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Petrography, Mineralogy, and Compositional Characteristics of Rare-Metal-Bearing Pegmatite of Côte d'Ivoire: A Review

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Abstract

Côte d'Ivoire's pegmatite occurrences have been the subject of limited studies. Fifteen areas of interest have been identified, including the Issia, Boundiali, and Comoé Basin regions. Only those in the Issia region, associated with the Issia peraluminous granites, have undergone rigorous studies. The Issia pegmatites are columbite-tantaliferous deposits, interpreted as deriving petrogenetically from differentiated residual fluids of the granite systems. Research in the Comoé Basin region has identified several pegmatite outcrops with significant potential for rare metals, including lithium, tantalum, niobium, and beryllium-bearing minerals. Four groups of pegmatites are categorized based on their mineralogy: spodumene-albite-tourmaline pegmatite, beryl-muscovite pegmatite, green-micas-tourmaline pegmatite, and muscovite-garnet pegmatite. These pegmatites exhibit traits that indicate a para-derivative origin and closely resemble the lithium-cesium-tantalum type, which features beryl and spodumene mineralization (similar to Ewoyaa pegmatites in Ghana). The Boundiali region pegmatites appear to be the most interesting regarding rare metal enrichment. These pegmatites are intrusive into the Birimian Supergroup (Palaeoproterozoic), either in metamorphic formations (mainly micaschist) or in granites. This region is characterized by five main types of pegmatites: the lepidolite-muscovite-spodumene-colombo-tantalite type, the green micas and colombo-tantalite type, the green beryl type, the muscovite-beryl type, and the biotite-magnetite type, grouped into two main families, including a lithium-bearing family and a non-lithium-bearing type (similar to the Bougouni-Goulamina pegmatites in Mali). They are primarily peraluminous, though it is not uncommon to find some of metaluminous origin, highlighting the pegmatitic diversity of this region. A recent investigation classified the Boundiali pegmatites as Lithium-Cesium-Tantalum pegmatites due to the discovery of lithium-bearing minerals (spodumene and lepidolite) in outcrops and the detection of lithium anomalies through soil sampling analyses. The exposures of the Boundiali and Comoé Basin pegmatites present valuable opportunities for further research, including lithium exploration and assessment of potential resources through detailed mineralogical and geochemical studies; geochronological analysis to determine timelines and genetic connections between the pegmatites and their potential parent rocks; refining petrogenetic and metallogenic models; analysis of alteration, metamorphic, and tectonic influences on pegmatite emplacement; and comparison of data with emerging LCT pegmatite fields worldwide.

Keywords

Rare Metals, Spodumene, LCT, Pegmatites, Côte d'Ivoire

1. Introduction

Technological advancement driven by the global energy transition is one of the most significant aspects of the 21st century. This trend is fueling a growing demand for critical raw materials, particularly lithium (Li), tantalum (Ta), niobium (Nb), cesium (Cs), and beryllium (Be), which are essential for battery technology and renewable energy storage. Understanding the under-explored geological occurrences of these materials is important to meet this demand, with pegmatites serving as a primary source.

The African continent is rich in pegmatites mineralized with rare metals [1]-[3]. Several regions on the continent are recognized for their significant rare-element pegmatite deposits [4] [5] (**Figure 1**), including Central African countries such as the Democratic Republic of Congo (one of the richest sources of tantalum), Rwanda (pegmatite deposits containing tantalum, beryllium, and lithium), Burundi (niobium, tantalum, and tin deposits), and Uganda (tin and tantalum production dating back almost 100 years). Other resources are found in Egypt, Ethiopia (tantalum-rich pegmatites), Somalia, Mozambique, Madagascar, Namibia, Zimbabwe, and South Africa. Many West African countries possess abundant lithium, tin, niobium, tantalum, beryllium, and cesium mineral occurrences that are demonstrated resources and/or prospects. These include: Mali (Bougouni, Goulamina, Falea), which hosts the region's most advanced and substantial lithium deposits; Ghana (Winneba, Mankoadze, Cape Coast), with the near-production

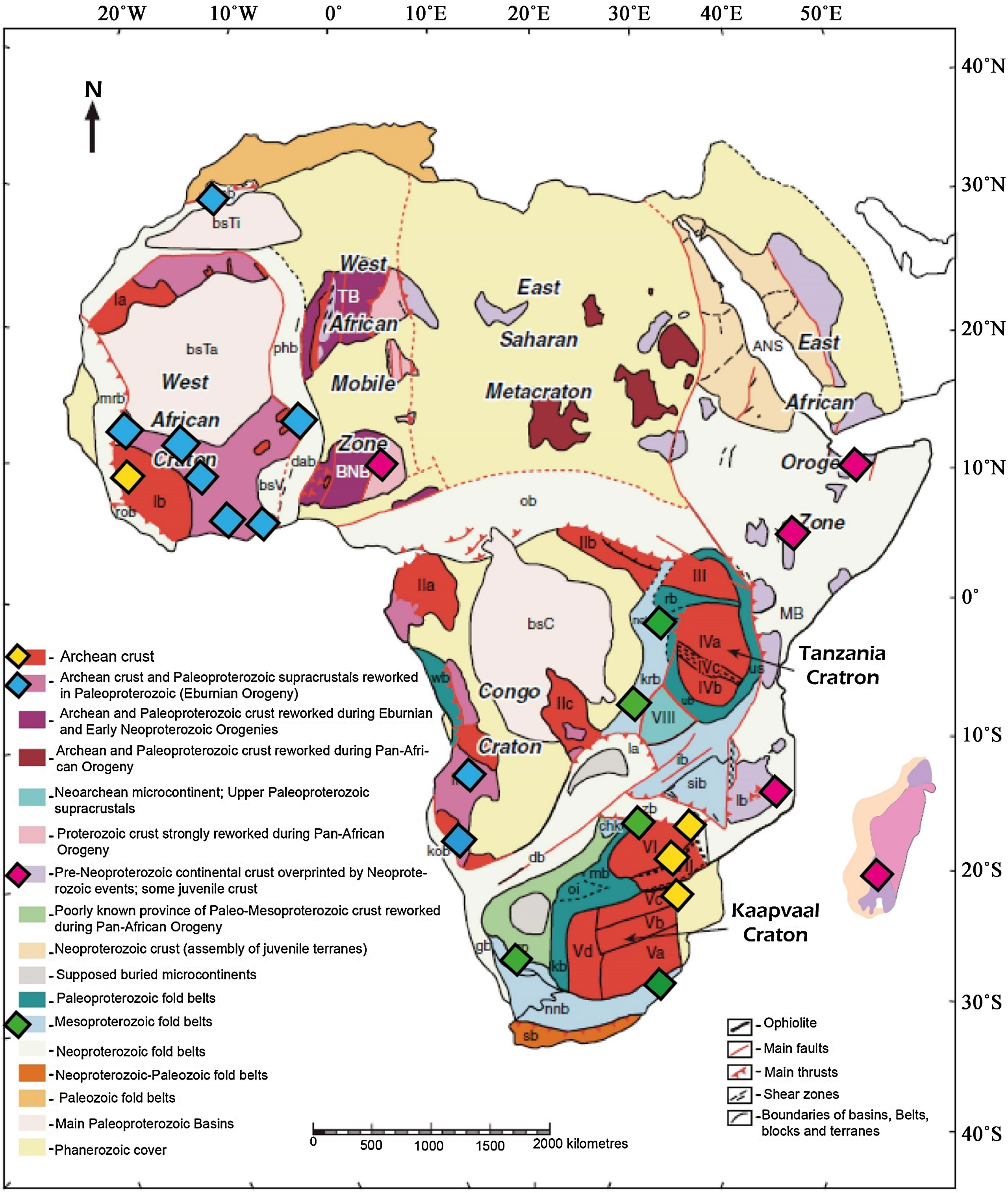

Figure 1. Field of LCT-type pegmatites in Africa (modified from [4] [5]).

Ewoyaa project; Nigeria (Jos Plateau, Nasarawa, Kogi, Ekiti), with widespread lithium discoveries and notable niobium-tantalum occurrences; Côte d'Ivoire (Issia, Boundiali, Agboville), where several promising lithium-bearing and columbo-tantalite-bearing pegmatite prospects are under exploration; Guinea (Gaoua, Boromo, Houndé) and Senegal (Kedougou, Saraya), which contain regional pegmatitic occurrences; Niger (Liptako, Air Massif), known for historical tin production and minor lithium potential; and Sierra Leone (Kono, Kenema, Bo) and Liberia (Nimba, Bong, Grand Cape Mount), where mineralization remains at an artisanal or early prospecting stage.

In West Africa (Côte d'Ivoire, Mali, Ghana, Senegal, Niger, Burkina Faso), a number of pegmatites with high potential for rare metals have been identified in the Birimian basement (Palaeoproterozoic supergroup). However, Côte d'Ivoire covers about 35% of the Birimian basement exposures. Indeed, pegmatites containing elements of interest are known in Côte d'Ivoire following numerous exploration efforts that have been conducted. This characteristic suggests that Côte d'Ivoire possesses significant geological potential for discovery, particularly regarding rare metal mineralization. However, the necessary detailed characterization research remains limited. Since 1963 [6], SODEMI (Société pour le Développement Minier de Côte d'Ivoire) has been exploring and studying pegmatites and their mineralization (including primary, alluvial, eluvial, and colluvial deposits), leading to the identification of 15 areas of interest throughout the country [7]. Among these pegmatites, only those from the Issia locality in central-western Côte d'Ivoire have undergone detailed studies [8]-[10], documented in the literature as columbo-tantaliferous (coltan) deposits. Recent studies [10]-[13], along with mining company reports [14]-[17], have indicated significant metal potential in pegmatites throughout Côte d'Ivoire, especially in the Boundiali area (northwest region of the country) and the Comoé Basin (southeast Côte d'Ivoire; Agboville, Alépé). The results of these investigations indicate that the pegmatites of Côte d'Ivoire contain potentially substantial metal-bearing resources, which justifies further study and exploration to gain a deeper understanding of their economic implications. This review constitutes the first comprehensive synthesis of academic, governmental, and corporate data on Côte d'Ivoire's rare-metal pegmatites. It aims to establish a baseline framework for future exploration and research by integrating field mapping, petrology, structural analysis, geochemistry, geochronology, and metallogenic data to characterize the mineralization styles and geological features of pegmatites across the country.

2. Geology

2.1. Regional Geology

The Paleoproterozoic basement is mainly exposed within two major shields of the WAC: northern and southern, each consisting of a western Archean domain and an eastern Birimian domain. The southern shield, known as the Man-Leo Shield, includes the Archean Man domain and the Birimian Baoulé-Mossi domain [18]-[20].

Côte d'Ivoire is primarily composed of Precambrian basement, which accounts for 97.5% of the country. It is situated south of the West African Craton in the

Man-Leo Ridge (**Figure 2**) [4] [18] [21]. The Precambrian basement consists of two domains divided by the Sassandra Fault: an Archean core (3600 - 2500 Ma) located to the west of the fault and a Paleoproterozoic domain (Baoulé-Mossi domain; 2500 - 1800 Ma) situated to the east of this fault [22]. Accretion of juvenile crust into the Archean craton occurred through the Birimian event, followed by intrusion of granitoid complexes. The crystalline basement of the West African Craton (WAC) was assembled during the Siderian to Orosirian periods of the Paleoproterozoic Era (ca. 2.35 - 1.95 Ga), primarily through the Birimian orogenic event [18]. This involved the tectonic accretion of extensive juvenile crustal terranes alongside reworked Archean cratonic blocks. The resulting Birimian crust comprises linear volcanic greenstone belts and associated sedimentary basins, which were later intruded by successive generations of granitoid and mafic to felsic plutonic rocks and affected by multiple tectonothermal events (**Figure 3**) [23] [24].

The geological framework of Côte d'Ivoire, featuring a range of significant lithological units, offers a wide variety of granitic intrusions, especially syn-orogenic to post-orogenic granitoids, including the TTG suites (tonalite-trondhjemite-granodiorite) typical of Archean crust; the granodiorites and monzogranites associated with the Eburnean orogeny (ca. 2.1 Ga); and the late-stage leucogranites and pegmatites, including LCT-type pegmatites (lithium-cesium-tantalum-enriched) [11]. These granitoids have also been subdivided into

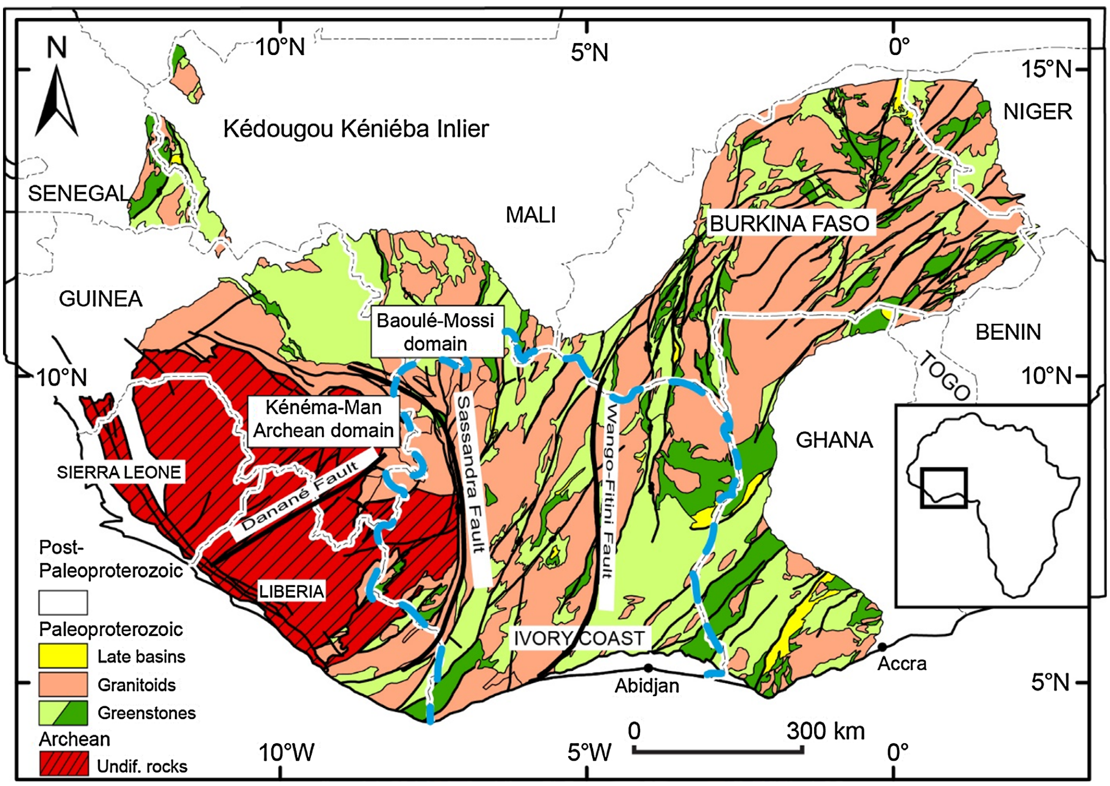

Figure 2. Geological map of the Man-Leo Shield, highlighting the geological units of Côte d'Ivoire (modified from [18]).

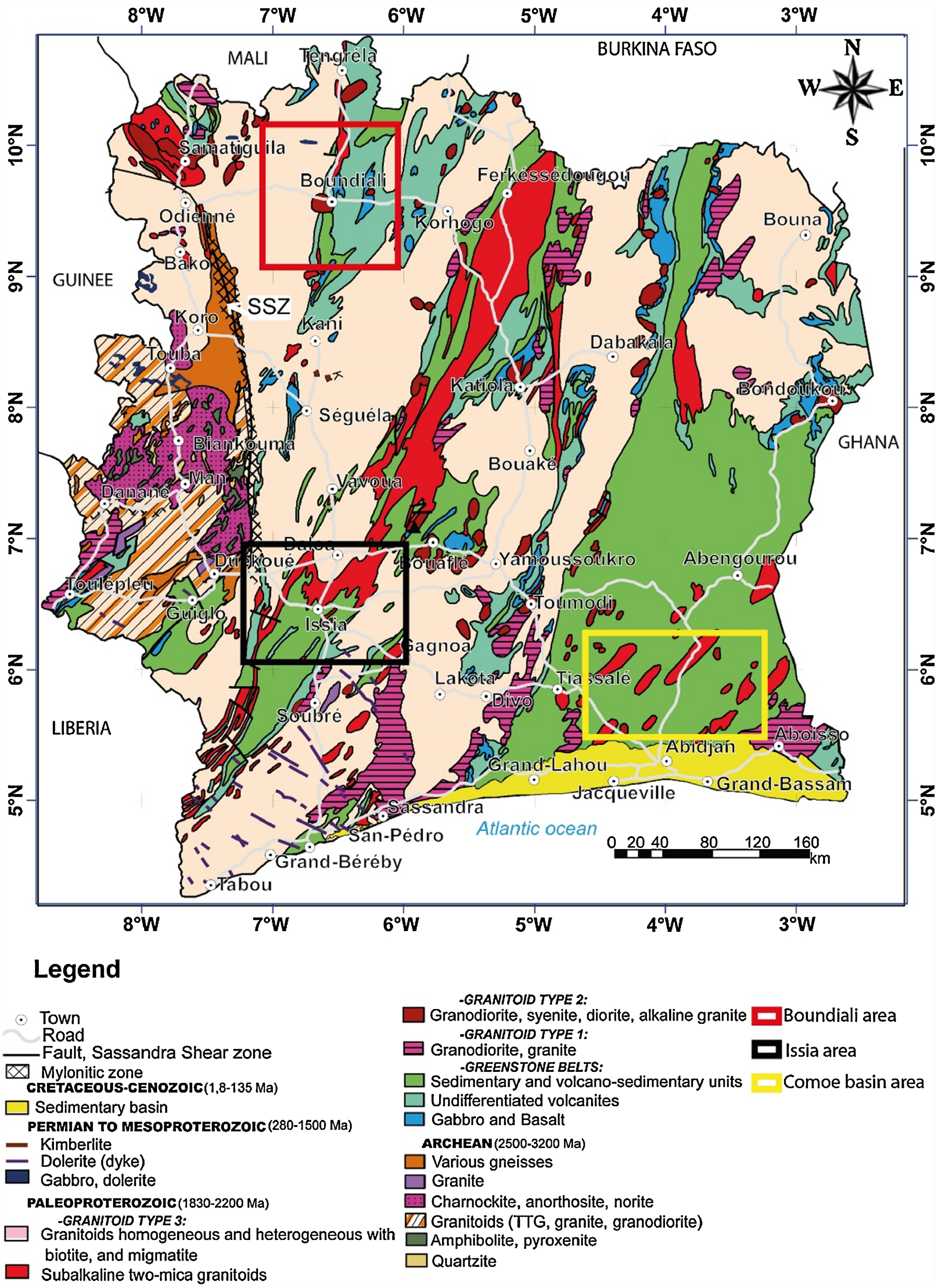

Figure 3. Geological map of Côte d'Ivoire illustrating the study areas (modified from [23] [24]).

three different types, based on their emplacement ages (1830 - 2200 Ma) and their mineralogy [23] [24]: Type 1 (~1.83 Ma), including granodiorite and granite; Type 2 (1.9 - 2.0 Ma), comprising granodiorite, syenite, diorite, and alkaline granite; and Type 3 (2.1 - 2.2 Ma), including biotite-bearing migmatitic homogeneous and heterogeneous granodiorite and subalkaline two-mica. These compositional characteristics and structural complexity of Archean and Birimian Paleoproterozoic rocks became the host environment for rare-metal pegmatites.

2.2. Local Geology and Petrography

Three regions of Côte d'Ivoire in which pegmatites are known will be examined in this paper. These regions are Issia, the Comoe Basin, and Boundiali. They are located in the central west, northwest, and southeast of the country, respectively (**Figure 3**). Primarily composed of Birimian geological formations (Paleoproterozoic greenstone belts and granitoid intrusions), these regions exhibit a diverse range of volcano-sedimentary rocks and granitoid complexes, with several pegmatite outcrops having been identified [11] [25].

The Issia region is primarily characterized by large granite massifs, including Lobo granite, Issia granite, Bitapia granite, and fine granites that contain two micas, all of which form the Issia granite complex (**Figure 4**). These massifs were formed in Lower Proterozoic metasedimentary formations, including clay schists, chlorite and sericite schists, staurotide, mica schist, micaceous quartzites, and amphibole quartzites. They were shaped by the Eburnian orogeny [8] [25]. Structural studies of the Issia granite complex reveal syntectonic emplacement along the structures of the D2 deformation phase [25] [26]. This deformation phase is characterised by several directions of schistosities, foliations, and stretching lineations, following the NE-SW to NNE-SSW oriented Birimian structural train [18]. These granites (the main host rocks of the Issia pegmatites) were subjected to Birimian polyphase deformation, as evidenced by elongation parallel to the tectonic directions and the schistosity of the surrounding metasediments [25] [27]. Furthermore, two other less evolved and more deformed granite massifs are present around the Issia granite complex, but the pegmatites of this region are only distributed around the Issia granites [8] [26] [27].

Several types of pegmatites have formed among the various types of granite identified, with a significant proportion of pegmatites observed in Bitapia- and Lobo-type granites (**Figure 4**) [27]. Based on the classification of [27] [28] have subdivided the pegmatites of the Issia region into four main types. Based on simple analyses of the mineralogy and internal structure of the pegmatites identified [25] [26], this classification essentially comprises: 1) type A, represented by the muscovite-bearing pegmatites, which are intrabatholitic and secondarily contain tourmaline, garnet, and apatite minerals; 2) type B, comprising beryl-bearing pegmatites, intra- and peribatholites, and incidentally containing tourmaline minerals; 3) type C, with zoned beryl-tantalite-columbite-bearing pegmatites that are hosted in the contact metamorphism zone of the Issia granite and secondarily contain tourmaline

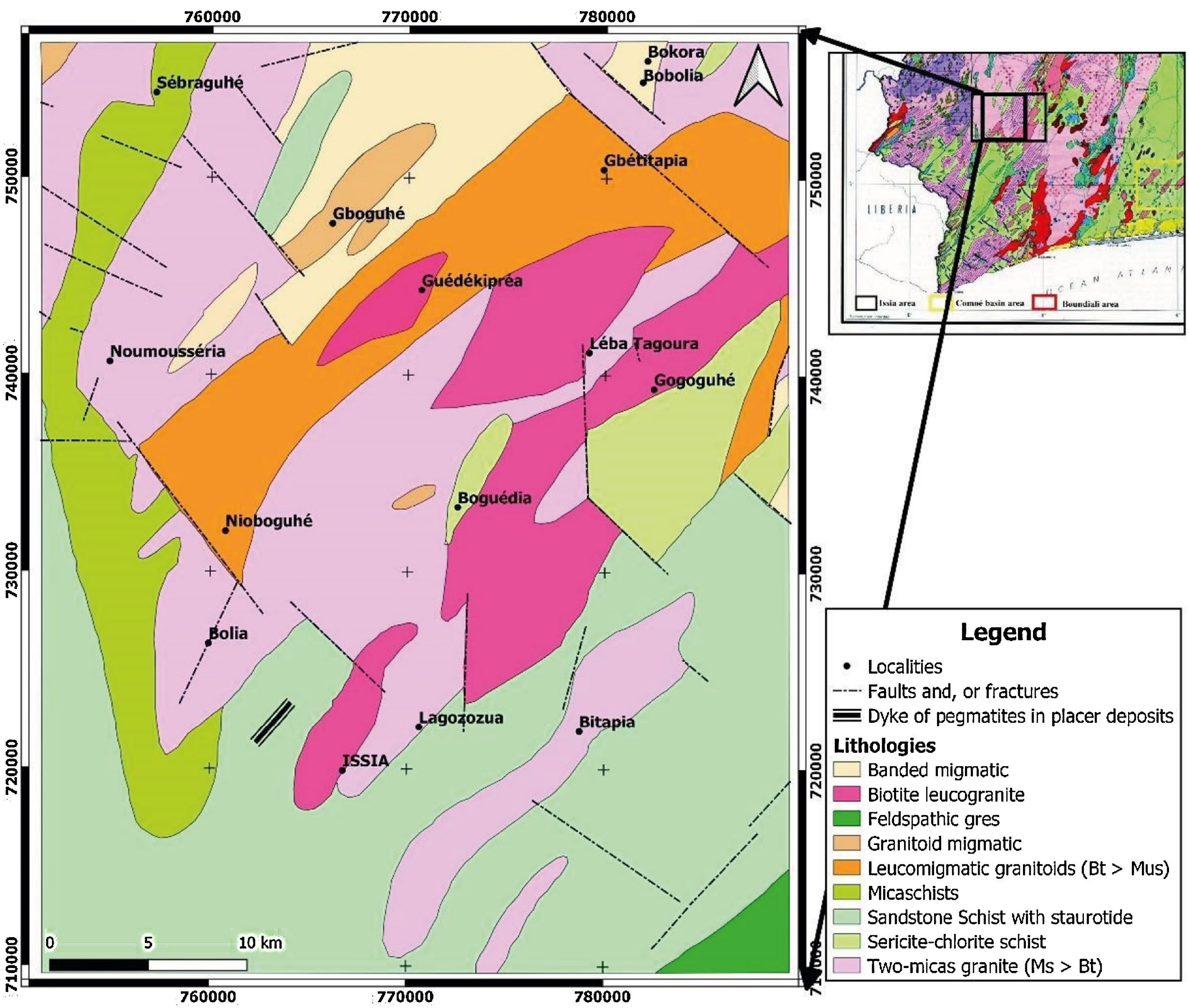

Figure 4. Geological map of the Issia region (modified from [10]).

and apatite minerals; and 4) type D, consisting of zoned beryl-tantalite-columbite-spodumene pegmatites outcropping in micaschists far from the Issia granite. They have the same characteristics as type C pegmatites but are distinguished by their greisenisation, highlighted by clusters of lithiniferous micas in the core zone of the pegmatite. They are distributed more or less zonally around the Issia granite complex. Type C and D pegmatites in particular show an internal zonation system, materialised by mineralogical variations, starting from the edges towards the core of the pegmatites and generally forming more or less six (06) distinct zones (**Figure 5**) [6]: Zone 0 (edge zones), comprising a muscovite-quartz-tourmaline association; Zone I, marked by an aplitic texture (aplite); Zone II, marked by a graphitic texture (graphite); Zone III, composed of an albite-microcline-beryl-columbite-tantalite mineral assemblage; Zone IV (core zone), much larger and marked by an abundance of massive microcline minerals associated with quartz; Zone V, generally present in clusters in Zone IV and composed of a unique quartz-tourmaline association.

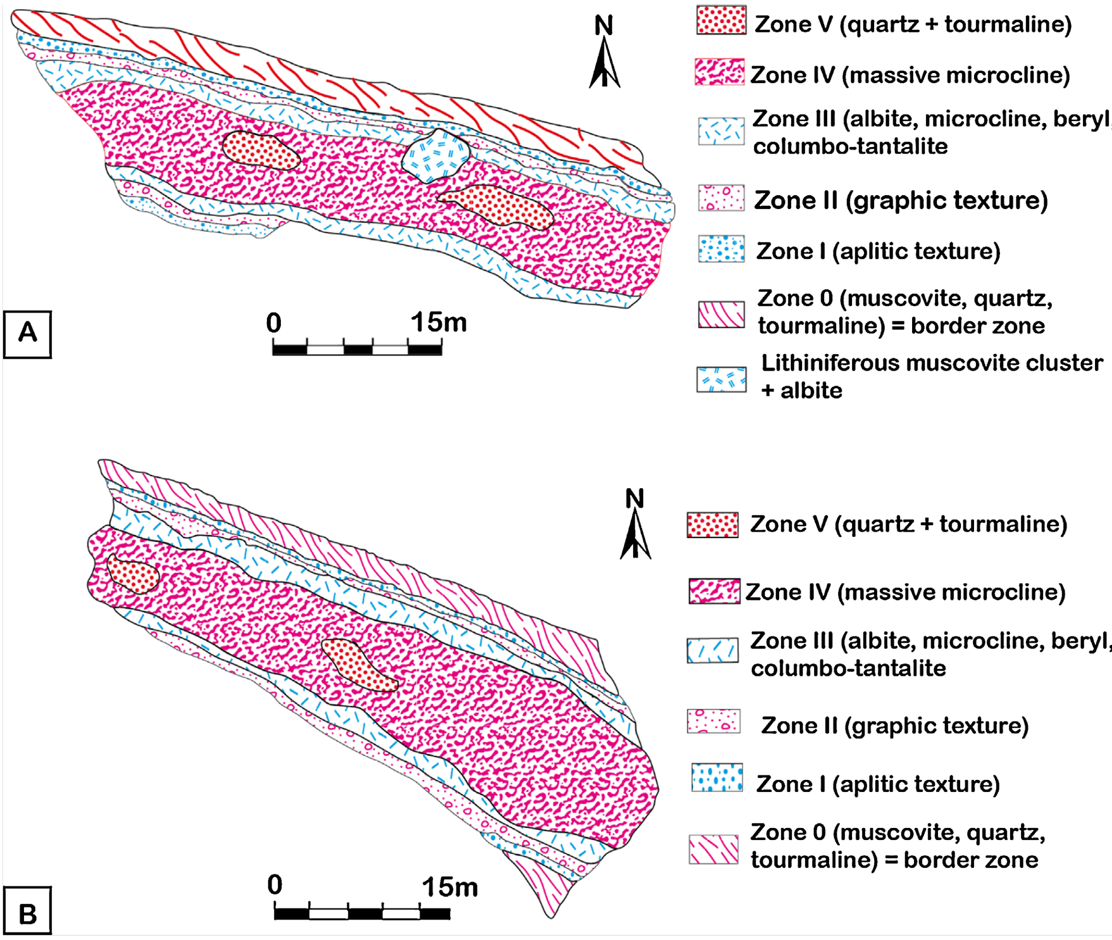

Figure 5. Schematic representation of the internal zonations encountered in the Issia region's pegmatites (A: Bitapia area; B: Lobo area) [6].

The Comoé Basin (**Figure 6**) is characterised by extensive Birimian greenstone belts composed of sedimentary and volcano-sedimentary units and associated with a variety of granitic intrusions [29]. The dominant lithologies in this region include metamorphic rocks such as amphibolite, schists, metasiltstones, metaarenites, and gneisses; and igneous intrusive bodies, notably granites, monzogranites, and granodiorites [30] [31]. Compared to the Issia region, the Comoé granitoid complex is less developed, more limited in areal extent, and often poorly exposed, largely due to the dominance of greenstone belts and the effects of weathering under temperate climatic conditions (**Figure 3**, **Figure 4**, and **Figure 6**). The volcano-sedimentary series is affected by deformation phases D1 to D3 of the Eburnean orogeny, manifested through WNW-trending shortening [32] [33]. Several regional-scale faults and ductile shear zones have been mapped along this NE-SW trend, often at the edges of particular granites. Nevertheless, as in Issia, the region hosts numerous leucogranites, layered mafic-ultramafic intrusions, and late-stage pegmatites with rare-metal potential. These pegmatites are typically associated with granitic intrusions of diverse mineralogical compositions (granite, granodiorite, monzogranite) and also occur within felsic and undifferentiated

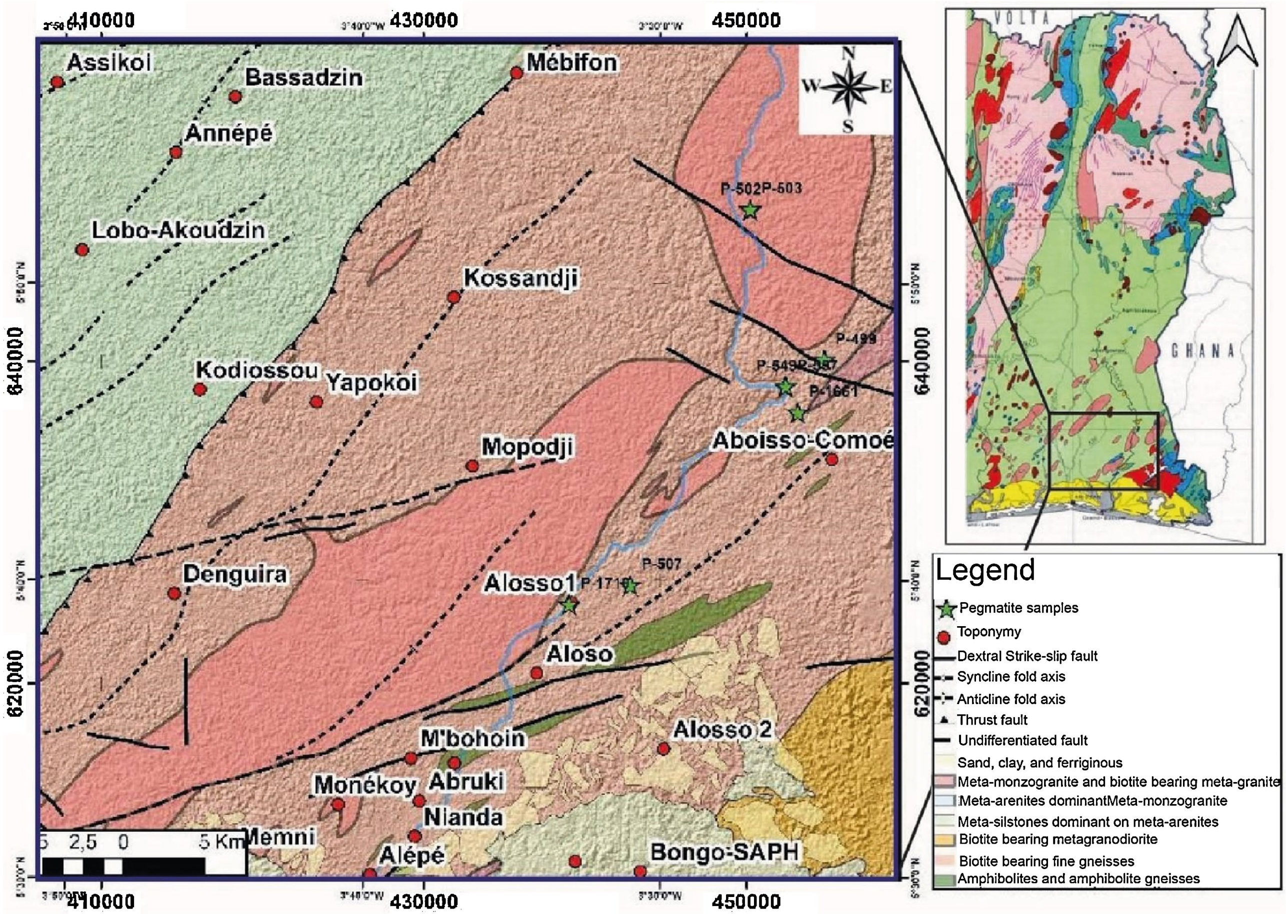

Figure 6. Geological map of the Comoe basin region, including the Agboville area at 1:200 000 (modified after [11] [31]).

schists [14]. Significant outcrops of pegmatites have been identified in this region, presenting much larger mineralogical assemblages than those identified in the Issia area. These can be subdivided into six main types on the basis of these assemblages. These essentially include the 1) muscovite-quartz-albite type, 2) the muscovite-quartz-albite-garnet-rich type, 3) the tourmaline-quartz-albite-muscovite-rich type, 4) the muscovite-quartz-albite-beryl type, 5) the biotite-muscovite-quartz-albite-apatite type, and 6) the spodumene-muscovite-albite type [16] [34].

The Boundiali belt is one of the known Birimian assemblages in the Lower Proterozoic of West Africa [35]. This region comprises a wide range of geological formations including: volcanic and volcano-sedimentary rocks (basalt, andesite lava, mafic and felsic schists) affected by general greenschist-type metamorphism; felsic intrusives (granite, granodiorite, monzogranite, and monzonite); mafic intrusives (gabbro, dolerite, amphibolite); detrital sediments and metasedimentary rocks (undifferentiated shale, metasiltite, metaarenite, quartzite) (**Figure 7**). Shaped during the Eburnean orogeny (ca. 2.2 - 1.8 Ga), this region experienced four main deformation phases [36]-[38]. The earliest, D_1, involved WNW-ESE compression, producing N-S to NNE-SSW-trending foliation, isoclinal folding, and sinistral shear zones, marking intense ductile deformation. This was

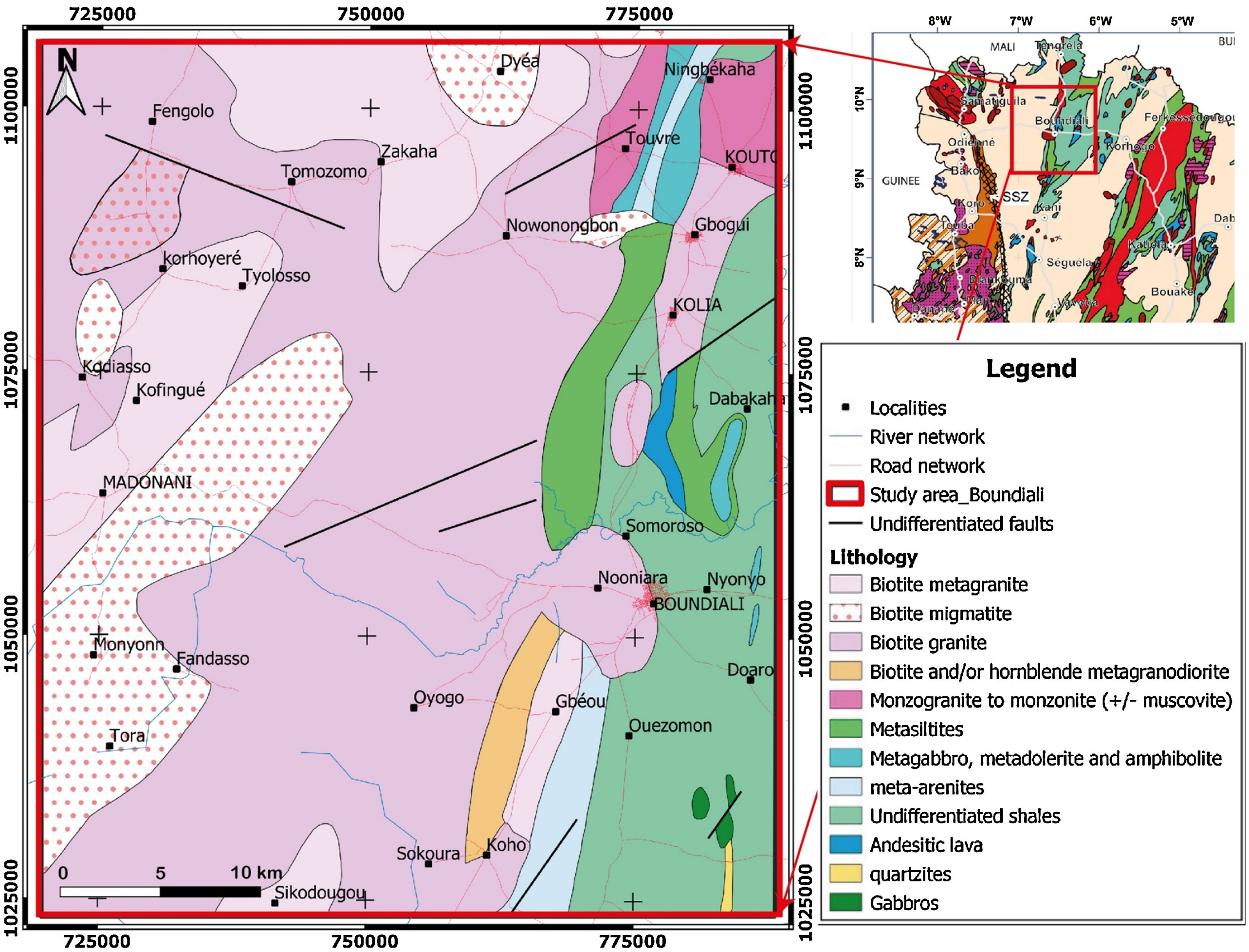

Figure 7. Geological map of the Boundiali area (modified after [31]).

overprinted by D_2, an E-W compressive phase generating NE-SW to ENE-WSW-trending dextral and sinistral transcurrent shear zones and folding of earlier structures. D_3 introduced NNE-SSW transpressional stress, resulting in crenulation cleavage, refolding, and tightening of prior folds, as well as a new set of fractures. The final phase, D_4, is marked by late-stage brittle-ductile deformation, producing NW-SE to NNW-SSE and E-W-trending extensional fractures and faults. This multi-phase evolution is recorded in the region's volcano-sedimentary sequences, granitoids, migmatites, and associated lithologies. Structurally, the area is dissected by five principal fracture orientations (N-S, NNE-SSE, NE-SW, E-W, NW-SE), each linked to a specific tectonic phase. To date, no detailed analysis has been conducted that explicitly links the four recognized deformation phases (D1-D4) to the emplacement and spatial distribution of the five distinct pegmatite types identified in the Boundiali region, highlighting a significant gap in understanding the structural controls on pegmatite evolution in this area. The pegmatites in this region intrude either into parametamorphic formations (primarily amphibolites) or into granites [39]. According to the research conducted by [39] and confirmed during the ATEX Mining Project [17] [40], this area is characterized by five main types of pegmatites, which are: the lepidolite-muscovite-spodumene-columbo-tantalite type, the green mica-columbo-tantalite type, the green beryl type, the muscovite-beryl type, and the biotite-magnetite type. In the Boundiali region, these pegmatites show distinct mineralogical assemblages, host lithologies, and spatial distributions. 1) Lepidolite-muscovite-spodumene-columbo-tantalite pegmatites, regarded as the most lithium-enriched, are concentrated around Spodumene Hill, approximately 3.5 km northeast of Tounvré. These pegmatites occur as aligned and altered blocks hosted in foliated amphibolites (locally granitized) and micaschists, with spodumene commonly associated with purplish lepidolite and columbo-tantalite. 2) Green mica-columbo-tantalite pegmatites are typically found along the contact zones of spodumene-bearing pegmatites and are similarly hosted in micaschists. They are characterized by green mica (likely zinnwaldite or ferroan muscovite) and columbo-tantalite mineralization. 3) Green beryl pegmatites are located in the northern part of the Tounvré pegmatite field, hosted in green mica-bearing pegmatites that contain beryl without associated tantalum phases. 4) Muscovite-beryl pegmatites, on the other hand, are situated in the southwestern sector of the same field and host both beryl and significant columbo-tantalite mineralization, especially concentrated in the eluvial horizon. 5) Biotite-magnetite pegmatites are the most widespread in the southwestern Boundiali zone and are hosted within granitoid terranes composed of biotite granite, metagranite, foliated biotite granite, monzogranite, monzonite, and granodiorite. While generally poor in lithium and tantalum minerals, this pegmatite type is important for understanding the magmatic and structural evolution of the region.

3. Compositional Information for Côte d'Ivoire's Rare-Metal Pegmatites

Recent research on rare-metal pegmatites has increasingly leveraged integrated approaches such as whole-rock geochemistry, mineralogical and textural analysis, in-situ mineral chemistry, and high-precision geochronology to unravel pegmatite petrogenesis and fertility. Notable examples include studies on the world-class Tanco pegmatite (Canada), where electron microprobe and LA-ICP-MS elucidated Li-bearing mineral chemistry (spodumene, petalite, lepidolite, and Li-muscovite) across zoned pegmatite domains [41]-[47], while fluid-inclusion work resolved volatile compositions during magmatic stages [48] [49]. Similar compositional frameworks have been applied to pegmatite fields in Zimbabwe [47] [50]-[52], Brazil [53] [54], Europe with LCT and NYF characterisation and classifications [55] [56], and various other African countries' pegmatite characterization, including Egypt [57]-[60], Namibia [61] [62], Ghana [63]-[65], Mali [66] [67], Burkina Faso [26] [68], etc. In contrast, Côte d'Ivoire, despite its position within the metallogenically fertile Leo-Man Shield, remains at an early stage of pegmatite compositional and geochronological investigations. To date, only a limited number of areas in Côte d'Ivoire, notably the Issia region and the Comoé Basin, have undergone geochemical, geochronological, and mineralogical investigations of rare-metal pegmatites [10] [11]. However, the Boundiali area, despite showing clear economic potential due to the presence of lithium-bearing minerals such as spodumene and lepidolite, as well as beryllium-bearing minerals (beryl), has not yet been the subject of systematic or detailed compositional studies.

3.1. Mineralogical and Geochemical Studies

3.1.1. The Issia Region

The mineralogy of the pegmatites in the Issia region is marked by the presence of Li-rich pegmatites and granite (indicated by the occurrence of spodumene, Li-rich tourmaline, and micas), beryllium-rich pegmatite (beryl minerals), and columbite group minerals (ferrocolumbite, manganocolumbite, ferrotantalite, manganotantalite, and ferrotapiolite), all found in granitic pegmatite and sediments [6] [10] [25] [27]. Centimetric prisms of stony beryl, ranging in color from pale green to white, have been identified in several pegmatites, notably within the Issia granite dome and along the upper Prouhou and Gbéguehi streams [6]. Although columbo-tantalite minerals have not been observed in pegmatitic rocks, their spatial association with beryl is noted. Estimated beryl reserves reach up to 20 tonnes, with a BeO content of 11%. Additional mineralogical occurrences include a tourmalinite with lithiniferous mica (228 ppm Li_2O) associated with beryl-bearing pegmatite, and spodumene mineralisation (9600 ppm Li_2O) within an aplogranitic scree located 3 km south of Zuzua, though no *in situ* spodumene or lepidolite pegmatites have been confirmed to date.

Geochemical investigations using Li_2O assays (flame spectrophotometry, SODEMI laboratory) indicate strong lithium dispersion in soils and alluvium [6]. Whole-rock analyses of various lithologies containing lithiniferous muscovite yielded the following Li_2O concentrations: granites at 280 and 450 ppm; pegmatites ranging from 170 to 1203 ppm (with individual values of 170, 200, 215, 245, 315, 390, and 1203 ppm); tourmalinites at 228 ppm; and greisens showing elevated values between 180 and 4600 ppm (180, 183, 280, 450, 550, 2100, and 4600 ppm). A notably high value of 1360 ppm Li_2O (0.136%) was recorded in large muscovite lamellae from pegmatites. Investigations on pegmatites and host granites in this area (Allou *et al.*, 2004; Brou *et al.*, 2021) reveal three granite series (G1, G2, G3) displaying progressive fractionation and increasing peraluminosity. G1 granites are biotite-rich, metaluminous to weakly peraluminous (A/CNK= 1.00 - 1.16) and geochemically resemble the upper continental crust. G2 and G3 granites are muscovite-bearing, strongly peraluminous (A/CNK> 1.18 - 1.19), and highly evolved, enriched in Be (up to 22 ppm), Cs (57 ppm), Rb (505 ppm), Sn (16 ppm), and Ta (11 ppm), with Nb/Ta ratios<1. G2 is distinguished from G3 by higher Th, Hf, and Zr but lower Cs and Ta. Associated pegmatites and G3 granites contain tourmaline, garnet, and Nb-Ta-rich ilmenite. Complementary geochemical trends include decreasing ΣREE (9.13 - 50.98 ppm), La/Yb ratios (8.29 - 95.86), and K_2O (1.56 - 4.77 wt.%), and increasing Na_2O (3.71 - 6.18 wt.%) from Lobo- to Issia-type granites and pegmatites. Modal evolution is characterized by a decrease in K-feldspar and biotite, and an increase in albite, muscovite, and lithiferous micas. These features support a petrogenetic continuum from granites to pegmatites, with late-stage Li-Cs-Ta-rich melts possibly derived from partial melting of fractionated G3 granites ~40 Ma after emplacement. [10] analyze the columbite-group minerals (CGM) of six placers in the Issia area (mineral chemistry, SEM and EPMA; whole-rock analysis, XRF). The chemical analyses present a wide range of compositions: 12.42 - 81.45 wt.% Ta_2O_5, 2.84 - 66 wt.% Nb_2O_5, 0.72 - 16.09 wt.% MnO, 0.5 - 15 wt.% FeO, 0 - 0.65 wt.% SnO_2, 0 - 0.75 wt.% UO_2, 0.05 - 1.4 wt.% TiO_2, 0 - 0.06 wt.% Sc_2O_3 and 0 - 0.15 wt.% PbO (**Figure 8**). Interpreted analysis of these data in a columbite-tantalite quadrilateral diagram showed all compositional fields of the CGMs for different samples, including ferrocolumbite, manganocolumbite, ferrotantalite, manganotantalite, and ferrotapiolite. This attests to the existence of significant variability in the geochemical elements in these pegmatites, at the origin of the mineralogical and metallogenic diversity observed in these pegmatites.[ph318] These investigations place Issia's columbium-tantaliferous-bearing pegmatite deposits within a genetic framework of compositional trends.

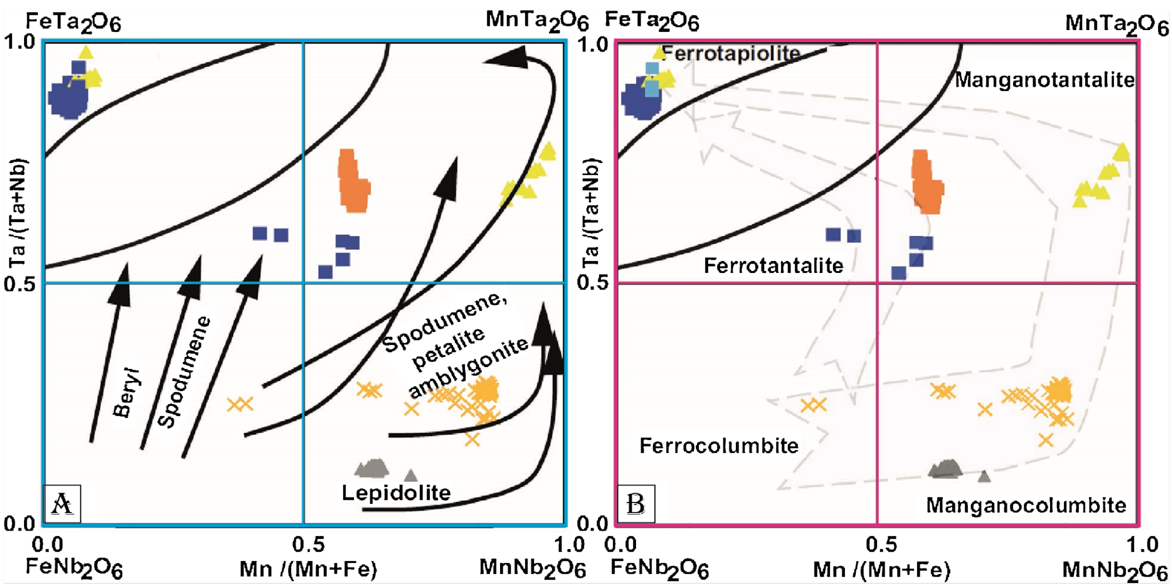

Figure 8. Columbite Group Minerals (CGM) chemical evolution of the Issia area [10].

3.1.2. The Comoé Basin

The Comoé Basin features various metal enrichments, including lithium-bearing minerals such as spodumene, lepidolite, and green micas; beryllium-bearing minerals such as beryl; cesium-bearing minerals, such as pollucite and lepidolite; tantalum-bearing minerals such as columbo-tantalite; and light rare earth elements (LREEs), including La, Ce, Nd, and Pr [6] [11] [16] [34] [69]. Beryl-bearing and spodumene-bearing pegmatites are currently being explored in this region (Atlantic Lithium; Milenium Resources; Khaleesi Resources), highlighting the mineralization potential of the area.

Indeed, initial prospecting efforts on the pegmatites in this region, which led to the discovery of spodumene indications, date back to one of the works conducted by the former Geology and Mineral Prospecting Directorate of Côte d'Ivoire [6]. Its geochemical investigations, including soil geochemistry and portable XRF analyses, have identified a lithiferous zone on the south-eastern margin of the Adzopé massif, north of the Yakassé road. This zone hosts spodumene-bearing muscovite-albite pegmatites, occurring as multiple veins over an area of approximately 1 km². The main vein reaches 4 - 5 m in thickness and 80 m in length, with an average Li_2O grade of 0.09%. In contrast, smaller surrounding veins display significantly higher grades, ranging from 2.0% to 2.8% Li_2O. Additional portable XRF analyses of the Kondiebouman spodumene pegmatite (Agboville region) have reported Li_2O contents between 0.23% and 0.35%. These results have attracted the interest of researchers and mining companies in the pegmatites of this area.

Furthermore, multiple alluvial beryl occurrences have been identified in the Agboville region, along with a beryllium-rich zone of approximately 150 km² and a smaller zone near Karaikro within the Adzopé massif [6]. Probable reserves in the prospected area are estimated at 100 - 200 tonnes of beryl. The highest recorded grades reach 500 - 800 g/m³, though the average content is 10 to 20 times lower. An isolated record grade of 2800 g/m³ was reported from Kpassin (Agboville), but most eluvial occurrences show significantly lower values. Direct exploration of beryl-bearing pegmatites through trenching and pitting yielded a maximum grade of 2.340 g/m³ in a well from the Adzopé region—near the lower limit of economic feasibility. Chemical analyses of gravel fines (<1 mm fraction) from four pits considered berylliferous by standard prospecting methods (50 - 200 g/m³) revealed Be concentrations ranging from 10 to 80 ppm. These values suggest that the fine fractions may host a greater beryl content than is reflected in bulk grade estimates.

[11] conducted a more recent investigation using portable XRF and XRD analyses on pegmatites from the Comoe Basin sector, precisely near the town of Aboisso-Comoé (**Figure 9**). The XRD results confirmed the presence of albite, muscovite, and lepidolite, as well as additional phases such as andesine and phengite. Portable XRF measurements on muscovite samples revealed tantalum concentrations of 50, 150, and 270 ppm, niobium concentrations of 30 and 50 ppm, and rubidium concentrations ranging from 47 to 2697 ppm. In feldspar samples, rubidium contents ranged from 9 to 149 ppm. The K/Rb ratios varied between 26.27 and 91.52. Geochemical diagrams, including K/Rb vs. Rb [70], K/Rb vs. Cs [71], and Rb vs. Sr [72], were used to classify the pegmatites (**Figure 9**). The samples correspond to mineralized pegmatites, with some classified as beryl-type and others as spodumene-subtype. Based on Rb-Sr relationships, some pegmatites were inferred to be emplaced approximately 30 km from their source plutons. XRD analyses also confirmed the presence of lepidolite in muscovite-granite-bearing pegmatites from the Songan Forest and phengite in beryl-muscovite pegmatites

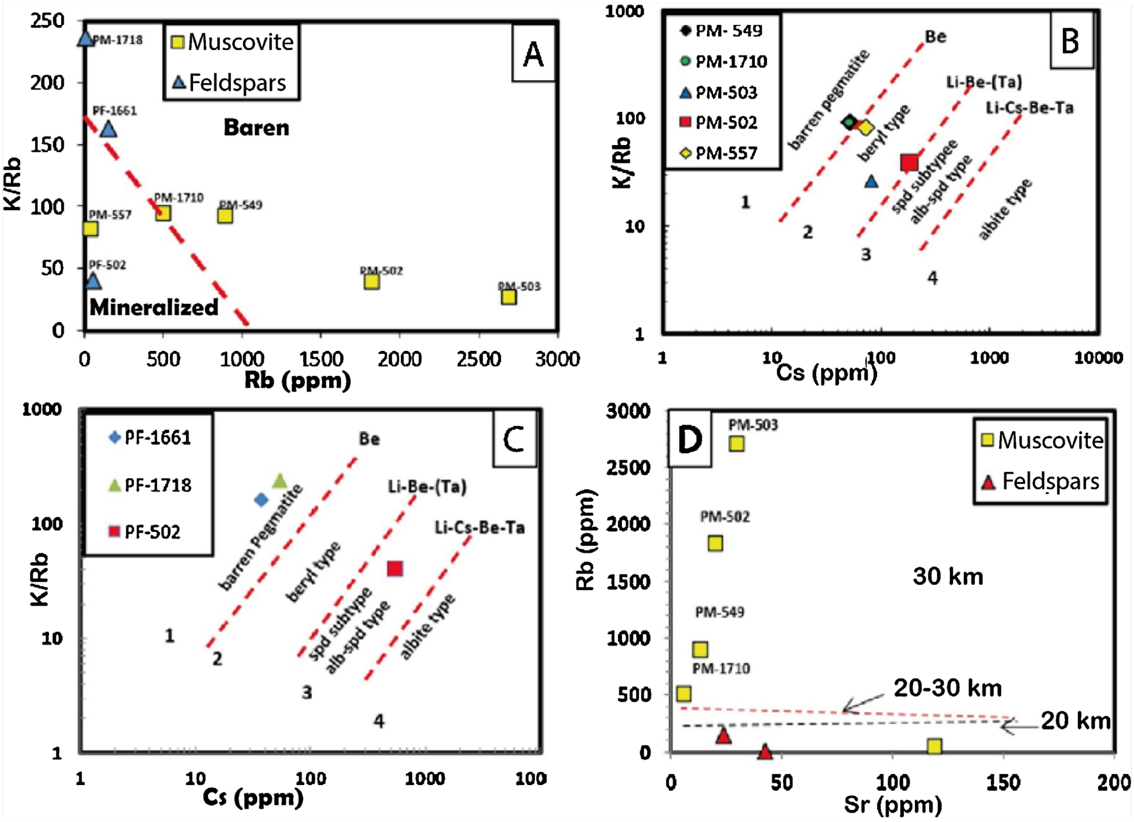

Figure 9. Geochemical diagrams applied to muscovites and feldspars from pegmatites in the south-eastern part of the Comoé Basin [11]. (A) K/Rb versus Rb diagram [70] applied to muscovites and feldspars from pegmatites of the south-eastern part of the Comoé Basin. (B) and (C) K/Rb versus Cs diagrams [71] applied respectively to the muscovites and feldspar from pegmatites in the south-eastern part of the Comoé Basin; (D) Rb versus Sr diagram [72] applied to muscovites and feldspars from pegmatites of the southeastern part of the Comoé Basin.

from the Aboisso-Comoé area. Soil geochemistry and stream sediment sampling conducted by Africa Lithium (2023) in the Agboville region revealed coincident anomalies in beryllium, lithium, cesium, tantalum, and rubidium (**Table 1**). Our recent field investigations carried out in 2025 [34] [69] identified pegmatite outcrops containing spodumene, beryl, apatite, garnet, tourmaline, biotite, muscovite, and green micas (**Figure 10**). These mineral occurrences are spatially associated with leucogranite, granodiorite, monzogranite, and mica schist. The observed mineralogy is consistent with the geochemical anomalies (Li, Be, Cs, Ta, Rb) previously reported by [11] in the same area (**Figure 9** and **Figure 10**). More recent geochemical analyses of soils and spodumene-bearing pegmatite outcrop samples found in the Agboville and Rubino areas highlighted lithium concentrations above 0.2 and up to 1.25% Li_2O [34].

3.1.3. The Boundiali Region

Mineralogical analyses of pegmatites in the Boundiali region [6] [17] [34] [73] have revealed significant lithium mineralization, primarily represented by spodumene, lepidolite, and green micas, particularly in the Tounvre area (**Figure 11**). These lithium-bearing minerals occur within muscovite-rich pegmatites.

Table 1. Summary of significant results (anomalies) from the multi-element analysis of stream sediment samples (modified from [16]; annual report).

Sample ID	Easting	Northing	Cs ppm	Li ppm	Ni ppm	Rb ppm	Ta ppm
GI 1502	378012	648743	1.32	9.6	16	9.42	<5
GI 1507	368087	646746	2.7	11.2	50	11	<5
GI 1510	363512	638841	2.06	11.7	50	10.5	<5
GI 1521	365958	646234	5.74	18.5	20	14.8	<5
GI 1522	368105	646791	2.3	9.3	44	11.1	<5
GI 1523	362825	645950	7.2	26.9	16	17	<5
GI 1525	360548	641113	4.3	14.7	12	15.5	<5
GI 1526	354731	648137	1.6	6.8	16	9.78	<5
GI 1527	354835	649443	1.74	12	16	10.9	<5
GI 1528	354423	650562	0.98	7.5	12	7.56	<5
GI 1529	358861	643679	2.76	10.5	10	10.6	<5
GI 1530	358861	643677	2.64	10	14	10.1	<5
GI 1531	355285	645559	1.44	10.6	18	13.6	<5
GI 1535	360191	646201	3.28	10.4	16	16.1	<5
GI 1536	360692	646239	3.78	13.3	10	12.7	<5
GI 1538	361765	650278	5.14	16.6	8	18.6	<5
GI 1546	368742	651961	5.22	12.4	6	11.1	<5
GI 1551	346632	624137	7.62	30	4	16.8	<5
GI 1554	350916	618661	9.98	26.8	12	81.6	<5
GI 1558	348939	624430	5.04	20.2	8	13.1	<5
GI 1563	350154	633945	1.38	12.3	60	6.62	<5
GI 1569	328391	616083	3.02	8	10	9.12	<5

Additional mineral associations identified in the southern Boundiali area include niobium, tantalum, rare earth elements (REEs), and rubidium, hosted in biotite-magnetite-garnet-xenotime-bearing pegmatites, indicating a diverse and metal-enriched pegmatitic assemblage (**Figure 12**).

In contrast to the more detailed geochemical investigations conducted in the Issia and Agboville regions, geochemical data on the Boundiali pegmatites remain limited and largely restricted to basic soil and stream sediment analyses. Despite this scarcity, available studies have provided important preliminary insights into the geochemical characteristics of the region's pegmatites. According to [6], pegmatites in the Touvré-Kouto area are among the most enriched in rare metals, notably lithium, as indicated by the presence of spodumene, lepidolite, and green micas. Soil sample analyses from this area revealed significant lithium anomalies ranging from 1.07% to 1.9% Li_2O. Based on their mineralogical composition

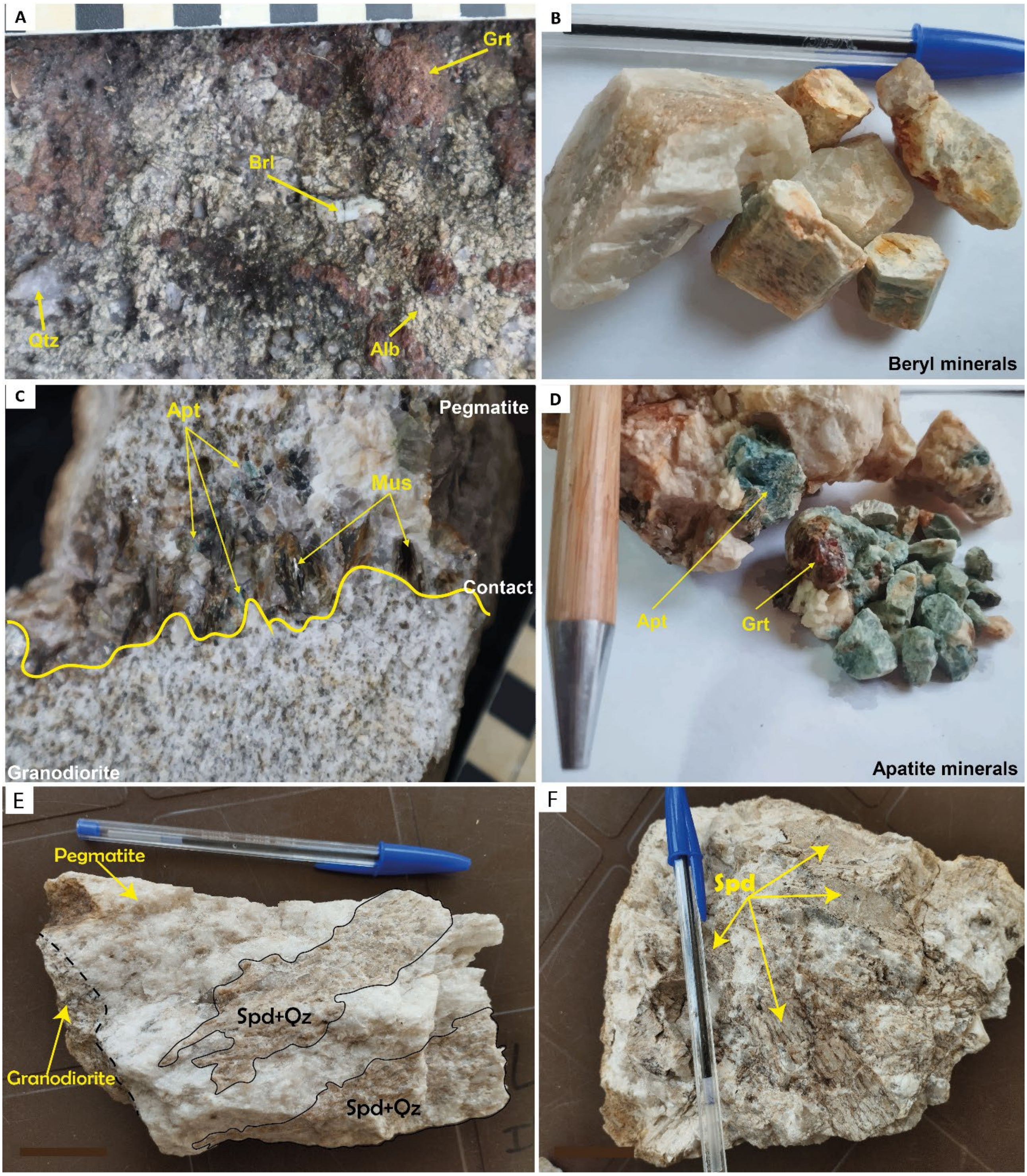

Figure 10. Photograph of pegmatite samples with beryl, apatite, garnet, muscovite, albite, and spodumene minerals (Agboville area) from recent fieldwork (PhD research work) conducted by the research team of the Geology Department at the University Félix Houphouët-Boigny in Abidjan-Cocody [34] [69].

(primary muscovite and biotite content), [6] proposed a classification of the pegmatites into two geochemical types: a "cold type" composed mainly of muscovite, spodumene, and lepidolite, and a "hot type" enriched in biotite, magnetite, allanite, molybdenite, and garnet (Southern Boundiali, **Figure 11**) [69] and (Northern Boundiali, **Figure 12**) [69]. This early typology aligns closely with the current distinction between LCT and NYF pegmatite families, with the "cold type" corresponding to highly fractionated LCT-type pegmatites, characterized by enrichment in Li-bearing phases such as spodumene and lepidolite, while the "hot type" shows affinities with NYF-type systems, marked by biotite, garnet, allanite, and molybdenite mineralization.

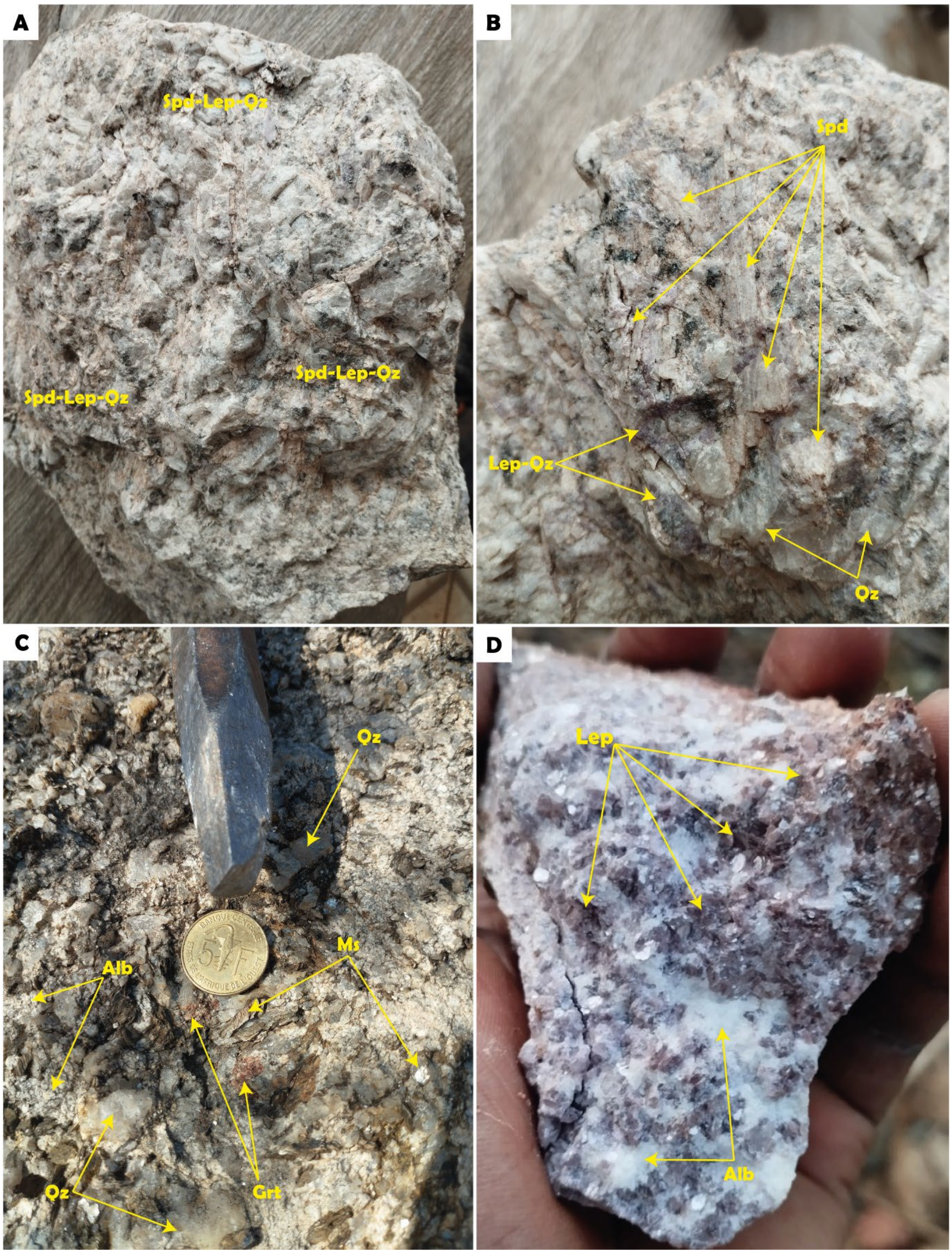

Figure 11. Photograph of pegmatite samples from the northern part of the Boundiali area.

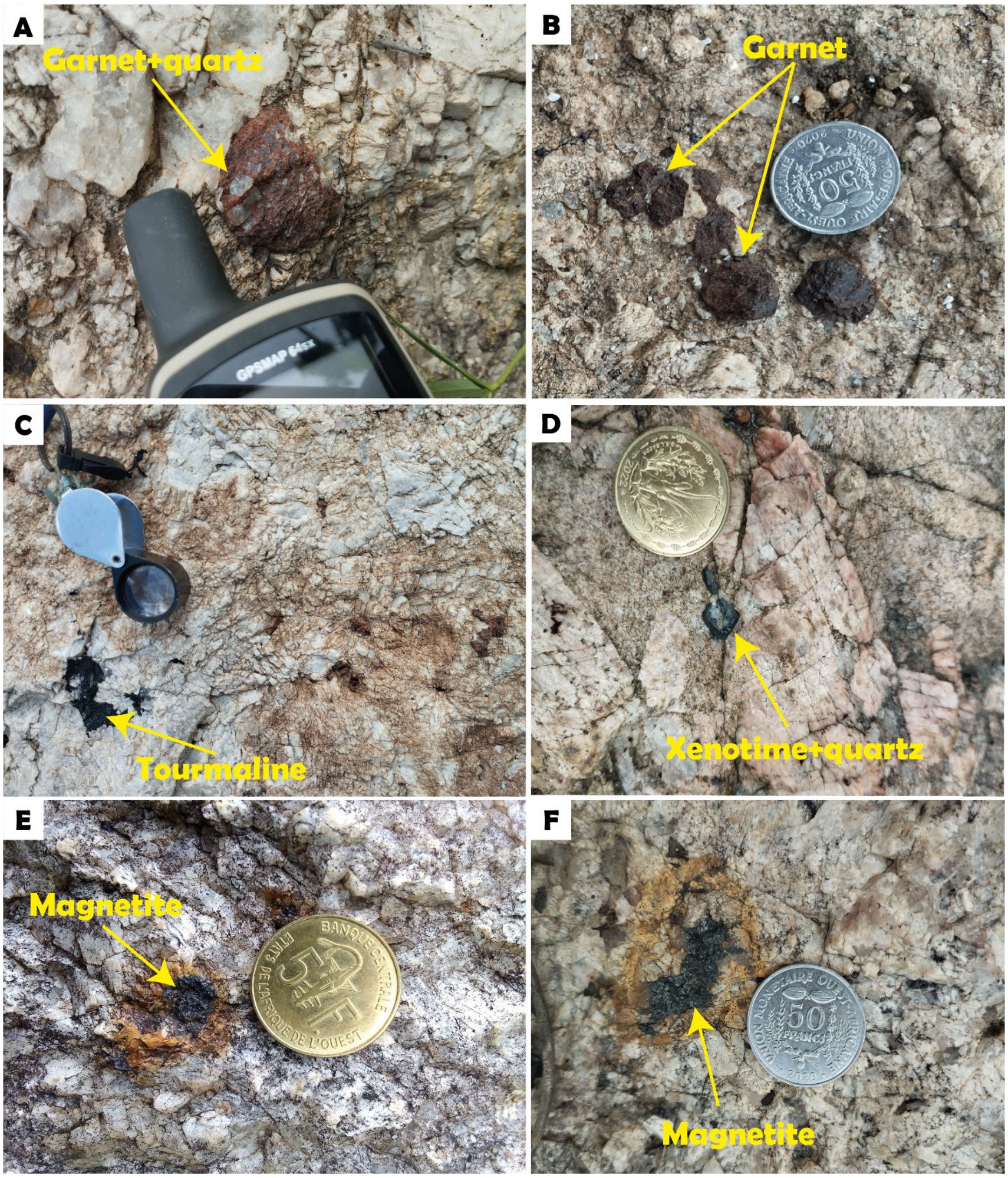

Figure 12. Photograph of pegmatite samples from the southern Boundiali area.

Further geochemical data from the region remain sparse. [73], using atomic absorption spectrometry, identified calc-alkaline pegmatites and reported minor molybdenum anomalies, with average concentrations of 0.0010% and a maximum value of 0.0032%. More recently, geochemical sampling from pegmatite outcrops located 40 km north of Boundiali and approximately 100 km northwest of Korhogo yielded Li_2O contents ranging from 1.42% to 2.01% [40].

Mineralogical association of spodumene, lepidolite, muscovite, quartz, albite, and garnet within pegmatite bodies; from recent fieldwork (PhD research work) conducted by the research team of the geology department at the University Félix Houphouët-Boigny in Abidjan-Cocody [69].

Mineralogical association of garnet, albite, quartz, magnetite, and xenotime within pegmatite bodies: from recent fieldwork (PhD research work) conducted by the research team of the Geology Department at the University Félix Houphouët-Boigny in Abidjan-Cocody [69].

4. Discussion

Côte d'Ivoire, located in the West African Craton, has undergone several tectonic events that have impacted its geological evolution [21]. The Eburnean orogeny, linked to the collision between the West African Craton and the Liberian province, significantly influenced the development of regional structures, which created favorable conditions for pegmatite formation [21]. The structural components of the country's regional geology, such as fold structures, shear zones, and faults, have been interpreted as significant contributors to the formation of rare-metal pegmatites by creating pathways for the ascent of pegmatitic melts to develop pegmatite bodies [11] [74]. The presence of metasedimentary and metavolcanic rocks in the Birimian greenstone belts has also been interpreted to have enhanced the diversity of rare-metal pegmatite occurrences observed in Côte d'Ivoire, with variations in mineralogical compositions shaped by the host rocks.

Derived from peraluminous sources [10], the Issia pegmatites are zonally distributed around this granite, with the fluid responsible for their formation primarily originating from deep-seated sources. Those containing rare elements (columbo-tantalite) are typically surrounded by aplites, demonstrating rapid crystallization along the edges of an allochthonous magmatic bath in a cold environment. The crystallization of these pegmatites may have occurred in a closed system from successive pulsations of the pegmatitic compositional bath. By comparing Issia's CGMs with pre-existing compositions of various types of rare-element pegmatites documented by [75] [76], Issia's CGMs can be associated with two distinct development models: the Li trend featuring only spodumene (SnO_2 content above 0.11%; rich in Sn and found in beryl-columbite pegmatites) and the Li-rich trend that includes spodumene, petalite, amblygonite, and lepidolite (SnO_2 content below 0.07%; Li-rich pegmatites; **Figure 9**). These two categories align with observations by Allou *et al.* (2004), who indicate that a concentric arrangement of pegmatite dikes surrounds the granitic batholith. This petrogenetic relational analysis reveals a broad spectrum of CGM compositions in the Issia region, highlighting the significant variability of geochemical elements in these pegmatites. This variability is, therefore, the origin of the mineralogical and metallogenic diversity observed, imparting notable economic characteristics, such as LCT, NYF, and mixed LCT+NYF, found in this locality. The pegmatites of the Issia region have been interpreted as originating from differentiated residual fluids resulting from the crystallization of the Issia granite [8] [27]. Numerous geochemical studies conducted in various regions, including the Damara Belt of Namibia, the Variscan chain in France, and the Sveconorwegian, have also provided results that support those presented here [77]-[80]. Based on petrographic, structural, geochemical, and geochronological data [10], the Issia rare-metal pegmatites could have formed during a geodynamic process that began with delamination of the lithospheric mantle, triggering asthenospheric upwelling in a context of post-collisional extension. This process led to decompression and partial melting of the pre-existing granite and metasedimentary rocks, both of which were potentially fertile [81]. The resulting magma, enriched in boron (B), phosphorus (P), fluorine (F), and rare metals (lithium, columbo-tantalite, niobium), would have migrated upwards through extensional fractures and then crystallized in the form of LCT-type pegmatite. Although more geochemical and mineral-chemistry analyses are needed to fully evaluate the compositional characteristics of Issia's rare-metal pegmatite occurrences, the analyses conducted so far provide a solid understanding of their key traits. These studies also interpreted a strong petrogenetic link between the pegmatites and three defined granite series of the region. This link facilitates evaluation of the potential correlation between the peraluminous granites and Li-Cs-Ta-rich pegmatites in the southern Issia region (**Figure 9**).

The pegmatites in the south part of the Comoé Basin, particularly in the Agboville and Aboisso-Comoé regions, exhibit compositional and mineralogical features that are broadly consistent with LCT-type pegmatites but show spatial and geochemical variability that warrants closer interpretation. The presence of spodumene, lepidolite, and green micas across several pegmatite bodies, along with elevated concentrations of Li, Rb, Cs, Ta, and Be, points to a highly fractionated magmatic system, likely derived from evolved felsic melts under volatile-rich conditions.

The wide range of Li_2O values, from <0.5% in coarse spodumene pegmatites to >2% in narrower veins [16], suggests that melt evolution was not homogeneous across the region. Instead, localized zones of high-grade mineralization likely reflect variable degrees of melt focusing, volatile saturation, or late-stage fluid enrichment. These spatial differences also correlate with mineralogical zoning, such as the progressive substitution of biotite by muscovite and eventually lithiniferous micas (e.g., lepidolite), which is characteristic of pegmatite fractionation sequences. In addition to lithium, the detection of elevated Ta (up to 0.027%), Nb, and Be (with beryl concentrations exceeding 2,000 g/m^3 in some alluvial sites) reinforces the rare-metal potential of this region. The K/Rb and K/Cs ratios derived from muscovite and feldspar analyses [11] further support the classification of these pegmatites as evolved, with some falling into the spodumene-subtype field. These geochemical indicators also suggest potential proximity to fertile parental granites, although in some cases, the geochemical distance diagrams imply formation up to 30 km from the source, highlighting the mobility and independence of some pegmatitic fluids from their granitic roots. The coexistence of both beryl-type and spodumene-subtype pegmatites, as interpreted from geochemical classification diagrams and field mineralogy [16] [69], indicates a diverse genetic environment. This diversity may be explained by varying degrees of crustal anatexis, melt-rock interaction, and fluid evolution across the basin. The association of beryl with coltan in placer settings, despite its absence in primary pegmatites [6], also points to possible undersampling or post-emplacement remobilization, highlighting the need for more targeted structural and mineralogical investigations. However, despite these compelling indicators, geochemical data for the Comoé Basin remain sporadic and methodologically limited. Most studies rely on portable XRF [11] or bulk soil/sediment geochemistry [16], with very few employing high-resolution techniques such as ICP-MS or *in situ* mineral chemistry [6] [11]. This limitation makes it difficult to rigorously constrain the petrogenesis of the pegmatites or to assess their economic potential beyond preliminary indicators. Moreover, the timing and source of the pegmatite-forming melts remain unresolved due to the absence of geochronological data. Whether these pegmatites represent direct melts from crustal anatexis or evolved offshoots of granitic intrusions remains an open question, one that could have major implications for rare-metal exploration models in the West African Craton.

Compared with the more advanced Ewoyaa pegmatite project in Ghana, the rare-metal pegmatites of the Comoé Basin (Agboville-Rubino areas) in Côte d'Ivoire share notable geological, structural, and compositional similarities, as both occur within the Paleoproterozoic Birimian terranes of the West African Craton and are associated with the Eburnean orogeny. Structurally, pegmatites in both regions are hosted within granitoid and metavolcanic sequences and are predominantly oriented NE-SW to NNE-SSW, with local NW-SE trends, typically emplaced along shear zones or lithological contacts. The Comoé Basin pegmatites can be broadly grouped into two families: (i) granitic pegmatites that lack lithium minerals but are enriched in muscovite, tourmaline, apatite, and beryl, with beryllium and cesium contents reaching ~82 ppm and ~37 ppm, respectively; and (ii) spodumene-bearing LCT-type pegmatites containing coarse to small spodumene crystals, with surface rock-chip assays returning values of up to 1.25 % Li_2O [34]. Soil geochemistry at Rubino has revealed lithium anomalies over a 2.5 × 2.0 km area, supporting the presence of a dual-family pegmatite system. In contrast, the Ewoyaa pegmatites are compositionally similar, comprising albite, quartz, muscovite, spodumene, and lepidolite, but represent a significantly more mature exploration project, with over 100,000 m of drilling completed [82]. The project currently boasts a JORC-compliant Mineral Resource of 36.8 Mt at 1.24 % Li_2O and Ore Reserves of 25.6 Mt at 1.22 % Li_2O. Hence, while both regions exhibit analogous geological and structural frameworks, the Ewoyaa deposit in Ghana stands as a well-defined and economically viable lithium resource, whereas the Comoé Basin pegmatites remain at an earlier, yet geologically promising, stage of investigation.

The Boundiali region in northwestern Côte d'Ivoire hosts a diverse assemblage of rare-metal pegmatites that, despite being relatively underexplored geochemically, display compelling features indicative of a highly evolved magmatic system. The available data point to the presence of LCT-type pegmatites enriched in lithium, tantalum, rubidium, niobium, and rare earth elements, with mineralogical zoning and compositional gradients that strongly suggest advanced magmatic fractionation. Petrographically, the pegmatites range from muscovite-albite-bearing types in the north to more biotite-, magnetite-, and monazite-rich assemblages in the south. This mineralogical zonation reflects the "cold-type" versus "hot-type" classification proposed by [6], based on the biotite and muscovite content, and corresponding respectively to more evolved, lithium-rich pegmatites with muscovite minerals, and less evolved, REE-molybdenum-xenotime-bearing pegmatites with biotite minerals (**Figure 11** and **Figure 12**). These distinctions may reflect differences in melt temperature, oxygen fugacity, or the timing of emplacement relative to host rock deformation and metamorphism. Mineralogical evidence, especially the presence of spodumene, lepidolite, and green lithium micas in the northern Touvré-Kouto sector, confirms the presence of evolved LCT pegmatites. The association of spodumene with muscovite-albite assemblages and its occurrence in discrete veins suggest late-stage magmatic crystallization from volatile-rich melts. Moreover, accessory phases such as garnet, tourmaline, and Nb-Ta oxides, although not systematically documented in primary mineralogy, are likely present based on geochemical enrichment patterns. Geochemically, the region presents clear indicators of fractionated melts. Soil geochemistry and rock assays have revealed Li_2O contents ranging from 1.07% to 1.9% in the Touvré-Kouto area [6], and up to 2.01% in pegmatite outcrops north of Boundiali and northwest of Korhogo [40]. These values are consistent with fertile, highly evolved LCT pegmatites. The classification into "hot" and "cold" types aligns with this geochemical gradient, with "cold-type" pegmatites showing greater enrichment in Li-bearing phases and associated elements such as Cs and Rb, while "hot-type" bodies are more enriched in REEs, Mo, and other high field strength elements.

Additional geochemical work by [73] revealed a molybdenum anomaly, with concentrations averaging 0.0010% and reaching 0.0032%, especially in the southern zones. This REE-Mo enrichment, along with the presence of allanite and monazite, suggests the influence of a separate geochemical fractionation trend, possibly reflecting either source heterogeneity or interaction with metasedimentary country rocks. However, unlike the Issia and Agboville regions, the Boundiali pegmatites suffer from a marked scarcity of detailed whole-rock geochemistry, mineral chemistry, and isotopic data. Most available data are based on soil surveys, stream sediment sampling, and portable XRF analysis. While these methods have provided important preliminary insights, they lack the resolution to characterize fractionation mechanisms, melt evolution paths, or source-rock contributions with certainty. Despite these limitations, the consistency between mineralogical observations and the available geochemical signatures supports a model of progressive magmatic fractionation, possibly from a crustally derived granite or partial melt of metasedimentary material. The Li-Rb-Cs enrichment, coupled with low Nb/Ta ratios observed in similar systems, is compatible with the presence of fluid-saturated, peraluminous granitic melts undergoing prolonged evolution. The spatial distribution of lithium anomalies, averaging beyond 40 km north of

Boundiali, may suggest either a large, unrecognized parental pluton or fluid mobility beyond the immediate pegmatite host rocks.

The pegmatites of the Boundiali region and those of the Bougouni-Goulamina region in southwestern Mali share several geological, structural, and compositional similarities, while also presenting some notable differences [40] [67] [83] [84]. Both regions are located within the Birimian terranes of the West African Craton and are associated with the Eburnean orogeny, which provides a favorable tectono-magmatic environment for the emplacement of LCT-type pegmatites. In terms of structure, pegmatites in both regions exhibit NE-SW (to NNE-SSW) orientations, with steep to subvertical dips; in the Bougouni-Goulamina area, additional NW-SE-trending dykes are also observed. The pegmatites in both regions can be broadly grouped into two main families. The first family consists of granite-derived pegmatites composed of K-feldspar, albite, muscovite, garnet, and tourmaline, but typically devoid of lithium-bearing minerals. In Boundiali, these pegmatites appear relatively undeformed, whereas in the Bougouni-Goulamina region, they are often affected by folding and structural deformation. The second family comprises coarse-grained, LCT-type pegmatites enriched in spodumene and other lithium-bearing minerals such as lepidolite, green micas, and petalite, and displaying significant mineralogical differentiation. In the Bougouni-Goulamina field, these two families are well-characterized, and numerous lithium-rich bodies have been extensively evaluated, with published resource estimates. The Bougouni Lithium Project currently holds a JORC-compliant resource of 31.9 Mt at 1.06% Li_2O [83], while the Goulamina Project reports a significantly larger resource of 211 Mt at 1.37% Li_2O, with ore reserves of 52 Mt at 1.51% Li_2O [84]. These figures underscore the maturity and economic significance of the Mali pegmatite field compared with the early-stage exploration status of the Boundiali region. Although exploration is still at an early stage in the Boundiali region, both non-lithium granitic pegmatites and spodumene-bearing lithium-rich pegmatites have been identified, confirming the presence of a similar dual-family system. Preliminary fieldwork and geochemical analyses in Boundiali have revealed spodumene-rich pegmatites with lithium contents reaching up to 1.25% Li_2O, alongside tourmaline- and mica-rich pegmatites lacking lithium phases, highlighting the region's promising potential for rare-metal enrichment and the need for further detailed investigation.

From an exploration standpoint, the occurrence of pegmatites with Li_2O contents exceeding 1.25%, coupled with mineralogical zoning and confirmed spodumene occurrences, underlines the strategic potential of the Boundiali region for lithium resource development. However, the current lack of precise geochronological and high-resolution geochemical datasets hinders the delineation of fertile versus barren pegmatites and the assessment of their economic viability.

Indeed, the emplacement of pegmatites, especially rare-metal pegmatites, is interpreted to be generally influenced by a combination of factors. These factors include tectonic settings, crustal dynamics, regional geological features, and local geological controls, which affect their formation processes and the concentration of rare elements [79] [5]. While studies conducted over many years have interpreted pegmatite emplacement as part of a relatively continuous process of magmatic crystallization [28] [49] [79] [85] [86], more recent analyses involving petrological modeling, detailed geochemical, structural, and especially geochronological methods have made these interpretations significantly more complex [5] [64] [87]. It has been consistently demonstrated that regions with significantly higher metamorphic activity (high-grade metamorphic belts) can host highly fractionated pegmatites resulting from partial melting and metasomatism associated with metamorphic processes [5] [79] [87]. However, the processes leading to the formation of economic deposits, such as lithium-bearing pegmatites, remain particularly enigmatic. This is particularly true regarding the precipitation of lithium ores (spodumene), which, based on experiments and model simulations, requires lithium concentrations in the melt to exceed 5000 ppm, approximately 500 times the levels found in the upper crust [87]. This result cannot be accomplished through typical magmatic processes or a single metamorphic event. These significant gaps between the effectiveness of magmatic and metamorphic processes and the emplacement of pegmatites complicate the understanding of rare-metal pegmatite formation, making the geodynamic emplacement model of these pegmatites even more intriguing.

Aiming to define the available background information that will facilitate more focused research to broadly identify the mineralization characteristics of pegmatites across Côte d'Ivoire, this paper effectively highlights the necessary and significant information related to key previous work. This information creates a compelling and robust database that will serve as an excellent foundation for future research, particularly our ongoing PhD studies, which focus on the litho-structural setting, geochronological aspects, and compositional characteristics related to the mineralization of rare-metal pegmatites in the Boundiali and Agboville regions. This research will significantly enhance our understanding of the Boundiali and Agboville pegmatites through analyses of petrography, structural features, mineralogy, geochemistry, mineral chemistry, and geochronology, highlighting the following:

- Detailed mapping of pegmatites and their metal distribution in this region.
- compositional characteristics through petrography, mineralogy, and mineral chemistry to assess mineralogical composition and distribution, and evaluate rare-metal potential;
- Whole-rock chemistry to analyze rock composition, identifying magmatic and metamorphic events responsible for lithium and other rare-metal enrichment in the pegmatites of target zones;
- Lithium exploration and assessment of potential resources (economic viability of lithium resources) through detailed mineralogical and chemical studies (LIBS, ICP-MS);
- geochronological analyses (U-Pb on zircon, monazite, or columbite-tantalite)

to determine timelines and genetic connections between the pegmatites and their potential parent rocks, as well as the emplacement ages of rare-metal pegmatites in relation to the formation of the West African Craton;

- Comparison of the data with emerging LCT pegmatite fields worldwide (such as Manono and Arcadia in the DRC) could provide comparative frameworks for evaluating economic potential.

5. Conclusions

This review highlights the compositional diversity, fractionation trends, and rare-metal potential of pegmatites across three key regions of Côte d'Ivoire: Issia, the southern part of the Comoé Basin, and Boundiali. The Issia area stands out as a coherent and well-differentiated granitic-pegmatitic system, marked by strong peraluminosity and enrichment in tantalum, beryllium, cesium, and lithium. The genetic continuum from evolved granites to rare-metal pegmatites is well supported by geochemical and geochronological data, and the confirmed presence of columbite-tantalite and spodumene-bearing pegmatites attests to the region's proven economic significance.

In the southern part of the Comoé Basin, pegmatites display many features typical of evolved LCT systems, including complex mineralogy, high rare-metal contents, and geochemical indicators of advanced magmatic evolution. However, uncertainties remain regarding their precise origin and classification. Addressing these gaps will require more integrated and high-resolution studies, particularly in mineral chemistry, structural geology, and melt inclusion analyses.

The Boundiali pegmatite field represents an underexplored but highly promising segment of the Leo-Man Shield pegmatite belt. Preliminary data point to significant Li-Cs-Ta and Rb enrichment, with mineralogical zoning and geochemical signatures indicative of fractionated LCT-type systems. However, due to limited analytical resolution and sparse isotopic data, the genetic models remain only partially constrained.

Taken together, these three regions form a metallogenically diverse and evolutionarily significant pegmatite province with clear implications for the exploration of strategic metals. Advancing our understanding of their genesis and resource potential will depend on multidisciplinary approaches combining petrography, whole-rock and *in situ* geochemistry, geochronology, and structural mapping, particularly in regions where current data remain fragmentary. This integrated framework will be critical for classifying these pegmatites within global rare-metal systems and assessing their role in the transition to a sustainable, resource-secure future.

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Declarations

This review paper has been written entirely without financial connotation or interest by the first author, with significant pedagogical input from the four co-authors. The first author is also covered by the Pan-African Scholarship offered by the African Union Commission, which provides him with access to several benefits, including research facilities with suitable conditions, such as a monthly stipend, accommodation in the host country (Nigeria, Ibadan), computer rooms with high-speed internet access, and a specialist library for documentation. The institution declares, however, that it has no (financial) interest in the work of its students, other than to help them carry out their research to promote the technological and scientific development of African nations through the results of these students' work.

Data Availability

The authors declare that the data supporting the results of this study are available in the article, in the supplementary information files, and are referenced throughout the article and in the reference list. You can obtain the relevant documents by consulting the references below.

Conflicts of Interest

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

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