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Research Article

THE CHARACTERIZATION OF ANGWA-KEDE LITHIUM ORE, KOKONA LOCAL GOVERNMENT AREA, NASARAWA STATE, NIGERIA

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ABSTRACT

This research on the characterization of Angwa-Kede lithium ore, Kokona Local Government Area, Nasarawa State, Nigeria, was carried out to identify the mineralogical content, elemental composition, and the percentage content of lithium (Li) present in the ore. The research employed a systematic sampling method for obtaining lithium ore at various lithium mine pits and a weighted sample of 100 g was pulverized and analyzed using X-ray fluorescence analysis (XRF) for elemental characterization, X-ray diffraction analysis (XRD) for identification of mineralogical phases, and the flame test analysis for identification of lithium concentration. The flame test result revealed that lithium concentration in the ore samples from the mining pit sites is found to be 0.3% and 1.85%, respectively, and thus is low-grade lithium ores. The XRD results revealed that the mineral phases in the lithium ore are quartz, albite, and muscovite as major phases whereas petalite, lepidolite, and spodumene are the minor phases in the matrix of the ore samples. XRF result shows that Al, Cl, S, Si, Mg, K, Ca, Fe, and P have percent significance values and are the major elements whereas others such as Cu, Ti, Mo, and Sr have minor percent values (minor elements). Conclusively, a more appropriate beneficiation process can aid in increasing the grade of the ore and this can be beneficial to the nation's metallurgical industry.

Keywords: Lithium ore, Lithium demand, Lithium mineralogy, Lithium characterization.

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INTRODUCTION

Lithium ranks about the 33rd element in abundance among elements in the Earth's crust and it constitutes approximately 0.006 wt%. It tends to concentrate in acidic igneous rocks and sedimentary alumino-silicates. The mean lithium content varies across rock types with magmatic rocks displaying lower concentrations (0.5–40 ppm) compared to sedimentary rocks (5–75 ppm). Its presence is detected in diverse geological formations such as primary and sedimentary mountains, marbles, granites, syenites, gneisses, and calcareous rocks (Hayyat *et al*., 2021).

One of the crucial minerals required for electric vehicle production is lithium, which is not widely available and needs to be obtained by mining or brine extraction that can potentially lead to various negative environmental and social consequences. The lithium-rich areas, in some cases, have faced (or could face) a paradox of clean energy transition by turning into a sacrifice zone for a green economy (UNCC, 2015).

Most of the lithium's economic importance is used as a material for the production of batteries for electrical devices, solar systems, and electric cars. Lithium is one of the lightest and the most highly reducing of metals, this confers to the battery having the highest gravimetric and volumetric energy densities (typically over 160 Wh/kg and 400 Wh/L). 50% greater than conventional batteries and it is a good conductor of electricity.

RESEARCH STUDY AREA

The "Research Study Area" is located in Kokona Local Government Area, Nasarawa State, Nigeria. The LGA has an area of 1844 km^2 and a population size of 109,749 whereas the study area (Angwa–Kede) is a village in Kokona LGA. The people in Angwa–Kede are predominantly farmers but are also into artisanal mining of lithium ore. The coordinates of the study area are N8°47'11.3928", E7° 57' 1.0332" and N8°49' 40.74", E7°58' 52.28", respectively. The visited lithium mine sites and pits are represented in Fig. 1.

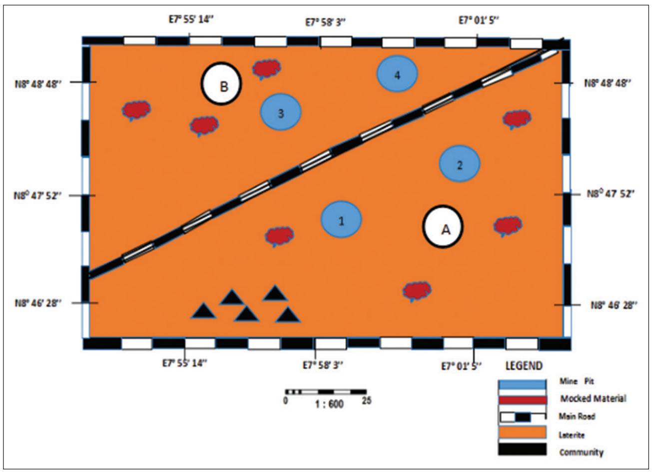

Fig. 1: A digitized map showing various visited mine pits within the study area (Site A and B)

SURGE IN LITHIUM MINERAL DEMAND

The heightened demand for lithium minerals is intricately linked to the escalating adoption of electric-driven vehicles (EDVs), a trajectory fueled by the imperative to control carbon emissions and foster an eco-friendly transportation system. Lithium batteries emerge as the pre-eminent choice, aligning seamlessly with the ethos of sustainability. The trajectory of current EDV demand projections is dynamic and contingent upon consumer preferences, with the United States and China emerging as a focal point for this transformative trend.

Recent projections underscore the burgeoning demand for EDVs in the United States, culminating in a market share exceeding 9% of total vehicles sold in 2017, as visually represented in Fig. 2a-c. The surge in EDV sales inherently propels a concurrent demand for batteries,

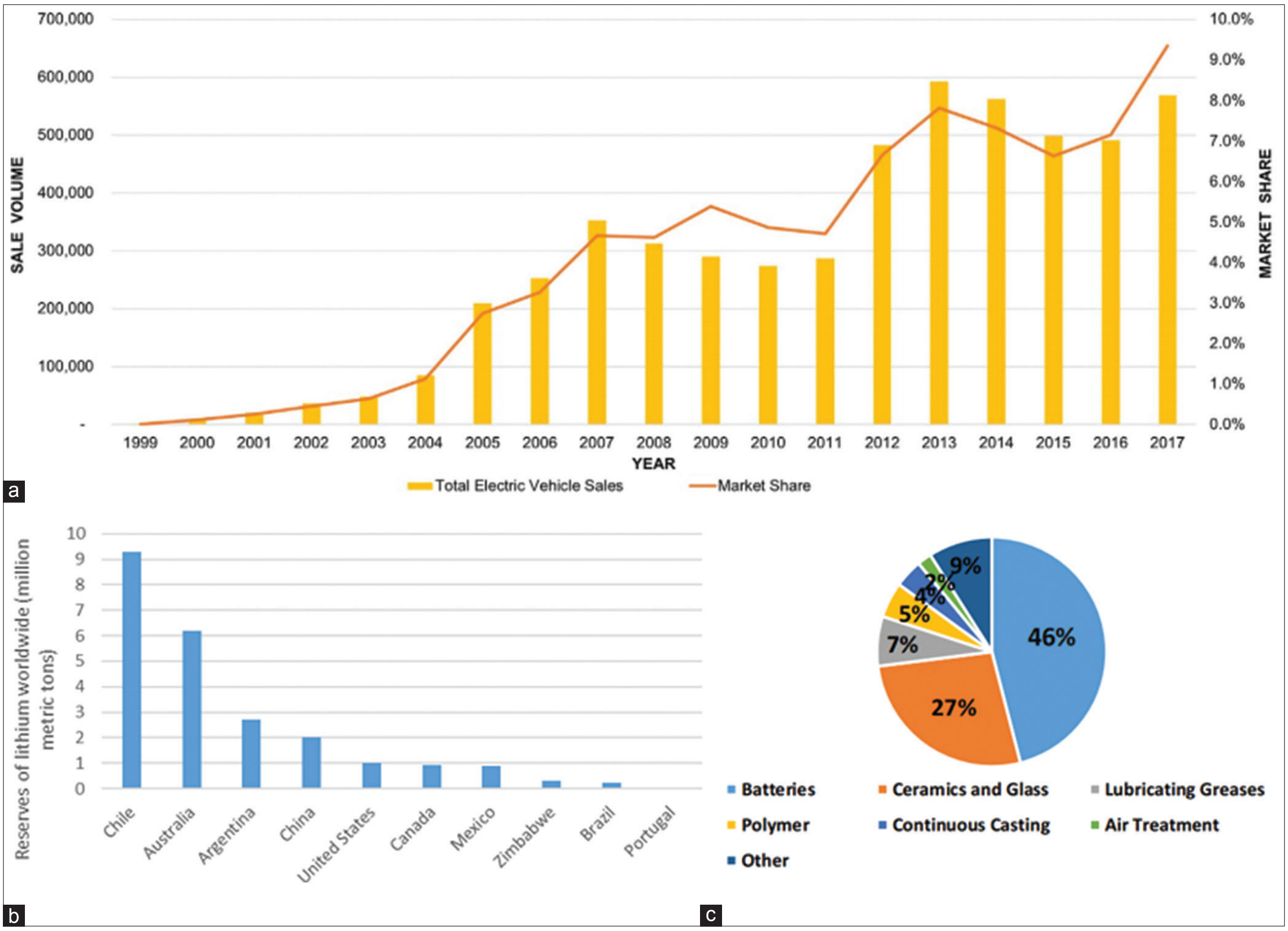

Fig. 2: (a) The United States sales volume and market share for electric vehicles, Source: Datu *et al.* (2018). (b) Top ten countries with largest lithium reserves in the world in 2022, Source: Azevedo *et al.* (2022). (c) Diagram of lithium usage proportions, Source: Jaskula (2018)

thereby amplifying the clamor for lithium minerals in the market. In the realm of power capacity, embarking on a 40-mile journey in an electric vehicle on a single charge necessitates 1.4–3.0 kg of lithium equivalent (equivalent to 7.5–16.0 kg of lithium carbonate). This underscores the pivotal role of lithium in extending the range and efficiency of EDVs (Agusdinata *et al.*, 2018).

The classification of lithium grade by percentage is seen in Table 1 and the prices for different grades of ore as sold in Nigeria are seen in Table 2 (using the 2023 price).

MATERIALS AND METHODS

Materials

(a) Sample bag, (b) global positioning system, (c) notebook.

Methods

Obtained lithium samples from site A and site B were gotten from different lithium mining pits as represented on the map shown in Fig. 3. These lithium mining pits are all in Angwa–Kede, Kokona LGA. The obtained lithium samples were crushed and pulverized and a representative sample of 100 g each was taken to the laboratory for X-ray fluorescence analysis (XRF), X-ray diffraction analysis (XRD), and flame test analysis.

RESULTS AND DISCUSSION

The result in Table 3 reveals that the lithium ore (Lithium Sample 1) contained associate minerals which are 30.6%Si, 0.006%V, 0.021%Cr, 0.093%Mn, 0.76%Fe, 0.79%Cs, 0.79%Nb, 0.134%Ba, 0.45%P, 0.192%S, 0.779%Ca, 8.46%K, 8.81%Al, 0.057%Ta, 0.12%Ti, 0.94%Rb, 0.00296%Zr, and 0.0161%Zn. Lithium Sample 2 also contains 28.56%Si, 0.0112%V, 0.0274Cr, 0.496%Mn, 2.19%Fe, 0.066%Cs, 0.0318%Nb, 0.0715%Ba, 2.65%P, 0.408%S, 5.72%Ca, 4.75%K, 6.69%Al, 0.057%Ta, 0.18%Ti, 0.32%Rb, 0.0296%Zr, and 0.048%Zn but cobalt (Co) is absent in both lithium samples. Furthermore, both analyzed lithium samples

Table 1: Classification of lithium grade by percentage

S. No.	Lithium percentage	Grade/Remarks
1	0.00–0.99	Poor Grade
2	1.00–1.99	Low Grade
3	2.00–2.99	Medium Grade
4	3.00–4.00 and above	High/Highest Grade

Ebikemefa and Martins (2023)

Table 2: Different prices for different grades of lithium in Nigeria (2023 Price)

S. No.	Grade of Lithium	Local Price (s)/50 kg
1	Low-grade lithium (1.00–1.99%)	N10,000–N13,000
2	Medium-grade lithium (1.99–2.00%)	N13,000–N20,000
3	Poorly formed crystals but a good trace of lithium	N35,000 – above
4	Highest grade lithium (well-formed crystals) - (4–5.00%)	N130,000/N150,000 – above

Ebikemefa and Martins (2023)

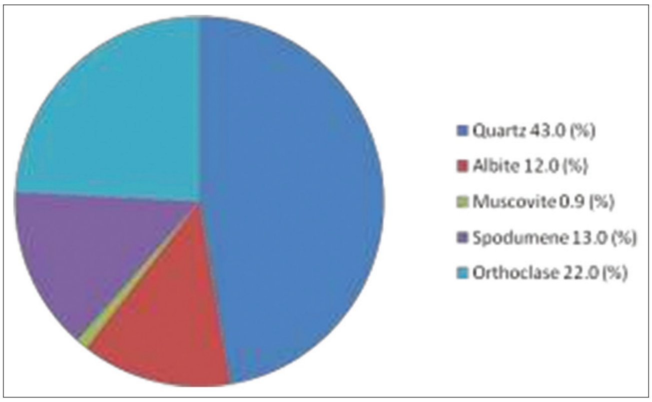

Fig. 3: Relative abundance of mineral phase (%) Sample 1 point A

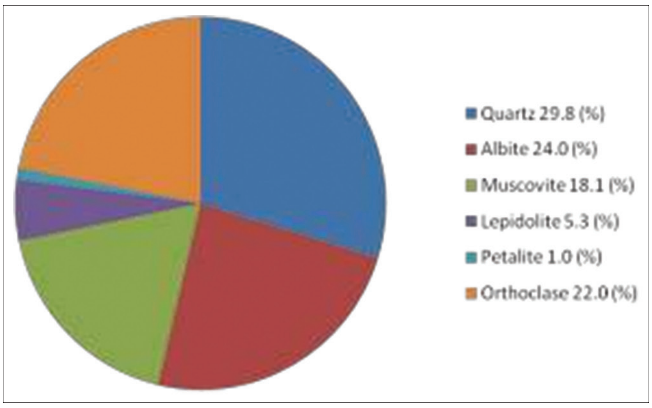

Fig. 4: Relative abundance of mineral phase (%) of Sample 2 site B

have silicon (Si) having a higher percentage concentration followed by aluminum (Al) and then potassium (K).

Table 4 and Fig. 3 present the results of the XRD analysis of lithium ore samples sourced from the two mining sites, respectively. The results in Table 4 and Fig. 3 reveal that the lithium ore of Lithium Sample 1 site A contains 43%quartz, 22%orthorclase, 13%spodumene, 12%albite, and 0.9%muscovite. However, it can be observed that the major mineral phases in Sample 1 of site A are Quartz, Orthoclase, Spodumene, Albite, and Muscovite been the major phase. More so, the XRD result can be said to confirm the presence of lithium (spodumene) in the ore sample of site A.

The results of Table 5 and Fig. 4 reveal that Sample 2 of site B lithium ore contains 29.8% quartz, 24% albite, 22% orthorclase, 18.1% muscovite, 5.3% lepidolite, and 1% petalite. However, it can be observed from the result in Table 4, and quartz, albite, orthoclase, and muscovite are the major and predominant mineral phases whereas lepidolite and petalite are the minor mineral phases in the matrix of Sample 2 site B.

Table 6 shows the various lithium types as revealed from the flame test analysis. Lithium Sample 1 of site A has 23% spodumene which appears to be the major mineral with petalite and lepidolite absent but lithium Sample 2 of site B has 5.3% lepidolite and 1% petalite with spodumene absent. Lepidolite is the major mineral in lithium Sample 2 obtained from site B.

The result in Table 7 reveals that the lithium ore contains 1.85% Li and 0.3% Li from the two samples sourced from mining points A and B, respectively. The variation in the percentage of lithium content from the two mining sites (A and B) could be attributed to the geochemical and mineralization of the lithium host rocks.

Table 3: XRF analysis of lithium ore of samples 1 and 2

Elements	Lithium sample 1 (%)	Lithium sample 2 (%)
Si	30.6	28.56
V	0.006	0.0112
Cr	0.021	0.0274
Mn	0.093	0.496
Fe	0.76	2.19
Cs	0.79	0.066
Co	-	-
Nb	0.024	0.0318
Ba	0.134	0.0715
P	0.45	2.65
S	0.192	0.408
Ca	0.779	5.72
K	8.46	4.75
Al	8.81	6.69
Ta	0.057	0.057
Ti	0.12	0.18
Rb	0.94	0.32
Zr	0.00296	0.0296
Zn	0.0161	0.048

Table 4: Mine site point A, XRD analysis showing relative abundance of mineral phase (%Li) sample 1

Mineral	Chemical Formula	Conc. (%)
Quartz	SiO_2	43.0
Albite	$Na\ (AlSi_3O_8)$	12.0
Muscovite	$KAl_2(AlSi_3O_{10})(F, OH)_2$	0.9
Spodumene	$LiAlSi_2O_6$	13.0
Orthoclase	$Al_2O_3.K_2O._6SiO_2$	22.0

Table 5: Mine site point B, XRD analysis showing relative abundance of mineral phase (%Li) sample 2

Mineral	Chemical formula	Conc. (%)
Quartz	SiO_2	29.8
Albite	$Na\ (AlSi_3O_8)$	24.0
Muscovite	$KAl_2(AlSi_3O_{10})(F, OH)_2$	18.1
Lepidolite	$K\ (Li, Al)_3Al, Si, Rb)_4O_{10}(F, OH)_2$	5.3
Petalite	$LiAlSi_2O_6$	1.0
Orthoclase	$Al_2O_3.K_2O._6SiO_2$	22.0

Table 6: Flame spectrophotometric analysis of lithium types in lithium ore samples 1 and 2

S. No.	Lithium samples	Spodumene (%)	Petalite (%)	Lepidolite (%)
1	Li sample 1 (Site A)	23	-	-
2	Li sample 2 (Site B)	-	1	5.3

Table 7: Flame spectrophotometric analysis of lithium content in lithium ore samples 1 and 2

S. No.	Lithium (Li) samples	Li content (%)	Li grade remark
1	Li sample 1 (Site A)	1.85	Low Grade
2	Li sample 2 (Site B)	0.30	Poor Grade

CONCLUSION

The characterization of lithium ore from the mining site in Angwa–Kede using the flame test analysis revealed that the lithium ore samples at point A contain 1.85% Li and those obtained from site B contain 0.3%Li, respectively. Other associated minerals in the ore samples as revealed from XRF analysis show that Al, Cl, S, Si, Mg, K, Ca, Fe, and P have percent significance values as the major elements whereas others such as Cu, Ti, Mo, and Sr have minor percent values (minor elements). The mineralogical analysis of the lithium ore using XRD revealed that the lithium ore sample obtained from site A contains 43% quartz(SiO_2), 12% albite($Na(AlSi_3O_8)$), 22% orthoclase($Al_2O_3.K_2O.6SiO_2$), and 13.0% spodumene($LiAlSi_2O_6$) in proportion as the major phases and 0.9% muscovite ($KAl_2(AlSi_3O_{10})(F,OH)_2$) as the minor mineral phase. Lithium ore sample in site B contains 29.8% quartz(SiO_2), 24% albite ($Na(AlSi_3O_8)$), 22% orthoclase($Al_2O_3.K_2O.6SiO_2$), 18.1% muscovite ($KAl_2(AlSi_3O_{10})(F,OH)_2$) as the major mineral phases whereas 5.3% lipedolite ($K(Li,Al)_3Al,Si,Rb)_4O_{10}(F,OH)_2$) and 1.0% petalite ($LiAlSi_2O_6$) as the minor mineral phases. Both XRD and flame test result reveals that lithium (Li) is present in the matrix of the ore samples but of low grade.

Recommendations

(i) Appropriate beneficiation process of lithium ore from the study area (Angwa–Kede) will enhance the grade of the ore
(ii) Laws to regulate the illegal mining of lithium ore should be enforced and fully driven by various mining ministries and bodies
(iii) Proper mining practices should be adopted for lithium mining in the study area and in other places where lithium ore is mined
(iv) Proper reclamation should be done immediately after the mining operation to prevent land degradation.

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AUTHORS CONTRIBUTIONS

EEC was involved in the fieldwork, site visitation, collection of data, writing, and typing of the research whereas RAM and DT were research supervisors. All authors have read and approved the final manuscript.

COMPETING INTERESTS

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

As approved by the Department of Metallurgical and Materials Engineering; Ahmadu Bello University, Nigeria, for the purpose of "Academic Research" and "Addition to Knowledge."

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

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