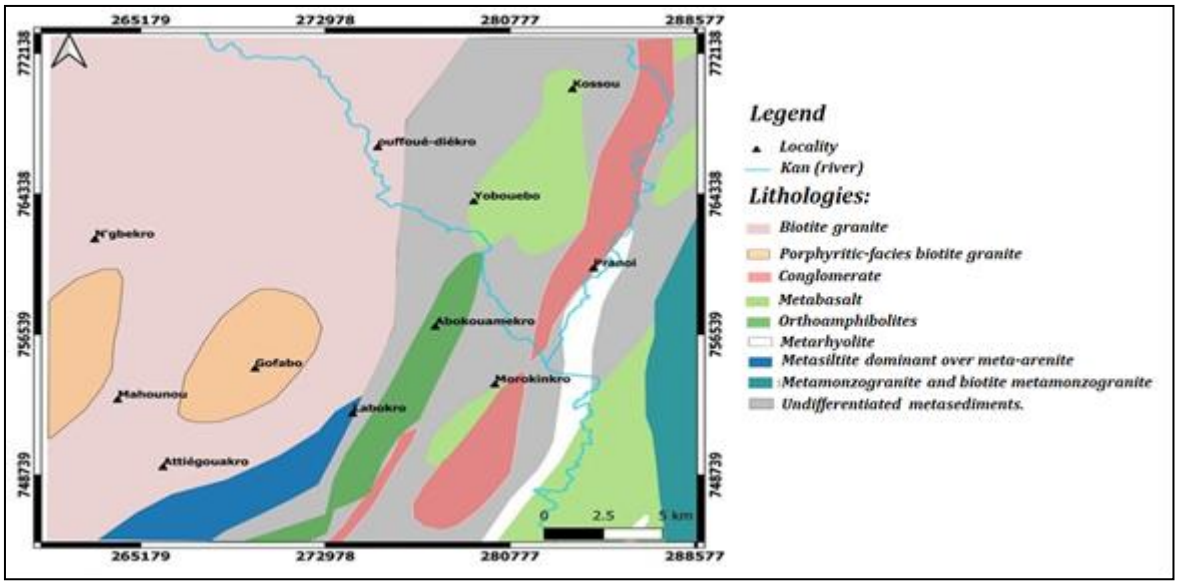


Figure 3: Geological map of the study area [8, modified].

4.1.1.4 Andesites s.s

These rocks are massive, melanocratic, often deformed, and crop out between the localities of Morokinkro and Pranoua, near the metasediments **(figure 5A).** Under the microscope, the andesites display a porphyritic microlitic texture with amphibole phenocrysts **(figure 5B).** These amphibole phenocrysts are often altered and transformed into chlorite and epidote. Feldspars (alkali feldspars and plagioclase) and opaque minerals are also present. Some sections contain quartz, resulting from the partial recrystallization of the groundmass.

4.1.1.5 Pillow andesites

The andesites, observed at Akakro N'Zikpri, are generally deformed and display well-developed pillow structures. At the outcrop, these rocks show vesicles that are often filled with carbonates and quartz **(figure 5C).** Under the microscope, these andesites have a porphyritic microlitic texture with quartz phenocrysts set in a groundmass composed of carbonates, chlorite and epidote minerals **(figure 5D).** Veinlets composed of chlorite–carbonate–epidote–quartz are also observed.

4.1.2 Felsic volcanic rocks

The felsic volcanic rocks are represented by dacites, rhyodacites and rhyolites.

4.1.2.1 Dacites

The dacites are observed along the watercourse of the village of Lomo Nord. They are massive, slightly deformed rocks. At the outcrop they are generally greenish-grey, showing rhyolitic textural similarities **(figure 6A).** Microscopic observation reveals a porphyritic microlitic texture with phenocrysts of plagioclase, quartz and albite. The plagioclase phenocrysts are sometimes altered into carbonates (calcite ± dolomite), epidote and sericite **(figure 6B).** The groundmass is composed of carbonates, sericite and epidote minerals. Some sections display a quartz–epidote mineral assemblage. These rocks are also crosscut by quartz veinlets often associated with carbonates, chlorite and epidote.

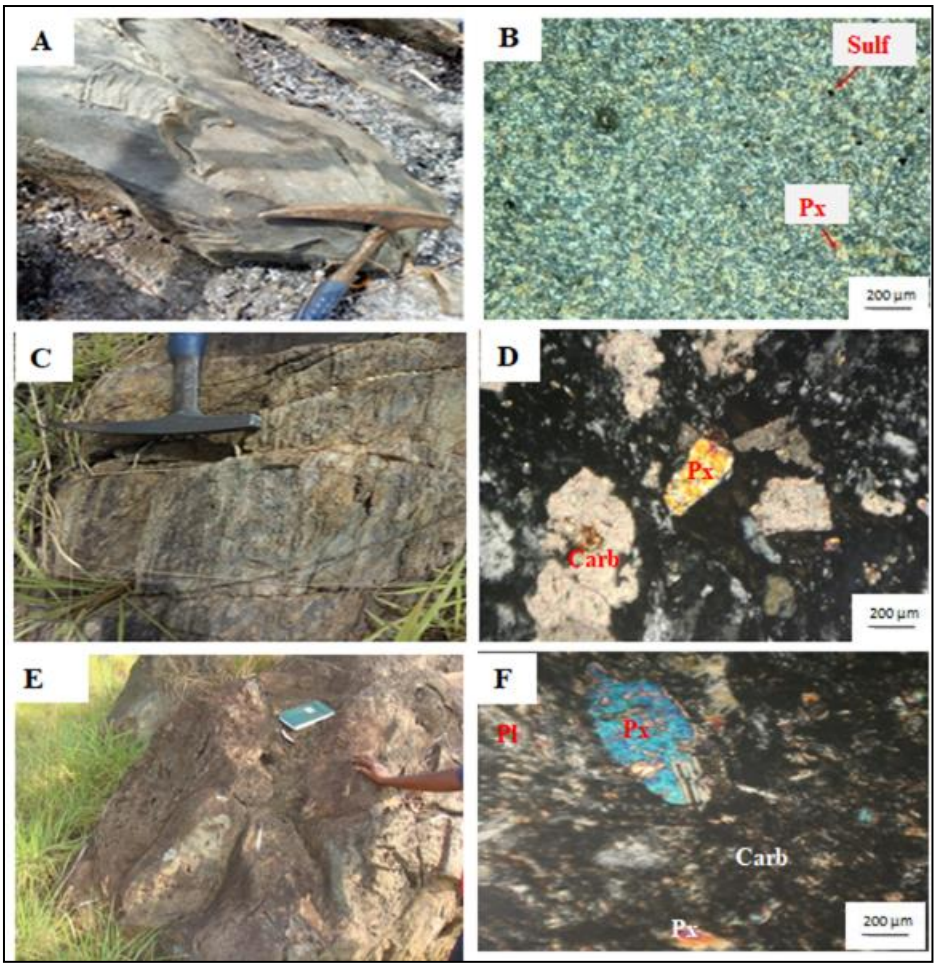


Figure 4: Macroscopic and microscopic aspects of the basaltic lavas. A–B: Basalt s.s.; C–D: Porphyritic basalt; E–F: Pillow basalt. Px: Pyroxene; Carb: Carbonates; Pl: Plagioclase; Sulf: Sulfide.

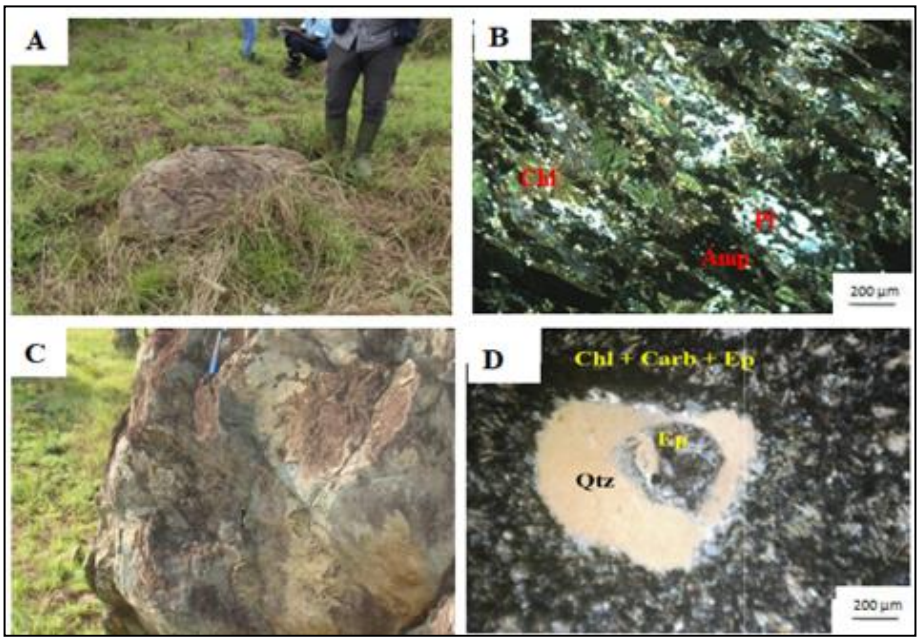


Figure 5: Macroscopic and microscopic aspects of the andesitic lavas. A–B: Andesite s.s .; C–D: Pillow andesite. Amp: Amphibole; Chl: Chlorite ; Ep: Epidote ; Qtz: Quartz.

4.1.2.2 Rhyodacites

The rhyodacites are greenish-grey, massive and rich in quartz and feldspar phenocrysts **(figure 6C).** These rocks crop out at Akakro N'Zikpri and Lomo Nord and are affected in places by numerous fractures and quartz veins. Some outcrops show lobes between 1 cm and 15 cm or quartzo-feldspathic amygdales. In thin section, their porphyritic microlitic texture can be seen, with feldspar phenocrysts most often altered and transformed into sericite and epidote **(figure 6D).** The matrix is cryptocrystalline and composed of quartz and feldspars more or less transformed into carbonates and sericite. The observed amygdales are generally filled with quartz–carbonate, quartz–carbonate–chlorite or carbonate assemblages. These various assemblages are sometimes combined with ferro-titaniferous oxides.

4.1.2.3 Rhyolites

They are massive, leucocratic, generally deformed, and crop out at Gbofia, Akayaokro, Tokoréyaokro and Akakro N'Zikpri, often as hills **(figure 6E).** These formations consist of quartz and feldspar phenocrysts. Under the microscope, the rhyolites are composed of feldspar, carbonate, epidote and sericite minerals **(figure 6F).** Quartz often occurs as phenocrysts with a remarkable undulose extinction. These rocks are also crosscut by sometimes deformed quartzo-feldspathic veinlets.

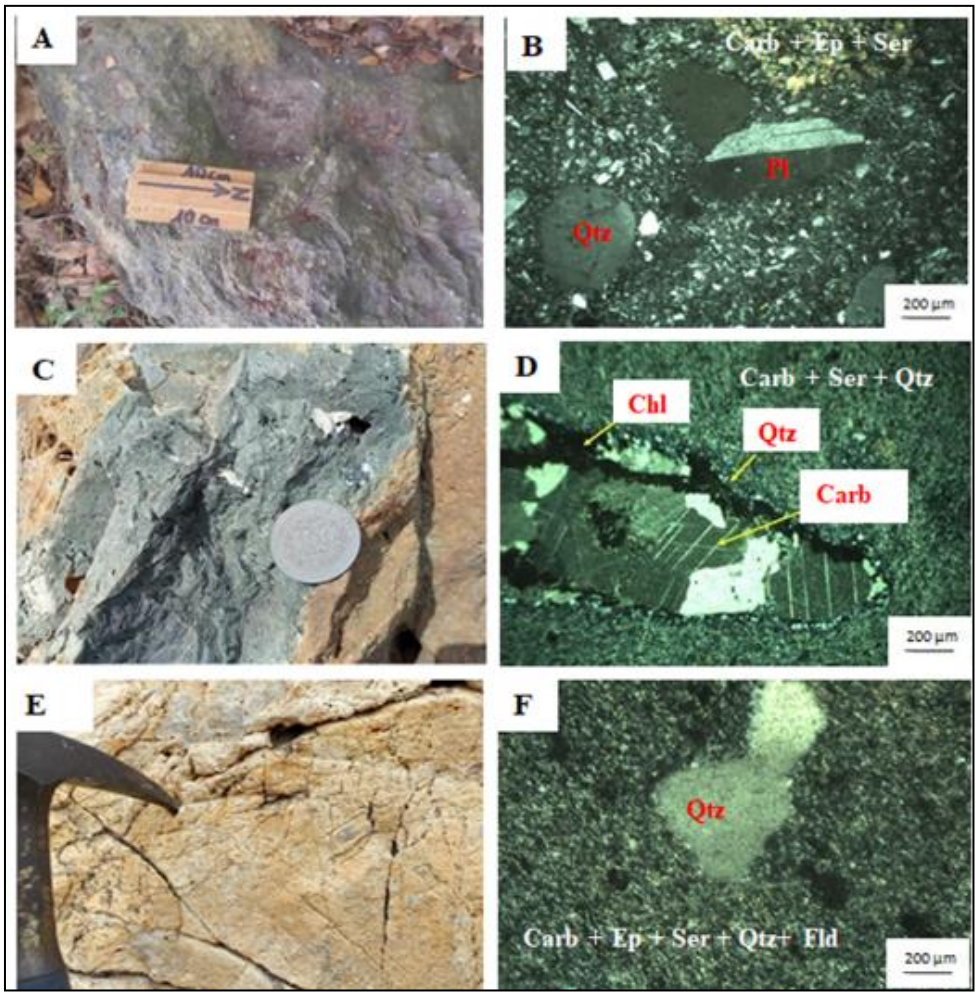


Figure 6: Macroscopic and microscopic aspects of the felsic lavas. A–B: Dacite; C–D: Rhyodacite; E–F: Rhyolite. Fld: Feldspars.

4.2 Volcanoclastic rocks

This group is composed of mafic volcaniclastic rocks (breccias, lapilli tuffs and cinerites) and felsic volcaniclastic rocks (ignimbrites).

4.2.1 Mafic volcaniclastic rocks

The mafic volcaniclastic rocks are breccias, lapilli tuffs and cinerites.

4.2.1.1 Volcanic breccias

The breccias are melanocratic and crop out at Lomo Nord, Tokoréyaokro, Koffi Djékro, Akakro N'Zikpri and Angoda **(figure 7A).** They crop out as sub-rounded to sub-angular blocks with an approximate thickness reaching up to 10 m. They are composed of amphibole, pyroxene and fragments of mafic rock (basalt). These fragments are angular to sub-angular, 3 to 25 cm in size. However, rare clasts of about 50 cm are present, with a difference in proportion between clasts and matrix. Under the microscope, these rocks display a porphyritic microlitic texture with a predominance of pyroxene and plagioclase phenocrysts **(figure 7B).** The pyroxene minerals are often altered into amphibole, chlorite and epidote. The carbonate, sericite and epidote minerals observed result from the transformation of plagioclase. The groundmass consists of plagioclase laths more or less transformed into carbonates, associated with chlorite, epidote and sericite minerals. A few sulfides, as well as iron oxides and hydroxides, are observable.

4.2.1.2 Lapilli tuffs

These rocks are massive, melanocratic and generally crop out as blocks or domes at Lomo Nord, Akakro N'Zikpri, N'Guessankro and Angonda **(figure 7C).** With the naked eye, sub-angular to sub-rounded pyroxene and amphibole porphyries can be observed, ranging in size between 2 and 64 cm. The matrix hosting the fragments is light green and represents 70% of the clastic deposit. Microscopic observation of the lapilli tuffs shows a porphyritic microlitic texture, with a predominance of pyroxene minerals **(figure 7D).** Phenocrysts, most often resulting from the destabilization of pyroxenes, are also observed. These rocks also contain plagioclase, carbonates, chlorite, sericite, epidote, sphene, opaque minerals, volcanic glass and plagioclase. Some sections consist of feldspar microlites sometimes showing a preferred orientation in a sericitized matrix, giving rise to a trachytic texture.

4.2.1.3 Cinerites

The cinerites are melanocratic, massive and crop out in the localities of Angonda, Lomo Nord, Akakro N'Zikpri and Gbofia **(figure 7E).** Some of the laminae that compose them have thicknesses between 1 cm and 50 cm and show better sorting compared with the breccias and mafic tuffs. The beds with thicknesses between 5 cm and 20 cm show normal grading. Near these beds, others with very fine grain size, thicknesses varying from 1 to 5 cm, can be observed. The facies change is upward and distinct, from the base to the upper levels. In these formations, high-amplitude parallel laminations and, in places, tight-angle cross-laminations are observed. Under the microscope, the cinerites display a microlitic texture and consist of fine plagioclase laths, amphibole, pyroxene, carbonates, epidote, chlorite, sericite and opaque minerals **(figure 7F).**

4.2.2 Felsic volcaniclastic rocks

The felsic volcaniclastic rocks are massive, beige to light-grey in color, and crop out at Kouamé-Bonou and southeast of Akakro N'Zikpri **(figure 7G).** They crop out either as blocks or as ovoid-shaped domes. The clasts are angular to sub-angular, reaching 5 cm in size. They are lithic fragments of the host rock, well visible in places, from millimetric to multi-centimetric. This facies is abundant in free quartz crystals, millimetric pumice and fiamme. The matrix also contains pale-green glass fragments (about 20%), with a felsic matrix (feldspars and quartz). The ignimbrites show neither chilled margins nor injection into the host rock, but rather rare enclaves of aphyric-textured rhyolite. Under the microscope, these ignimbrites show a porphyritic microlitic texture marked by quartz and plagioclase phenocrysts, usually transformed into carbonates and sericite **(figure 7H).** The groundmass contains glass and is specifically composed of plagioclase and quartz minerals. The presence of sericite, carbonates, altered glass fragments, oxides and often-deformed quartzo-feldspathic veinlets is noted.

5 DISCUSSION

The northern part of Toumodi belongs to the Toumodi–Fètêkro volcano-sedimentary belt, which is itself an inherent part of the West African Birimian belts. The study carried out shows that the volcanic lavas have the compositions of basalts, andesites, dacites, rhyodacites and rhyolites. The mafic volcaniclastic rocks are composed of breccias, lapilli tuffs and cinerites. This assemblage is specifically similar to the pyroclastites described in the Bonikro deposit [28]; the basic and intermediate pyroclastites of Wendené in the Haute-Comoé series [11]; the mafic pyroclastites of the Agbaou deposit [17]; and the pyroclastites described by Yao [37] in the Boundiali region. Our work at northern Toumodi has also revealed felsic volcaniclastic rocks marked by the presence of ignimbrites. This lithological variation of the volcanic rocks of the study area corroborates the works of Coulibaly [7] and Tegan [33] in the Toumodi–Fètêkro belt. The study area was affected by effusive, explosive and submarine effusive volcanism. Indeed, the emplacement of explosive volcanism is to be linked to Birimian volcanism. This explosive character has already been reported elsewhere in this belt [10-11, 27-28]. However, the absence of submarine effusive volcanism is noted in the Bonikro [28] and Dougbafla-Bandama [27] deposits.

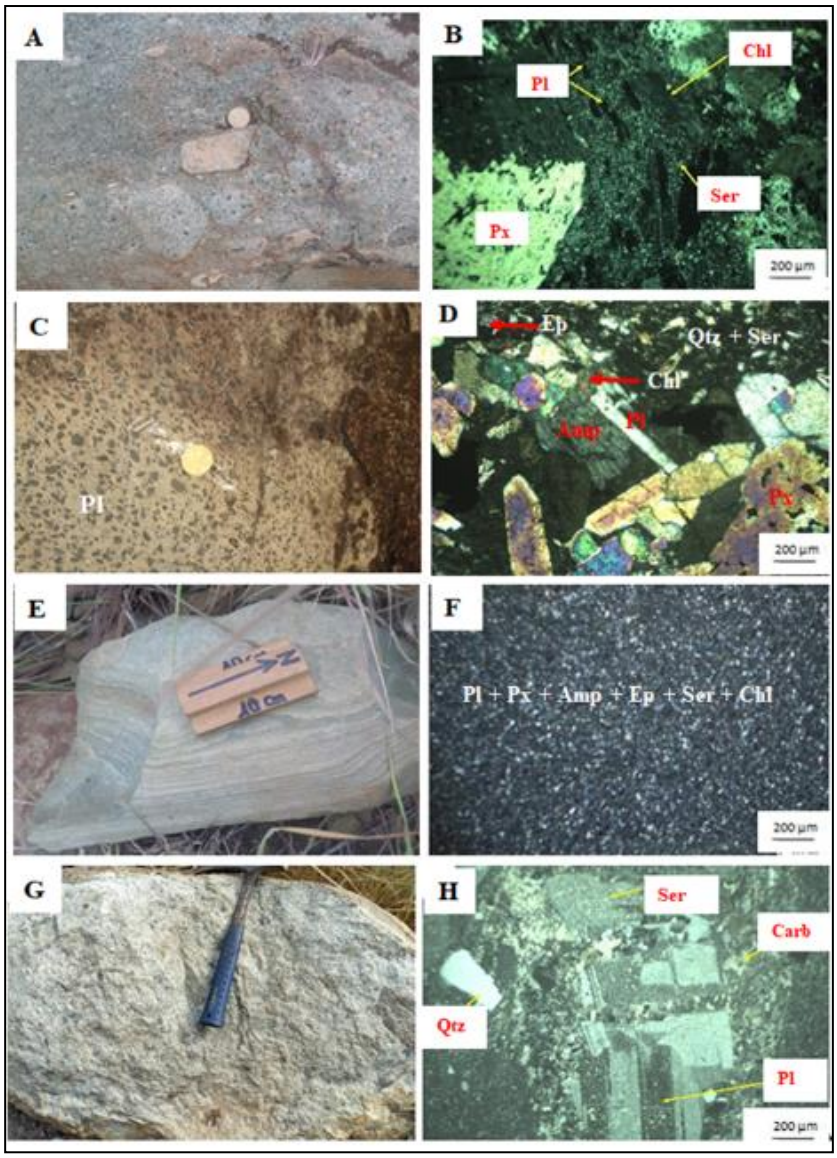


Figure 7: Macroscopic and microscopic aspects of the volcaniclastic rocks. A–B: Breccia; C–D: Lapilli tuff; E–F: Cinerite; G–H: Ignimbrite.

Several authors such as [8, 25-26, 35, 37], have pointed out that this kind of character in the Birimian would indicate the onset of the opening of a volcanic-arc edifice. Indeed, the basalts and most of the effusive rocks are thought to have formed between 2.2 and 2.15 Ga (Lower Birimian) [6, 13, 19], and the volcaniclastic rocks and sediments generally between 2.15 and 1.9 Ga (Upper Birimian), more or less contemporaneous with the granitoids that crosscut them [4, 9, 12, 15]. The studied rocks indicate that the lithostratigraphy of the northern Toumodi area is similar to that of most Birimian belts [1-2, 30, 32, 34]. The presence of secondary minerals such as chlorite, epidote and sericite indicates greenschist-facies metamorphism. These metamorphic conditions are similar to those observed by some authors in Ivorian Birimian belts [7, 10-11, 17, 28, 35] and West African belts [5, 14, 16, 31]. However, locally identified the amphibolite facies [7, 17], as did [35].

6 CONCLUSION

At the end of our study, carried out in the northern Toumodi area, we conclude that the volcanic rocks consist of lavas and volcaniclastic rocks. The volcanic lavas comprise basalts, andesites, dacites, rhyodacites and rhyolites. The volcaniclastic rocks, for their part, are represented by breccias, lapilli tuffs, cinerites and ignimbrites. A mafic, intermediate and felsic volcanic complex is thus observed at northern Toumodi. The volcaniclastic rocks constitute the majority of the lithologies. The presence of volcanic lavas, pillow lavas and volcaniclastic rocks respectively attests that effusive, submarine effusive and explosive volcanism prevailed during the emplacement of the metavolcanic rocks of northern Toumodi. The primary minerals underwent alteration and/or metamorphic processes, leading to silicification, carbonation, chloritization, epidotization, sericitization, oxidation and weak albitization. The study area was affected by greenschist-facies metamorphism.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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