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Lithium Mineralization in Basement Rocks of the Kusaki Area, North-Central Nigeria

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Abstract

Lithium mineralization within the Nigerian Basement Complex remains underexplored despite increasing global demand for lithium resources. This study investigates the lithological characteristics and lithium enrichment of basement rocks in the Kusaki area, North-Central Nigeria (Southeastern part of Federal Capital Territory), using an integrated petrographic and spectroscopic approach. Fifteen representative samples, comprising gneiss, calc-silicate rocks, and pegmatites, were analyzed through thin-section petrography, Fourier Transform Infrared Spectroscopy (FTIR), and Ultraviolet–Visible (UV–Vis) spectroscopy. Field relationships have shown that the pegmatites are hosted by high-grade metamorphic rocks. Petrographic study, on the other hand reveals that the pegmatites are, as expected characterized by very coarse grains dominantly of quartz, feldspars, and ubiquitous muscovite, indicative of crystallization from volatile-rich, highly evolved granitic melts. FTIR spectra show consistent absorption bands between ~600 and 1502 cm^{-1}, including prominent features at ~670–672 cm^{-1} and 710–712 cm^{-1}, corresponding to Li–O vibrational modes reported for lithium-bearing silicate phases. UV–Vis analyses further reveal systematic absorption bands in the 254–260 nm range across all pegmatite samples, consistent with electronic transitions associated with lithium incorporation in silicate and oxide matrices. The uniformity of the petrographic

and spectroscopic signatures indicates pervasive lithium enrichment rather than localized mineralization, suggesting a common magmatic–hydrothermal origin linked to late-stage fractionation of Pan-African granitic magmas. These results provide new evidence for lithium-bearing pegmatites within the southeastern FCT and highlight the Kusaki area as a prospective target for rare-metal exploration within Nigeria's crystalline basement.

Keywords: Lithium, Mineralization, Basement Rocks, Kusaki Area, North-Central Nigeria.

Introduction

The study area (Fig. 1) is situated at Kusaki, Kuje, in the southeastern Federal Capital Territory (FCT), Abuja, between latitudes 8°46′30″–8°50′00″N and longitudes 7°24′15″–7°27′45″E. The area is underlain predominantly by crystalline rocks of the North-Central Nigerian Basement Complex, which forms part of the Pan-African mobile belt and records multiple Pan-African orogenic, metamorphic, and tectonic events. Lithologies within the FCT include granite gneiss, migmatite, quartzo-feldspathic gneiss, marble, and undifferentiated schist, while Lower Turonian Nupe Sandstone covers less than 5% of the area (Agunleti & Arikawe, 2014).

Lithium occurs predominantly as a trace element in geological materials, typically at parts-per-million (ppm) levels. Average lithium concentrations are approximately 1.6 ppm in the Earth's mantle and 4.3 ppm in the oceanic crust (Sun & McDonough, 1989), increasing to about 20 ppm in the upper continental crust (McLennan, 2001). This distribution ranks lithium as the 30th most abundant element in the crust, with an abundance lower than copper but higher than lead, tin, and silver (Upadhyay, 2025). Economically significant lithium mineralization is mainly associated with lithium–cesium–tantalum (LCT) pegmatites, hosted in coarse-grained granitic rocks. The principal lithium-bearing minerals are spodumene and petalite (lithium aluminum silicates) and lepidolite (potassium lithium aluminum silicate). In sedimentary settings, lithium is chiefly hosted by the clay mineral hectorite (Kadir *et al.,* 2025).

Although Nigeria is not currently recognized as a major global lithium producer, active mining and substantial lithium occurrences indicate significant potential to contribute to global supply. Economically viable lithium mineralization—critical for lithium-ion battery production used in electric vehicles and consumer electronics—has been identified in several states, including Kwara, Plateau, Oyo, Kaduna, Kogi, Cross River, Nasarawa, and Ekiti. Preliminary assessments show that the grades of Nigerian lithium-bearing ores are comparable to those of established global lithium producers (Oniowo *et al.,* 2026). The occurrence of lithium within the Kusaki area may be linked to the ongoing artisanal mining activities.

Despite the recognized lithium potential of the Nigerian Basement Complex, detailed geological and geochemical investigations of

lithium mineralization within the southeastern FCT, particularly the Kusaki area, remain limited. The Pan-African basement architecture, coupled with the presence of granitic and pegmatitic lithologies and evidence of artisanal mining, suggests a favorable geological setting for lithium enrichment. This study therefore aims to principally differentiate the rock types in the areas and determine the lithium concentrations in them using integrated petrographic and spectral analyses approach. The findings are expected to contribute to a better understanding of lithium prospectivity in the FCT and provide baseline data to support future exploration and resource evaluation in Nigeria's crystalline basement.

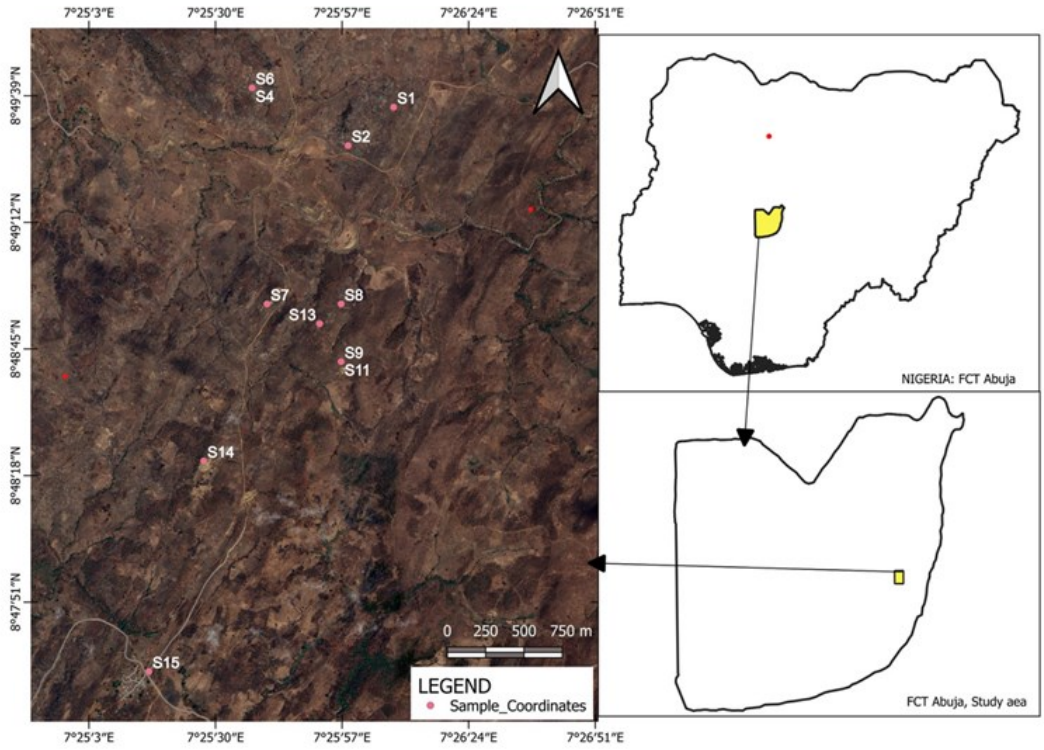


Figure 1: Map of Nigeria showing the study area

GEOLOGICAL SETTING

Nigeria is located within the Pan-African mobile belt, bounded by the West African Craton to the west and the Congo Craton to the southeast. The adjoining cratonic blocks were stabilized during the Eburnean orogeny (~2.0 Ga), with Archean nuclei of Liberian/Leonian age (~2.5 Ga), while the mobile belt records polycyclic deformation marked by Archean tectonism and subsequent Eburnean and Pan-African orogenic events (~600 Ma) (Turner, 1983; McCurry, 1971; Dada, et al., 2024; Tijjani, 2023).

The geology of Nigeria comprises three principal litho-petrological units: the Precambrian Basement Complex, Jurassic Younger Granite complexes, and Cretaceous–Tertiary sedimentary basins (Fig. 2). The Basement Complex consists of the Migmatite–Gneiss

Complex, Schist Belts, and Pan-African Older Granites, whereas the Younger Granites form Jurassic ring complexes concentrated around Jos and parts of north-central Nigeria and are petrologically and structurally distinct from the Older Granites. The sedimentary basins include the Niger Delta, Benue Trough, Anambra, Sokoto, Chad, Dahomey, and Mid-Niger (Bida–Nupe) basins.

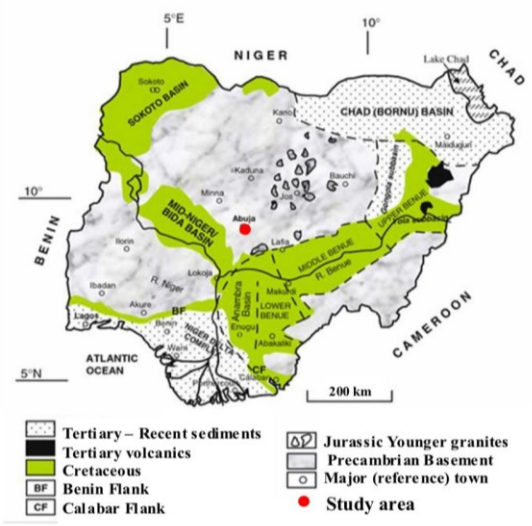


Figure 2: Geological map of Nigeria showing the study area (Obaje, 2009)

Pegmatites of granitic affinity are well known for hosting rare metals and gemstones, including Ta, Nb, Be, and Li (London, 2016; Linnen *et al.,* 2012; Beskin and Marin, 2020). In Nigeria, pegmatite-hosted mineralization within the Basement Complex occurs along an extensive belt from Iregun in the southwest through Ago-Iwoye to north-central Nigeria (Fig. 3), commonly occupying fracture- and shear-controlled zones (Chukwu and Obiora, 2021; Kolawole *et al*., 2025; Melcher *et al*., 2017).

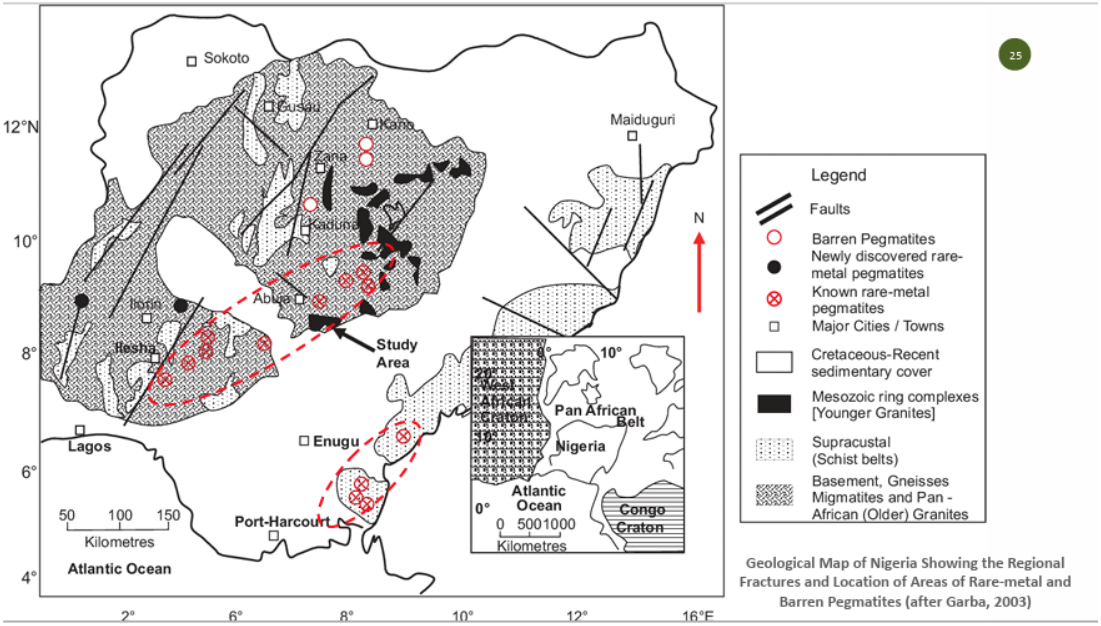


Figure 3: Geological map of Nigeria showing pegmatite distribution and regional fracture patterns (modified after Gideo, 2022).

Basement Complex

The study area (Fig. 4) is underlain by the Precambrian Nigerian Basement Complex, comprising the Migmatite–Gneiss Complex, Schist Belts, and Pan-African Older Granites. The Schist Belts consist mainly of metasedimentary and metavolcanic assemblages with associated gneisses, intruded by Older Granites including granite, syenite, pegmatite, gabbro, diorite, charnockite, and dolerite bodies (Belt *et al*., 2024; Obaje, 2009; Nazir *et al*., 2022). Jurassic intracratonic rifting within the crystalline basement led to the emplacement of the Younger Granite complexes, which are petrologically and temporally distinct from the Older Granites (Hunziker *et al.,* 2009; Leake, 1990; Haapala *et al.,* 2005). The Nigerian Basement Complex records polycyclic tectono-metamorphic evolution, culminating in the Pan-African orogeny (~600 Ma) related to collision between the West African Craton and the Pharusian continental margin. Earlier deformation events include the Liberian (~2.7 Ga), Eburnean (~2.0 Ga), and Kibaran (~1.1 Ga) cycles, followed by intense deformation, isoclinal folding, regional metamorphism, and widespread migmatization and granitization (Dada et al., 2024). Late- to post-tectonic emplacement of granites and granodiorites, accompanied by contact metamorphism, marked the waning stages of the orogeny, which terminated with extensive faulting and fracturing (Hutton, 1988; Leake, 1990; Nweke, 2025). In western Nigeria, schist belts are extensive and host gold and rare-metal mineralization within pegmatites and quartz veins, commonly localized along major regional fracture systems (Oyibamiji *et al.,* 2018; Kolawole *et al*., 2021; Babatude, 2021). While many fertile and barren rare-metal pegmatites are genetically linked to Pan-African granites, pegmatites in the present study area are hosted by metamorphic gneissic rocks, indicating a distinct structural and lithological control on mineralization.

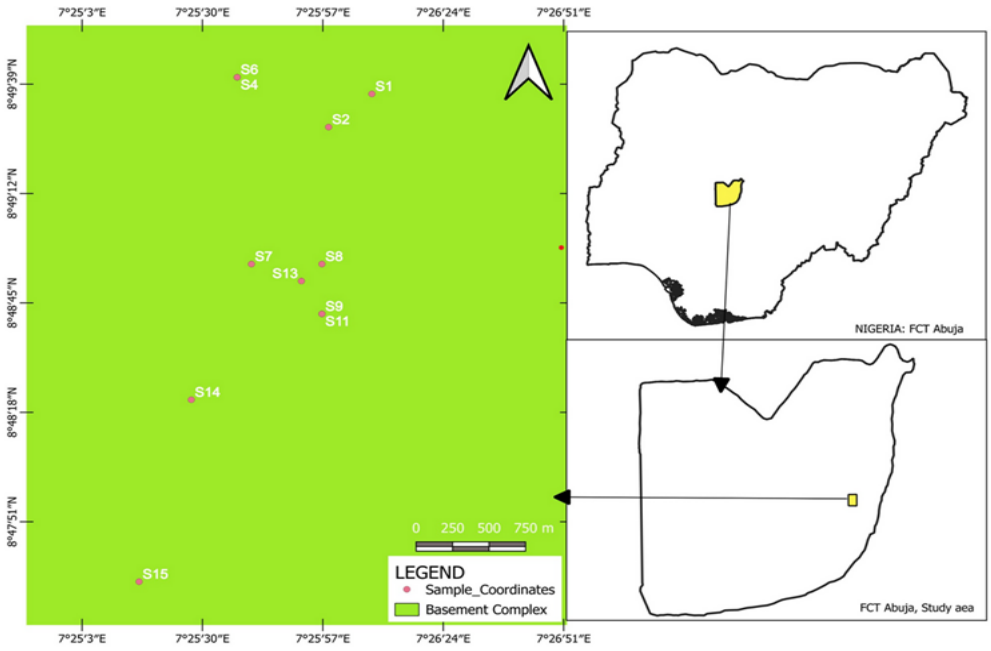


Figure 4: Geological map of the study area

Pegmatites are coarse-grained igneous rocks of predominantly granitic composition, distinguished by exceptionally large, irregular crystals and common skeletal, graphic, or strongly directional growth textures (London, 2016). They typically occur as dykes, lenses, and veins spatially associated with large felsic plutons. Their extreme crystal coarseness is attributed to volatile- and flux-rich magmas that suppress nucleation while enhancing ionic diffusion, resulting in the growth of fewer but larger crystals during late-stage fractional crystallization of fertile granitic melts (London, 2014). Although pegmatites are widespread, lithium-bearing pegmatites are relatively rare (Kesler, *et al*., 2012). Historically, they have been a principal source of lithium; however, their global contribution has declined due to the increasing dominance of continental brine deposits, particularly in South America (Munk, 2016). The origin and enrichment mechanisms of lithium in pegmatites remain debated, reflecting complex evolutionary pathways that may involve magmatic fractionation, magma mixing, metamorphic processes, and partial melting of enriched source materials, modulated by evolving pressure–temperature conditions and melt chemistry (Martin and De Vito, 2005; Koopmans et al., 2024; London, 2016).

Petrographic Analysis

Thin sections of selected host rocks and pegmatites were prepared and analyzed at the University of Malaya, Kuala Lumpur. Fifteen samples (nine country rocks and six pegmatites) were examined under petrological microscope using both plane-polarized light (PPL) and crossed-polarized light (XPL) to determine the mineral assemblages, texture , and structural relationships as well as to constrain the petrological evolution.

to determine mineral assemblages, textures, and structural relationships, and to constrain lithology and petrogenetic evolution.

Fourier Transform Infrared Spectroscopy (FTIR)

Powdered pegmatite samples were analyzed using Fourier Transform Infrared Spectroscopy (FTIR) in transmission mode over the spectral range of 400–4000 cm^{-1} to characterize mineralogical composition and structural features. Analyses were conducted at the Central Analytical Laboratory, Universiti Teknologi PETRONAS.

Ultraviolet–Visible Spectroscopy (UV–Vis)

The optical properties of the powdered samples were measured using an Agilent Cary 60 UV–Vis spectrophotometer in absorbance mode over the wavelength range of 200–800 nm at room temperature. The analyses were performed at the Chemistry Laboratory, Universiti Teknologi PETRONAS, to assess lithium-related optical responses in the pegmatite samples.

RESULTS AND DISCUSSIONS

The field observations indicates that the Kusaki area is underlain by gneiss, pegmatite, and calc-silicate lithologies, with pegmatites hosted within gneissic units. FTIR spectra exhibit characteristic absorption bands between ~600 and 1502 cm^{-1}, consistent with previously

reported pegmatite signatures (Eeckhout et al., 2002; Bosi et al., 2021; Łodziński et al., 2005). All six pegmatite samples display this spectral range. UV–Vis analyses show absorption features between 200 and 360 nm, indicative of lithium-bearing phases and consistent with published lithium spectral responses (Saran, 2022; Zhang et al., 2025). Detailed results are presented and discussed in the following subsections.

Petrographic Analysis

Photomicrograph of the calc-silicate rock, showing a mineral assemblage dominated by calcite, quartz, nepheline, and accessory phases as shown in figure 3. The host rock samples (S1, S2, S3, S6, S7, S11, S14, and S15; Figures 4 and 5) display gneissic textures characterized by weak foliation and medium- to coarse-grained mineral assemblages dominated by quartz, biotite, plagioclase, K-feldspar, hornblende, microcline, muscovite, and accessory phases, consistent with metamorphic gneiss.

Pegmatite samples (S4, S5, S8, S9, S10, and S12; Figures 6 and 7) consist mainly of quartz, plagioclase, muscovite, and accessory minerals, and exhibit extremely coarse-grained textures diagnostic of pegmatitic crystallization. These assemblages are comparable to mineralized pegmatites reported from various literatures (Chakraborty and Upadhyay, 2020; Simmons et al., 2024; London, 2016). The ubiquitous presence of muscovite in all pegmatite samples suggests a genetic association with lithium and other rare-element enrichment, consistent with previous studies (London, 2016).

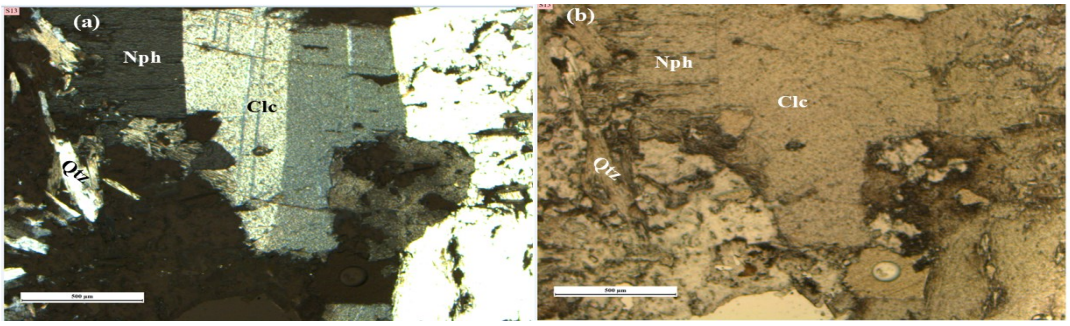
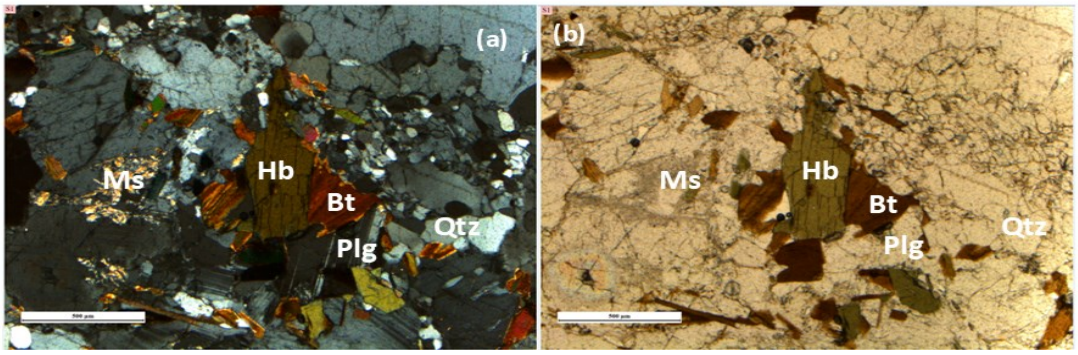


Figure 3: Photomicrographs of S13 (calc-silicate) in crossed polarized light (a) and plane polarized light (b) showing, quartz (Qtz), and Calcite (Clc) and nepheline (Nph).



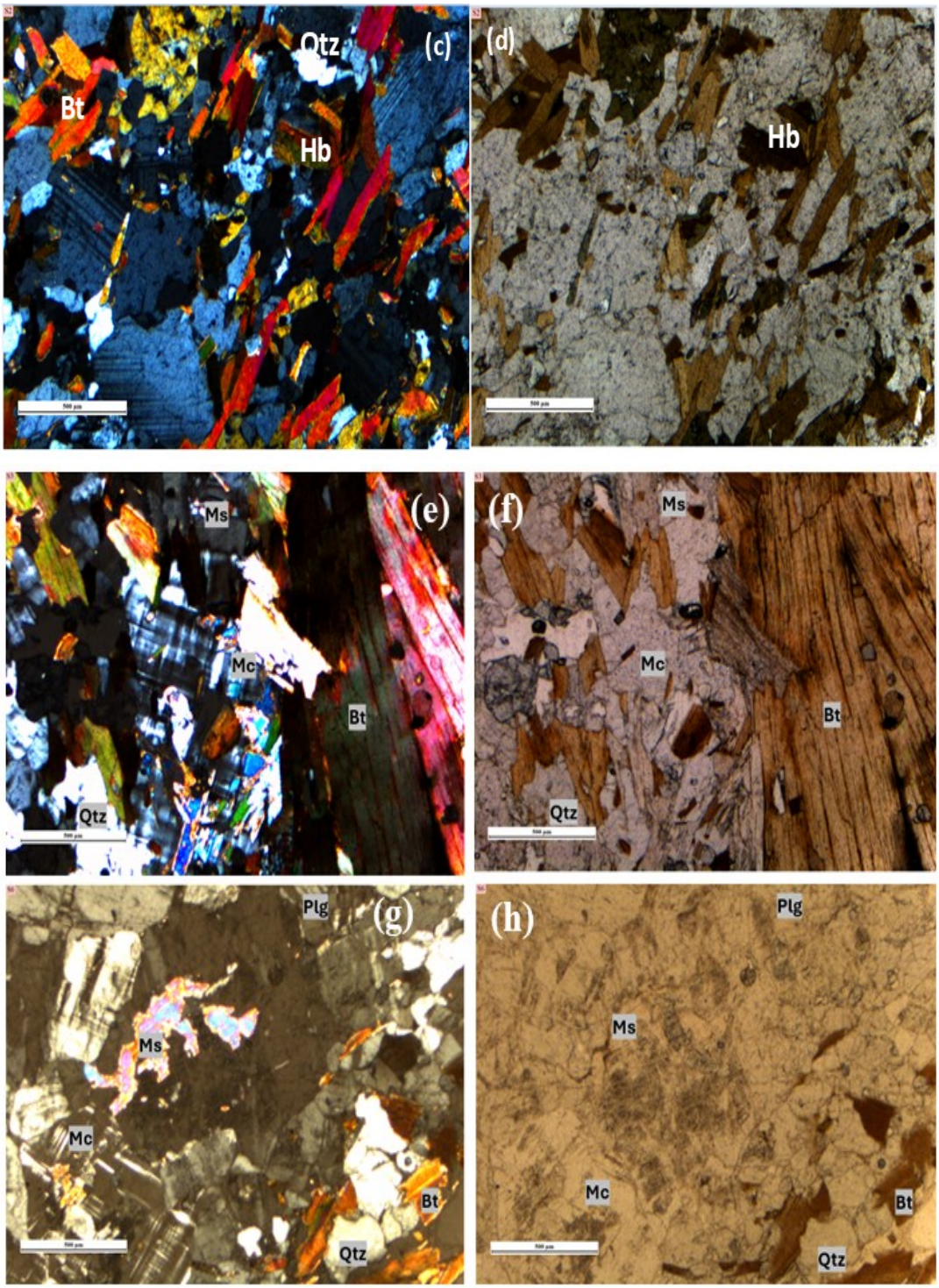


Figure 4: Photomicrographs of country rocks samples (a, c, e, and g) in crossed polarized light (left) and plane polarized light (b,d,f, and h) showing, quartz (Qtz), plagioclase feldspar (Plg), microcline (Mc), biotite (Bt), muscovite (Ms) and hornblende (Hb)

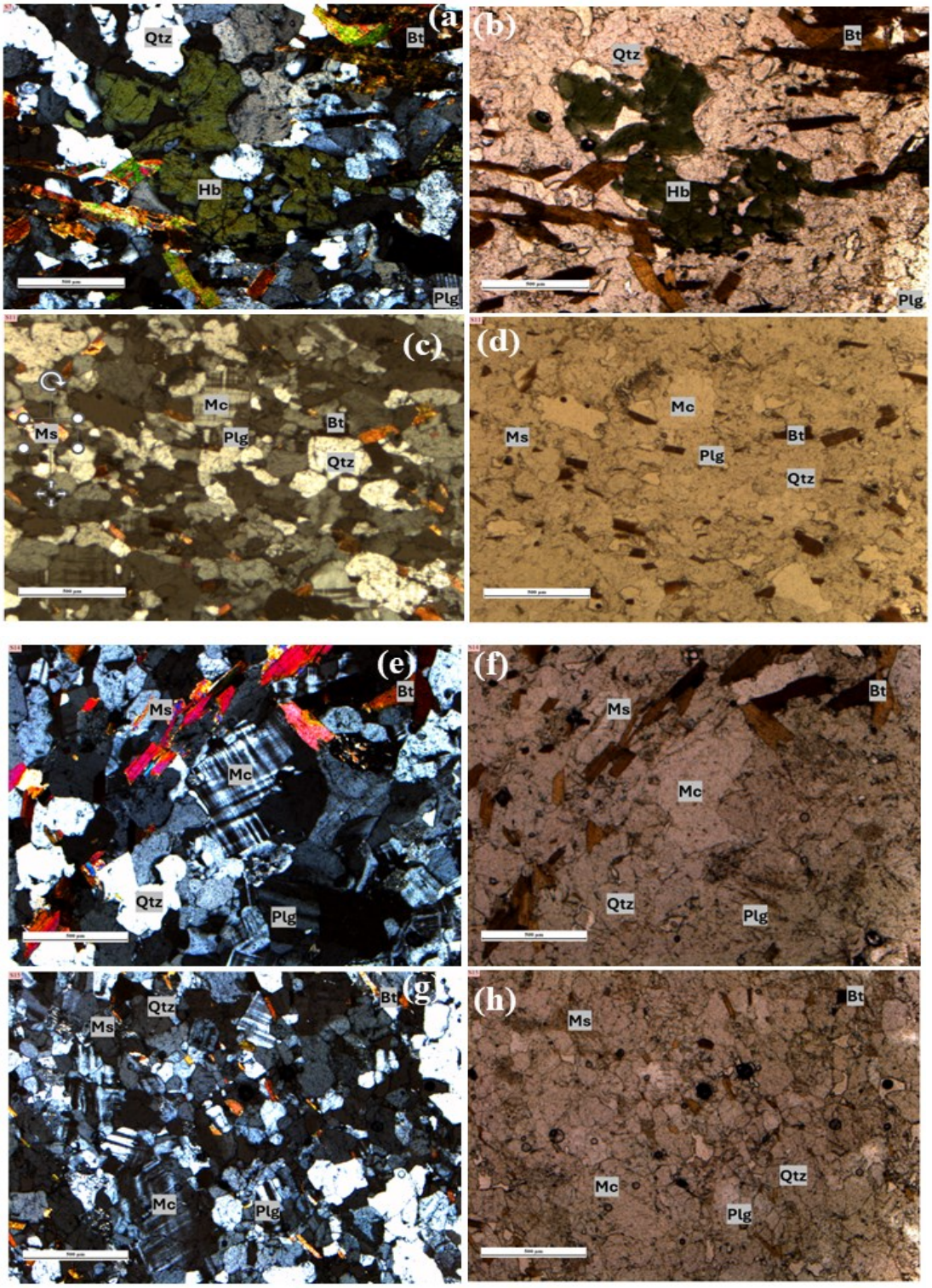


Figure 5: Photomicrographs of country rocks samples (S7, S11, S14 and S15) in crossed polarized light (a, c ,e, and g) and plane polarized light (b, d, f, and h) showing, quartz (Qtz), plagioclase feldspar (Plg), microcline (Mc), biotite (Bt), muscovite (Ms) and hornblende (Hb).

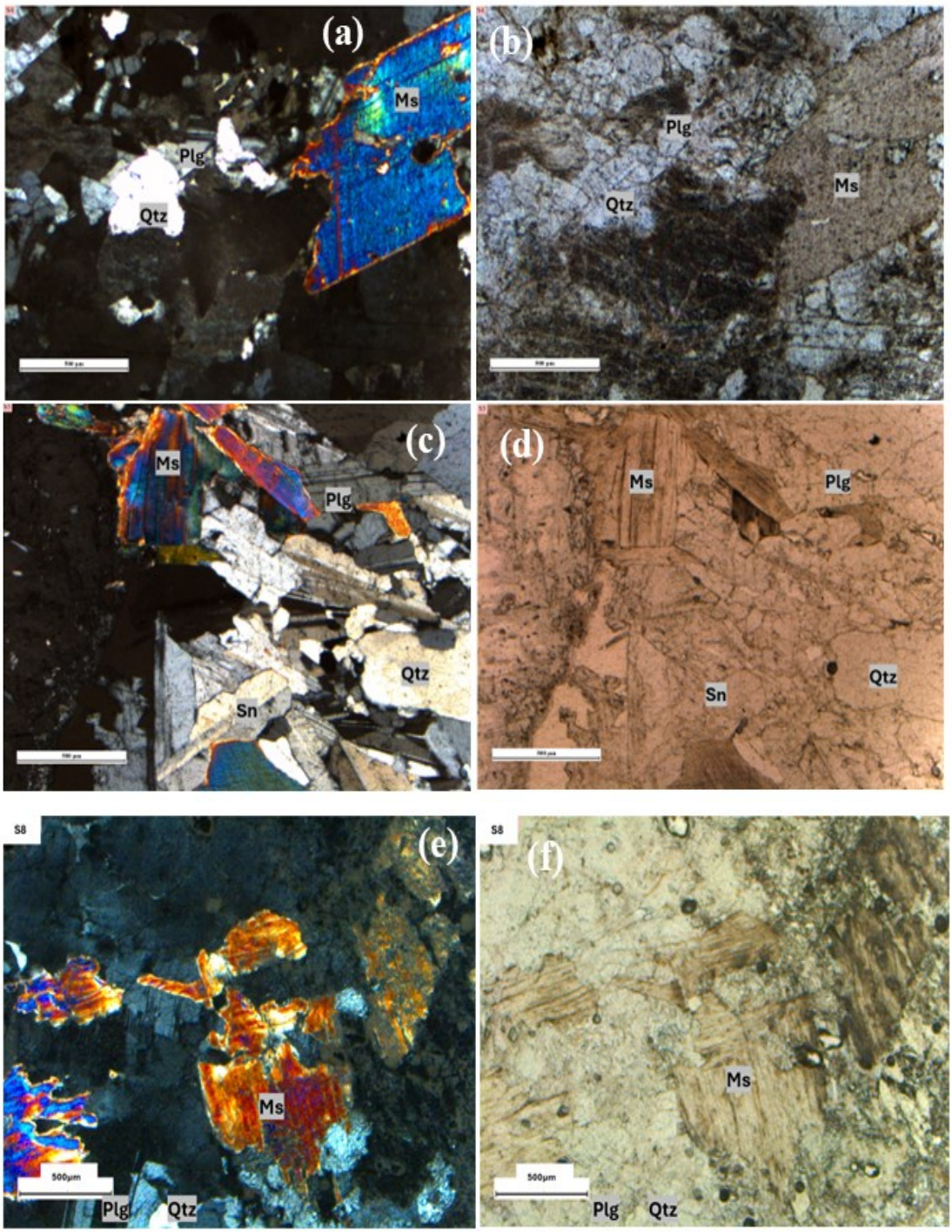


Figure 6: Photomicrographs of pegmatite samples (S4, S5 and S8) in crossed polarized light (a, c, and e) and plane polarized light (b, d, and f) showing, quartz (Qtz), sanidine (Sn), plagioclase feldspar (Plg), and muscovite (Ms).

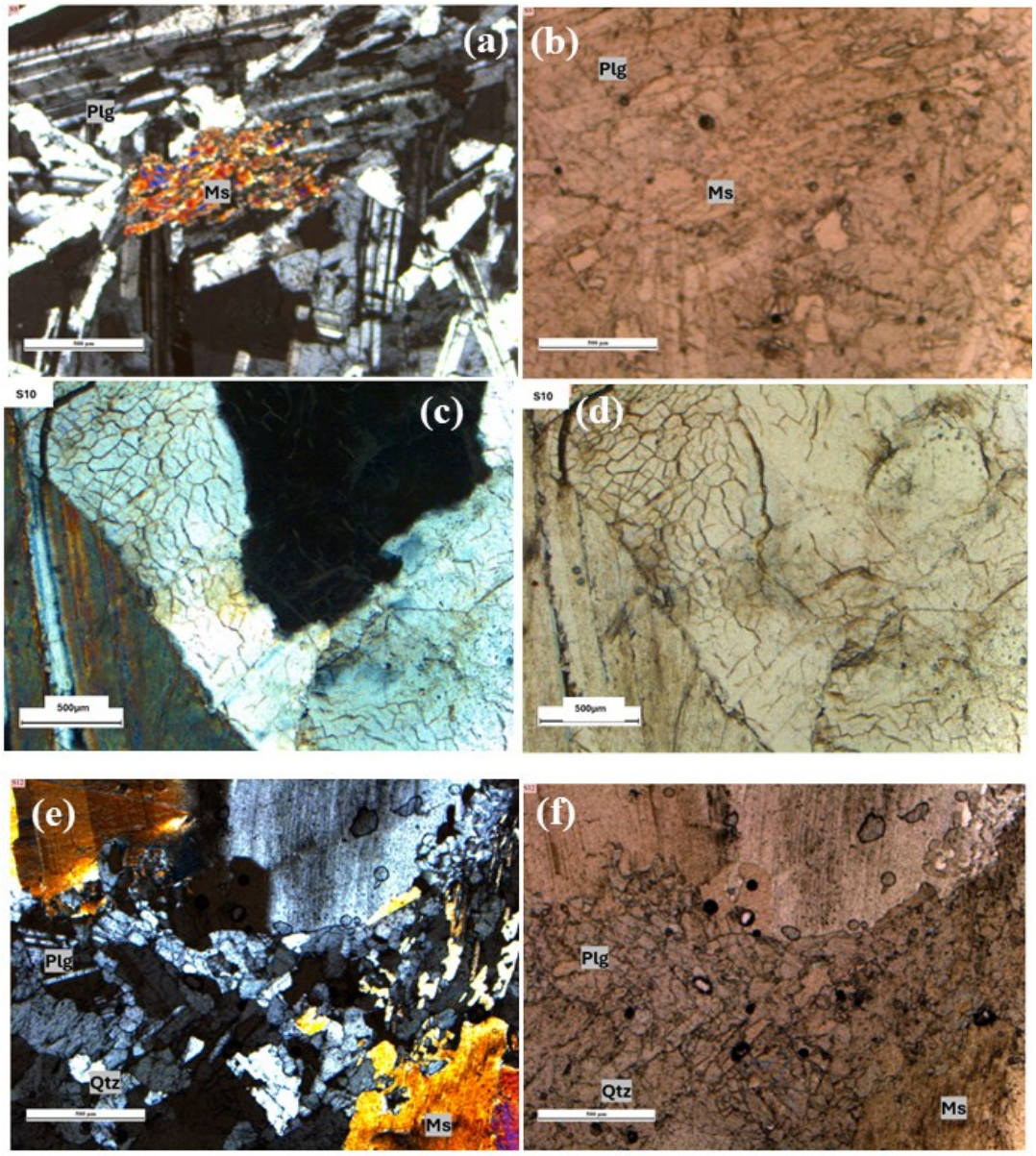


Figure 7: Photomicrographs of pegmatite samples (S9, S10 and S12) in crossed polarized light (a, c, and e) and plane polarized light (b, d, and f) showing, quartz (Qtz), plagioclase feldspar (Plg), and Muscovite (Ms).

The petrographic features of the analyzed samples indicate a lithological assemblage formed through high-grade metamorphism and late-stage magmatic processes. The calc-silicate rock (Figure 3) is dominated by calcite, quartz, nepheline, and sanidine, with accessory phases, suggesting formation by high-temperature metasomatic alteration of carbonate-rich protoliths.

The presence of nepheline and sanidine reflects alkali enrichment and fluid–rock interaction, likely related to alkaline or silica-saturated magmatic fluids during regional or contact metamorphism.

The host rock samples (S1, S2, S3, S6, S7, S11, S14, and S15; Figures 4 and 5) display gneissic textures defined by weak foliation and medium- to coarse-grained assemblages of quartz, biotite, plagioclase, K-feldspar, hornblende, microcline, and muscovite. These features are consistent with amphibolite- to granulite-facies metamorphic gneiss, reflecting recrystallization and partial melting during Precambrian tectonothermal events typical of the Nigerian Basement Complex.

Pegmatite samples (S4, S5, S8, S9, S10, and S12; Figures 6 and 7) are characterized by extremely coarse-grained textures and assemblages dominated by quartz, sanidine, plagioclase, muscovite, indicative of crystallization from volatile-rich, highly evolved granitic melts. Their mineralogy and textures closely resemble mineralized pegmatites reported from Nasarawa, north-central Nigeria.

The ubiquitous presence of muscovite in all pegmatite samples suggests a peraluminous affinity and a genetic association with lithium and other rare-elements enrichment, consistent with previous studies. Overall, the pegmatites are interpreted as late-stage differentiates of granitic magmatism emplaced within high-grade metamorphic basement rocks, with favorable conditions for rare-element mineralization.

FTIR Characterization

FTIR spectroscopy over a broad frequency range was employed to examine the structural characteristics of the powdered pegmatite samples (Figures 8 and 9; Table 1). Absorption bands observed at ~670–672 cm^{-1} and 710–712 cm^{-1} are commonly associated with lithium-bearing compounds. Previous studies have reported infrared bands related to lithium compounds within the range of ~582.66–1502 cm^{-1} (Yan et al., 2025). The present results are consistent with these findings, as all six pegmatite samples exhibit absorption peaks between 600 and 1502 cm^{-1}. Spectral interpretation was carried out using the KnowItAll Wiley Informatics System software (2024).

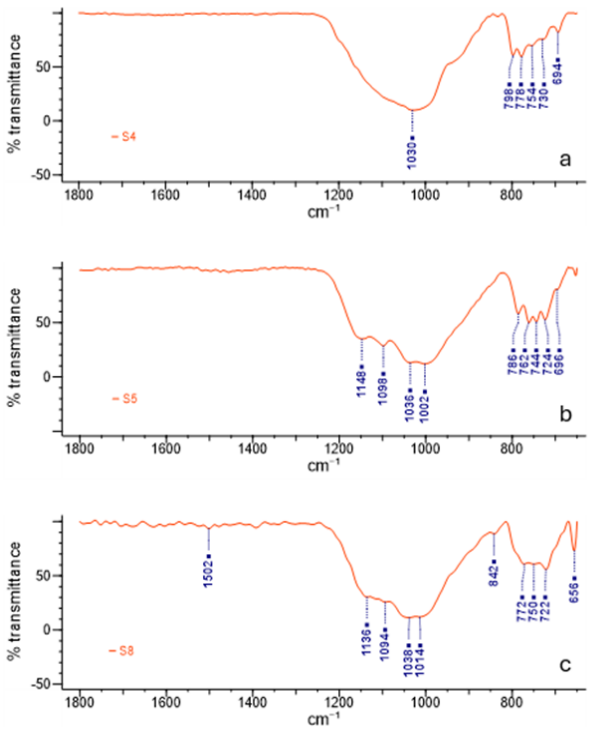


Figure 8: FTIR Spectrum for samples: (a) S4; (b) S5; (c) S8

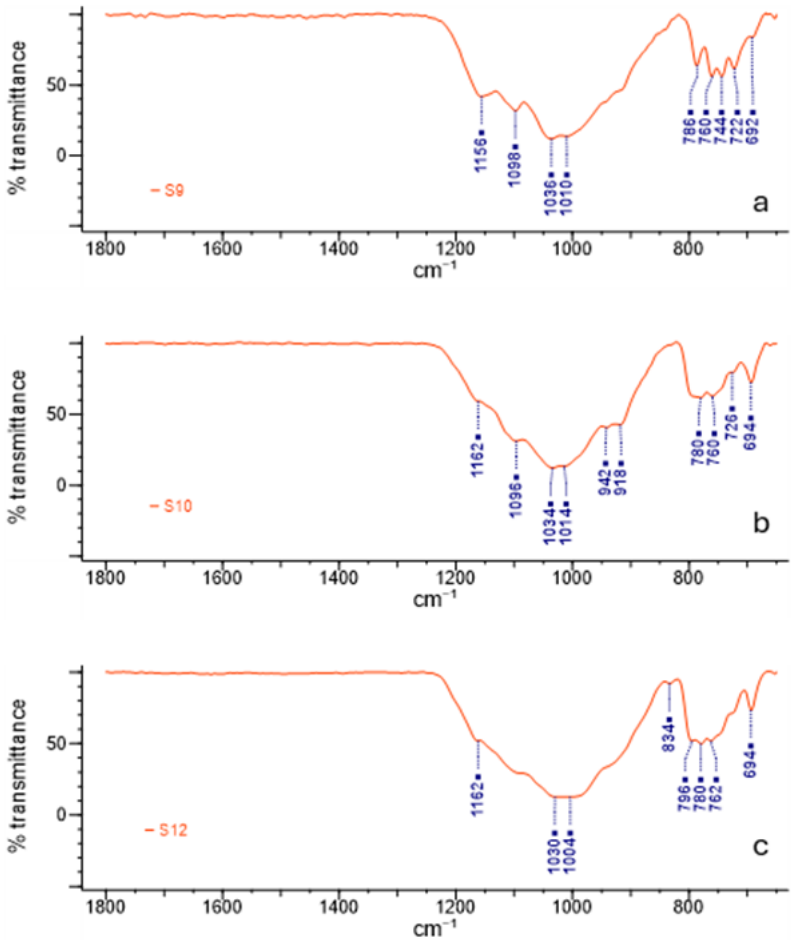


Figure 9: FTIR Spectrum for samples: (a) S9; (b) S10; (c) S12

Table 1: Major infrared (IR) spectra peaks observed for all six pegmatite samples.

Sample Id	Peaks Observed (cm^{-1})
S4	694, 730, 754, 778, 1030
S5	696, 724, 744, 762, 786, 1002, 1036, 1098, 1148
S8	656, 722, 750, 772, 842, 1014, 1038, 1094, 1136, 1502
S9	692, 722, 744, 760, 786, 1010, 1036, 1098, 1156
S10	694, 726, 760, 780, 918, 942, 1014, 1034, 1096, 1162
S12	692, 762, 780, 796, 834, 1004, 1030, 1162

FTIR spectra of the powdered pegmatite samples (Figures 8 and 9; Table 1) reveal absorption features diagnostic of lithium-bearing mineral phases. Prominent bands at ~670–672 cm^{-1} and 710–712 cm^{-1} are characteristic of Li–O vibrational modes commonly reported in lithium-containing silicates and related compounds. In addition, the systematic occurrence of

absorption bands within the ~600–1502 cm^{-1} range across all samples corresponds to vibrational modes previously attributed to lithium-associated structural units.

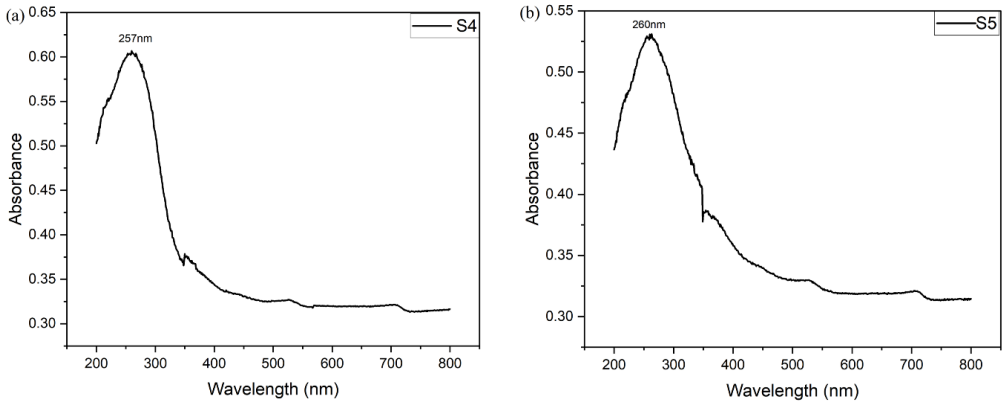
The consistency of these spectral features among the six pegmatite samples indicates a uniform incorporation of lithium within the mineral framework, likely hosted in Li-bearing silicate phases or structurally bound within mica and feldspar lattices. This interpretation is consistent with the petrographic evidence of pervasive muscovite and supports the classification of the pegmatites as evolved, rare-element–enriched systems. Collectively, the FTIR data provide independent spectroscopic confirmation of lithium enrichment and reinforce the interpretation of these pegmatites as products of highly fractionated granitic melts. Spectral assignments were validated using the KnowItAll Wiley Informatics System software (2024).

4.3 UV-VIS Characterization

Distinct absorption bands occurring in the 254–260 nm range were recorded for all analyzed samples, as summarized in Table 2 and illustrated in Figure 10. These absorption features are consistent with previously reported UV–Vis spectra of lithium-bearing compounds, including absorption near 254 nm (Niu et al., 2024) and a peak at approximately 272 nm (Kumar & Singh, 2013). The UV–Vis spectra were processed and plotted using OriginPro 2024b software.

Table 2 Major infrared UV-VIS spectra peaks observed for all six pegmatite samples.

Sample	Shoulder Peak (nm)
S4	257
S5	260
S8	258
S9	256
S10	255
S12	254



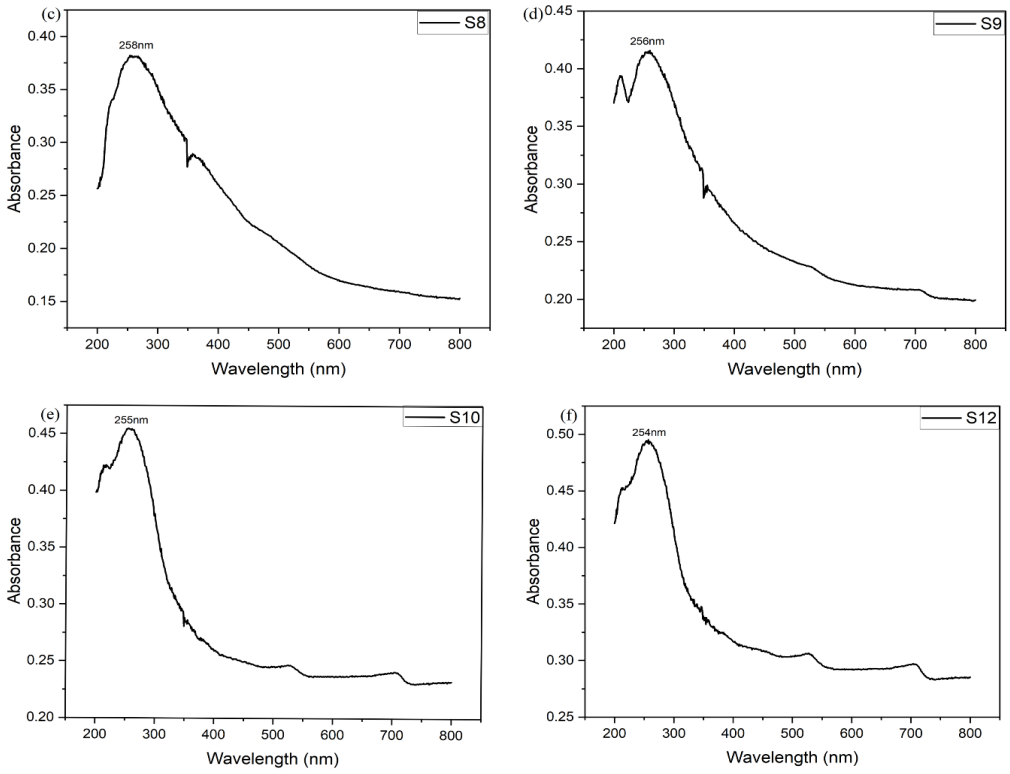


Figure 10: UV-VIS spectra for samples: (a) S4; (b) S5; (c) S8; (d) S10; (e) S10; (f) S12

The UV–Vis spectra of the analyzed samples (Figure 10; Table 2) display consistent absorption bands in the 254–260 nm region, indicating the presence of electronic transitions characteristic of lithium-bearing mineral phases. Absorption in this wavelength range has been widely attributed to charge-transfer and ligand-to-metal transitions associated with lithium in silicate and oxide matrices. The close correspondence between the observed absorption maxima and previously reported lithium-related peaks at ~254 nm and ~272 nm provides further spectroscopic evidence for lithium incorporation within the studied pegmatites.

The uniformity of these absorption features across all samples suggests a systematic enrichment of lithium rather than localized or incidental occurrence, consistent with a common magmatic–hydrothermal origin. When considered alongside the FTIR and petrographic data, the UV–Vis results strengthen the interpretation that the pegmatites represent highly evolved, rare-element–enriched systems derived from fractionated granitic melts. Together, these findings support the classification of the studied pegmatites as prospective lithium-bearing bodies with implications for rare-metal mineralization.

CONCLUSION

This study provides new petrographic and spectroscopic constraints on lithium mineralization within the Kusaki area of the southeastern Federal Capital Territory, north-central Nigeria, a region previously lacking detailed investigation despite its favorable Pan-African basement

setting. Integrated thin-section petrography, FTIR, and UV–Vis spectroscopy reveal that lithium enrichment in the study area is primarily associated with pegmatites emplaced within high-grade metamorphic gneissic host rocks.

Petrographic analyses demonstrate that the pegmatites are coarse-grained, muscovite-rich, and mineralogically dominated by quartz and feldspar, consistent with crystallization from volatile-rich, highly evolved granitic melts. The pervasive occurrence of muscovite indicates a peraluminous affinity and provides a key mineralogical indicator of rare-element–enriched pegmatitic systems. The associated calc-silicate rocks record high-temperature metasomatic processes, reflecting fluid–rock interaction during late-stage magmatic or metamorphic evolution.

Spectroscopic data independently confirm lithium incorporation within the pegmatites. FTIR spectra exhibit systematic absorption bands between ~600 and 1502 cm^{-1}, including diagnostic Li–O vibrational modes, while UV–Vis spectra display consistent absorption features in the 254–260 nm range characteristic of lithium-related electronic transitions. The reproducibility of these spectral signatures across all analyzed pegmatite samples indicates pervasive lithium enrichment rather than localized or incidental mineralization.

Collectively, the petrographic and spectroscopic evidence supports the interpretation that the Kusaki pegmatites represent late-stage differentiates of fractionated Pan-African granitic magmatism, emplaced into structurally favorable gneissic basement rocks and subsequently enriched in lithium through magmatic–hydrothermal processes. These findings highlight the Kusaki area as a promising target for lithium and rare-metal exploration within the Nigerian Basement Complex and underscore the broader prospectivity of southeastern FCT for critical mineral resources.

RECOMMENDATIONS

Based on the petrographic and spectroscopic evidence for pervasive lithium enrichment in the Kusaki pegmatites, further integrated studies are recommended to refine genetic interpretations and assess resource potential. Quantitative whole-rock geochemical analyses are required to constrain lithium concentrations, degree of magmatic fractionation, and geochemical signatures characteristic of lithium–cesium–tantalum (LCT) pegmatite systems. Detailed mineral-scale investigations using EPMA and LA-ICP-MS would help identify lithium host phases and elucidate trace-element zoning and enrichment mechanisms. Isotopic and geochronological studies are also necessary to establish the timing of pegmatite emplacement and its relationship to Pan-African magmatic and tectonothermal events. In addition, systematic structural mapping and geophysical surveys are recommended to delineate pegmatite geometry and controls on emplacement. Finally, preliminary metallurgical and economic assessments are suggested to evaluate the viability of the Kusaki pegmatites as potential lithium resources. Collectively, these approaches would advance the understanding of lithium prospectivity within the Nigerian Basement Complex. Future work integrating whole-rock geochemistry, mineral chemistry, and isotopic studies is recommended to quantify

lithium grades, refine genetic models, and assess the economic potential of the identified mineralization.

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