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Alternative beneficiation of tantalite and removal of radioactive oxides from Ethiopian Kenticha pegmatite–spodumene ores

Berhe Goitom Gebreyohannes[1,2], *Velázquez del Rosario Alberto*[1], *Abubeker Yimam*[3], *Girma Woldetinsae*[4], *and Bogale Tadesse*[5]

1) School of Materials Science and Engineering, Jimma Institute of Technology, Jimma University, P.O. Box 378, Jimma, Ethiopia
2) Chemistry Department, College of Natural and Computational Science, Mekelle University, P.O. Box 823, Mekelle, Ethiopia
3) School of Chemical and Bio Engineering, AAiT, Addis Ababa University, P.O. Box 1176, Addis Ababa, Ethiopia
4) Research and Development Directorate, Federal Democratic Republic of Ethiopia, Ministry of Mines, Petroleum and Natural Gas, P.O. Box 486, Addis Ababa, Ethiopia
5) Department of Mining Engineering and Metallurgical Engineering, Western Australian School of Mines, Curtin University, Egan St, Kalgoorlie, WA 6430, Australia
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Abstract: The beneficiation methods for Ethiopian Kenticha pegmatite–spodumene ores were assessed through mineralogical and quantitative analyses with X-ray diffraction (XRD) and energy-dispersive X-ray fluorescence (EDXRF). The tantalite in the upper zone of the Kenticha pegmatite–spodumene deposit is 58.7wt% higher than that in the inner zone. XRD analysis revealed that the upper zone is dominated by manganocolumbite, whereas the inner zone is predominantly tantalite–Mn. Repeated cleaning and beneficiation of the upper-zone ore resulted in concentrate compositions of 57.34wt% of Ta_2O_5 and 5.41wt% of Nb_2O_5. Washing the tantalite concentrates using 1vol% KOH and 1 M H_2SO_4 led to the removal of thorium and uranium radioactive oxides from the concentrate. The findings of this study suggest that the beneficiation and alkaline washing of Kenticha pegmatite–spodumene ores produce a high-grade export-quality tantalite concentrate with negligible radioactive oxides.

Keywords: beneficiation; manganocolumbite; pegmatite-spodumene; radioactive oxides; tantalite

1. Introduction

In the modern electronics and nuclear industries, both tantalum (Ta) and niobium (Nb) are key and critical metals [1–2]. Columbo–tantalite, which is the major source for these rare metals, occurs mainly in pegmatites associated with granites. The common name for the mineral is tantalite when tantalum predominates over columbium (Nb) and columbite/niobite when columbium is dominant [1,3]. The world resources available today may not meet future demands for Ta and Nb. These metals are recovered mainly from the minerals of “calton” (columbite-tantalite ore), which consists oxides of Ta and Nb (OTN) in the form of ($(Fe,Mn)(Ta,Nb)_2O_6$) and small amounts of other Ta oxides such as microlite, ixiolite, and wodginite [2–9]. The concentrates from this ore typically contain Ta_2O_5 between 10wt% and 60wt% in the case of concentrates from leading producers such as Greer Lake (Manitoba), Tanco pegmatites (Canada), Kenticha pegmatites (Ethiopia), Greenbushes and Wodgina pegmatites (Western Australia), Yichun complex (China), granitic pegmatites of the Pampean Ranges (Argentina), and rare-metal granitoids of the Eastern Desert (Egypt) [10]. The classification of pegmatite ores is based on the metamorphic environment, mineralogy, elemental composition, and texture; the ores are divided into classes, subclasses, types, and subtypes. On the basis of their mineralogical composition, the Li–Cs–Ta (LCT) family of the rare-element class is the economically most important family for Ta and Nb, and four pegmatite types (beryl, complex, albite-spodumene, spodumene) exist [6,11–17]. According to the mineralogical composition of Kenticha pegmatite, it is classified into beryl, feldspar-muscovite, albite–spodumene,

Corresponding author: Berhe Goitom Gebreyohannes E-mail: goitish2500@gmail.com

and spodumene. Spodumene contains the highest compositions of Mn-tantalite, along with radioactive elements such as Th and U, which require careful removal for the concentrate product to meet export standards [13]. The beneficiation of OTN also requires the removal and separation of associated impurities from each other because Nb, Ta, Fe, and Ti are usually associated with one another in minerals. Because of their similar chemical properties, these elements are separated with difficulty [11–12]. This Kenticha pegmatite is the site of the open-pit tantalum mining operations and is the main subject of this paper.

According to Küster *et al.* [13] and Kim *et al.* [14], the Kenticha rare-element pegmatite (Ta–Li–Nb–Be–Cs) mineralized zone is located in the ophiolitic fold and thrust complex of southern (Oromia Regional State) Ethiopia, spanning approximately 2 km in length and 400–700 m in width, which represents a globally important tantalum source. Exploration by Ethiopian Mineral Petroleum and Biofuel Corporation (EMPBC) under the Federal Democratic Republic of Ethiopia, Ministry of Mines, Petroleum and Natural Gas is ongoing exporting high-grade or 50wt%–60wt% Ta_2O_5. The possible standby resource of primary Kenticha pegmatite ore is 17000 t at the Ta_2O_5 grade of 0.017wt%, whereas it was estimated to be 2400 t at 0.015wt% Ta_2O_5 in the weathered zone. The deposit of Kenticha is related to late Neoproterozoic I-type granites, a highly complex sub-horizontal pegmatite sheet with a thickness approaching 100 m and classified into three zones—the upper zone (UZ), the inner zone (IZ), and the lower zone (LZ), on the basis of the scheme of Černý and Ercit [13–15]. The exploitable and highly concentrated tantalite occurs in the UZ and is characterized by spodumene. Spodumene-bearing pegmatite is white (Fig. 1) and characteristically occurs in giant wedge-shaped crystals up to 4 m in length and with various Ta/Nb mass ratios from 3:1 to 1:1 and lower, which imitates the Ta mineralization potential. The Ta/Nb mass ratio is the highest in the spodumene unit, which is the focus of the present mining and future development for the extraction of Ta [13–17].

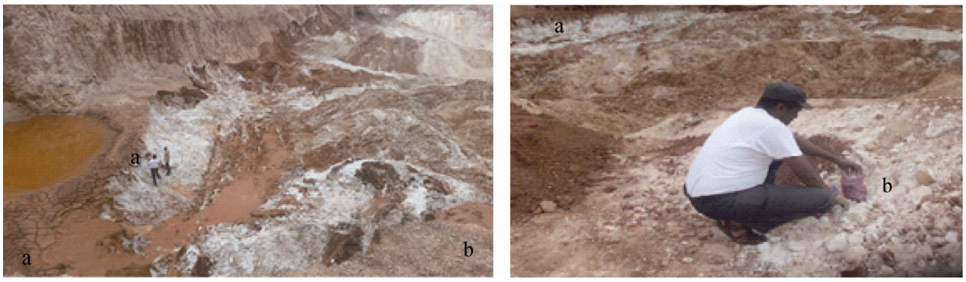

Fig. 1. View of the Kenticha pegmatite mined by EMPBC: (a) 20-m inner zone; (b) upper zone of the mined spodumene.

The beneficiation of tantalite ores often involves pre-concentration, feather concentration, and concentrate clean-up for less than 0.1wt% Ta_2O_5. The choice of any or all of these processes and their success would normally depend on the physiochemical properties of the ore, its Mn/Fe and Ta/Nb ratios, its response to magnetic fields, the presence of radioactive materials, the nature of the ore, and particularly the content of Ta_2O_5 in the ore relative to its associated minerals and impurities. The primary choice of the beneficiation process of an ore containing OTN usually starts with an enrichment step, which may involve mineral processing steps such as sizing and classification, washing, gravity separation, and magnetic separation steps [1–2]. However, the most well known beneficiation processes for concentrating tantalite ore are gravity and magnetic separations. Secondary ore concentration stages are generally required to increase the content of Ta_2O_5 before further processing to recover Ta and Nb and to remove associated Ta-bearing minerals, impurities, and radioactive elements to acceptable levels [1–2,18]. The chemical separation or purification of Ta and Nb from their minerals is a complex and difficult process, mainly because of the chemical and physical similarities between these two elements; for example, their ionic radii, resistance to chemical attack, and the ease with which their compounds are hydrolyzed in aqueous solutions are all similar [19]. Associated heavy minerals such as hematite, manganese oxides, and rutile are subsequently subjected to magnetic separation, where the hematite transformed to ferromagnetic magnetite is concentrated from nonmagnetic ore minerals [4].

Some studies have indicated the successful removal of up to 97wt% Fe and 86wt% Ti from tantalite using magnetic separation and 76.32wt% ThO_2 and 44.98wt% U_3O_8 radioactive elements using acid leaching from high-grade ores. In addition, 93.65wt% Nb and 93.6wt% Ta were recovered from a low-grade ore using a KOH roast–water leach system. However, approximately 80wt% Sn, 50wt% Ti, 20wt% Fe, and 20wt% Mn were also leached from