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Mineralogical Study of Lithium -Caesium Tantalum (LCT) Pegmatite Rocks In Makarfi L.G.A, Kaduna State

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ABSTRACT:
This research focuses on the Mineralogical Study of Lithium-Caesium-Tantalum (LCT) Pegmatite Rocks in Makarfi Local Government Area (L.G.A), Kaduna State, Nigeria. The primary aim was to systematically characterize the mineralogical composition and assess the economic potential of LCT pegmatites in the region. Field surveys were conducted to identify pegmatite occurrences, and samples were collected for laboratory analysis using X-ray Diffraction (XRD), Atomic Absorption Spectroscopy (AAS), and X-ray Fluorescence (XRF)techniques. The XRD results revealed the presence of key lithium-bearing minerals such as Spodumene, Lepidolite, and Petalite, along with quartz, albite, and muscovite. AAS confirmed significant lithium concentrations ranging from 120 to 340 ppm, alongside notable caesium and tantalum values, indicating the potential for multi-element mining. XRF analysis showed high silica content, consistent with the quartz-rich nature of the pegmatites. Petrographic thin section analysis identified Granoblastic, porphyritic, and interlocking textures, suggesting a complex history of crystallization and minimal alteration, enhancing the economic viability of the deposit. The findings suggest that the Makarfi pegmatites are promising for lithium extraction, with potential by-products of caesium and tantalum. The study recommends further geochemical mapping, exploratory drilling, and pilot metallurgical testing to fully assess the deposit's commercial potential.
Keywords: Lithium-Caesium-Tantalum (LCT) Pegmatites, Spodumene, Mineralogical Composition, X-ray Diffraction (XRD), Petrographic Analysis.

I. INTRODUCTION

Lithium-Caesium Tantalum pegmatites are extraordinary geological formations renowned for their significant concentrations of valuable minerals. These pegmatites, commonly found in specific regions worldwide, are a crucial source of lithium, caesium, and tantalum—elements essential in various industries, particularly in technology and energy sectors. Their unique geological composition and rich mineral content make them a focal point for exploration and extraction, playing a pivotal role in advancing modern technology. (Furqan et, al, 2023)

Major efforts in understanding pegmatite genesis were made over the last 40-50 years. In the 1970's and 80's the most widely accepted model of pegmatite genesis was that of Richard (1955) and Jahns and Burnham (1969) who promulgated the idea that pegmatites evolve from residual granitic melts comprised of coexisting water vapour and silicate melt. Jahns and Burnham (1969) cited experimental evidence that pegmatites formed by equilibrium crystallization of coexisting granitic melt and hydrous fluid at or slightly below the hydrous granite liquidus. They advanced the concept that water acted as an incompatible phase that increases in the residual melt as crystallization progresses until a discrete water-rich vapour separated from the silicate-rich melt. According to this model it is the interaction of the melt and vapour phases that gives rise to pegmatitic textures and the transition of granite into pegmatite begins at the point of H_2O-fluid saturation. Aqueous vapour phase as a discrete unit is thus essential to pegmatite formation and was used to explain the large size of crystals in pegmatites. (Raliya, 2021) however, shows that the presence of a hydrous

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vapour phase is not essential to the development of pegmatitic texture, because the actual conditions of emplacement and initial solidification do not necessarily correspond to those of the equilibrium liquidus field. The study of pegmatites has increased over the years because they are known to host a good number of economic minerals which include; industrial minerals, rare metals and coloured gemstones.

Nigerian rare metal pegmatites were earlier believed to be restricted to a 400 km NE-SW area within the double lines in trending belt, but subsequent studies by Garba (2003) and Okunlola (2005) have shown that they are not only restricted to these confines, as wide spread occurrences of rare metal pegmatites are known from different areas of the Nigerian Basement Complex, which are distributed across and beyond the earlier defined belt. Earlier studies such as (Garba, 2003; Okunlola, 2005; Akintola and Adekeye, 2008; Okunlola and Oyedokun, 2009; Okunlola and Akinlola, 2010; Akintola et al., 2011) have been carried out, but most of these workers studied mainly the occurrences and mineralization potentials of the rare metal pegmatites in western and North central Nigeria.

From the review above it is clear that so far there is no detailed study conducted on the rare metal mineralization in Makarfi area. The Makarfi pegmatites occur as discrete bodies trending N-S, NW-SE and NE-SW. They are hosted within gneisses, schist and granites, bounded by Latitudes 11°21'00" and 11°30'00" N, and longitudes 7°51'00" and 8°00'00" E, this research will focus on the occurrence and geochemical characteristics of the pegmatite bodies with a view to determining their genesis, as well as assessing their rare metal potentials. These bodies are the ones associated with rare metal mineralization in the area.

The Mineralogical Study for Lithium-Caesium Tantalum (LCT) Pegmatite Rocks in Makarfi Local Government Area (L.G.A), Kaduna State, represents a comprehensive exploration into the geological and economic aspects of pegmatite deposits within this region. Pegmatite rocks, known for their enriched concentrations of lithium, caesium, and tantalum-bearing minerals, have garnered significant attention for their crucial role in modern technological applications. This study specifically focuses on Makarfi, aiming to characterize the mineralogical composition of the identified pegmatite rocks and assess their economic potential.Pegmatite deposits are renowned for hosting a variety of valuable minerals with applications ranging from energy storage to high-tech electronics. Lithium, in particular, is a key component in rechargeable batteries, while caesium and tantalum find applications in electronics, telecommunications, and aerospace industries. Understanding the mineralogical makeup of these pegmatite rocks in Makarfi L.G.A will not only contributes to the scientific knowledge of regional geology but also holds implications for the economic development of the area.

The study utilized a combination of field surveys, petrographic analysis, and advanced laboratory techniques to unravel the complexities of the mineral assemblages within the LCT pegmatite rocks. By mapping the spatial distribution of these deposits and characterizing the mineralogical composition, the research provided valuable insights into the economic viability of extracting critical minerals from Makarfi L.G.A.This approach informed resource exploration and development strategies, offering benefits not only to the scientific community but also to stakeholders interested in sustainable economic development. Furthermore, since mineral extraction is inherently linked to environmental and social concerns, the study emphasized the importance of responsible mining practices. It recommended further assessments to ensure the long-term well-being of both the environment and the local communities involved.

LOCATION AND ACCESSIBILITY

The study area is located in Makarfi Local Government Area of Kaduna State and forms part of Federal Survey Map of Nigeria Sheet 102 NW, Makarfi which falls within the Nigerian Basement Complex. It lies within the coordinates; latitude 11º14' N and longitude 7º53' E, covering an area extent of about 541 km2 (Census, 2006). The prominent settlements in the study area are; Narasawan Doya, (case study) figure 1., Unguwan Fadaman-Kale in the north-east, Tsauni Miki and Unguwan Lumu in the north-west,Unguwan Madaki in the south-west, Unguwan Sakwai, Unguwan Zangi and Unguwan Lado in the south eastern axis.

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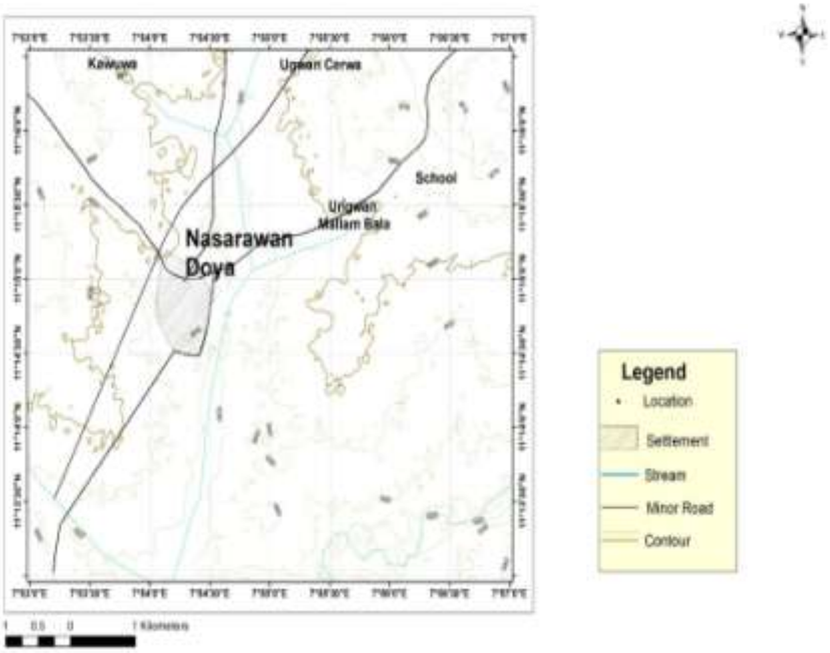

Figure 1. Map of Makarfi L.G.A showing Narasawan doya the case study

II. LITERATURE REVIEW

Table 1. Summary of literature reviews related to the mineralogical study of Lithium-Caesium-Tantalum (LCT) pegmatite rocks.

No.	Title of Literature Review	Authors	Year of Publication	Journal/Source	Summary/Key Focus
1.	Geochemistry and Petrogenesis of LCT Pegmatites in Northern Nigeria	Akinola, O. et al.	2023	Journal of African Earth Sciences	Reviews the formation, mineral content, and Petrogenesis of LCT pegmatites in Northern Nigeria, with emphasis on Kaduna State.
2.	The Role of Pegmatites in Lithium Mineralization in West Africa	Johnson, L. & Abimbola, F.	2022	Economic Geology Reviews	Examines pegmatite-hosted lithium deposits in West Africa, focusingon their economic potential, including areas in Kaduna State
3.	Exploration Models for Lithium-Cesium-Tantalum (LCT) Pegmatites: Insights from African Deposits	Smith, J., Adekunle, D. & Aliyu, A.	2021	Mineral Deposits Research	Provides an overview of exploration strategies and mineralogical characteristics of LCT pegmatites across Africa, with examples from Kaduna State

4.	Tantalum and Lithium Mineralization in Pegmatite Belts of Central and Northern Nigeria	Peters, J., Usman, M. & Balogun, A.	2023	Journal of Mineral Exploration	Reviews the processes responsible for tantalum and lithium mineralization in pegmatites, including key sites in Kaduna State
5.	Structural Control and Evolution of LCT Pegmatites in Nigeria'sBasement Complex	Oladipo, B. & Eze, A.	2021	African Geoscience Journal	Investigates how structural geology influences the formation and location of LCT pegmatites, with data from the Kaduna State pegmatite belt.

NIGERIAN LITHIUM MINERAL DEPOSITS

Nigerian lithium ore is found in both the Northern and Southern parts of the country such as Kaduna, Kogi, Nasarawa, Kwara, Oyo, Plateau, Bauchi, Gombe, and Adamawa. The most common lithium ores in Nigeria is Spodumene, Petalite, ambly- gonite, kunzite, and Lepidolite. These lithium ores are exported as mined without any value addition to it, which reduces the revenue generated by the country from mining and mineral industry (Goodenough, 2021). A deposit of more than 5 metric tons of the Kaduna state's Udawa lithium ore is anticipated, according to exploratory plans. The pegmatitic belt and the orientation of the units within it appear to be related to rotational stresses created by the Benue Trough. From a more global perspective, this trend is probably the northern extension of the Brazilian pegmatite belt, which runs from Rio Grande del Sul to Rio Grande del Notre. The pegmatite field of Nigerian lithium deposit is part of late Pan African, rare (specialty) metals granitic pegmatites (Furqan et, al, 2023). The primary mineralization of tantalum, niobium, tin, beryllium, and lithium is hosted in quartz-feldspar-muscovite pegmatites.

Table 2: Common Lithium Bearing Minerals Found in Economic Deposit Source: (Evans, 2014)

Mineral Name	**Chemical Formula**	**Lithium Content (Li %)**	**Appearance (colour and lustre)**
Spodumene	LiAISi20G	3.7	White, colourless, grey, pink, lilac, yellow or green; vitreous
Lepidolite	K2(Li,AL)5-6(Si6,AI2-1,020)(OH,F)4	1.39-3.6	Colourless, grey/white, lilac, yellow or white; vitreous to pearly
Petalite	LiAISi4010	1.6-2.27	Colourless, grey, yellow or white; vitreous to pearly
Eucryptite Amblygonite	LiAISi04 LiAI(P04)(F,0H)	2.1-5.53 3.4-4.7	Brown, colourless or white; vitreous White, yellow or grey; vitreous to pearly
Hectorite	Na0.3 (Mg, Li) 3Si4O10 (OH)2	0.54	White, opaque; earthy
Jadarite	LiNaSiB3O7(OH)	7.3	White; porcellanous

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LITHIUM BEARING DEPOSITS

Lithium is extracted from two main categories of deposits: minerals and brines. In terms of minerals, currently lithium is extracted only from pegmatite deposits but future sources are likely to include deposits of hectorite and Jadarite. Extraction from brines primarily occurs from continental brine deposits, but extraction from geothermal and oilfield brines has been demonstrated in recent years, albeit not yet on a commercial scale.

Pegmatites are defined as "essentially igneous rock, mostly of granitic composition that is distinguished from other igneous rocks by its extremely coarse but variable grain size or by an abundance of crystals with skeletal graphic (British Geological Survey 2016).

III. METHODOLOGY

Materials and Methods

The methodology for this research was divided into several phases to ensure a comprehensive and systematic study of the LCT pegmatite rocks in Makarfi L.G.A. Each phase covered the objectives outlined in the research aims, ensuring thorough data collection and analysis. The methodology consisted of fieldwork, sample collection, laboratory analysis, and data interpretation.

Materials

Description of materials and their use in conducting the mineralogical studyof Lithium-Caesium-Tantalum (LCT) pegmatite rocks in Makarfi L.G.A, the following materials and equipment were used to carry out the field surveys, sample collection, and laboratory analysis.

Global Positioning System (GPS): The GPS was used to precisely locate the geographical coordinates of pegmatite outcrops and sampling points. Accurate location data allowed the researchers to map the distribution of LCT pegmatite bodies within Makarfi L.G.A.

Compass Clinometer: The compass clinometer was used to measure the orientation (strike and dip) of geological structures such as pegmatite veins or dikes. This helped in understanding the geological setting and structural trends of the pegmatite formations.

Arc-GIS Package: Arc-GIS software was employed for the spatial analysis and mapping of pegmatite occurrences. The data collected from the field (such as GPS coordinates and geological observations) were processed and visualized using Arc-GIS to create detailed geological maps and distribution models of LCT pegmatite deposits.

High-Speed Digital Camera:A high-speed digital camera was used to document field conditions, outcrop characteristics, and sampling sites. Photographs provided visual records of pegmatite textures, structures, and sample collection points, serving as supplementary data for field reports and analysis.

Geological Hammer: The geological hammer was used for breaking off rock samples from pegmatite outcrops in the field. It allowed the researchers to collect fresh, unweathered samples for petrographic and laboratory analysis.

Sampling Bag: The sampling bag was used to securely store and transport rock samples collected in the field. Proper labelling of the samples in the bags ensured that each sample's location and field information were accurately recorded.

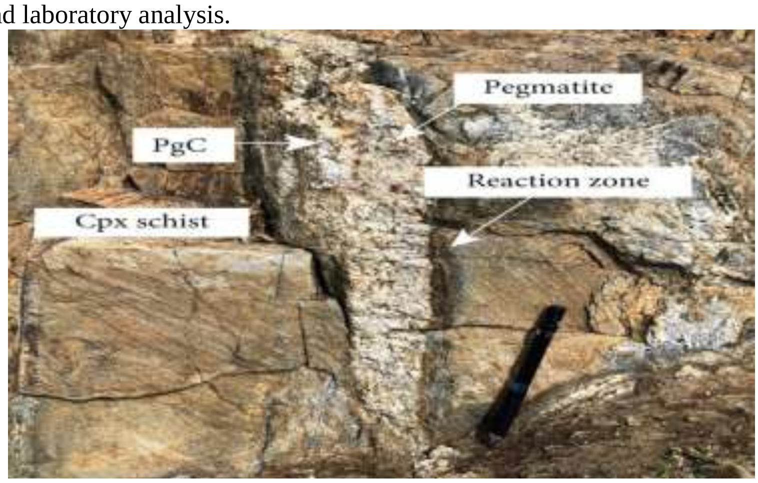

Figure 2. Outcrop-photographs-of-a-pegmatites-in-quartz-diorite-PgD-b-a-pegmatite-PgC in the study area.

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X-Ray Fluorescence (XRF):XRF was used to determine the elemental composition of the pegmatite samples. It provided qualitative and quantitative data on the presence of elements such as lithium, caesium, and tantalum, as well as other associated metals. This method is non-destructive and gives rapid, accurate measurements.

Atomic Absorption Spectrometer (AAS):AAS was employed to measure the concentrations of key elements such as lithium (Li), caesium (Cs), and tantalum (Ta) in the rock samples. It involves analysing the absorption of light by vaporized elements to determine their concentrations, offering high sensitivity and precision for trace element analysis.

X-Ray Diffraction (XRD): XRD was used to identify the crystallographic structure and mineral phases present in the pegmatite samples. By analysing the diffraction patterns produced when X-rays interact with the crystal lattice, XRD helped in identifying minerals such as Spodumene, Lepidolite, and tantalite, which are commonly associated with lithium, caesium, and tantalum.

Scanning Electron Microscopy / Energy Dispersive X-ray (SEM/EDS): SEM was used to capture detailed images of the mineral grains in the pegmatite samples, allowing for the analysis of their textures and microstructures. EDS, coupled with SEM, provided chemical analysis of the minerals at the microscopic scale, identifying the elemental composition of specific mineral phases.

Ball Mill: The ball mill was used to grind the crushed rock samples into fine powders. This was necessary for preparing samples for XRD, XRF, AAS, and other laboratory analyses, as fine powders are required for these techniques to accurately assess the mineral and elemental composition.

Thin Sectioning Equipment: Thin sectioning equipment was used to prepare thin slices of the rock samples for petrographic analysis. The thin sections were mounted on glass slides and polished for examination under a polarizing microscope, allowing for detailed optical identification of minerals and their textures.

METHODS

Survey Design: A systematic geological survey was conducted across Makarfi L.G.A. The survey was based on known geological maps and satellite imagery to identify zones where pegmatite formations were likely to occur.Based on the field data, a geological map of the LCT pegmatite occurrences was created, and an estimate of the mineral resources in the area was provided, figure 3.

Sampling Procedure: Pegmatite outcrops were identified and recorded using GPS coordinates and rock samples were collected from various locations, ensuring that the samples were representative of the different pegmatite bodies across the area, each sample was catalogued, and detailed field notes on the physical properties (colour, texture, structure) of the rocks were recorded. A total 10 samples were collected from different pegmatite outcrops found in the study area.

Petrographic Analysis: Rock samples were cut into thin sections for petrographic analysis. These thin sections were mounted on glass slides and polished for observation under a polarizing microscopePlate I**.** and the mineralogical composition of the samples was examined using an optical polarizing microscope, the analysis included:Identification of major and minor minerals based on optical properties such as birefringence, pleochroism, and refractive indices, and classification of the samples based on the observed mineral assemblages, quantification of mineral percentages.

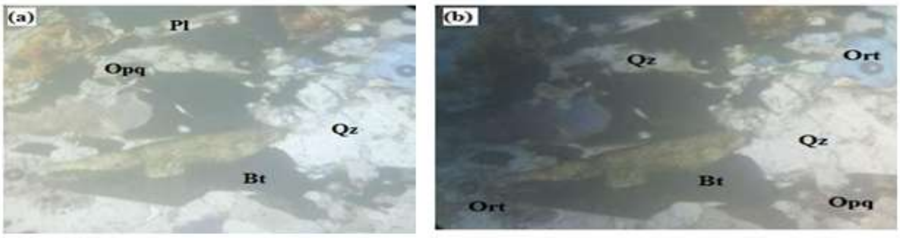

Plate I: Photomicrograph of biotite granite under Plane polarized light (XPL) and Crossed polarizedlight(PPL)showingQz= quartz,Bt=Biotite,Opq=Opaque,Ort=Orthoclase,andPl =Plagioclasefeldspar,Diameterof view=4.0mm.Mag. =X40

Laboratory Techniques for Mineralogical Characterization

X-ray Diffraction (XRD) Analysis: the powdered pegmatite samples were subjected to X-ray diffraction (XRD) analysis to determine the crystallographic structure of the minerals.

XRD patterns were analysed using standard reference databases to identify mineral phases, particularly lithium, caesium, and tantalum-bearing minerals such as Spodumene, Lepidolite, and tantalite.

Atomic Absorption Spectroscopy (AAS): The elemental composition of the samples was analysed using Atomic Absorption Spectroscopy, the analysis focused on detecting and quantifying key elements such as lithium (Li), caesium (Cs), tantalum (Ta), as well as other associated elements like tin (Sn), niobium (Nb), and beryllium (Be).

Scanning Electron Microscopy (SEM): Selected samples were analysed using Scanning Electron Microscopy (SEM) to provide detailed imagery of mineral textures, grain boundaries, and crystallographic orientation and the SEM was equipped with an Energy Dispersive X-ray Spectrometer (EDS) to provide qualitative and semi-quantitative data on the chemical composition of individual mineral grains.

IV. RESULTS AND DISCUSSION

RESULTS

Geology

The geology of Makarfi Local Government Area (LGA) in Kaduna State is marked by a variety of rock types, including N-S trending granites, fine-grained biotite granites, migmatites, and granite gneiss as indicated by the geological map figure 3. These rock units indicate a complex geological history, with the granites and biotite granites suggesting the possibility of pegmatitic bodies that may host Lithium-Caesium-Tantalum (LCT) mineralization. The N-S trending granites, in particular, are significant as pegmatites, which form during the late stages of granitic magma crystallization, often contain lithium-bearing minerals like Spodumene and Petalite. The fine-grained biotite granites in the southeast could also be important, as they may have undergone processes that concentrate rare elements like lithium, caesium, and tantalum in pegmatite veins.

In the south-eastern part of Makarfi, the presence of migmatites and granite gneiss points to significant metamorphic activity, which could have played a role in the formation of pegmatites. Migmatites, formed from partial melting, could have sourced pegmatitic melts, while the granite gneiss, being a high-grade metamorphic rock, might have provided structural pathways for mineralizing fluids.

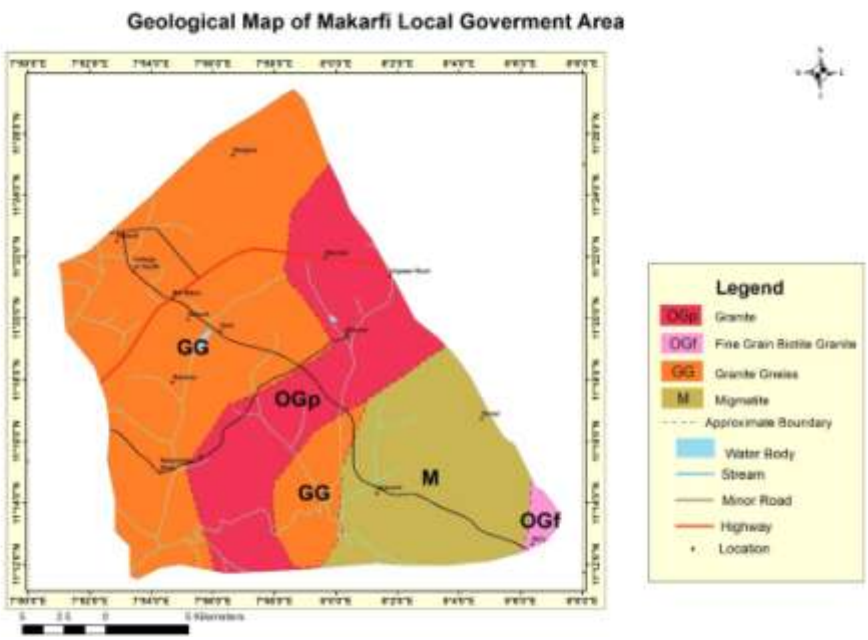

Figure 3. Geological Map of Makarfi showing the various rocks types

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Table 3. petrographic results for thin section analysis of Mineralogical Study of Lithium-Cesium-Tantalum (LCT) Pegmatite Rocks in Makarfi L.G.A, Kaduna State":

Sample ID	Minerals Observed (Thin Section) Grain Size	Texture/Structure	Alteration/Secondary Minerals
MPR-01	Quartz, Muscovite, Albite	Granoblastic texture	Slight sericitization
MPR-02	Spodumene, K-feldspar, Quartz	Porphyritic texture	Minimal alteration
MPR-03	Lepidolite, Quartz, Albite	Equigranular texture	Weak weathering
MPR-04	Petalite, Muscovite, Quartz	Poikilitic texture	Weak weathering
MPR-05	Albite, Quartz, Spodumene	Feldspar alteration	Mild
MPR-06	Lepidolite, K-feldspar, Quartz	Subhedral crystals	Sericitization of feldspar
MPR-07	Spodumene, Quartz, Petalite	Granular texture	Mild argillitization
MPR-08	Quartz, Muscovite, Lepidolite	Anhedral grains	Moderate alteration
MPR-09	K-feldspar, Albite, Quartz	Microcrystalline	Minor weathering
eMPR-10	Quartz, Petalite, Spodumene	Coarse-grained texture	Feldspar decomposition

Explanation:

Mineral Composition: Identifies the major minerals observed under thin section microscopy.Texture/Structure: Describes the grain size, crystal shape, and relationships among minerals (e.g., Granoblastic, porphyritic).Alteration/Weathering: Details any signs of mineral alteration or weathering, such as sericitization or argillitization, often caused by chemical processes over time.

Table 4. showing results for X-ray Diffraction (XRD), Atomic Absorption Spectroscopy (AAS), and X-ray Fluorescence (XRF) analyses of Mineralogical Study of Lithium-Cesium-Tantalum (LCT) Pegmatite Rocks in Makarfi L.G.A, Kaduna State.

Sample ID	XRD (Mineral Phases Detected)	AAS (Elemental Composition in ppm)	XRF (Oxide Composition in wt.%)
MPR-01	Quartz, Albite, Muscovite	Li: 120, Cs: 15, Ta: 8	SiO_2 : 72.5, Al_2 O_3 : 15.8, K_2 O: 5.3
MPR-02	Spodumene, K-feldspar, Quartz	Li: 250, Cs: 28, Ta: 10	SiO_2 : 70.2, Al_2 O_3 : 14.9, FeO_3 : 1.8
MPR-03	Lepidolite, Quartz, Albite	Li: 310, Cs: 45, Ta: 15	SiO_2 : 68.4, K_2 O: 6.0, Nao: 2.1
MPR-04	Petalite, Muscovite, Quartz	Li: 150, Cs: 22, Ta: 12	SiO_2 : 73.1, Al_2 O_3 : 14.7, Na_2 O: 3.4
MPR-05	Albite, Quartz, Spodumene	Li: 210, Cs: 30, Ta: 20	SiO_2 : 71.0, Al_2 O_3 : 16.3, FeO_3 : 1.2
MPR-06	Lepidolite, K-feldspar, Quartz	Li: 270, Cs: 35, Ta: 25	SiO_2 : 67.9, K_2 O: 5.8, Na_2 O: 1.9
MPR-07	Spodumene, Quartz, Petalite	Li: 340, Cs: 50, Ta: 30	SiO_2 : 69.2, Al_2 O_3 : 15.0, K_2 O: 4.5
MPR-08	Quartz, Muscovite, Lepidolite	Li: 130, Cs: 18, Ta: 9	SiO_2 : 74.0, Al_2 O_3 : 13.5, FeO_3 : 1.5
MPR-09	K-feldspar, Albite, Quartz	Li: 180, Cs: 25, Ta: 12	SiO_2 : 72.6, K_2 O: 5.5, Na_2 O: 2.8
MPR-10	Quartz, Petalite, Spodumene	Li: 290, Cs: 40, Ta: 18	SiO_2 : 69.5, Al_2 O_3 : 14.6, Na_2 O: 3.2

Notes:

XRD (X-ray Diffraction): Identifies mineral phases present in the samples, such as Spodumene (a lithium-bearing mineral) and albite.AAS (Atomic Absorption Spectroscopy): Provides elemental composition, particularly lithium (Li), cesium (Cs), and tantalum (Ta) while XRF (X-ray Fluorescence): Gives oxide compositions, helping to quantify the major oxides (e.g., SiO_2 , Al_2 O_3).

V. DISCUSSION OF RESULTS

XRD, AAS, and XRF Analysis: The X-ray Diffraction (XRD) results identified key minerals in the pegmatite samples such as Spodumene, Petalite, albite, muscovite, Lepidolite, and quartz. These are all indicative of Lithium-Cesium-Tantalum (LCT) pegmatites, which are known for their lithium-bearing minerals like Spodumene and Lepidolite sampleMPR-02, MPR-05, MPR-07 and MPR-10. The presence of quartz and albite reflects the common gangue minerals found in pegmatitic environments.The Atomic Absorption Spectroscopy (AAS) results show significant concentrations of lithium (Li), cesium (Cs), and tantalum (Ta). For example, Sample MPR-07 recorded the highest lithium content (340 ppm), and tantalum concentrations were elevated in several samples (up to 30 ppm), reflecting the economic potential of the Makarfi pegmatites for rare element extraction.X-ray Fluorescence (XRF) revealed the oxide composition of the samples, with silicon dioxide (SiO_2) consistently dominating, which aligns with the quartz-rich nature of the pegmatites. The presence of significant amounts of alumina (Al_2O_3) and potash (K_2O) supports the identification of K-feldspar and muscovite. Minor iron oxide (FeO_3) in some samples suggests possible alteration or minor accessory minerals like garnet or tourmaline.

Thin Section Analysis: Thin section petrography provided detailed mineralogical and textural insights: Quartz, Muscovite, and Albite: These minerals exhibited Granoblastic textures (e.g., MPR-01), reflecting high-grade metamorphic origins and suggesting slow cooling during crystallization. The anhedral shapes in Sample MPR-08 suggest recrystallization or possible hydrothermal overprinting.Spodumene and Petalite**: Observed in several samples (MPR-02, MPR-07, MPR-10) with porphyritic and granular textures, these minerals are essential indicators of lithium mineralization in pegmatites. Alteration: Evidence of sericitization, particularly in feldspars (MPR-05, MPR-06), suggests low-grade metamorphism or hydrothermal alteration. Argillitization in Sample MPR-07 also indicates fluid interaction during or after crystallization.

VI. CONCLUSIONS ANDRECOMMENDATION

The combined XRD, AAS, XRF, and petrographic analyses confirm the presence of economically important minerals in the LCT pegmatites of Makarfi L.G.A. The identification of Spodumene, Lepidolite, and Petalite, along with high lithium concentrations, suggests these rocks have significant potential for lithium extraction. Additionally, the presence of cesium and tantalum points to potential by-products that could enhance the economic viability of mining these pegmatites.
The consistent presence of quartz, feldspar, and muscovite, along with the geochemical signatures **(high SiO_2 and Al_2O_3),** further suggests that these pegmatites formed from a highly evolved granitic melt, characteristic of LCT pegmatites.

The textures observed under thin section analysis, particularly the porphyritic and granular structures, indicate a complex history of crystallization, likely involving slow cooling and possible hydrothermal processes. The moderate to low-grade alteration suggests minimal weathering, which is advantageous for mining.

RECOMMENDATION

Future work should focus on detailed geochemical mapping, mineral separation, and beneficiation studies to evaluate the economic feasibility of mining these pegmatites, particularly in zones rich in lithium and tantalum. Additionally, investigating deeper sections of the pegmatite bodies might uncover further mineralization zones with even higher concentrations of these critical elements.

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