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RESEARCH ARTICLE

PETROGRAPHY OF THE MAGMATIC AND METAMORPHIC ROCKS OF THE WESTERN KORHOGO AREA (NORTHERN CÔTE D'IVOIRE)

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Abstract

The study area, located northwest of Korhogo, covers the southern part of the Korhogo greenstone belt and the granitoids along the eastern margin of the belt. This study aims to contribute to improving the geological knowledge of the north-west of Korhogo. The petrographic data made it possible to identify volcanic rocks (basalts); plutonic rocks comprising gabbros, quartz diorites, granodiorites, two-mica granites, biotite granites and alkaline granites; hypovolcanic and vein rocks (microdiorites and pegmatites); and metamorphic rocks (migmatitic gneisses). These lithologies were affected by intense silicification, associated with secondary minerals such as carbonates, sericite, epidote and chlorite. Scanning electron microscopy analysis revealed the presence of pyrite, chalcopyrite, pyrrhotite, sphene, apatite, ilmenite and iron oxide. The presence of pyrite, pyrrhotite and chalcopyrite could indicate the occurrence of gold mineralization in the study area.

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Introduction:-

The Poro region is located in the north of Côte d'Ivoire, with Korhogo as its administrative capital. The study area lies to the west of Korhogo, specifically within the Proterozoic domain of the Man Ridge. It straddles the southern part of the Korhogo greenstone belt, trending NNE-SSW, and the granitoids bordering the eastern part of this belt. Indeed, gold production in West Africa generally originates from the Proterozoic domain (Milési *et al.*, 1989). Exploration work carried out on the Korhogo trench by the company Randgold Resources led to the discovery of the Tongon deposit, with an estimated probable reserve of 38.25 million tons at 2.57 g/t. (Randgold Resources, 2008). However, this region remains little studied geologically apart from the exploration work conducted by mining companies and a few academic studies. The scientific work carried out is limited to the studies of Yacé. (2002) and Fofana. (2022). It is with the aim of improving the geological knowledge of Côte d'Ivoire, in order to contribute to the revival of the Ivorian mining sector, that this work fits within the drive to improve the geological knowledge of the Korhogo region.

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Geological setting:-

Since Côte d'Ivoire is located in the Man Ridge, its geological history is part of that of the West African Craton (Bessoles, 1977). Two Precambrian geological domains separated by the Sassandra Fault occur in Côte d'Ivoire and cover about 97.5% of its area (**figure 1**). In the west lies the Archean domain, formed of gneisses metamorphosed in the granulite facies during the orogenic cycles of the Leonian (3 to 2.7 Ga) and the Liberian (2.7 to 2.6 Ga) (Beckinsale *et al.*, 1980).

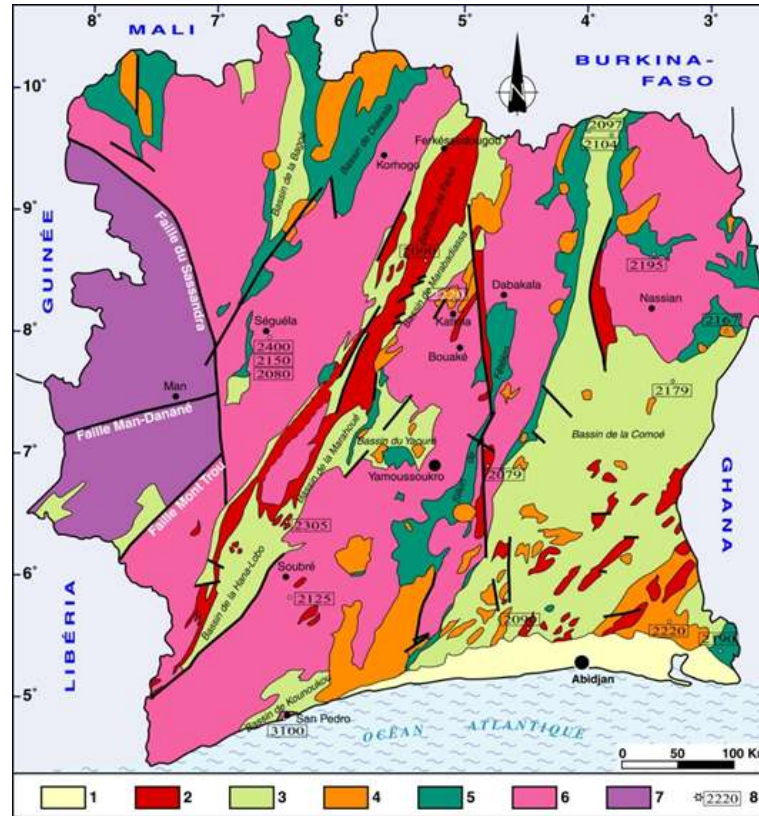


Figure 2: Simplified sketch of the geological units in Côte d'Ivoire. After the 1/1,000,000 geological map of Côte d'Ivoire (Tagini. (1972), modified).

1. post-Birimian formations; coastal sedimentary basin. 2. Ferké batholith: two-mica granitoids, with or without association with meridian strike-slip structures. 3. Sedimentary and volcano-sedimentary basins. 4. calc-alkaline granitoids located within the sedimentary basins. 5. Undifferentiated volcanism and volcano-sediments. 6. Granitoids and banded granites, undifferentiated gneisses and migmatites (ages greater than 2.4 Ga). 7. Archean domain. 8. Age. Boxed figures: 1. Odienné belt; 2. Toulepleu belt; 3. Guiglo belt; 4. Soubré belt; 5. Boundiali-Korhogo belt (Senoufo belt); 6. Séguéla belt; 7. Ferké belt; 8. Katiola belt; 9. Bouaflé belt; 10. Bouaké-East belt; 11. Téhini belt; 12. Nassian-North belt; 13. Bouna-South-East belt; 14. Bondoukou-North belt; 15. Dimbokro-Abengourou belt; 16. Aboisso belt; 17. Bondoukou belt.

These gneisses are overlain by greenstones associating metasediments, metavolcanics and banded iron formations (BIF). The Proterozoic domain lies in the eastern part of the country and is composed of Paleoproterozoic metasediments, metavolcanics and granitoids emplaced around 2.2–2.1 Ga (Abouchami *et al.*, 1990). In the southern part of the country, there is a sedimentary basin covering 2.5% of the country's area, which is the westernmost of the basins bordering the Gulf of Guinea. The Boundiali-Korhogo belt extends into Mali and Burkina Faso. It is composed of two branches, namely a western branch trending N-S, that of Boundiali, and an eastern branch trending NNE-SSW, which represents the Korhogo belt.

A large-scale reconnaissance interpretation shows that it can be subdivided into three lithostratigraphic belts separated by major structures (**figure 2**):-

- the western igneous province appears as a vast zone of syn- to post-tectonic granitoids, basaltic and andesitic lavas, rare rhyolites, and fine- to coarse-grained sedimentary rocks including conglomerates;
- the central sedimentary basin comprising fine-grained sedimentary rocks, secondary tuffs and coarse-grained volcanoclastics, locally developed jasperoid cherts and recent (subordinate) intrusive granites;
- the eastern volcanic belt comprising fine-grained clastic rocks, abundant volcanoclastics, basaltic and andesitic lavas, and post-tectonic diorites and granodiorites.

The study area straddles the southern part of the Korhogo belt, trending NNE-SSW, and the granitoids bordering the eastern part of this belt (**figure 3**). It is composed of undifferentiated granitoids, leucogranite, metasediments, basic volcanic rocks, basic and ultrabasic complexes, felsic volcanoclastic rocks and dykes (Sems exploration, 2012; figure 3).

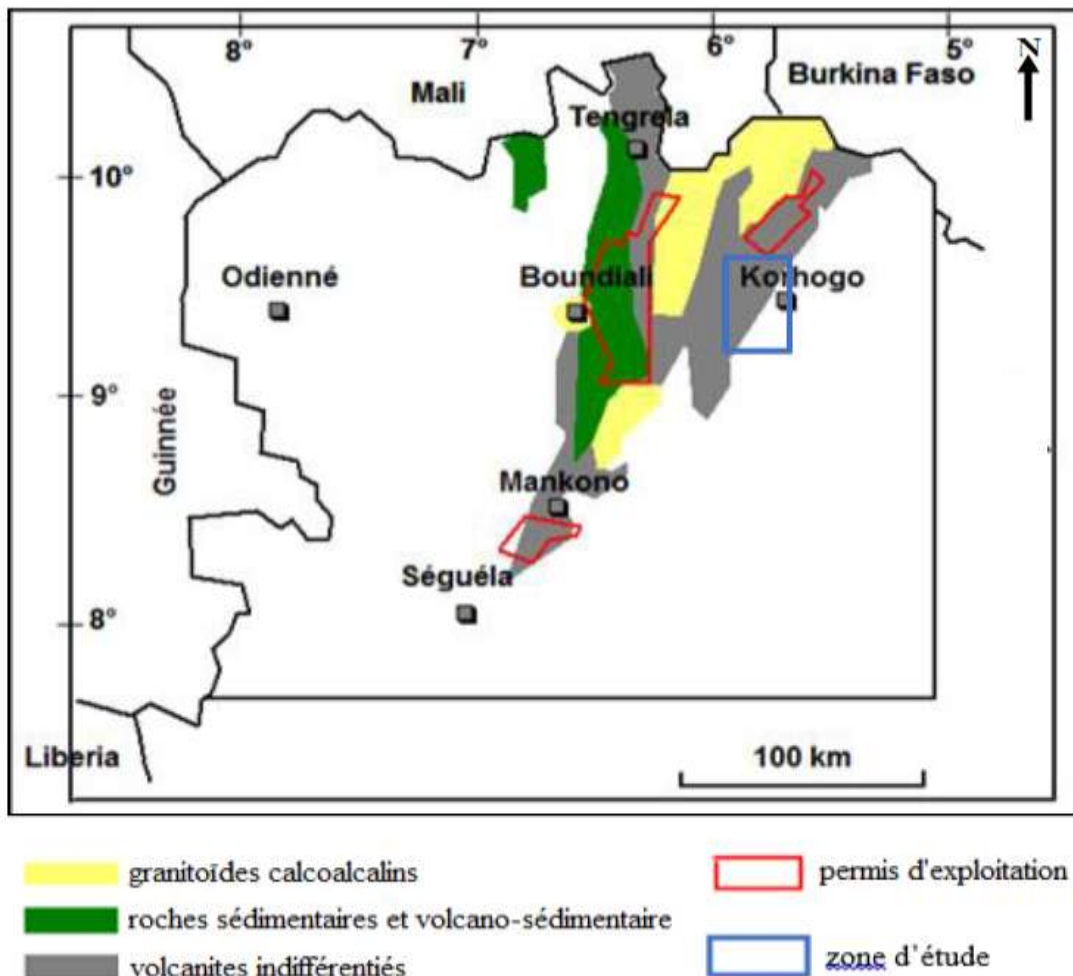


Figure 2: Map of north-western Côte d'Ivoire showing the Boundiali-Korhogo volcano-sedimentary belt and the study area (Grogba, 2011).

Methodology:-

The methodology began with a field phase, which consisted of carrying out macroscopic petrography. Then, careful sampling was performed in order to prepare thin sections for laboratory analyses. This phase combined optical microscopy and scanning electron microscopy (SEM) analyses. The thin sections were prepared at the litholamellage workshop of the Georessources laboratory in Nancy, France, and at the Laboratory of Geology, Mineral and Energy Resources of the Félix HOUPOUËT-BOIGNY University of Abidjan Cocody. The study of the thin sections was carried out at the Laboratory of Geology, Mineral and Energy Resources of the Félix HOUPOUËT-BOIGNY University of Abidjan Cocody.

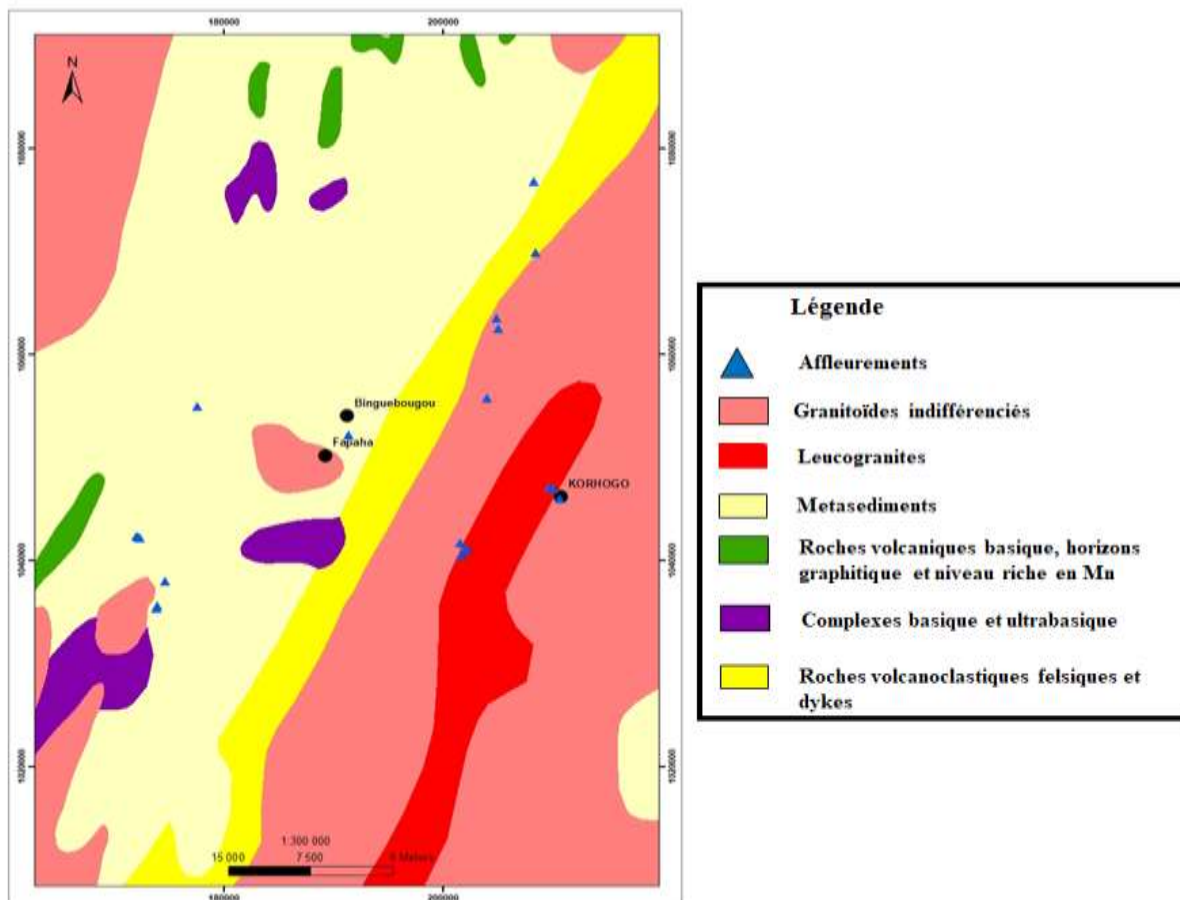


Figure 3: Geological map of the study area, extracted from the West Africa Geological Map, Sems exploration (2012).

Results:-

Petrography:-

The lithologies encountered in the study area consist of volcanic rocks, plutonic rocks, hypovolcanic and vein rocks, and metamorphic rocks.

Volcanic rocks:-

The volcanic rocks encountered in the study area are essentially composed of basalts, outcropping to the south of Ouobolo. At outcrop, these basalts are melanocratic and deformed (**figure 4A**). Under the microscope, they display a porphyritic microlitic texture with pyroxene phenocrysts, mainly clinopyroxene (**figure 4B**). These pyroxenes are generally altered and transformed into amphibole, chlorite and epidote. The plagioclase is mostly altered into carbonates and sericite.

Plutonic rocks:-

The plutonic rocks consist of gabbros, quartz diorites, granodiorites, two-mica granites, biotite granites and alkaline granites.

Gabbros:-

At outcrop, these rocks, observed at Tchelegaha and Ouobolo, are massive, melanocratic, strongly magnetic and contain pyroxene phenocrysts (**figure 4C**), as well as feldspars. Under the microscope, the gabbros display a porphyritic granular texture with pyroxene phenocrysts (**figure 4D**). These pyroxenes are euhedral and most often altered and transformed into amphibole, chlorite and epidote. The matrix consists of plagioclase, generally altered into carbonates, sericite and epidote, associated with chlorite and epidote resulting from the alteration of the pyroxenes. However, some preserved thin laths of plagioclase are noted.

Quartz diorites:-

The quartz diorites are melanocratic, granular and outcrop as enclaves within the granites of the Korhogo quarry and within the Benguedougou granodiorite (**figure 4E**). Under the optical microscope, these rocks are composed of green hornblende, subhedral to euhedral, very abundant, with sections showing alteration into chlorite and epidote (**figure 4F**). Plagioclase and alkali feldspars are generally anhedral, abundant, and alter in some sections into epidote and carbonates (dolomite $\pm$ calcite). Quartz occurs in microcrystalline form and is scarce. The opaque minerals are mainly composed of pyrite, the principal sulphide, subhedral, associated either with chalcopyrite or with iron oxide. Chalcopyrite, for its part, is also subhedral, breaking down into iron oxides.

Granodiorites:-

These rocks, encountered in the localities of Ouobolo, Tawara, Koni and Benguedougou, are granular, often deformed and outcrop as slabs or as enclaves within the granites (**figure 5A**). With the naked eye, feldspar, quartz, biotite and amphibole minerals can be observed. Under the optical microscope, the granodiorites display a granular texture (**figure 5B**) and are composed of plagioclase, anhedral to subhedral, abundant, often in large patches and altered into carbonates, epidote and sericite. Quartz is anhedral and scarce. Biotite, subhedral, with zircon inclusions, is often altered into chlorite. Orthoclase and microcline are also observed. The green hornblende is generally subhedral and alters in some sections into chlorite. Some sections show andesine, as well as magnetite within the biotite crystals. The opaque minerals are also present in small quantity.

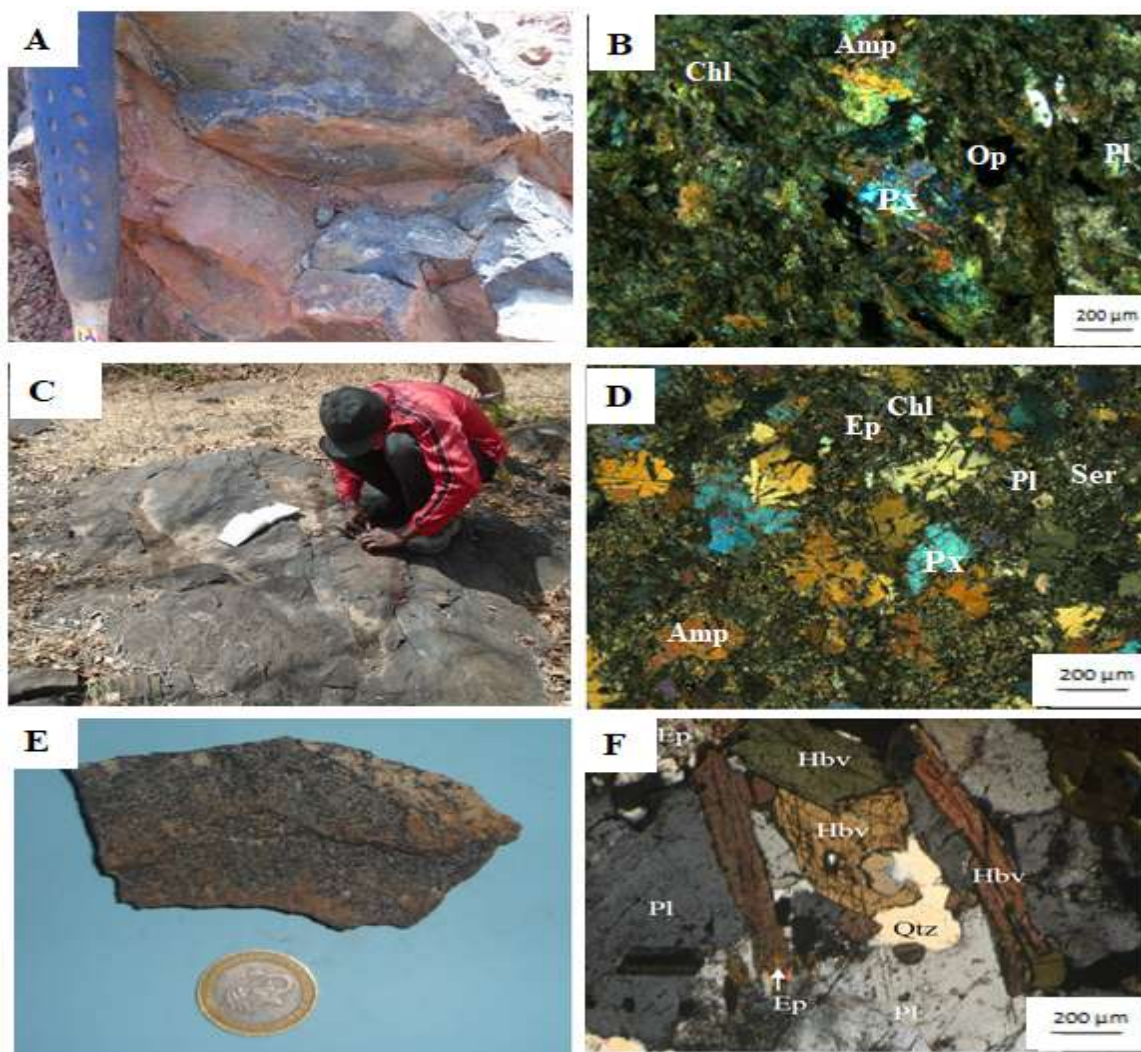


Figure 4: Macroscopic and microscopic features of the basalts (A-B), gabbros (C-D) and quartz diorites (E-F). Px: Pyroxene; Amp: Amphibole; Chl: Chlorite; Pl: Plagioclase; Op: Opaque; Hbv: Green hornblende; Ser: Sericite; Ep: Epidote; Qtz: Quartz.

Two-mica granites:-

These massive rocks were observed in the locality of Djougoublé and contain quartz, feldspars and micas (**figure 5C**). They are large, homogeneous granitic massifs emplaced following the direction of the major geological structures of the Korhogo belt. Under the microscope, these rocks display a porphyritic granular texture with sanidine phenocrysts (**figure 5D**). Plagioclase is anhedral to subhedral and most often altered into sericite and carbonates. The feldspars generally show albitisation. Quartz is anhedral, with a remarkable undulose extinction. These rocks also contain muscovite, perthite, and biotite altering in some sections into chlorite.

Biotite granites:-

The biotite granites are observed at the Korhogo quarry, at Kapélé, Foro, Koni and Tawara and display almost identical characteristics. They occur as blocks, slabs or as hills. These rocks are generally leucocratic, granular and composed of quartz, feldspars and biotite (**figure 5E**). Under the optical microscope (**figure 5F**), these rocks contain plagioclase, anhedral, abundant, and alkali feldspars (microcline). These feldspars are often altered into carbonates, epidote and sericite. Quartz is anhedral, less abundant than plagioclase, with a remarkable undulose extinction. Biotite is anhedral to subhedral and often breaks down into chlorite. The opaque minerals are generally anhedral and present in low proportion.

Alkaline granites:-

These rocks outcrop as blocks or slabs at the Korhogo prefecture and in the Foro area (**figure 5G**). At outcrop, the feldspars show various colors, ranging from white to pink, the biotites occur as flakes and the quartz is greyish, more or less translucent. A few dark minerals are also observed as black flakes. Under the optical microscope, they are composed of quartz, generally light grey in color (**figure 5H**). Orthoclase is the most abundant feldspar, with a remarkable simple twin. Plagioclase is present in small quantity, as is biotite. Epidote, sericite, chlorite and opaque minerals are observed as accessory phases.

Hypovolcanic and vein rocks:-

The hypovolcanic and vein rocks encountered consist of microdiorites and pegmatites.

Pegmatites:-

They generally occur as centimetric to metric veins in all the granite outcrops (**figure 6A**). However, in the migmatitic gneiss of the Korhogo prefecture, a pegmatite lens was observed. The mineralogy is dominated by large crystals of quartz and alkali feldspars. Sheets of biotite are also found.

Microdiorites:-

These rocks are melanocratic, deformed and outcrop at the Tawara artisanal gold-mining site (**figure 6B**). Under the optical microscope, the microdiorites have a porphyritic microgranular texture and contain green hornblende in very abundant quantity (**figure 6C**). Plagioclase generally occurs as phenocrysts altered into carbonates. Biotite, often chloritized, rare orthoclase, as well as calcite veinlets are also observed. The feldspars are often altered and transformed into epidote. The accessory minerals observed consist of oxides and sphenes generally associated with sulphides. The sulphides consist of pyrite, the principal sulphide, with which chalcopyrite and pyrrhotite are associated, as well as iron oxides and ilmenite.

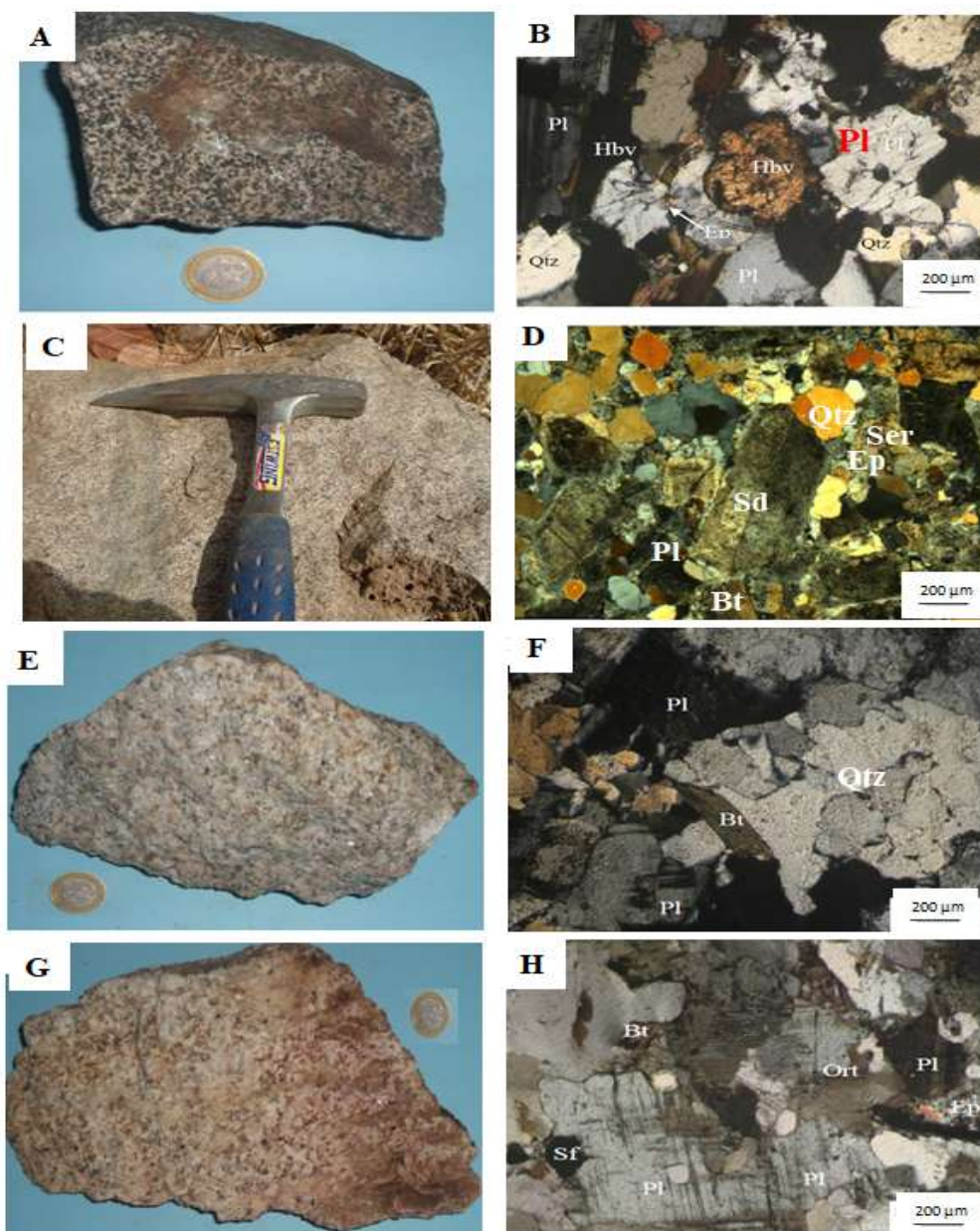


Figure 5: Macroscopic and microscopic features of the granodiorites (A-B), two-mica granites (C-D), biotite granites (E-F) and alkaline granites (G-H). Bt: Biotite; Sf: Sulphide; Ort: Orthoclase

Metamorphic rocks:-

The metamorphic rocks encountered are migmatitic gneisses and quartzites.

Migmatitic gneisses:-

They outcrop as slabs or blocks at Mount Korhogo and at the Korhogo prefecture, with a foliation that is often weakly marked or indistinct (**figure 6E**). Under the optical microscope, these rocks have a granoblastic texture and are composed of plagioclase, abundant, anhedral to subhedral (**figure 6D**). To this are added quartz, orthoclase, and green hornblende. The secondary minerals consist of epidote, chlorite and sericite. The sulphides consist essentially of pyrites, generally associated with sphenes. They also contain iron oxides and small zircons.

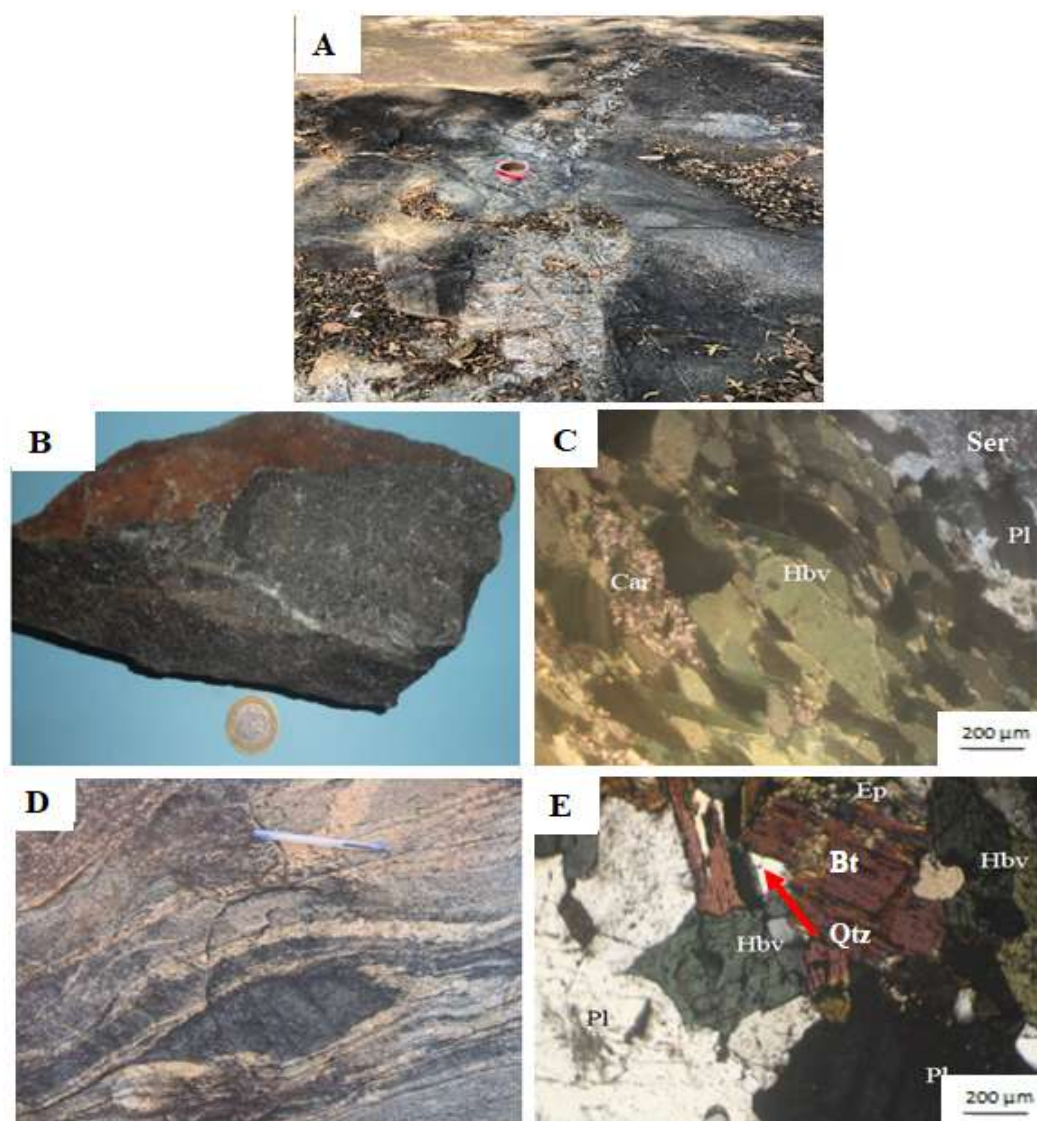


Figure 6: Macroscopic and microscopic features of the pegmatites (A), microdiorites (B-C), and migmatitic gneisses (D-E).Car: Carbonates

Discussion:-

Petrography:-

The lithologies identified in the study area consist of volcanic rocks represented essentially by basalts, plutonic rocks (gabbros, quartz diorites, granodiorites, biotite granites and alkaline granites), hypovolcanic and vein rocks (microdiorites and pegmatites), and metamorphic rocks comprising only the migmatitic gneisses. The lithologies observed in the study area fall within the range of rocks known to characterize the Birimian formations (Yacé, 2002). The work of Fofana. (2022) carried out in the Korhogo belt shows more or less similar lithologies, with however some differences. Indeed, this author identifies basic to acid volcanic lavas (basalts, andesites, rhyodacites and rhyolites), mafic to intermediate volcanoclastics (tuffs and breccias), plutonic rocks (gabbros, diorites, granodiorites and granites), and metamorphic rocks (amphibolites). Indeed, based on the lithostratigraphy of the Birimian, the basalts and most of the effusive rocks would have formed between 2.2 and 2.15 Ga (lower Birimian) (Kouamelan, 1996; Hirdes and Davis, 1998; Castaing *et al.*, 2003). The volcanoclastics and sediments formed generally between 2.15 and 1.9 Ga (upper Birimian), more or less contemporaneous with the granitoids that cut through them (Hirdes *et al.*, 1996; Bossière *et al.*, 1996; Doumbia *et al.*, 1998; Gasquet *et al.*, 2003). The lithostratigraphy of the study area is similar to that of most Birimian belts (Arnould, 1961; Tagini, 1971; Pouclet *et al.*, 1996; Vidal *et al.*, 1996, 2009; Baratoux *et al.*, 2011). The granitic gneisses would be of Dabakalian age (2.3-2.15 Ga).

The majority of the primary minerals observed in the rocks of the study area show transformations into secondary minerals, thus generally altering into carbonates, sericite, epidote and chlorite. To this are added silicification, oxidation and sulphidation. These observations are similar to those noted by several authors in West African Birimian belts (Hirdes *et al.*, 1992; Sylla and Ngom, 1997; Gnanzou, 2014; Ouattara, 2018). The lithological diversity observed in the magmatic rocks implies several episodes of magmatism and therefore several formation processes, as elsewhere in the Birimian (Ouattara and Koffi, 2014; Teha, 2019). The granitoids of the study area consist of granodiorites and granites (biotite granites and alkaline granites) and contain microcline. This corroborates the observations made in the granitoids of the Ivorian Birimian (Casanova, 1973; Gnanzou, 2014; Ouattara, 2015; Coulibaly, 2018). Indeed, this microclinization attests to a late input of water, even later than the emplacement of the rocks, which took place between 400 and 500°C (Casanova, 1973). The granodiorites of the study area are for the most part very poor in potassium feldspars, like those of the south-west of the Comoé basin and the Singrobo sector (Teha, 2019). This could reflect an emplacement during the deformation of these rocks. In the Boundiali belt, Turner. (1993) groups the granites, granodiorites and migmatitic gneisses under the term syntectonic granitoids. The granitoids of the study area often contain subparallel enclaves, and we note the presence of migmatitic gneisses. Indeed, the work of Thomas (2010) shows, for the Margeride granite (Lozère), that the subparallel enclaves present in the leucogranite massifs can also be interpreted as being due to magma flow (magmatic fluidity). This author also mentions that many granites originate from a migration-accumulation of partial melting products that takes place in the migmatites.

Metallogeny:-

Gold mineralization in West Africa still faces questions related to the temporal and spatial distribution of these gold occurrences, their modes of occurrence, their origins and the nature of the mineralizing fluids (Goldfarb *et al.*, 2001; Lawrence *et al.*, 2013). The answers to these questions, both at the lithostructural and metallogenic level, remain at the center of Birimian research concerns. In the study area, the sulphides encountered are pyrite (the principal sulphide), chalcopyrite and pyrrhotite. Iron oxides resulting from the alteration of the sulphides, ilmenite and sphene are also encountered. These sulphides have more or less been identified in Ivorian gold deposits as well as in some promising prospects [Agbaou deposit (Houssou, 2013); Bobosso prospect (Gnanzou, 2014); Bonikro deposit (Ouattara, 2015); Dougbafla-Bandama deposit (Ouattara, 2018); Tondabo prospect (Dai Bi, 2020)]. Such observations have been made in Birimian belts of Côte d'Ivoire such as the southern part of the Toumodi-Fètèkro belt (Coulibaly, 2018) and the Korhogo belt (Fofana, 2022). The alterations observed, marked by the presence of carbonates, sericite, epidote and chlorite, associated with silicification, oxidation and sulphidation, are similar to those already reported in most deposits of the Ivorian Birimian (Aféma: Assié, 2008; Kadio *et al.*, 2010; Bonikro: Gnanzou, 2006; Tongon: Coulibaly *et al.*, 2008) and of West Africa (Milési *et al.*, 1989; 1992). Indeed, these deposits and promising prospects are controlled by various factors. Hydrothermal fluids are strongly involved in West African gold deposits (Klemd *et al.*, 1997; Yao *et al.*, 2001; Coulibaly *et al.*, 2008; Lawrence *et al.*, 2013a; Treloar *et al.*, 2014). This is corroborated by the quartz and carbonate veins and veinlets observed in the study area.

Conclusion:-

At the end of this study, it appears that the western Korhogo area is composed of volcanic rocks represented essentially by basalts, plutonic rocks (quartz diorites, granodiorites, biotite granites and alkaline granites), hypovolcanic and vein rocks (microdiorites and pegmatites), and metamorphic rocks (migmatitic gneisses and quartzites). The majority of the primary minerals observed in the rocks of the study area show transformations into secondary minerals, thus generally altering into carbonates, sericite, epidote and chlorite, associated with significant silicification. Silicification, oxidation and sulphidation are also observed. The scanning electron microscopy study made it possible to show that the sulphides encountered are pyrite (the principal sulphide), chalcopyrite and pyrrhotite, as well as iron oxides, ilmenite and sphene.

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