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Research Article

Geology, Geochemistry, and Economic Evaluation of Feldspar Quartz Pegmatites in the Kenticha Serpentinite Massif, Southern Ethiopia

Mitiku Tamene*, Wakjira Tesfaye

Mineral Industry Development Institute, Ministry of Mines, Addis Ababa, Ethiopia

Abstract

The Kenticha pegmatite deposits, which are known as world-class rare element deposits of the Lithium-Cesium-Tantalum (LCT) type, occur in the Adola Belt, specifically within Ethiopia. This report presents a comprehensive geological, geochemical assessment of pegmatite deposits of feldspar-quartz composition, which occur in the Gara Kenticha serpentinite massif. The study has been done by analyzing five principal pegmatite veins, whose orientation, geochemical differentiation, and estimates of mineral composition have been determined. The chemical analysis of 12 representative pegmatite samples indicates that the region has high-quality feldspar of 17.2% Al_2O_3, 13.5% total alkalis, and very low Fe_2^+ oxide of less than 0.3%. The massif has been estimated to contain 7.2 million tons of high-quality pure quartz, while that of the major pegmatite deposits is over 2.7 million tons of feldspar deposits. Geochemically, the pegmatite deposits were formed as a consequence of post-collisional extension of the East African Orogeny at 530 Ma, which was due to extreme fractionation of peraluminous granitic magma. Although of high geological feasibility, development of this project is currently impeded by socio-economic conditions of development of the Guji zone as well as by its centralized regulation. This report combines mineralogical information available with industrial standards to promote the development of local processing plants, which could be a boost for the industrial mineral industry in Ethiopia.

Keywords

Geology, Geochemistry, Feldspar, Quartz, Pegmatite, Serpentinite

1. Introduction

The rare metal/industrial mineral survey in Ethiopia is greatly underway given the need to diversify the economy and develop the fledgeling local manufacturing industries. The Adola Belt in the south of the country has long represented the focus of the mining activities in Ethiopia because of the belt's large gold resources in the Mesothermal gold belt represented by the Lega Dembi Mine. [1] It was the evaluation of the pegmatite rare element field in the Kenticha deposits that exposed the fact that a highly complex and diverse metallogenic province exists that can provide essential metals to the technological/construction industries of the world [2].

*Correspondence: Mitiku Tamene (kakuumiteef@gmail.com)

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LCT-type pegmatites are special types of rock environments, reflecting the last stage of extreme granitic fractionation. LCT-type pegmatites are special types of rock environments, reflecting the last stage of extreme granitic fractionation. They are the primary sources for lithium, tantalum, and cesium, but provide high-purity deposits of feldspar and quartz as well [3]. In the Kenticha deposit, these pegmatite deposits are discordantly cut within an Upper Proterozoic serpentinite massif, forming a conspicuous mineralogical contrast between this ultramafic host rock and the felsic intrusive stocks. The Gara Kenticha serpentinite massif, spanning 7 km x 1 km, forms the structural control for the linear north-south pegmatite vein deposits, showing diverse degrees of mineralogical zonation and rare element enrichment.

The economic importance of these pegmatites goes beyond their content of tantalum and niobium. With the Ethiopian government's target of the mining industry contributing 10% GDP by 2025, the development of industrial minerals for the production of glass and ceramic products has now become a matter of high priority. [4] Feldspar is a critical flux material, and high-purity quartz has a crucial application in the manufacture of containers and solar panels. [5] Though there is potential in the deposits at Kenticha in the feldspar and quartz minerals, their development has been below their size and quality because of the inaccessibility of the Guji Zone and the past emphasis on gold and tantalum concentrates. [6]

This study also ensures a holistic analysis of the Kenticha feldspar-quartz pegmatite through the integration of primary observations and current geochemical modeling. The work also explores the internal zonation of the pegmatites from the quartz-dominant core of Vein No. 1 to the spodumene-enriched zones of Vein. Through the comparative analysis of the geochemical characteristics of the pegmatites against global standards and giant pegmatites such as the Tanco deposit in Canada, the study explains the magmatic and hydrothermal controls that controlled the formation of the pegmatites [3]. The report also addresses the socio-economic standing of the Guji Zone, elaborating on how sustainable mining and value addition through industrial processing will offset the regional food insecurity and bridge infrastructure gaps. [7]

1.1. Regional Geological Setting

1.1.1. The Arabian-Nubian Shield and East African Orogeny

The geological history of South Ethiopia has closely linked its background to that of the formation of the Arabian-Nubian Shield-a vast Neoproterozoic crustal segment that developed as a result of the accretion of oceanic arc terranes and the later collision of East and West Gondwana. [2] This was collectively identified as the East African Orogeny, which took place in the span of 880 to 550 Ma, forming complex lithotectonic belts of different metamorphic and deformation intensities. [2]

The Adola Belt is one of the most significant portions of the ANS in Ethiopia, classically divided into two major associations: the high-grade granite-gneiss complex and the low-to-medium grade ophiolitic fold and thrust belts. [2] The GGC consists of quartzo-feldspathic gneisses with amphibolite facies and deformed granitoids that represent the basement or early stages of arc magmatism. OFTB includes the Kenticha and Megado belts. It consists of metasedimentary and metavolcanic rocks belonging to Neoproterozoic oceanic basins and island arcs. [2]

1.1.2. Structural Evolution of the Adola Belt

The structural framework of the Adola Belt is commonly depicted by north-south-trending shear zones, ranging from ductile to brittle-ductile, and thrust faults. [1] These structure systems were important in placing different lithotectonic units alongside one another towards the end of Gondwana integration. At least four deformation events, namely D1-D4, have been observed in the Adola Belt. Deformation events D1 and D2 were more dominated by compressions and subsequent thrusting, which caused thickening of the continental crust, thus creating "flower structure characteristics" at gold deposits. [1]

D3 and D4: This corresponded to the onset of transcurrent faulting and regional variations, marking the end of the orogenic cycle and the beginning of extension of the crust. [1] The late extensional phase culminated in the intrusion of the Kenticha rare metal pegmatite deposit at about 530 Ma. [2] The structural pattern created by the deeply rooted normal faults oriented N-S facilitated the rapid ascent of the highly fractionated granitic magma, coupled with the invasion of the Kenticha ophiolitic belt zones of lower grade metamorphic rocks. [8]

1.2. Post-Orogenic Magmatism

The pegmatites in the Kenticha deposit are related in both space and time to a series of post-orogenic granitic rocks that intruded in the Adola Belt at 570-520 Ma. [2] The granitic rocks in this case, such as those in the Kilta Shanbeli and Lega Dima plutons, are generally peraluminous with geochemical signatures typical of I-type/S-type magma formed as a consequence of partial melting of metasedimentary crust and/or highly fractionated magmas derived from the mantle. [3]

The Kilta Shanbeli pluton, which is a protracted biotite to biotite/muscovite granite, is regarded as the prospective source of the regional pegmatite zonation. [2] The pegmatites have a regular progression of increasing degrees of fractionation and the enrichment of rare elements away from the pluton. [2]

The near regions are dominated by pegmatites that are either barren or poorly mineralized, while the more distant areas, like the Main Kenticha and Bupo pegmatites, symbolize the most evolved and metallic aspects of the belt. [2]

1.3. Geology of the Kenticha Serpentinite Massif

1.3.1. Physiography and Local Context

The Gara Kenticha serpentinite mountains occur some 50 km southwest of the town of Shakisso in Sidamo Province. The region can be defined by the western slopes of the Kenticha mountains, having a direction of southwest to northeast (azimuth 20-25°), with a maximum height of 1960 meters. The landscape in this region can best be described as rough, with the deposit occurring over 500 meters above the source head of the Mormora River. [9]

The local flora constitutes sparse vegetation, mainly acacia trees, and the local climate enables the semi-nomadic way of life of the local population, whose livelihood revolves around cow herding and maize farming. A large number of the local workforce is also employed at the Adola gold mines, which go to demonstrate the mining economy of the area. The road linking Shakisso and Dermi-Dama offers important transport artery links to the sites, whose infrastructure is, however, elementary. [9]

1.3.2. Lithological Composition of the Massif

The Kenticha serpentinite massif is an Upper Proterozoic body measuring 7 km in length and 1 km in width. [9] Structurally, it is enclosed by a sequence of tremolite-talc schists, actinolite-chlorite rocks, and carbonates. [9] The serpentinite is in transitional contact with the surrounding schists over a distance of 3-5 meters, though there are frequently found localized lenses of tremolite-talc up to 100 meters thick within the serpentinite body itself. [9]

The serpentinite is massive to fractured, and the colors range from pale green to dark bluish-grey. The rock consists, under the microscope, of fine-grained granoblastic aggregates of quartz and chalcedony in its "cherry" varieties, and its unaltered sections are primarily composed of serpentine minerals and chromite. The presence of bastite pseudomorphs (up to 4 mm), anthophyllite, and relict olivine and orthopyroxene grains strongly suggests that the serpentinite was a peridotite or harzburgite that underwent extensive hydration. [9]

Table 1. *Mineralogical composition of the Gara Kenticha serpentinite host rock [9].*

Mineral Constituent	Percentage (%)	Optical and Physical Properties
Serpentine (Chrysotile/Antigorite)	70-85	Fibrous to flaky, 0.1-0.2 mm across.
Chromite	Up to 12	Idiomorphic grains, often with magnetite edges.
Chlorite	Variable	Colourless to pale green, low interference colours.
Talc	Variable	Fine to coarse (1.5 mm), irregular aggregates.
Anthophyllite	Up to 20	Colourless rhombic crystals, possibly after pyroxene.

1.3.3. Host Rock Alteration and Metasomatism

Its emplacement into the ultramafic serpentinite massif caused very strong hydrothermal and metasomatic reactions. [3] The serpentinite has been hydrothermally altered into talc and chlorite within immediate contact between the pegmatite veins and the host rock. [2] In some cases, lenses of chlorite reach up to 30 cm in thickness. [9]

A unique feature of this contact zone is the development of "glimmerite" or exomorphic halos containing rare minerals like holmquistite, a lithium-bearing amphibole, and phlogopite. These halos are indicative of the exchange of elements between the lithium-rich pegmatitic melt and the magnesium-rich serpentinite. [2] In the north-eastern part of the area, chrysotile-asbestos fibers up to 12 cm long were identified at the contact between the tremolite-talc and serpentinite units, although surface weathering has rendered them ferruginous and talcy. [9]

1.4. The Feldspar–Quartz Pegmatite Suite

1.4.1. Structural Characteristics of the Veins

The main part of the massif contains five major pegmatitic veins, besides numerous satellites of smaller size. In orientation, these pegmatitic bodies are mainly North-South, dipping rather to the east, and variably up to 2 meters thick, besides others which are over 50 meters thick. [9] The presence of these features has been related to the late extensional faults of the Adola Belt, which favoredsuccessful emplacement of the lessdense pegmatitic melts into the moredense ultramafic sequence of rocks. [8]

1.4.1. The Quartz-Dominant System

Vein No. 1 is the most westerly and largest vein, which is traced over a distance of 790 meters. [5] The swelling topography of this vein is characterized by a narrow part at the north (9 m wide), a central maximum thickness of 52 m over the northern slopes of the Kenticha Range, and a narrowing to 15 m at the southern end. [9]

This aspect dominates as a very large quartz massive body with the middle 90% being made up of white and very translucent quartz. The edges or selvages are made up of quartz-muscovite-feldspar with thickness measures at 2-3 meters. This vein stands out as one having very little iron oxide material with the iron oxides occurring as fractures on the surface. [5] One of the interesting finds on the southern part of this deposit involves the occurrence of manganese niobite-tantalite crystals that are bipyramidal crystals measuring 3.0 x 1.5 cm. [9]

1.4.2. The Beryl-Bearing Feldspar Vein

Extending for 700 meters, the average thickness of Vein Number 2 is 20 meters, having a complex and inequable mineralization along the length. The main part of the vein consists of blocky microcline feldspar, which constitutes the main goal for industrial exploitation.[5] Feldspar masses measuring 0.9 x 0.9 meters has been noticed to be pure. [9]

The vein is marked by the presence of pale green fissured beryl crystals upto 2 cm long and irregular masses of tourmaline. Geochemically, metasomatism is evident in the vein, which in its eastward branches is characterized by the presence of blebs of fuchsite, indicative of chromium assimilation in the serpentinite. The vein gradually increases in quartz and muscovite as it moves towards the north, ultimately ceasing to be of prime importance as a source of feldspar. [5]

1.4.3. The Spodumene Grid

Vein No. 3 is probably the most mineralogically important body in the suite because of its extreme concentration of spodumene. Exposed for 150 meters along strike, with a thickness of 20 meters, the vein is made up of white microcline blocks cut by a dense, intersecting network of spodumene veins. In its central zone, these spodumene veins outline a grid with 20–30 cm spacing over more than 3 metres width, and visually an estimated 65-70% of the rock volume is spodumene. [9]

The spodumene crystals are greyish white, with a pearly lustre and reaching up to 15 cm in length. This vein represents a high-energy injection of a lithium-saturated melt, typical of the most fractionated portions of LCT pegmatite systems. [3] Small fragments of aquamarine (gem-quality beryl) were also noted in the chlorite margins of this vein. [9]

1.4.4. High-Quality Microcline

Vein No.5 sits 200 meters east of Vein No.3 and measures 440 meters long as a robust feldspar deposit. Its mean thickness measures 10 to 14 meters in length and comprises 80% of the feldspar that forms this deposit. Its quartz content, which measures between 15-20%, forms the filling and appears as white to grey transparent material. Vein No.5 stands out as the most promising deposit for the extracts due to the very low content of iron hydroxide and the ease with which the feldspar can be separated manually. [9]

Table 2. *Physical and mineralogical summary of the five major Kenticha pegmatite veins. [9].*

Vein ID	Primary Mineralogy	Strike Length (m)	Max Thickness (m)	Key Accessory Minerals
No. 1	Quartz (90%)	790	52	Mn-niobite-tantalite
No. 2	Microcline, Quartz	700	45	Beryl, Fuchsite, Tourmaline
No. 3	Spodumene, Microcline	150	20	Aquamarine, Muscovite
No. 4	Microcline, Quartz	100	20	Beryl, Spodumene
No. 5	Microcline (80%)	440	14	Quartz, Muscovite

1.5. Geochemistry and Internal Differentiation

1.5.1. Major Element Geochemistry of Feldspar Units

Geochemically, the Kenticha feldspar-quartz pegmatites represent peraluminous and highly silicic leucogranites. [3] Whole-rock chemistry of samples from the feldspar-rich veins (Nos. 3 and 5) shows that their chemical composition is very homogeneous and of the highest industrial standard. [9]

The silica (SiO_2) oxide content in the pegmatitic material is low, averaging 67.3%, which is well below the 75% requirement for high-grade feldspar for industrial production. The alumina (Al_2O_3), an oxide component, is very high, averaging 17.2%, and is essential for giving strength and stability in glass and ceramics. Total alkalis ($K_2O + Na_2O$) are approximately 13.5%, of which potassium oxide (K_2O) is 11.1%. Such high ratios of potassium to sodium indicate that the desired industrial type is potash feldspar (microcline). [9]

Table 3. *Chemical composition of Kenticha pegmatite samples compared to industrial standards [9].*

Oxide Component	**Average Content (%)**	**Range (%)**	**Industrial Requirement (Grade 2)**
SiO_2	67.3	64.9 - 74.5	< 75.0
Al_2O_3	17.2	13.9 - 18.5	> 13.0
Fe_2O_3	0.3	0.1 - 0.7	< 0.4
K_2O	11.1	4.9 - 13.9	-
Na_2O	2.4	1.3 - 3.7	-
$K_2O + Na_2O$	13.5	8.1 - 15.7	> 7.0

The iron content (Fe_2O_3) is perhaps the most important of the chemical constituents in the case of industrial minerals. The average (Fe_2O_3) content at Kenticha is 0.3% well within the permissible limits for porcelain and glass. It is pertinent to note in this respect that whereas the iron content in the top samples was appreciably higher at 0.7% iron because of iron hydroxide in the weathered areas, the iron content in the 2-meter deep trenches was lower than 0.1% in all samples. [9]

1.5.2. Rare-Metal Enrichment and Fractionation Trends

The Kenticha pegmatites display the significant feature of in situ fractionation of a remaining leucogranitic to pegmatitic melt. [3] This fractionation is traceable on the basis of different geochemical ratios, including K/Rb, K/Cs, and Nb/Ta ratios. [3]

The K/Rb ratio also varies in the Main Kenticha pegmatite complex from 36 in the granitic lower part to 19 in the upper part where spodumene is found in abundance. The Nb/Ta ratio likewise declines from 2.6 in the lower parts to a minimum of 0.7 in the central parts because of the accumulation of the heavier element, tantalum, in the remaining liquid at the end stages of differentiation. The upper part also shows high Li content (Li_2O up to 3.21%), Rb (up to 4,570 ppm), and Cs (up to 730 ppm). [3]

The trend of differentiation is according to columbite-tantalite fractionation from columbite-(Fe) to tantalite-(Mn). [3] Simultaneously, there is the substitution of albite by K-feldspar and muscovite in the alaskitic units, resulting in the depletion of aluminum, titanium, magnesium, calcium, and iron oxides in the melt. [10] High values of MgO in the upper units (up to 5.05%) are anomalous in the sense that it was caused by the postmagmatic hydrothermal alterations due to the leaching of magnesium out of the hanging wall serpentinite. [3]

1.5.3. Trace Element Spectrography of Quartz

Emission spectrograph, to identify trace-level contaminants that could affect high-technology applications, was performed on the quartz reserves in Vein No. 1. In addition to the iron and titanium, the quartz contains minor amounts of nickel (0.0005%), chromium (0.0002%), and lithium (0.006%). Manganese (0.01%) and copper (0.02%) were also found [9].

The silica content of quartz varies between 98.0% and 98.5%, with alumina ranging between 0.3% and 0.4%. Although these are relatively high purity values, the amount of iron(III) oxide (0.5–0.8%) included for some quartz samples may have been partially contaminated by the metal discs used during sample crushing in the laboratory. In fact, high-purity quartz calls for below 0.01% iron(III) oxide, requiring advanced methods of beneficiation, such as flotation or acid leaching, for the Kenticha material [2, 9].

1.6. Economic Evaluation and Industrial Potential

1.6.1. Industrial Applications of Feldspar

Feldspar is considered the main fluxing constituent in ceramic-glass materials. [11] The function of feldspar in ceramic-glass materials involves reducing the temperature of vitrification or melting of the composition, hence lowering the energy requirements for glass formation. [5]

The Kenticha feldspar, due to its higher K_2O content, is more suitable for the production of vitrified porcelain tiles, sanitaryware, and electrical insulators. [11] In this case, the potash feldspar acts as a viscosifying agent, thereby increasing the mechanical strength of the product. [5] For glass productions, a higher alumina content, as presented by the Kenticha ore at 17.2%, is desirable since it inhibits devitrification, making glass more resistant to chemical attack. [11]

1.6.2. Comparison with Global Industrial Standards

Generally, the Kenticha feldspar and quartz deposits fall within international standards for ceramic raw materials and glasses, for instance, those given by the International Organization for Standardization (ISO) and ASTM International. [12]

Table 4. *Comparative evaluation of Kenticha feldspar against global commercial grades [13].*

Feature	Kenticha Feldspar	Commercial Glass Grade	Commercial Ceramic Grade
Alumina (Al_2O_3)	17.2%	18 - 19%	15%
Iron Oxide (Fe_2O_3)	0.3%	< 0.08%	< 0.3%
Total Alkalis (K_2O+Na_2O)	13.5%	11 - 13%	7.8%
Silica (SiO_2)	67.3%	68 - 69%	75%

The Kenticha material is more preferable in terms of high alkali content with low silica content, which is quite efficient in functioning as a flux. [9] The iron content is at the boundary for high-quality glass but is desirable in "white-ware" ceramics in which high whiteness is needed. [14]

1.7. Resource and Reserve Estimation

Mineral reserve calculations followed a systematic approach involving the determination of the longitudinal area of the veins and the assumption that the depth of the mineral body extends to one-quarter of its exposed surface length. A conservative density of 2.6 g/cm^3 was applied to all volume to mass conversions. [9] Feldspar (Vein No. 5): The vein has been traced for over 440 meters with an average thickness of 10 meters. There is 1,300,000 tons of ore with a refined reserve of 1,040,000 tons5 at a visual estimate of 80% feldspar content. Feldspar (Vein No. 2): This vein has been traced over a length of more than 700 meters with an average thickness of 20 meters and contains approximately 2.55 million tons of ore, grading at 70%, gives a reserve of 1.7 million tons. [9] Quartz (Vein No. 1): The big core of Vein No. 1 is of an average thickness of 30 meters, longitudinal area 92,500 m^2, and gives a substantial reserve of 7.2 million tons of high-purity quartz. Taking into consideration only two of the major veins, the combined feldspar reserve is in excess of 2.7 million tons and is sufficient for several decades of supply for a large-scale industrial facility [9].

2. Discussion: Petrogenesis and Tectonic Context

2.1. Age and Magmatic Origin

U-Pb dating of manganese-tantalite indicated that the Kenticha rare-element pegmatite field was emplaced at about 530 Ma. This age is important because it signifies the transition from the compressional phase of the East African Orogeny to a postcollisional, extensional tectonic regime. [2] The temporal relationship of this event to the late stages of Katangan tectonogenesis and stabilization of the Gondwana supercontinent has been observed [10].

These pegmatite-forming magmas likely resulted from extensive fractionation of the syn- to late-tectonic granites or anatexis of the metasedimentary rocks in the Adola Belt. [10] The peraluminous nature of the suite of A/CNK indices is usually greater than 1.2, and the Eu anomaly strongly negative indicates that the source was rich in aluminosilicates, and that the melt underwent prolonged crystallization of plagioclase before its terminal emplacement [15].

2.2. Comparative Petrology: Kenticha vs. Tanco

From an aspect ratio and structural setting, the Kenticha pegmatite can be likened to the world-famous Tanco pegmatite in the Superior Craton in Canada. [15] They are both sub-horizontal sheet-style pegmatites with complex internal zonation and occuring in sequences of mafic to ultramafic rocks. [2]

Despite this, the extent of geochemical evolution is not the same. The Tanco pegmatite shows greater levels of cesium fractionation, which hosts a massive pollucite (Cs-zeolite) deposit, and the fractionation ratios (K/Rb ratios as low as 6) also show a greater degree of evolution than Kenticha (K/Rb ratio of 19). This indicates that even though Kenticha is a globally exceptional Ta and Li deposit, it corresponds to a slightly less evolved stage in the LCT melt series or that the initial magma was less enriched in volatile fluxes such as fluorine or boron [16].

2.3. Socio-Economic and Environmental Impact

2.3.1. The Guji Zone Economy

The development of the mining projects in Kenticha must also be set within the perspective of the socio-economic situation in the Guji Zone. The Guji Zone in the Oromia Region has a predominantly rural population (91%); the people's economy is highly vulnerable. Based on a 2024 survey, it was reported that 92% of the households in the Guji Zone and surrounding areas were food-insecure and were practicing emergency coping strategies such as the sale of livelihood assets like livestock or land. [7]

The mining industry, contributing 17-53% of the regional economy of areas such as Shakisso, remains dominated by informal ASM. [17] The formalization of the Kenticha mine, mixing it with the regional economic base, can be the catalyst needed to develop the region. The whole community can be moved from the informal gold panning activities to a formalized job within the mining industry through this approach. [18]

2.3.2. Regulatory and Licensing Hurdles

The prospect of the Kenticha deposits has, however, remained impaired by what has been described as a protracted saga of intrigue concerning its mining licenses. [19] The Kenticha Tantalum Mine has remained closed since 2017 due to environmental pollution, while efforts to establish joint ventures with foreign investors, for example, African Mining & Energy Pty Ltd, have remained impaired by red tape and legal battles. [19, 20]

In May of 2024, the Ministry of Mines released a “Notice of License Surrender” to the operating companies due to failure to commence production and upgrade the facilities. This kind of volatility in the regulations of the sector, together with accusations of the misapplication of the investment capital, has been preventing foreign direct investment at a time when the demand for lithium or tantalum has reached its pinnacle globally. [19, 21]

2.3.3. Environmental Sustainability

In fact, the environmental consequences of mining in Shakisso have attained a worrying state. ASM operations in the area result in mercury poisoning of soil and water resources, deforestation, and water shortages. [17] On a large scale, developing Kenticha feldspar-quartz pegmatites will demand a complete shift in following environmentally responsible and safety standards in mining operations. It will demand compliance with ISO 14001 (Environmental Management Systems) and ISO 45001 (Occupational Health and Safety) certified standards. [22] It is important to introduce "fluoride-free" flotation separation of feldspar from quartz. [23]

3. Conclusions and Recommendations

3.1. Summary of Geologic and Economic Value

The Kenticha serpentinite deposit boasts an exceptionally high quality of feldspar-quartz pegmatites, which make up a strategic resource for Ethiopia. On a petrochemical assessment, it can be confirmed that feldspar from Veins Nos. 2, 3, and 5 satisfies the most demanding industrial standards for alumina and alkalies with low iron content. The massive quartz vein of Vein No. 1 holds a substantial resource of high-purity silica.

The LCT type chemistry of these pegmatites, and their 530 Ma post-collar environment of emplacement, position these in a world setting in company with other giant rare-element deposits. While current attention has centered on tantalum and lithium commodity markets, there is more ready access in terms of underlying industry in feldspar and quartz.

3.2. Strategic Recommendations

Industrial Integration: The government and the private sector are advised to go beyond the export of raw concentrations. The setup of a ceramic and glass production village either at Kebre Mengist or Shakisso would aid in reducing the cost of transportation of goods and the formation of a new chain of added values to the economy. Infrastructure Development: Enhancement of the power connection from Mormora hydroelectric station and the renovation of roads connecting Shakisso to Addis Ababa are essential prerequisites for large-scale mining. Detailed Exploration: A scale geological and topographic survey with a scale ratio of 1:2000 should be carried out on the entire area of the pegmatite field to determine other reserves, as well as occurrences of gem-quality beryl and spodumene. [9]

Regulatory Stabilization: The Ministry of Mines must resolve the disputes related to licensing and ensure an equitable and stable regulatory regime for the international joint ventures. This will include addressing the status of the federal and local administration in the Guji Zone. [19] Environmental Stewardship: The adoption of modern beneficiation methods, like high intensity wet magnetic separation, will be essential to ensure that mineral products from Tanzania are of international standards despite minimal imprinting on the sensitive Kenticha environment. [23] With the execution of these measures, the potential of the Kenticha pegmatites in Ethiopia can be fully tapped to transform a dormant geological potential into a dynamic development powerhouse in the mining sector in the entire East African region.

Abbreviations

LCT	Lithium-Cesium-Tantalum
ANS	Arabian-Nubian Shield
GGC	Granite-Gneiss Complex
OFTB	Ophiolitic Fold and Thrust Belts
ASM	Artisanal and Small-scale Mining
ISO	International Organization for Standardization
ASTM	American Society for Testing and Materials

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Author Contributions

Mitiku Tamene: Conceptualization, Data curation, Formal Analysis, Methodology, Visualization, Writing – original draft

Wakjira Tesfaye: Data curation, Formal Analysis, Data curation, Writing – review & editing

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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