



Research Article

Physiochemical Characterization of the Asedo Feldspar Deposit, Mozambique Belt, Southern Ethiopia: Implications for Ceramic and Glass Industries

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Abstract

This study evaluates the industrial viability of the newly identified Asedo feldspar deposit, hosted within Neoproterozoic pegmatites of the Mozambique Belt in southern Ethiopia. Geochemical analysis of ten feldspar samples reveals a major oxide composition averaging 69.02 wt.% SiO₂, 21.19 wt.% Al₂O₃, 4.04 wt.% Na₂O, 3.10 wt.% K₂O, 2.96 wt.% CaO, 0.31 wt.% Fe₂O₃, and 0.11 wt.% MgO, with a low Loss on Ignition (LOI) of 0.43 wt.%, reflecting high mineralogical purity. However, significant compositional variability exists among samples, with Na₂O/K₂O ratios ranging from 0.29 to 6.15, indicating both potassic and sodic domains within the pegmatite. Physical property measurements demonstrate an average bulk density of 2.63 g/cm³, apparent porosity of 0.80%, and water absorption of 0.31%, indicating a dense, impermeable material suitable for ceramic and glass production. Minor impurities, including Fe₂O₃ (0.31 wt.%), are amenable to reduction through conventional beneficiation. Resource estimation suggests an in-situ exploration target of approximately 46.9 million tonnes over an area of 1.5 km² with an average thickness of 12 m. These results confirm the deposit's potential as a reliable source of raw materials for local industries. The Asedo deposit represents a promising domestic industrial mineral resource capable of supporting Ethiopia's expanding ceramic and glass sectors, thereby reducing import dependency and contributing to sustainable industrial development.

Keywords

Asedo Feldspar Deposit, Mozambique Belt, Geochemical Characterization, Mineral Beneficiation, Ceramic and Glass Industries

1. Introduction

Feldspar minerals, constituting approximately 60% of the Earth's crust [1], are indispensable industrial raw materials whose global market were valued at USD 2.37 billion in 2025 and are projected to reach USD 3.01 billion by 2030 [2], driven by escalating demand from the ceramics and glass sectors. The industrial value of feldspar is governed by its chemical composition—particularly SiO₂, Al₂O₃, alkali oxides

(K₂O and Na₂O), and iron-bearing impurities—along with its physical characteristics [3-6]. High-grade feldspar for ceramic and glass applications typically requires SiO₂ < 70 wt.%, Al₂O₃ > 17 wt.%, Fe₂O₃ < 0.1 wt.%, and total alkalis (K₂O + Na₂O) > 5 wt.%. The alkali ratio (Na₂O/K₂O) exerts a critical influence on fluxing behavior: sodic feldspar (albite-rich) is preferred for container glass and fast-firing ceramic bodies

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due to its lower liquidus temperature and superior refining behavior, whereas potassic feldspar (microcline-rich) is favored for high-viscosity porcelain and high-temperature ceramics requiring superior thermal shock resistance [3, 5].

Recent technological breakthroughs in feldspar beneficiation have fundamentally enhanced the industrial utilization of feldspathic raw materials. Yassin et al. [7] demonstrated that dry and wet magnetic separation followed by oxalic acid leaching can reduce Fe_2O_3 content in Egyptian feldspar from 2.25% to as low as 0.12%, with whiteness improving to 90%. Tinesha et al. [8] developed a two-step process combining magnetic separation and chemical treatment that reduced iron oxide in Malaysian sodium feldspar from 2.25% to 0.38%, producing a concentrate fulfilling glass and ceramic industry specifications. These advances have profound implications for the economic viability of feldspar deposits previously considered marginal due to elevated iron content.

Ethiopia's ceramic and glass manufacturing sectors are experiencing unprecedented growth, driven by rapid urbanization, infrastructure development, and population expansion. The Ethiopian government has prioritized ceramics in the Debre Birhan Industrial Park, and Chinese investment has catalyzed this growth: a major ceramic factory has been completed, and a float glass production line with a daily capacity of 300 tonnes is under construction and expected to commence production by the end of 2026, creating a "ceramic + glass" dual-engine industrial framework. This rapid industrialization has significantly increased national demand for high-quality feldspar resources, making the exploration and characterization of domestic deposits essential to reduce reliance on imported industrial minerals [4, 9].

Despite Ethiopia's geological favorability, the Precambrian

basement complex of the Mozambique Belt hosts numerous pegmatite bodies with significant feldspar potential. However, systematic geochemical and physical characterization of these deposits remains inadequate. The Asedo pegmatite-hosted feldspar deposit, situated in Uba Debretsay Woreda, Gofa Zone, southern Ethiopia, represents a newly recognized industrial mineral occurrence with potentially transformative implications for the national industrial mineral sector. However, comprehensive technical evaluations regarding its commercial viability are virtually absent. This study therefore aims to: (1) systematically characterize the physicochemical properties of the Asedo feldspar deposit; (2) evaluate its suitability for ceramic and glass manufacturing applications; and (3) establish its strategic significance through comparison with other Ethiopian and international feldspar deposits.

2. Materials and Methods

2.1. Study Area Location

The Asedo feldspar deposit is located in the Uba Debretsay Woreda, Gofa Zone, South Region, Ethiopia. The study area is situated approximately 505 km southwest of Addis Ababa and approximately 135 km southwest of Arba Minch, the nearest major town and administrative centre of the Gofa Zone. The study area is geographically bounded by latitudes $6^{\circ}15'N$ to $6^{\circ}25'N$ and longitudes $36^{\circ}45'E$ to $37^{\circ}00'E$, covering an area of approximately 1.5 km^2 (Figure 1). The Asedo deposit is accessible via the Addis Ababa–Arba Minch–Uba Debretsay road.

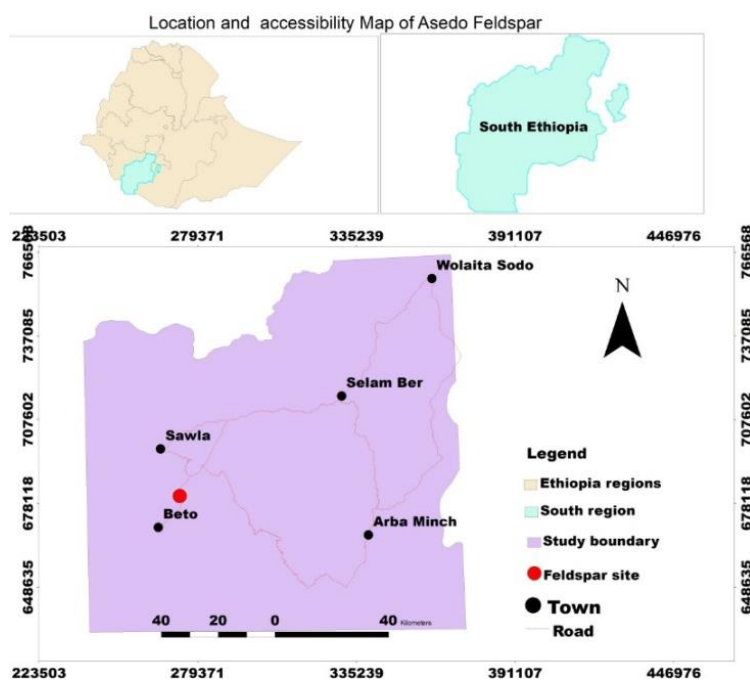


Figure 1. Location map of the study area.

2.2. Physiography, Climate, and Vegetation

The study area is characterized by rugged, mountainous topography typical of the southern Ethiopian highlands, with elevations ranging from approximately 1,200 to 2,100 metres above sea level (m.a.s.l.). The landscape is dominated by steep slopes, dissected plateaus, and narrow river valleys. The region experiences a tropical highland climate (Köppen classification: Cwb) [10], with distinct wet and dry seasons. The mean annual rainfall ranges from 1,200 to 1,600 mm, with the majority of precipitation occurring between June and September. Mean annual temperatures vary from 15 °C to 25 °C, with

cooler temperatures at higher elevations. The natural vegetation consists of scattered shrubs, grasses, and remnant patches of montane forest, while the lower slopes and valleys are cultivated with enset (false banana), maize, sorghum, and coffee. The drainage pattern is dendritic, with seasonal streams and rivers flowing southward and eventually draining into the Omo River system. The Asedo feldspar-bearing pegmatites are exposed as prominent, light grey to pink, massive outcrops along hill slopes and ridge crests, making them amenable to surface mapping and sampling.

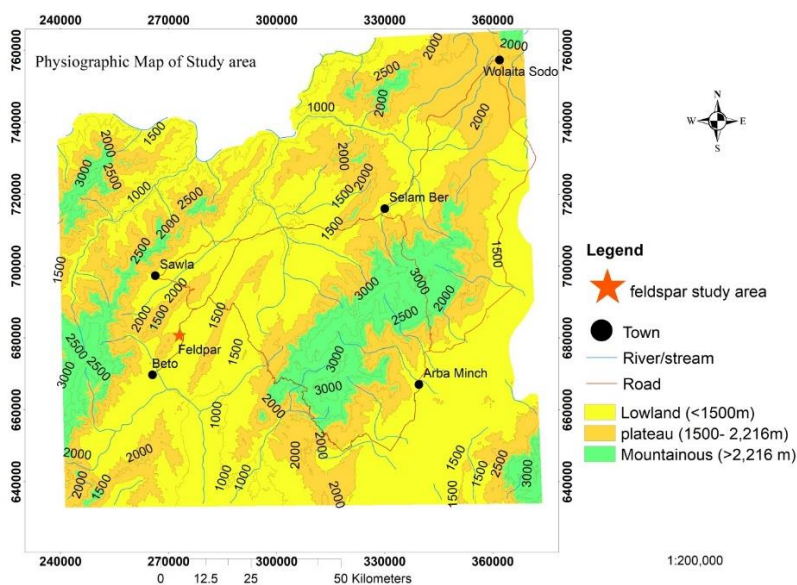


Figure 2. Physiographic map of the Asedo study area.

2.3. Geological Setting

The Asedo feldspar deposit is located within the southern Ethiopian Precambrian basement complex, which forms part of the northern extension of the Mozambique Belt of the East African Orogen. The geological evolution of the region records a prolonged history of crustal growth, high-grade metamorphism, granitoid magmatism, and subsequent Cenozoic rifting associated with the East African Rift System [11-14]. The oldest rocks exposed in the study area comprise high-grade Precambrian metamorphic rocks, including biotite-amphibolite gneiss, quartz-feldspathic gneiss, schist, migmatite, and amphibolite. These lithologies formed during the Pan-African Orogeny (ca. 900–550 Ma) through continental collision, regional metamorphism, and crustal thickening associated with the assembly of Gondwana [11, 13-15]. During the late

stages of the Pan-African Orogeny (ca. 650–550 Ma), granitoid intrusions emplaced granite and pegmatite bodies into the metamorphic basement. These pegmatites, representing the final volatile-rich differentiates of granitic magmas, are composed predominantly of feldspar, quartz, and mica and constitute the principal host of feldspar mineralization in the Asedo area [4, 16, 17]. Field mapping has identified extensive, coarse-grained, feldspar-rich pegmatite bodies that intrude the surrounding granitic gneiss with sharp, discordant contacts. The pegmatites are composed predominantly of potassium feldspar (microcline), plagioclase (albite), quartz, and minor biotite, with accessory opaque minerals. The mineralized bodies occur as discontinuous veins and lens-shaped intrusions that exhibit good lateral continuity, with individual bodies traceable for several hundred metres along strike. The regional geology and tectonic setting of Ethiopia are illustrated in Figure 3, and the geological map and cross-section of the Asedo feldspar deposit are present.

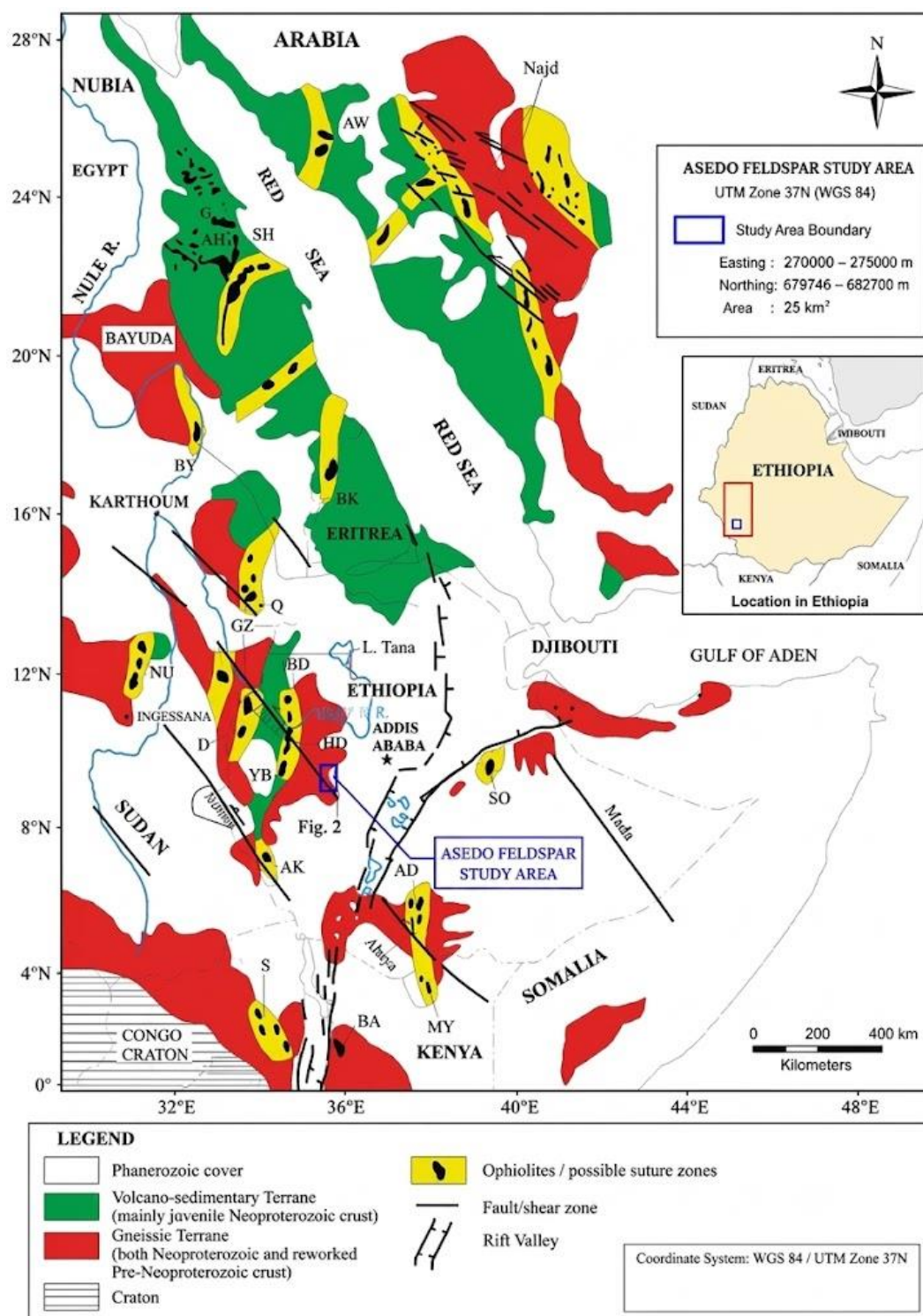


Figure 3. Regional geology and tectonic setting of Ethiopia. Source: Modified after Beyth et al. [18] and Geological Survey of Ethiopia (GSE).

2.4. Feldspar Distribution in Ethiopia

Feldspar in Ethiopia is hosted mainly by granitic pegmatites, granitic intrusions and the high-grade gneisses and migmatites of the Neoproterozoic basement [19, 20]. The most important deposits are Kenticha, a zoned pegmatite in the Adola Belt; Shebelle, where pegmatites cut biotite schist and gneiss about

80 km from Harar; Negelle-Borena, a single wide pegmatite dyke; and Hamariesa, a coarse-grained granite near Harar. Further occurrences have been reported in Wollega, Assosa and Kaffa [19]. Most of these localities are still at reconnaissance or preliminary stage. Estimated resources are about 500,000 t at Kenticha, 25,000 t at Shebelle and 14,500 t at Negelle-Borena, while Hamariesa has not yet been assessed [19, 20]. Kenticha's pure feldspar is the richest in alkalis

(11.9% K_2O , 7.0% Na_2O) with low iron (0.17–0.50% Fe_2O_3), Shebelle is a high-purity potassic feldspar (9.45% K_2O , 0.24% Fe_2O_3), and Negelle-Borena carries the most iron (average 0.58% Fe_2O_3) because of its biotite and magnetite content [19, 20].

All three evaluated deposits satisfy the ASTM C1466 alkali ($K_2O + Na_2O > 10\%$) and alumina (16–19%) requirements for ceramics, but raw Fe_2O_3 above 0.2% means iron removal is needed. This is minor for Shebelle and more substantial for Kenticha and Negelle-Borena [19, 20]. For glass, the pure

Kenticha feldspar meets first-grade sheet-glass requirements, Shebelle comes close, and Negelle-Borena and the mixed quartz-feldspar material fall short in their raw state [21]. Shebelle is also well suited to fillers and extenders. Upgrading should focus on removing iron-bearing minerals (Biotite, magnetite, garnet and tourmaline), mica and quartz, through crushing and grinding with hydrocyclone desliming, low- and high-intensity magnetic separation, and cationic amine flotation. Acid leaching can serve as a final purification step for low-grade ores or ultra-pure products [21].

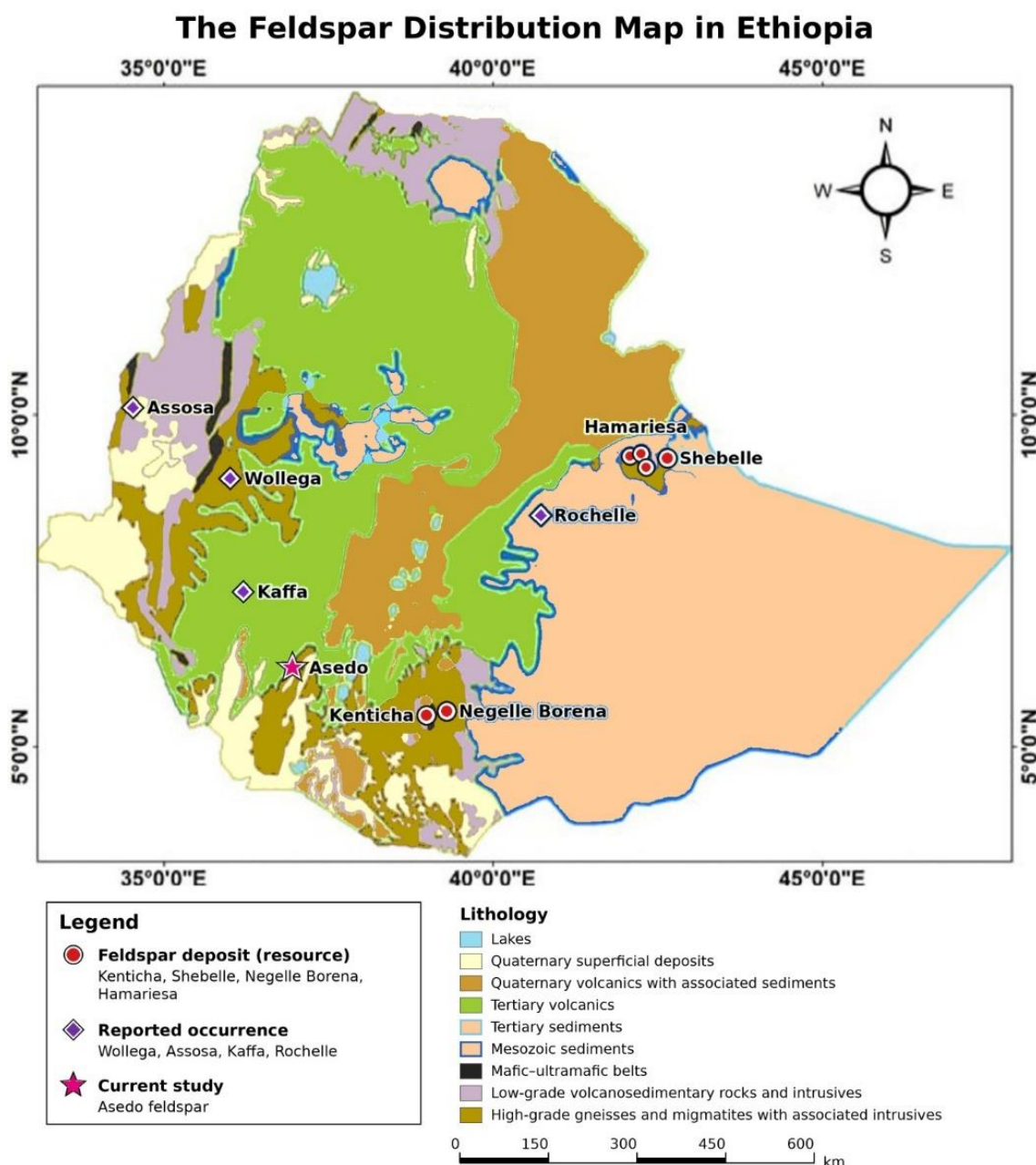


Figure 4. Feldspar distribution map in Ethiopia.

2.5. Asedo Feldspar Deposit Occurrence Map

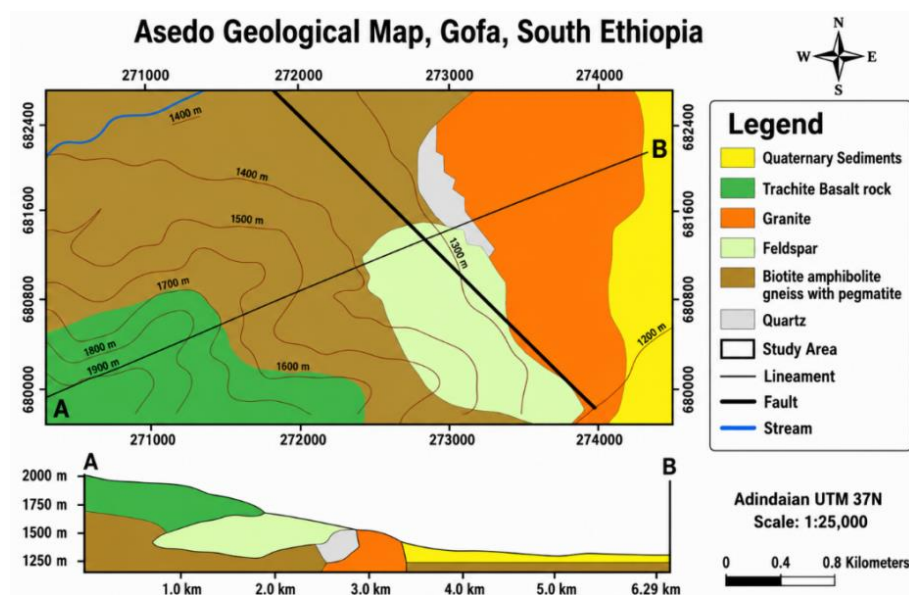


Figure 5. Geological map and cross-section of the Asedo feldspar deposit. Source: Authors' field mapping and geological interpretation.

2.6. Field Geology and Sampling

Detailed geological mapping was carried out at scales of 1:25,000 using systematic traverses across lithological contacts and well-exposed outcrops. Rock units were described based on lithology, mineral composition, grain size, texture,

structures, weathering characteristics, and field relationships. Representative feldspar sample collection locations are shown in Figure 5. A total of twelve geological samples were collected for analysis, comprising ten feldspar samples and two host-rock samples.



Figure 6. Representative feldspar sample collection locations. (a) Huge massive feldspar exposure; (b) Feldspar exposure in granite-pegmatite weathered; (c) Feldspar exposure in granitic-pegmatite weathered; (d) Feldspar exposure at hill side.

2.7. Laboratory Analysis

Laboratory testing was conducted at the Geological Institute of Ethiopia (GIE) Central Laboratory. To evaluate geochemical characteristics, ten feldspar samples were analyzed for major oxide composition using X-ray fluorescence (XRF) spectrometry. For mineralogical and textural evaluation, thin sections were prepared from the two host-rock samples for petrographic analysis.

The physical properties of the feldspar samples, including bulk density (BD), apparent porosity (P), and water absorption (WA), were determined for representative specimens using the Archimedes fluid displacement method in accordance with ASTM C373-18 [22]. Measurements of the oven-dry weight (W_d), saturated weight (W_{sat}), and suspended weight in water (W_{sub}) were recorded, and the physical parameters were subsequently calculated using the following equations:

$$\text{Water absorption (WA\%)} = \frac{W_{sat} - W_d}{W_d} * 100$$

$$\text{Apparent porosity (P\%)} = \frac{W_{sat} - W_d}{W_{sat} - W_{sus}} * 100$$

$$\text{Bulk density (BD (g/cm}^3\text{))} = \frac{W_d}{W_{sat} - W_{sus}}$$

Mineral resource estimation was done based on the derived surface mapping and rough average thickness of deposit, a delineated only feldspar surface area coverage and bulk density as and of 12 m, 1.5 km², and a bulk density of 2.61 g/cm³ respectively. To ensure data reliability, analytical precision was monitored through replicate analyses performed on the same prepared samples, while sampling reproducibility was assessed using duplicate samples collected independently from the same material.

3. Results

3.1. Feldspar Resource Deposit

The Asedo feldspar deposit is hosted by Precambrian granitic-pegmatitic rocks. Field mapping shows that feldspar mineralization occurs mainly within coarse-grained pegmatite bodies intruding the surrounding granitic gneiss. The pegmatites are light grey to pink, massive, and composed predominantly of potassium feldspar with subordinate quartz and minor mica. The mineralized bodies occur as discontinuous veins and lens-shaped intrusions with sharp contacts against the host rocks. Most outcrops are moderately weathered, although fresh exposures suitable for sampling were identified. Field observations indicate that the pegmatite bodies exhibit good lateral continuity and represent the principal host of feldspar mineralization in the study area.

3.2. Petrography

Representative thin sections show that the Asedo feldspar-bearing pegmatite is coarse-grained with a hypidiomorphic granular texture, consisting predominantly of potassium feldspar, quartz, plagioclase, and minor biotite. Potassium feldspar occurs as subhedral to euhedral crystals with low relief under PPL and locally displays tartan twinning under XPL, indicating microcline. Plagioclase is identified by well-developed polysynthetic (albite) twinning. Quartz occurs as anhedral interstitial grains with low first-order grey interference colors and weak undulose extinction, suggesting minor post-crystallization deformation. Biotite forms brown pleochroic flakes with bright second-order interference colors under XPL.

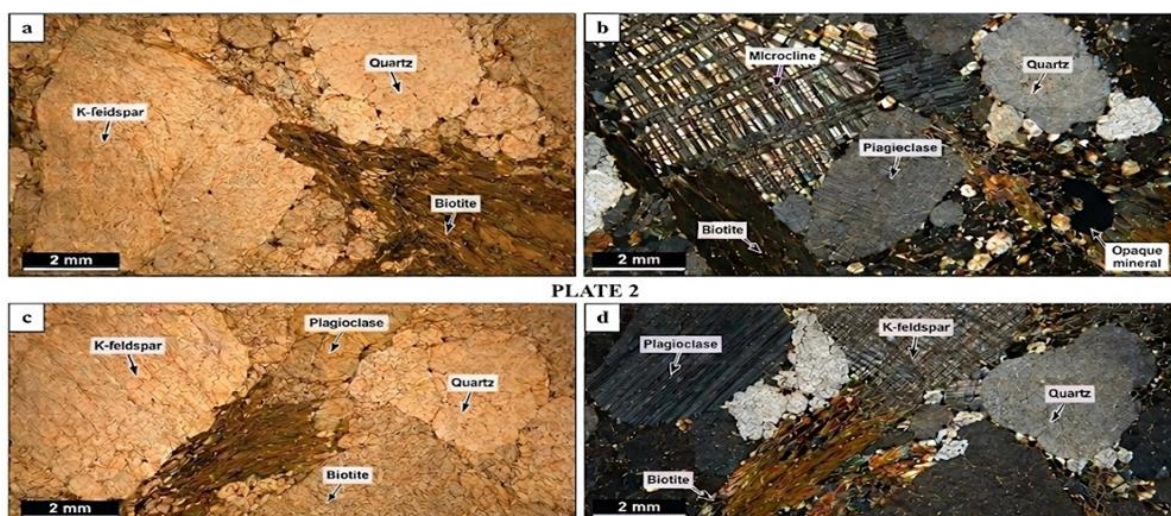


Figure 7. The photomicrographs of the pegmatite-hosted granite source of feldspar minerals.

In photomicrographs of pegmatite-hosted granite source of feldspar minerals. (a) PPL image showing K-feldspar intergrown with quartz and biotite. (b) XPL image showing microcline with tartan twinning, plagioclase with albite twinning, quartz with low first-order grey interference colors, biotite with bright second-order colors, and minor opaque minerals. (c) PPL image showing interlocking feldspar, quartz, plagioclase, and biotite. (d) XPL image showing interlocking K-feldspar and plagioclase with twinning, quartz with low first-order colors, and biotite with bright second-order colors.

The modal mineral composition consists predominantly of K-feldspar (microcline), which makes up 45–55 vol.% of the sample. Quartz is the second most abundant mineral at 20–30 vol.%, followed by plagioclase accounting for 10–20 vol.%. Minor constituents include biotite at approximately 5–10

vol.% and trace opaque minerals comprising less than 2 vol.%. Feldspar grains exhibit minor sericitization along fractures and cleavage planes, indicating limited hydrothermal alteration.

3.3. XRF Geochemistry

Table 1 presents the major oxide composition and summary statistics of ten representative feldspar samples from the Asedo deposit. The average composition is 69.02 wt.% SiO₂, 21.19 wt.% Al₂O₃, 0.31 wt.% Fe₂O₃, 2.96 wt.% CaO, 0.11 wt.% MgO, 4.04 wt.% Na₂O, 3.10 wt.% K₂O, with a low LOI of 0.43 wt.%. The total alkali content (Na₂O + K₂O) is 7.14 wt.%, and the Na₂O/K₂O ratio is 1.30.

Table 1. Major oxide composition and summary statistics of representative feldspar samples from the Asedo deposit.

Collector's Code	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	MnO	P ₂ O ₅	TiO ₂	H ₂ O	LOI
ED-02-54-2	68.50	20.64	0.30	1.44	0.005	2.31	7.98	0.020	0.005	0.60	0.005	0.26
ED-02-55	67.30	26.24	0.22	5.00	0.005	6.15	1.00	0.005	0.005	0.12	0.23	0.51
ED-02-59-1	69.20	22.20	0.46	4.06	0.46	3.28	1.32	0.005	0.42	0.20	0.19	0.46
ED-02-54	65.78	25.48	0.16	4.32	0.005	5.82	1.06	0.005	0.40	0.10	0.16	0.22
ED-02-56	76.90	14.86	0.40	1.06	0.005	3.22	4.56	0.005	0.005	0.18	0.22	0.73
ED-02-57	70.20	19.20	0.28	2.80	0.08	5.20	1.50	0.006	0.08	0.16	0.14	0.40
ED-02-58	66.50	21.80	0.24	1.80	0.02	2.80	6.00	0.010	0.15	0.30	0.10	0.35
ED-02-59	66.80	22.50	0.32	3.20	0.15	3.60	2.60	0.008	0.20	0.22	0.16	0.40
ED-02-60	74.00	16.20	0.35	1.50	0.01	3.80	3.20	0.005	0.12	0.20	0.12	0.50
ED-02-61	65.00	22.80	0.38	4.40	0.35	4.20	1.80	0.012	0.25	0.28	0.20	0.45
Minimum	65.00	14.86	0.16	1.06	0.005	2.31	1.00	0.005	0.005	0.10	0.005	0.22
Maximum	76.90	26.24	0.46	5.00	0.46	6.15	7.98	0.020	0.42	0.60	0.23	0.73
Mean	69.02	21.19	0.31	2.96	0.11	4.04	3.10	0.008	0.164	0.24	0.154	0.43
Standard Deviation	3.79	3.63	0.09	1.44	0.17	1.29	2.37	0.005	0.155	0.14	0.067	0.14

Source: Authors' original field and laboratory data.

3.4. Physical Properties

The physical properties of representative feldspar specimens are presented in Table 2. The measured average water absorption is 0.31%, apparent porosity is 0.80%, and bulk density is 2.63 g/cm³.

Table 2. Physical properties of representative feldspar samples determined using the Archimedes method.

Sample No.	Lab No.	Dry weight (g)	Wet weight (g)	Suspended weight (g)	Water absorption (%)	Porosity (%)	Bulk density (g/cm ³)
ED-02-51-2	3162/25	79.08	79.50	49.24	0.53	1.39	2.61
ED-02-51-2	3162/25	119.81	120.42	74.43	0.51	1.33	2.61
ED-02-55-1	3163/25	84.99	85.08	52.92	0.11	0.28	2.64
ED-02-55-1	3163/25	143.25	143.37	89.22	0.08	0.22	2.65
Average					0.31	0.80	2.63

Source: Authors' original field and laboratory data.

4. Discussion

4.1. Geochemical Characterization and Variability

The integrated geochemical and physical characterization confirms that the Asedo feldspar deposit possesses highly favorable properties for industrial utilization. Table 3 presents the individual sample compositions along with calculated total alkali contents and Na₂O/K₂O ratios.

O ratios.

Table 3. Individual major oxide compositions, total alkalis, and Na₂O/K₂O ratios of the ten feldspar samples from the Asedo deposit.

Sample	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	Total Alkalis	Na ₂ O/K ₂ O	Feldspar Type
ED-02-54-2	68.50	20.64	0.30	1.44	0.005	2.31	7.98	10.29	0.29	Potassic
ED-02-55	67.30	26.24	0.22	5.00	0.005	6.15	1.00	7.15	6.15	Sodic
ED-02-59-1	69.20	22.20	0.46	4.06	0.46	3.28	1.32	4.60	2.48	Sodic
ED-02-54	65.78	25.48	0.16	4.32	0.005	5.82	1.06	6.88	5.49	Sodic
ED-02-56	76.90	14.86	0.40	1.06	0.005	3.22	4.56	7.78	0.71	Potassic-sodic
ED-02-57	70.20	19.20	0.28	2.80	0.08	5.20	1.50	6.70	3.47	Sodic
ED-02-58	66.50	21.80	0.24	1.80	0.02	2.80	6.00	8.80	0.47	Potassic
ED-02-59	66.80	22.50	0.32	3.20	0.15	3.60	2.60	6.20	1.38	Sodic
ED-02-60	74.00	16.20	0.35	1.50	0.01	3.80	3.20	7.00	1.19	Sodic
ED-02-61	65.00	22.80	0.38	4.40	0.35	4.20	1.80	6.00	2.33	Sodic
Average	69.02	21.19	0.31	2.96	0.11	4.04	3.10	7.14	1.30	Sodic (avg.)

Source: Authors' original field and laboratory data.

The average SiO₂ concentration (69.02 wt.%) comfortably falls within the standard commercial specification of 65–75 wt.% required for ceramic and glass raw materials [4, 6, 20]. Silica serves as the principal glass-forming network provider, facilitating vitreous phase development during thermal treatment. Meanwhile, the high Al₂O₃ content (21.19 wt.%) underlines excellent refractory performance, substantially enhancing thermal shock resistance, chemical durability, surface

hardness, and deformation resistance during firing [23, 24].

However, the individual sample data reveal significant compositional variability. Sample ED-02-56 exhibits the highest SiO₂ (76.90 wt.%) and lowest Al₂O₃ (14.86 wt.%), consistent with a quartz-rich pegmatite domain. In contrast, sample ED-02-55 has the highest Al₂O₃ (26.24 wt.%) and Na₂O (6.15 wt.%), indicating a plagioclase-rich (albite) composition. Sample ED-02-54-2 is notable for its high K₂O (7.98

wt.%) and low Na₂O (2.31 wt.%), classifying it as a potassic feldspar (microcline-rich). Sample ED-02-58 also shows potassic affinity (K₂O = 6.00 wt.%; Na₂O/K₂O = 0.47). These variations suggest that the Asedo pegmatite is internally zoned, with discrete domains of sodic, potassic, and intermediate compositions.

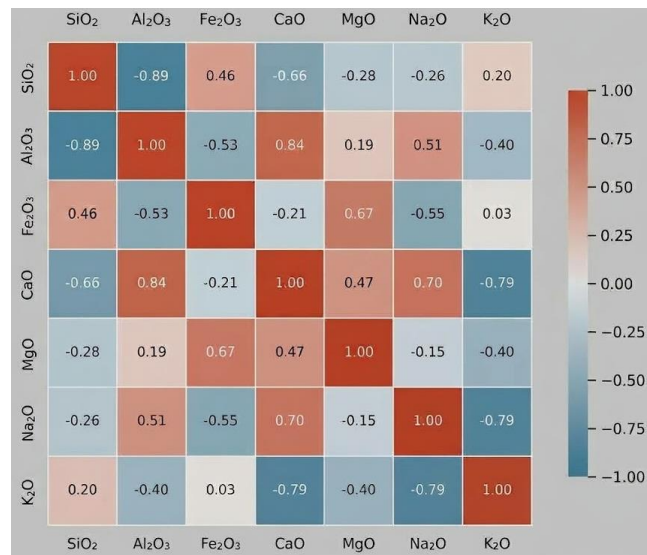


Figure 8. Pearson correlation matrix of major oxides for Asedo feldspar samples.

The total alkali content varies from 4.60 wt.% (ED-02-59-1) to 10.29 wt.% (ED-02-54-2), with an average of 7.14 wt.%. The Na₂O/K₂O ratio ranges from 0.29 (strongly potassic) to 6.15 (strongly sodic), with an average of 1.30, classifying the bulk deposit as a medium-grade, sodium-dominant alkali feldspar. This sodium-rich nature is especially advantageous for container glass manufacturing. Potassium oxide complements this behavior, working synergistically to reduce thermal energy requirements while promoting body densification [5].

The matrix illustrates the strength and direction of linear geochemical relationships among SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO, Na₂O, and K₂O [25]. Strong negative correlations occur between SiO₂ and Al₂O₃ (r = -0.89) and between Na₂O and K₂O (r = -0.79), whereas strong positive correlations occur between Al₂O and CaO (r = 0.84). These relationships reflect compositional variation among sodic, potassic, and intermediate feldspar domains within the Asedo deposit [26].

4.2. Physical Properties and Their Consistency

The samples demonstrate minimal water absorption (0.31%), low apparent porosity (0.80%), and a uniform bulk density (2.63 g/cm³). These physical attributes reflect a tightly packed, impermeable microstructure necessary for long-term structural durability and tight dimensional tolerances [3, 23]. The narrow density range aligns closely with typical well-crystallized alkali feldspars (2.55–2.63 g/cm³), indicating homogeneous mineralogy and consistent texture across the sampled ore body [4, 27, 28].

4.3. Comparison with International Feldspar Deposits

Table 4. Comparison of average major oxide compositions (wt.%) between the Asedo deposit and selected commercial feldspar deposits.

Oxide	Asedo Deposit (Ethiopia)	Wadi Al-Jayshiah (Jordan)	Wadi Zerabi (Egypt)	Spruce Pine Minspar (USA)	Çine-Milas Raw (Turkey)	Norfloat K (Norway)
SiO ₂	69.02	67.96	68.29	68.60	66.03	65.90
Al ₂ O ₃	21.19	17.74	18.69	18.50	15.56	18.60
Fe ₂ O ₃	0.31	2.33	0.07	0.06	0.40	0.07
Na ₂ O	4.04	4.13	6.33	6.50	5.68	2.90
K ₂ O	3.10	4.33	5.83	4.10	13.40	11.80
LOI	0.43	0.09	—	0.30	—	0.20

Sources: [4, 6, 29-31].

The elevated Al₂O₃ content (21.19 wt.%) is notably higher than many commercial deposits (typically 15–19 wt.%), suggesting superior refractory properties and enhanced mechanical strength. This comparison is visually summarized in Table 4.

4.4. Comparison with Other Ethiopian Feldspar Deposits

Table 5 compares the major oxide composition of the Asedo feldspar with that of other Ethiopian feldspar deposits, including

Shebelle, Negelle Borena and the Kenticha occurrences.

Table 5. Detailed chemical composition of Ethiopian feldspar deposit.

m. oxide (wt.%)	Asedo (This Study)	Shebelle	Negelle Borena	Kenticha Pure Feldspar	Kenticha Feldspar-Quartz	Kenticha (Adola Belt)	Kenticha Serpentine Massif
SiO ₂	69.02	70.96	66.0	65.7	70.5	67.3	67.3
Al ₂ O ₃	21.19	18.04	18.5	18.6	16.3	17.2	17.2
Fe ₂ O ₃	0.31	0.24	0.58	0.5	0.7	<0.1–0.3	<0.3
K ₂ O	3.10	9.45	10.0	4.9	4.8	11.1	11.1
Na ₂ O	4.04	1.41	2.75	7.0	5.4	2.4	2.4
Total alkalis	7.14	10.86	12.75	11.9	10.2	13.5	13.5
Na ₂ O/K ₂ O	1.30	0.15	0.28	1.43	1.13	0.22	0.22
Feldspar type	Sodic	Potassic	Potassic	Sodic	Sodic	Potassic	Potassic
Resource (Mt)	46.9	0.025	0.0145	0.5	0.5	2.7	2.7

Sources: [19-21, 32-34].

The most striking advantage of the Asedo deposit is its Al₂O₃ content of 21.19 wt.%, which is significantly higher than all other Ethiopian feldspar deposits. The Asedo deposit exhibits a Na₂O/K₂O ratio of 1.30, classifying it as sodium-rich alkali feldspar, in contrast to Shebelle (0.15), Negelle Borena (0.28), and Kenticha (0.22), which are strongly potassic. The Fe₂O₃ content of Asedo feldspar (0.31 wt.%) is competitive and meets the permissible limit of <0.50 wt.% for colored container glass and ceramic tiles without beneficiation. The low LOI of 0.43 wt.% confirms high mineral purity. With a preliminary exploration target of 46.9 Mt, the Asedo deposit dwarfs the resource estimates for Kenticha (2.7 Mt) and Kenticha Serpentine Massif (2.7 Mt).

4.5. Beneficiation Requirements

The main industrial constraint is the Fe₂O₃ content, which averages 0.31 wt.% and slightly exceeds the strict threshold of <0.15 wt.% set for premium whiteware and clear optical glass

[3, 5]. However, recent advances in beneficiation technology demonstrate that this constraint is readily surmountable. Yassin et al. [7] achieved Fe₂O₃ reduction to as low as 0.12% using dry and wet magnetic separation followed by oxalic acid leaching, while Tinesha et al. [8] successfully reduced iron oxide from 2.25% to 0.38% using a two-step magnetic separation and chemical treatment process. Applying such established methods to Asedo feldspar—which contains significantly lower initial iron (0.31 wt.%)—would readily achieve the <0.10 wt.% Fe₂O₃ threshold required for premium applications. The low LOI and absence of deleterious minerals such as sulfides or carbonates simplify the beneficiation process, as no roasting or acid leaching is likely required for most applications.

4.6. Comparison with Industrial Specifications

Table 6 compares the Asedo feldspar with the industrial specifications for ceramic and glass manufacturing.

Table 6. Comparison of the Asedo feldspar deposit with industrial specifications for ceramic and glass manufacturing.

Parameter	Asedo Feldspar	Ceramic Tiles	Sanitary Ware	Porcelain Stoneware	Structural Ceramics	Container Glass (Coloured)	Premium White Ceramics
SiO ₂ (wt.%)	69.02	65–75	65–75	67–75	65–75	68–75	68–75
Al ₂ O ₃ (wt.%)	21.19	17–22	18–23	18–23	16–22	17–20	18–22
Na ₂ O (wt.%)	4.04	2–6	2–6	3–7	2–6	3–8	2–5

Parameter	Asedo Feldspar	Ceramic Tiles	Sanitary Ware	Porcelain Stoneware	Structural Ceramics	Container Glass (Coloured)	Premium White Ceramics
K ₂ O (wt.%)	3.10	2–8	2–8	2–8	2–8	1–5	2–6
Total Alkalis	7.14	>7	>7	>7	>6	>7	>7
Fe ₂ O ₃ (wt.%)	0.31	<0.50	<0.50	<0.40	<0.80	<0.40	<0.10
LOI (wt.%)	0.43	<1.0	<1.0	<1.0	<1.0	<0.8	<0.5
Bulk Density (g/cm ³)	2.63	2.55–2.65	2.55–2.65	2.55–2.65	Typical	Typical	Typical
Water Absorption (%)	0.31	Low	Low	Low	Low	—	—
Apparent Porosity (%)	0.80	Low	Low	Low	Low	—	—
Overall		✓	✓	✓	✓	✓	X (Fe ₂ O ₃)

✓ = Meets industrial specification; X = Does not meet specification without beneficiation.

Sources: [4]; [6]; [23]; [22].

5. Conclusions

The Asedo feldspar deposit, hosted within pegmatites emplaced in the Precambrian basement of the southern Mozambique Belt, represents a newly identified industrial mineral resource in Ethiopia. Geochemical analysis of ten feldspar samples reveals favorable major oxide composition, with average concentrations of 69.02 wt.% SiO₂, 21.19 wt.% Al₂O₃, 4.04 wt.% Na₂O, 3.10 wt.% K₂O, 0.31 wt.% Fe₂O₃, and 0.43 wt.% LOI. Significant compositional variability exists among the ten analyzed samples, with Na₂O/K₂O ratios ranging from 0.29 to 6.15, indicating both potassic and sodic domains. The total alkali content (Na₂O + K₂O = 7.14 wt.%) and average Na₂O/K₂O ratio of 1.30 classify the bulk deposit as a sodium-rich alkali feldspar. Physical testing confirms excellent material integrity, with an average bulk density of 2.63 g/cm³, apparent porosity of 0.80%, and water absorption of 0.31%. These physicochemical characteristics demonstrate that the deposit is suitable for manufacturing ceramic tiles, sanitary ware, structural ceramics, porcelain stoneware, and colored container glass. Based on surface geological mapping, structural sections, and an assumed thickness of 12 m over an area of 1.5 km², a resource of approximately 46.9 Mt has been estimated. While the Fe₂O₃ content slightly exceeds the stringent specifications for premium white ceramics and clear optical glass, recent advances in magnetic separation and acid leaching technologies [7, 8] demonstrate that conventional beneficiation can readily reduce iron-bearing impurities to commercially acceptable levels. Overall, the Asedo feldspar deposit shows strong potential to supply Ethiopia's expanding ceramic and glass industries, reducing dependence on imported raw materials. Future research should focus on subsurface core

drilling to define three-dimensional ore continuity, detailed mineralogical characterization using XRD, pilot-scale beneficiation studies, and systematic resource estimation to support sustainable commercial development.

Abbreviations

ASTM	American Society for Testing and Materials
BD	Bulk Density
Wd	Oven-dry Weight
W _{sat}	Saturated Weight
W _{sub}	Suspended Weight
Cwb	Temperate Highland Climate with Dry Winter and Warm Summer (Köppen Climate Code)
EIGS	Ethiopian Institute of Geological Surveys
GIE	Geological Institute of Ethiopia
LOI	Loss on Ignition
Ma	Million Years Ago
m.a.s.l.	Metres Above Sea Level
Mt	Million Tonnes
ORCID	Open Researcher and Contributor ID
P	Apparent Porosity
PPL	Plane-polarized Light
USD	United States Dollar (\$)
WA	Water Absorption
wt.%	Weight Percent
XPL	Cross-polarized Light
XRF	X-ray Fluorescence

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Data Availability Statement

All relevant data supporting the findings of this study are presented in the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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