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Lithium extraction from lepidolite by different processes: the case of the Antsirabe II, Ikalamavony and Ambatofinandrahana districts of Madagascar

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ABSTRACT

This study compares the efficiency of several lithium extraction processes applied to lepidolite. Principal Component Analysis (PCA) reveals clear statistical signatures specific to each process, attesting to the robustness of the measurements and the differentiation of digestion mechanisms. A one way ANOVA confirms a highly significant "process" effect on yields. In practice, the alkaline NaOH route ranks first, followed closely by the sulfuric acid route (H_2SO_4), whereas Na_2CO_3 and HCl remain less efficient. These findings provide a rational framework for technology selection in lepidolite valorization and are consistent with recent literature.

Keywords: Lepidolite; lithium extraction; PCA; ANOVA; acid/alkaline processes.

Introduction

Amid global climate urgency and the accelerating energy transition, lithium has emerged as a strategic element of primary importance (International Energy Agency [IEA], 2025; Wood Mackenzie, 2022; IEA, 2023). As the main vector of electrochemical storage, it forms the cornerstone of lithium-ion batteries, now indispensable for electric mobility and portable electronics (IEA, 2025). This demand has reshaped supply dynamics between salar brines and hard-rock ores (Wood Mackenzie, 2022; IEA, 2023).In this context, lithium-bearing minerals are attracting growing interest, both for the diversity of their matrices and for the process-dependent specificities of lithium extraction (Segal et al., 2023).The Among them, lepidolite offers real potential, provided that thermo-chemical treatments are finely tuned and yields optimized while controlling environmental impacts (Xiong et al., 2023; Barbosa et al., 2023).Madagascar, rich in still underexplored pegmatites, thus offers an opportunity to develop a local industry producing lithium carbonate or hydroxide (Segal et al., 2023).The aim of this study is to compare, on representative Malagasy lepidolites, different extraction routes and to quantify the "process" effect on yield.

Materials and methods

Sampling sources

Four representative samples were collected: two at Antanifotsy Nord and Tsarafara (Antsirabe II District), one at Mandrosonoro (Ambatofinandrahana District), and one at Tsitondroina (Ikalamavony). Sampling (geological hammer, GPS georeferencing, cartographic support) was immediately conditioned in polyethylene bags to preserve integrity and traceability up to the laboratory.

Lithium extraction

Lepidolite, ground to 80–250 µm then sieved, was prepared in 100 g batches (80 µm). Reactive pastes were formed with H_2SO_4, an $HF–H_2SiF_6$ mixture, $Ca(OH)_2$, sulfates, and NaOH, at various ore/reagent ratios (1:1; 1:2; 3:2; 3:4). Digestion was carried out between 100 and 350 °C for 0.5 to 3 h, followed by aqueous leaching (250 mL, 1 h) and concentration of the clear liquors, in line with reported operating windows for lepidolite (Meshram et al., 2014; Gao et al., 2020; Park et al., 2023; Mulwanda et al., 2023).These conditions are often optimized to limit temperature and effluent loads (Park et al., 2023). Lithium carbonate (Li_2CO_3) was then precipitated by adding Na_2CO_3, recovered by centrifugation, dewatered, and dried.

Data-processing tools

Experimental data were processed with Excel/XLSTAT to perform PCA and one-way ANOVA.

Results

Sampling

Table 1. Geographic location of lepidolite samples (Source: Author).

No.	Sample code	Coordinates	Site	District
1	Lep-ANT	20°02′32″ S, 46°58′11″ E	Antanifotsy Nord	Antsirabe II
2	Lep-TSR	19°59′05″ S, 46°57′08″ E	Tsarafara	Antsirabe II
3	Lep-AMB	20°35′13.20″ S, 46°00′23.40″ E	Mandrosonoro	Ambatofinandrahana
4	Lep-IKA	21°17′48.48″ S, 45°59′06.72″ E	Tsitondroina	Ikalamavony

Principal Component Analysis (PCA)

The PCA (Figure 1) shows a clear separation of processes. The NaOH process occupies a dominant position in the factorial space (~98%), followed by H_2SO_4 (~96–97%). The Na_2CO_3 and HCl processes appear more dispersed, revealing their lower efficiency. The collinearity of replicate vectors confirms the reproducibility of the measurements.

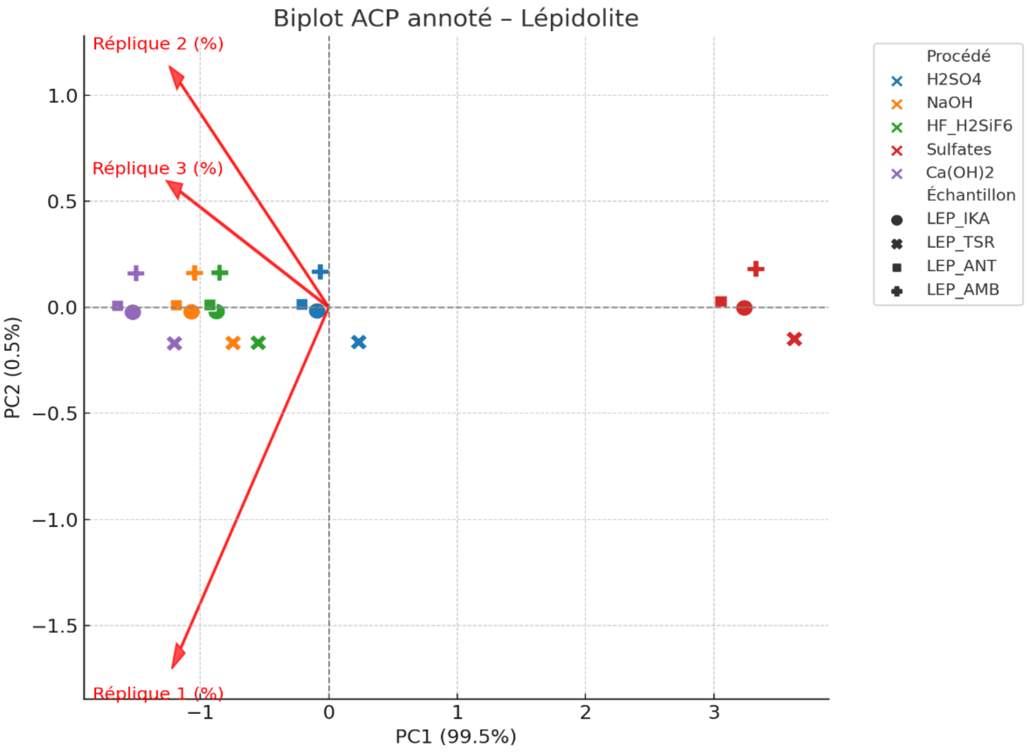

Figure 1. PCA biplot.

Analysis of Variance (ANOVA)

The ANOVA (Figure 2) indicates that the “Process” factor exerts a highly significant effect on yield (F = 392.36; $p < 0.0001$), confirming that the observed differences are not due to chance but to the intrinsic efficiency of the methods.

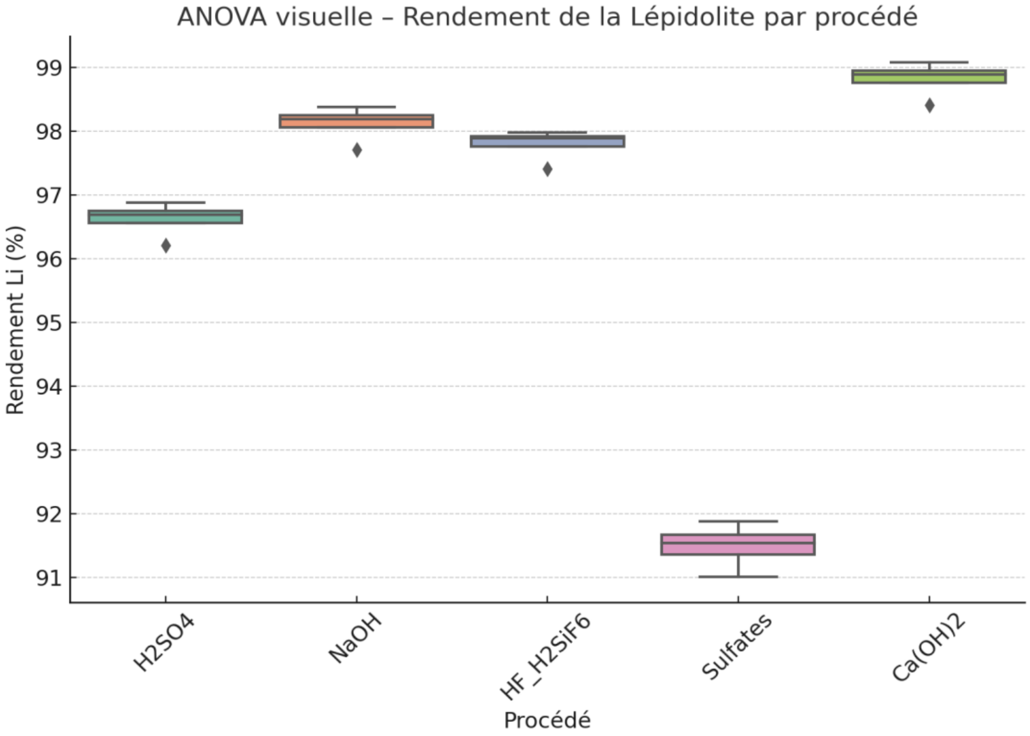

Figure 2. Visual ANOVA—lepidolite yield by process.

Global and by-sample comparison

The global comparison (Figure 3) indicates: NaOH (~98%) ≳ H_2SO_4 (~96–97%) > HF/H_2SiF_6 and HNO_3 (~92–95%) ≫ Na_2CO_3, HCl (~85–90%). Trends are homogeneous by sample, confirming the superiority of strong alkaline and strong acid processes.

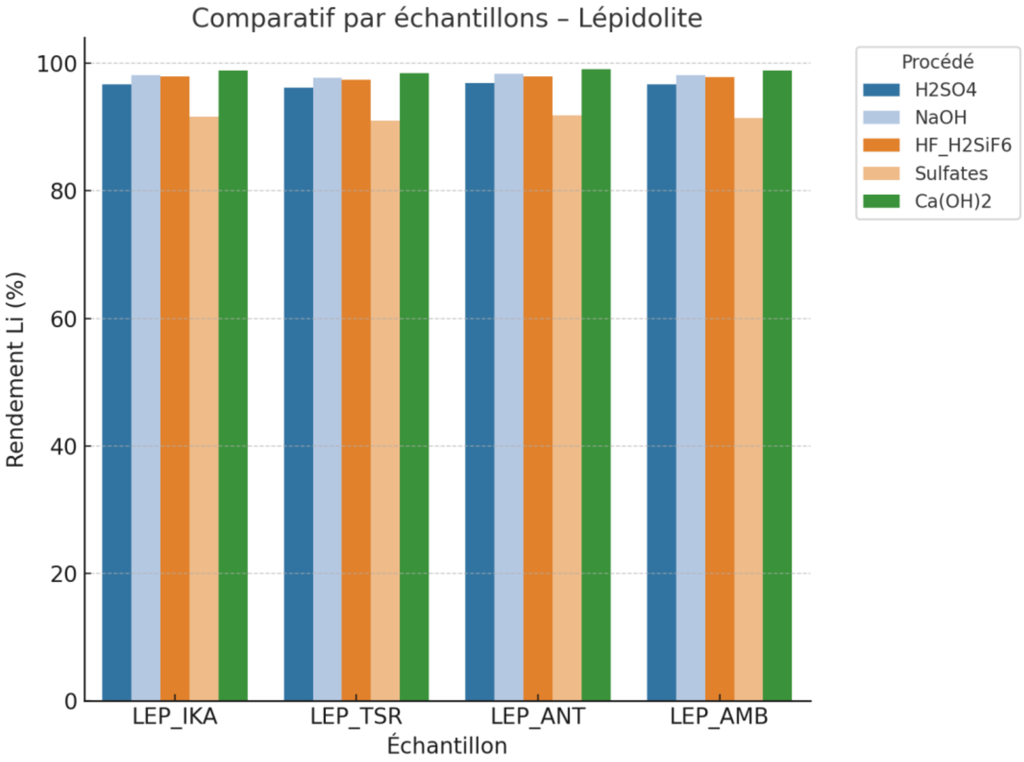

Figure 3. Global comparison by samples.

Discussion

The results show that lepidolite responds differently depending on the process. The NaOH route stands out (~98%) through its effective disruption of the aluminosilicate framework, while H_2SO_4slightly lower (~96–97%) remains an industrial benchmark (Choubey et al., 2016; Tian et al., 2011; Novák et al., 2012). Na_2CO_3 and HCl are clearly less efficient, underscoring the determining role of reagent chemistry. These observations are consistent with trends reported for other lithium-bearing minerals, while highlighting the structural specificity of lepidolite (Choubey et al., 2016; Tian et al., 2011; Novák et al., 2012).

Conclusion

Statistical analysis highlights the central role of process choice in lithium extraction from lepidolite. NaOH dominates, followed by H_2SO_4, whereas Na_2CO_3 and HCl are less efficient. These elements guide technological choices for optimal valorization of this mineral.

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