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ENHANCING EU ECONOMIC RESILIENCE: EXPLORING NEW SOURCES AND BENEFICIATION OF CRITICAL RAW MATERIALS NIOBIUM AND TANTALUM FROM CENTRAL AFRICA

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ABSTRACT – Raw materials are vital to Europe's economy, which is why the EU has identified specific Critical Raw Materials (CRM) that are crucial for its economic stability but pose significant supply risks. These include niobium and tantalum, for which there are currently no active mines in the EU. About 92% of the EU's niobium is imported from Brazil, primarily used in various alloys. The situation is similar for tantalum, with 63% being imported from several African countries, where it is mainly utilized in producing capacitors and superalloys. We have started exploring potential new sources in Central Africa to improve the diversity of supply. We are focusing on two types of mineral deposits: niobium- and tantalum-rich laterite and pegmatite ores. These ores were analyzed using techniques such as ICP-OES, XRPD, and SEM-EDS to determine the chemical and mineralogical compositions, as well as the grain sizes, to facilitate subsequent mineral liberation. Based on our findings, we have developed and implemented a test program using gravity and magnetic beneficiation methods. This program aims to produce an industrial-grade concentrate, thereby strengthening the resilience of the EU's raw material supply chain.

Keywords: Tantalum, Niobium, Magnetic Separation, Gravity Separation, CRM.

INTRODUCTION

The increasing demand for specific strategic materials, amplified by the political risks associated with their geographically concentrated supply chains, presents a potential threat to the advancement of low-carbon energy technologies due to possible shortages. Tantalum and niobium have been recognized as critical metals in the EU [1]. Niobium is essential in the nuclear sector, while both metals are vital for technologies related to carbon capture and storage and other upcoming sustainable innovations. This emphasizes the importance of improving their recovery from natural ores and recycling them from electronic waste, a process known as urban mining. Currently, tantalum and niobium are widely used across various fields, including optics, electronics, mechanical engineering, aerospace, nuclear technologies, and other advanced applications. The

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demand for niobium is expected to rise significantly in high-strength, low-alloy (HSLA) steel applications, advanced Li-ion batteries, drones, and 3D printing [2].

Belonging to group 5 of the periodic table, tantalum and niobium have average crustal abundances of 1.7 mg/kg (Ta) and 20 mg/kg (Nb), respectively. They mostly exist in nature as refractory oxides, with no known deposits of the metals in their elemental form [3]. The primary sources for extracting niobium and tantalum are various minerals and concentrates, with a considerable amount obtained from the columbite-tantalite mineral, also known as coltan ($(Fe, Mn)(Ta, Nb)_2O_6$). Another significant source of niobium is the mineral pyrochlore ($(Na, Ca)_2(Nb)_2O_6(OH, F)$), highlighting the varied origins of these critical elements. These primary ores can contain various impurities such as ilmenite ($FeTiO_3$), silica (SiO_2), hematite (Fe_2O_3), wolframite $(Fe, Mn)WO_4$, cassiterite (SnO_2), and zircon ($ZrSiO_4$), as well as davidite $(La, Ce, Ca)(Y, U)(Ti, Fe)_{20}O_{38}$ and uraninite (UO_2) [4].

Given their low crustal abundances, extensive beneficiation processes are implemented to concentrate and upgrade them to a commercial grade of 25% of their pentoxide form equivalent.

Low-grade Nb-Ta ores, usually containing less than 0.1% Nb_2O_5/Ta_2O_5, present challenges for processing and recovery. This underscores the necessity of efficient ore enrichment and beneficiation to enhance extraction processes. The differences in properties between Nb and Ta and other gangue oxides can be leveraged in separating the two rare metals from one another as well as from impurities. Certain impurities in the mineral ore can thus be removed at specific mineral particle sizes and conditions before the digestion process, easing extraction complexity and potentially reducing recovery steps. Additionally, the routes for the beneficiation processes of these minerals can vary, ranging from ore pre-concentration to primary concentration and concentrate clean-up processes [5]. Ore preconcentration and primary concentration processes mainly include froth flotation, gravity, magnetic separation, and electrostatic separation, which are the beneficiation routes that effectively enrich and prepare ores for further concentrations and separations [6].

Gravity concentration (GC) is a long-established method for the physical separation of columbite/tantalite mineral ores, utilizing differences in density or specific gravity. This technique, as detailed in studies [5], involves the movement of mineral particles under external forces such as gravity, centrifugal force, buoyancy, and drag. These forces act on the particles in different directions, facilitating their separation based on density. The process employs equipment like jigs, shaking tables, sluices, and centrifugal and spiral concentrators, often operated in media such as water, viscous heavy liquids, or air. Screening processes frequently accompany gravity concentration to boost efficiency [7]. Researchers acknowledge the effectiveness of gravity concentration, noting its operational simplicity and cost-effectiveness as significant advantages. Both wet and dry gravity concentration methods have been successfully implemented, with various combinations of jigs, shaking tables, sluices, air floaters, and spiral concentrators proving effective across different studies. This body of research highlights the ongoing relevance and adaptability of gravity concentration techniques in mineral processing, emphasizing continual advancements and applications in the field [8].

EXPERIMENTAL

Two different "Ta-Nb" ore samples from laterite (S1) and pegmatite (S2) were analyzed to evaluate their potential as mineral resources. These investigations included extensive physicochemical and mineralogical assessments to grasp the ore's properties and processing potential for commercial use in various industries.

Both samples (S1 and S2) underwent identical preparation procedures, beginning with homogenization. Sub-samples were extracted from the homogenized ore to determine gross moisture, granulometric composition, and bulk density, with particle size distribution assessed via dry sieving using a standard Tyler sieve series. After analyzing the size of the raw samples, the ore was initially crushed (15.6 – 0.1 mm). We then re-evaluated its size and bulk density. The ore was subsequently crushed a second time to produce the final samples (6.35 – 0.1 mm). Comprehensive physicochemical and mineralogical analyses were performed on these samples. The qualitative mineralogical analysis utilized X-ray diffraction, with classifications by size classes and polished sections prepared for optical and SEM microscopy. For elemental composition were used ICP_OES and XRF analyzers were used.

Additionally, gravity separation tests with a multi-gravity separator and super planner concentrator were conducted on the raw ore.

Table 1 Elemental composition of both samples made by ICP-OES

Sample Name	w (μg/g)							
	Al	**Ca**	**Fe**	**Mn**	**Nb**	**Si**	**Sn**	**Ta**
S1_RAW	132512	548	17808	182	152	297000	166	216
S2_RAW	134052	285	5515	185	228	314868	166	390

Reflected light microscopy and SEM (Figure 1) were used to analyze grain size and intergrowth of precious and gangue minerals, offering detailed insights into the samples mineral composition.

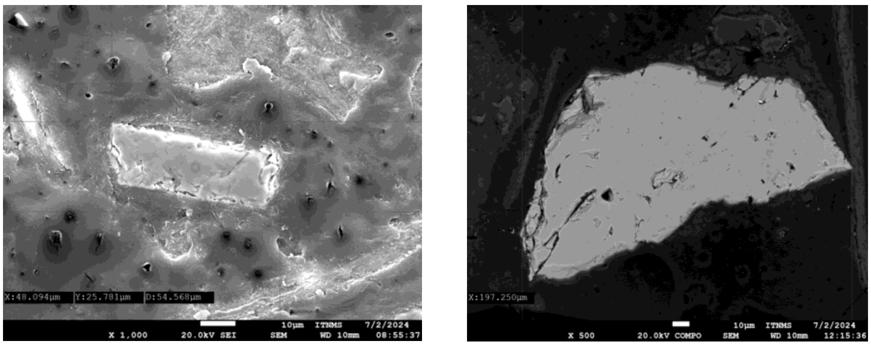

Figure 1 SEM images of a Columbite-Tantalite intergrown with albite in S1 (Left) and a grain of (ferro)wodginite embedded in clay in S2 (Right)

X-Ray Powder Diffraction (XRPD) was crucial in determining both the qualitative and quantitative mineralogical composition of the samples. This technique accurately identifies the minerals or crystalline phases present and their quantities, offering essential insights into the sample's properties and potential uses. Using the Rietveld refinement method, with χ2 = 1.88 and an R factor of 0.278, the mineral composition was quantified in weight percentages as follows:

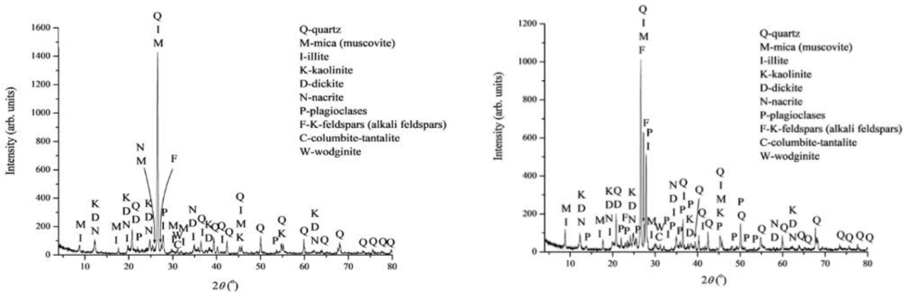

Figure 2 XRPD of both samples S1 (Left) and S2 (Right)

Table 2 Mineral composition of both samples

	S1	S2
	[%]	
Quartz	61.40	39.5
Muscovite	12.2	15.9
Kaolinite	13.1	8.00
Dickite	4.9	1.4
Nacrcite	0.4	3.1
Plagioclases	6.8	24.1
Alkali feldspars	0.8	7.3
Columbite-Tantalite	in trace	in trace

In this study, two different gravity separation methods were used as a Multi-Gravity Separator (MGS) and a Super Pan Separator to process the raw ore sample S1. The initial stage involved thorough washing of the raw material to eliminate fine clay fractions and all particles larger than 6.3 mm. Subsequently, the material underwent wet sieving using a 38-micron sieve, ensuring that only particles smaller than 38 microns were processed in the MGS. This approach was chosen due to the MGS's effectiveness in handling fine and ultra-fine materials. The MGS excels at separating grains based on their specific densities, allowing for the efficient concentration of Tantalum and Niobium, while effectively distinguishing these valuable minerals from less dense usable grains and non-valuable particles.

Following the MGS processing, the same raw ore samples S1 and S2 was subjected to testing with the Super Panner Separator with V-Tray. In this case sample had also been washed to remove clay and oversized grains larger than 6.3 mm. The material was subsequently dry-sieved into distinct size fractions. For the Super Panner Separator, the size fraction utilized was 180-125 µm. This stratification facilitated a comprehensive observation of the behavior of lighter grains in comparison to the heavier fractions, allowing for an enhanced understanding of the separation process to particle size and density.

RESULTS AND DISCUSSION

One of the important highlights of this study is the grain liberation, achieved through milling and additional milling of the samples. This study highlights the grain liberation of niobium-tantalum (Nb-Ta) bearing minerals, including columbite-tantalite, wodginite, and cassiterite. Results show that over 80% of grains were liberated, 15-16% were intergrown with silicates and/or limonite, and 2-3% were inclusions.

In this study, we concentrated on evaluating key parameters for each analytical method. The results highlight the material that exhibited the most favorable values for specific parameters across all tests conducted.

The multi-gravity separator effectively concentrated valuable elements from the initial sample (S1_MGS_-38_FEED1), where Aluminum, Iron, and Silicon were abundant. Post-separation, the concentrate (S1_MGS_-38_CONC1) showed significant enrichment of Niobium and Tantalum, with Tantalum increasing from 137 to 1,856 µg/g. In the tailings S1_MGS_-38_TAIL1), the concentrations of the elements showed minimal variation when compared to the feed (Table 3).

Table 3 Elemental Composition of Various Stages After Multi-Gravity Separation for Sample S1 made by XRF

	µg/g						
Sample	**Al**	**Fe**	**Si**	**Mn**	**Nb**	**Sn**	**Ta**
MMR_S1_MGS_-38_FEED1	174 212	16 530	229 485	114	42	104	137
MMR_S1_MGS_-38_CONC1	106 313	16 457	327 841	783	1 032	283	1 856
MMR_S1_MGS_-38_TAIL1	171 034	17 294	221 803	114	36	57	150

Results from the Super Panner concentrator on coltan ore sample S1 show significant variations in elemental concentrations across RAW, HEAVY, and LIGHT fractions. The HEAVY fraction contains high levels of niobium (Nb, 0.51 mg/g), tantalum (Ta, 0.47 mg/g), and tin (Sn, 1.05 mg/g), making it optimal for further processing. In contrast, the LIGHT fraction has high aluminum content (171.96 mg/g) but lower concentrations of Nb, Ta, and Sn. These findings suggest focusing on the HEAVY fraction to improve metal recovery, with further mineralogical investigations potentially enhancing separation techniques (Table 4).

Table 4 Elemental Composition of Various Stages After Multi-Gravity Separation for Sample S1 made by XRF

Sample	µg/g						
	Al	**Fe**	**Si**	**Mn**	**Nb**	**Sn**	**Ta**
PANER_180-125_RAW	125839	7476	252285	77	184	454	204
PANER_180-125_HEAVY	61495	13215	374334	361	513	1050	466
S1_PANNER_180-125_LIGHT	171959	6122	233223	48	33	53	139

CONCLUSION

The study of coltan ore from Central Africa, featuring laterite (S1) and pegmatite (S2) samples, highlights their significant potential as valuable mineral resources. Through various techniques such as XRPD, microscopy, ICP-OES, and XRF, we thoroughly assessed the physicochemical and mineral properties of these ores, confirming their favorable characteristics for commercial processing. The liberation of over 80% of Nb-Ta-bearing minerals underscores the effectiveness of milling. The application of gravity separation methods—Multi-Gravity Separator (MGS) and Super Panner Separator—on coltan sample S1 efficiently concentrated key minerals, particularly niobium and tantalum, by utilizing differences in density. The MGS achieved a remarkable increase in tantalum concentration, rising from 137 to 1,856 µg/g. Meanwhile, the Super Panner Separator identified the HEAVY fraction as optimal for further processing, being rich in valuable metals.

These results highlight the ores commercial potential and suggest improving metal recovery methods for better efficiency. This research provides insights to guide future exploration and utilization of tantalum and niobium, supporting their industrial use.

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