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BENEFICIATION OF GLAUCONITE ORE FROM THE CHANGI DEPOSIT (UZBEKISTAN) VIA GRINDING AND MAGNETIC SEPARATION

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Annotatsiya.
Ushbu tadqiqotda o'zbek glaukonitini tuproq konditsioneri va sekin ta'sir qiluvchi o'g'itlar uchun xomashyo sifatida boyitish maqsadida ikki bosqichli - maydalash va magnit separatsiya - jarayoni o'rganildi. Maydalash natijasida zarracha o'lchami 75 mkm dan kichik qiymatgacha kamaydi va solishtirma sirt maydoni taxminan 30 % ga oshdi. Magnit separatsiya glaukonit fraksiyasini boyitib, xom rudadagi K_2O miqdorini 1,20 % dan magnit bo'lmagan mahsulotda 2,14 % gacha oshirdi, Fe_2O_3 ning esa 48,7 % i magnit fraksiyada to'plandi. Natijada olingan magnit bo'lmagan mahsulot tarkibida kaliy miqdori yuqori, temir miqdori esa past bo'lib, uni qishloq xo'jaligida qo'llash uchun yanada maqbul holga keltirdi. Taklif etilgan texnologiya glaukonitning fizik-kimyoviy xususiyatlari va kaliyning o'simliklar tomonidan o'zlashtirilish imkoniyatini yaxshilaydi. Tadqiqot natijalari ushbu usulni barqaror tuproq yaxshilagichi va sekin ta'sir qiluvchi o'g'itlar uchun xomashyo sifatida qo'llash imkoniyatini ko'rsatadi. Mazkur yondashuv import qilinadigan kaliyli o'g'itlarga bo'lgan ehtiyojni kamaytirish hamda mahalliy mineral resurslardan samarali foydalanishga xizmat qilishi mumkin..
Kalit so'zlar:
Glaukonit, maydalash, magnit separatsiya, tuproq konditsioneri, kaliyning o'simliklar uchun mavjudligi.

Аннотация.
В данном исследовании изучен двухэтапный процесс - измельчение с последующей магнитной сепарацией - для обогащения узбекского глауконита в качестве потенциального почвоулучшителя и матрицы для медленно высвобождающихся удобрений. В результате измельчения размер частиц был уменьшен до менее 75 мкм, а удельная площадь поверхности увеличилась примерно на 30 %. Магнитная сепарация позволила обогатить глауконитовую фракцию, повысив содержание K_2O с 1,20 % в исходной руде до 2,14 % в немагнитном продукте, при этом 48,7 % Fe_2O_3 перешло в магнитную фракцию. Полученный немагнитный продукт характеризуется более высоким содержанием калия и пониженным содержанием железа, что делает его более пригодным для применения в сельском хозяйстве. Предложенная технология улучшает физико-химические свойства глауконита и доступность калия для растений, демонстрируя его потенциал в качестве экологически устойчивого материала для улучшения почвы и сырья для производства удобрений с замедленным высвобождением. Данный подход также может способствовать снижению зависимости от импортных калийных удобрений и более эффективному использованию отечественных минеральных ресурсов.
Ключевые слова:
Глауконит, измельчение, магнитная сепарация, почвоулучшитель, доступность калия.

Abstract.
This study investigates a two-step process-grinding followed by magnetic separation-for upgrading Uzbek glauconite as a potential soil conditioner and slow-release fertilizer matrix. Grinding reduced the particle size to below 75 μm and increased the specific surface area by approximately 30%. Magnetic separation enriched the glauconite fraction, increasing K_2O content from 1.20% in the raw ore to 2.14% in the non-magnetic product, while 48.7% of Fe_2O_3 was concentrated in the magnetic fraction. The resulting non-magnetic product has higher potassium and lower iron content, making it more suitable for agricultural applications. The proposed treatment improves the physicochemical properties and potassium accessibility of glauconite, demonstrating its potential as a sustainable soil amendment and raw material for slow-release fertilizers. This approach may also reduce dependence on imported potassium fertilizers and promote the use of domestic mineral resources.
Keywords:
glauconite, grinding, magnetic separation, soil conditioner, potassium availability.

INTRODUCTION

The global population has increased steadily over recent decades. According to the United Nations World Population Prospects 2024, the world population grew from 6.1 billion in 2000 to approximately 8.2 billion in 2026, representing an increase of about 34% [1]. This rapid growth, accompanied by economic development, has substantially transformed global food systems and dietary patterns, shifting consumption from cereal-based diets toward greater demand for meat, dairy, and processed products [2]. Satisfying this growing demand has largely relied on agricultural intensification, particularly through the extensive application of mineral fertilizers. Currently, nearly half of the global population depends directly on food produced with synthetic nitrogen fertilizers [3]. However, excessive and unsustainable fertilizer use has

led to severe environmental consequences, including water eutrophication and increased greenhouse gas emissions [4].

In response to these challenges, the fertilizer industry is shifting toward sustainable technologies. Particular attention is being given to microbially and biologically synthesized eco-friendly fertilizers, as well as smart encapsulated systems with controlled nutrient release [5, 6]. Within this framework, considerable research has focused on slow-release mineral fertilizers that improve both soil microbial activity and plant nutrition. Among these, potassium-containing fertilizers have become especially important.

Potassium is an essential macronutrient involved in plant growth, photosynthesis, enzymatic function, and water regulation [5]. Its deficiency impairs plant metabolism and reduces crop yields. Therefore, potassium is among the most agronomically critical nutrients. Consequently, the strategic importance of potassium fertilizer production continues to grow globally.

The global demand for potassium fertilizers is increasing significantly. This trend necessitates developing cost-effective alternatives from local mineral resources [7]. However, in many countries, particularly developing nations, most potassium fertilizers are still imported, creating a pressing need for sustainable domestic sources. Consequently, reducing dependence on imports and ensuring efficient utilization of local mineral resources are of considerable scientific and practical importance.

Glauconite has gained increasing attention as a potassium-bearing mineral due to its slow nutrient-release characteristics and abundance in many sedimentary deposits. Previous studies have shown that glauconitic materials can serve as sustainable potassium fertilizers while also improving soil properties. For instance, Franzosi et al. (2014) reported that glauconitic sandstones from the Salamanca Formation (Argentina) showed promising agronomic potential as potassium fertilizers [8]. Similarly, Karimi et al. (2012) found that glauconitic sandstone significantly enhanced potassium nutrition and growth of olive plants, confirming its agricultural value [9]. Collectively, these findings indicate that glauconite can be a viable substitute for conventional soluble potassium fertilizers, potentially reducing the environmental impacts associated with intensive fertilizer use.

Uzbekistan holds substantial reserves of potassium- and microelement-enriched glauconite-bearing rocks, which are promising agro-mineral raw materials [10]. These deposits are particularly valuable as strategic local mineral resources. They are primarily concentrated in the Gissar mountains, Ziaetdin–Zirabulak ranges, Kyzylkum plains, Sultan Uvaysdag, and the sandy-clayey formations of Northern Fergana and Tashkent [11]. In the Tashkent region, the Changi deposit contains glauconite-bearing sandstones with estimated C2 (preliminary) reserves of approximately 14 million tons [12]. Additionally, exploration in the Garm–Chashmasoy area revealed a ~2 m thick sandstone layer containing up to 15% glauconite.

In Karakalpakstan, a glauconite deposit was discovered in the Krantau mountains with estimated reserves of ~10 million tons. Current exploration for glauconite raw materials is ongoing in the Qiziljar area, on the left bank of the Amu Darya River. In Surkhandarya, the Kofrun deposit contains 6–12% glauconite in the host rock. In the Tagarasoy area of the Yakkabog mountains (Kashkadarya province), glauconite content ranges from 8% to 24% within sandstone layers 3.15–15.8 m thick [13]. Additionally, celadonite – a glauconite-analogous mineral – has been identified in Namangan region. This mineral contains potassium,

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phosphorus, and essential microelements (Fe, Mn, Cu, Co), making it a promising raw material for fertilizers.

Therefore, glauconite has considerable potential to partially replace imported potassium fertilizers [14]. It is a hydromica-type mineral that can serve both as a soil conditioner and as a slow-release fertilizer. Furthermore, its enrichment with phosphorus-containing compounds enables the production of complex, cost-effective, and efficient fertilizer materials. The general chemical composition of glauconite is as shown in table 1 (in wt%):

Table 1. ***The general chemical composition of glauconite***

Oxide	**Content(%)**
K_2O	4.4–9.4
Na_2O	0–3.5
Al_2O_3	5.5–22.6
Fe_2O_3	6.1–27.9
FeO	0.8–8.6
MgO	2.4–4.5
SiO_2	47.6–52.9
and structural H_2O^+	4.9–13.5

Physically, glauconite typically occurs in dark olive-green, bluish-green, or yellowish-green colors, with a dull luster and brittle structure. Its density ranges from 2.2 to 2.8 g/cm^3 [15]. The mineral is poorly fusible and decomposes in hydrochloric acid (HCl).

Although known to mineralogists since 1828, its origin was only scientifically substantiated in later studies. Glauconite is primarily considered a sedimentary mineral formed on the seabed under oxidation–reduction (redox) conditions.

The positive effects of glauconite in agriculture have been recognized since the late nineteenth century, with comprehensive studies by Odin (1988) and Huggett (2005) [16, 17]. Glauconite is a natural aluminosilicate mineral belonging to the hydromica group, containing potassium, iron, magnesium, and other beneficial elements [15]. Its high ion-exchange capacity, adsorption properties, and environmental safety make it promising for slow-release fertilizers. However, natural glauconite ores commonly occur with quartz, feldspars, carbonates, and iron-bearing minerals, which reduce the concentration of valuable components and lower agrochemical efficiency [15]. Therefore, beneficiation and activation of glauconite ores are scientifically and technologically important.

According to the AIPEA Nomenclature Committee, glauconite belongs to the mica group of clay minerals and should be classified based on its crystal-chemical characteristics and maturity [18]. Accurate mineralogical identification is thus essential when evaluating glauconite for agricultural or technological uses, as compositional variations directly affect potassium availability, cation-exchange capacity, and physicochemical properties during beneficiation and activation.

In recent years, grinding and magnetic separation have been increasingly used for mineral processing. Grinding reduces particle size, generates structural defects, and significantly increases surface reactivity. Magnetic separation is another effective beneficiation technique for glauconite ores, enabling the removal of iron-rich magnetic fractions and concentration of the glauconite phase [15]. The combined use of grinding and magnetic separation can substantially improve both the structural and agrochemical properties of glauconite materials.

Although numerous studies have separately investigated grinding or magnetic beneficiation of glauconite, little attention has been given to their integrated application for Uzbekistan glauconites as slow-release potassium fertilizers. Therefore, this study aims to examine the effects of combined grinding and magnetic separation on the physicochemical properties of Uzbekistan glauconite, and to evaluate its potential as a potassium fertilizer material.

MATERIALS AND METHODOLOGY.

Glauconite-bearing mineral raw materials from Uzbekistan were selected for this study. The initial samples, obtained in their natural state, contained glauconite together with quartz, feldspar, and iron oxide impurities.

The following materials and equipment were used:

- Natural glauconite ore samples.
- Jaw crusher (J-100×100, gap opening 10 mm, 300 rpm, 10 min) for primary crushing.
- Knife mill (IKA M20, 20,000 rpm, 5 min) for fine grinding.
- Distilled water for washing and sample preparation.
- Laboratory sieve set for granulometric analysis.
- Neodymium (NdFeB) permanent magnet (grade N42, surface field ~0.5 T) for magnetic separation.

For magnetic separation, the sample was spread as a thin layer on a glass plate. The magnet was passed at a distance of 10 mm above the sample for 5 minutes while the material was gently stirred manually. The attracted magnetic particles were collected, and the process was repeated three times to ensure complete separation.

The glauconite samples were obtained from the Changi deposit in the Parkent district, Tashkent region, Uzbekistan. Geological exploration by the USSR Geological Survey during 1963–1966 identified significant reserves of glauconite-bearing sandstones at this deposit [19]. The deposit has a monoclinal structure, with strata dipping westward at approximately 20–28°. In upper sections, glauconitic sandstones were exposed by mining to depths of about 9 m, while deeper horizons were drilled to depths of 71–102 m.

For this study, samples with varying iron content across stratigraphic layers were selected to develop slow-release complex fertilizers. The mineralogical composition of the Changi glauconite was reported as: glauconite 50%, clay minerals 26%, feldspars 10–15%, and quartz 26% [20, 21].

The morphology of the glauconite particles was examined using scanning electron microscopy (SEM). Figure 1 presents representative micrographs of the raw glauconite sample. Figure 1a shows a macroscopic view of glauconite grains, revealing irregularly shaped brittle agglomerates ranging from 100 to 600 μm. The high-resolution SEM image (Figure 1b) displays the surface morphology and particle structure of glauconite at a scale of 10 μm, showing a rough, layered texture with flaky edges, characteristic of the hydromica structure of glauconite.

The manually sorted samples were weighed using an analytical balance, and 200 g was prepared for subsequent experiments. To remove physically bound moisture, the samples were dried in a laboratory oven at 105 °C for 2 hours. After drying, the samples were reweighed. The mass decreased from 200 g to 190 g, corresponding to a 5% mass loss due to moisture removal.

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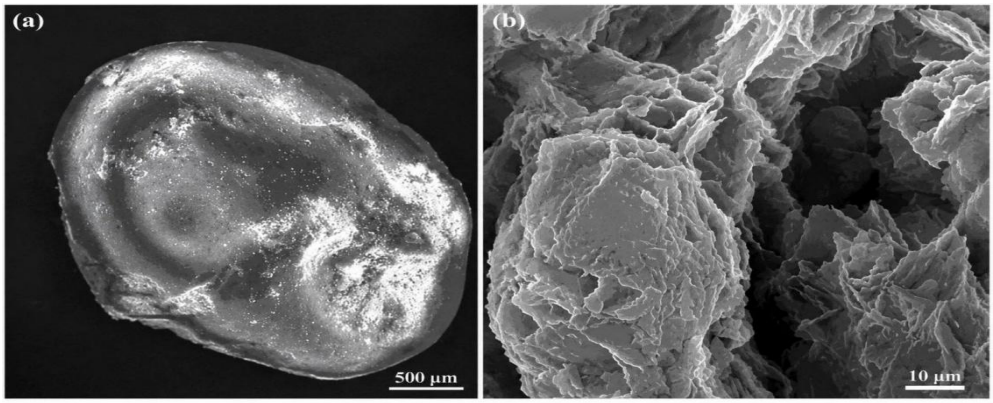

Figure 1. Morphology of glauconite particles: (a) macroscopic view of glauconite grain; (b) SEM micrograph of the glauconite

The dried samples were then crushed in a jaw crusher for 10 minutes, followed by knife milling to obtain finer fractions. Some mass loss occurred during grinding, but the total loss did not exceed 5% of the initial sample mass. This loss is mainly attributed to the formation of fine dust particles, which is typical for the mechanical processing of brittle glauconite minerals.

Following the grinding process, the samples were separated into different size fractions using a standard set of laboratory sieves. The mass fraction of each size class was determined, and the particle size distribution was evaluated. This stage served as the basis for identifying the optimal granulometric range required for subsequent processing. Sieve analysis was performed using sieves with aperture sizes ranging from 3.15 to 0.074 mm.

After granulometric classification, the magnetic susceptibility of each fraction was investigated in order to determine the optimal particle-size fraction for magnetic beneficiation. Subsequently, magnetic enrichment of the selected sample fraction was carried out using a permanent magnet. Previous studies have established that physicochemical characterization methods, particularly infrared (IR) spectroscopy and X-ray Fluorescence (XRF) analysis, are among the most informative techniques for studying natural aluminosilicate minerals, including glauconites. Therefore, the present investigation was conducted based on the application of these analytical methods.

RESULTS

3.1. Granulometric Analysis. The granulometric composition of the glauconite sample from the Changi deposit was investigated after drying and crushing procedures. The drying process was carried out at 105 °C for 30 minutes. As a result, the sample mass decreased from 200 g to 190 g. This reduction is explained by the evaporation of physically bound moisture present in the sample. The mass loss was calculated using the following equation:

$$\frac{200-190}{200}\times 100=5\%$$

Following the crushing stage, additional mass losses were observed. The total technological loss was approximately 5%, which can be attributed to the brittle structure of glauconite, leading to the formation of fine dust particles during comminution.

The crushed samples were then subjected to granulometric analysis based on standard laboratory sieving procedures. For this purpose, 80 g of the crushed mineral was accurately weighed using an analytical balance. Sieving was performed sequentially using standard laboratory sieves with mesh sizes of 3.15, 2.5, 1.7, 0.5, 0.150, and 0.075 mm. The results

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indicated that the main portion of the mineral mass was concentrated in the fine-grained fractions.

The mass distribution of each fraction was calculated using the following formula:

$$Yield(\%)=\frac{mi}{m0}\times 100$$

Here, m_i-denotes the mass of the fraction, g; m_0-denotes the initial sample mass, g. The results of the sieve analysis are presented in Table 2.

Table 2. ***Sieve Analysis Results of glauconite***

№	Fraction, mm	Mass, g	Yield, %
1	+3.15	9.65	12.06
2	-3.15+2.5	4.4623	5.58
3	-2.5+1.7	6.4235	8.03
4	-1.7+0.5	15.0215	18.78
5	-0.5+0.150	11.3013	14.13
6	-0.150+0.075	31.6775	39.60

The results showed that the main mass fraction of the sample was concentrated in the −0.150 +0.075 mm size class, accounting for 39.60% of the total mass. This indicates that the mineral readily disintegrates into a fine-dispersed state during the grinding process. At the same time, a considerable mass fraction (18.78%) was observed in the −1.7 +0.5 mm size range. The results of the granulometric analysis demonstrate that fine fractions play a technologically important role in subsequent beneficiation and magnetic separation processes of glauconite-bearing material. In particular, the −0.150 +0.075 mm fraction is considered promising for further physicochemical investigations due to the higher degree of mineral liberation expected in this particle size class. The total mass loss during sieving was approximately 1.84%, which can be attributed to dust formation, moisture loss, and general handling-related technological losses. An additional 3.16% material loss occurred during the crushing stage as fine dust. Thus, the total technological loss (3.16% + 1.84% = 5.00%) is consistent with the 5% mass reduction observed after drying and grinding, as calculated earlier.

3.2. XRF/EDS Analysis of Raw Glauconite. The investigated glauconite mineral sample was further analyzed using energy-dispersive X-ray spectroscopy (EDS/XRF). Elemental composition was determined using EDS (ISO 22309:2015) and XRF (ISO 12677:2011) methods on pressed powder pellets (Figure 2). The obtained spectra indicated that the sample was predominantly composed of Fe, Si, Al, K, and Mg elements. The spectral diagram showed high-intensity peaks at 1.49 keV (Al-Kα), 1.74 keV (Si-Kα), 3.31 keV (K-Kα), as well as Fe-Kα and Fe-Kβ lines in the 6.40–7.06 keV range. The pronounced intensity of iron-related peaks confirms a significant presence of iron-bearing phases in the glauconite mineral. Meanwhile, the silicon and aluminum peaks indicate the presence of aluminosilicate structures within the sample.

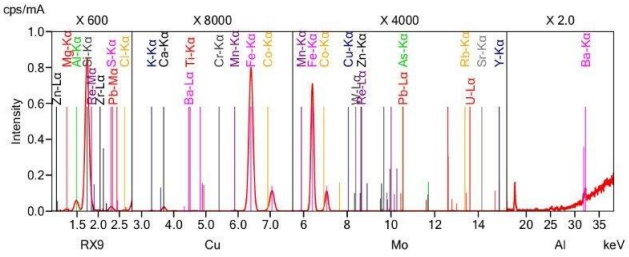

Figure 2. **EDS spectrum of raw glauconite.**

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The detection of potassium signals is fully consistent with the typical crystal-chemical composition of glauconite, as this mineral belongs to the group of layered potassium-iron aluminosilicates. In addition, supplementary peaks corresponding to Mg, Ca, Ti, and Mn were observed in the spectrum. The presence of these elements suggests possible accessory mineral phases such as carbonates, titanium-bearing minerals, or iron-manganese compounds within the sample.

Furthermore, low-intensity signals corresponding to Ba, Zn, and Pb were also detected, indicating trace-level impurities in the mineral matrix. The spectral analysis results confirm that glauconite-bearing raw material is a multicomponent mineral system, with iron-rich aluminosilicate phases forming its dominant structural framework. These findings provide an important scientific basis for the subsequent development of magnetic separation processes and their optimization for mineral beneficiation.

The results show that as the degree of comminution increases, the proportion of magnetically susceptible particles also increases. This phenomenon can be explained by the higher concentration of iron-bearing glauconite grains and iron oxide minerals in the finer granulometric fractions.

3.3. Magnetic Separation and Characterization of Fractions. Magnetic separation resulted in two types of products: magnetic (Figure 4) and non-magnetic (Figure 3) fractions. The magnetic fraction showed a higher concentration of iron-rich components, while the non-magnetic fraction was dominated by quartz and feldspar minerals. This confirms that magnetic separation is an effective method for the preliminary beneficiation of glauconite-bearing ores.

After magnetic separation, the elemental composition of the non-magnetic fraction was analyzed using energy-dispersive X-ray spectroscopy (EDS/XRF). The obtained spectral results showed that this fraction mainly contains Si, Al, K, and Fe elements. In the spectrum diagram, clear peaks were observed at 1.74 keV corresponding to Si-Kα, at 1.49 keV corresponding to Al-Kα, and at 3.31 keV corresponding to K-Kα lines. Although Fe-Kα peaks associated with iron are present, their intensity is lower compared to the magnetic fraction. This indicates that during magnetic separation, a portion of iron-bearing minerals with ferromagnetic and weakly magnetic properties was removed. As a result, the proportion of silicate and aluminosilicate components increased in the non-magnetic fraction.

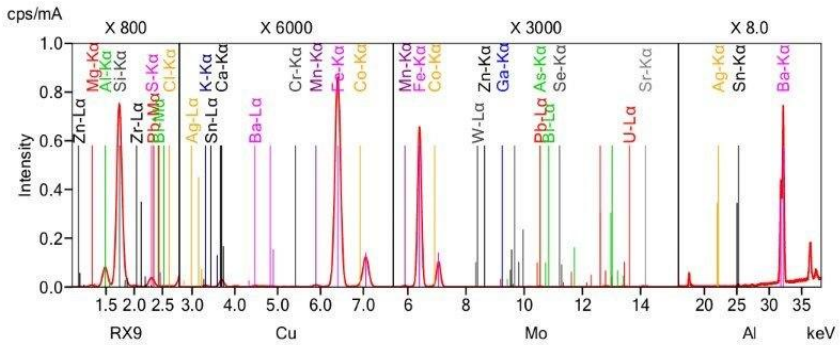

Figure 3. **EDS spectrum of non-magnetic fraction**

Additionally, low-intensity signals corresponding to Mg, Ca, and Mn were also detected in the spectrum. These elements suggest the presence of minor carbonate or clay mineral phases in the sample. In some cases, very low-intensity peaks corresponding to Zn, Ba, Sr, and Pb were also detected, which were interpreted as trace impurities. The spectral analysis results indicate

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that the magnetic separation process enabled partial recovery of iron-rich magnetic phases. In the non-magnetic fraction, an increased concentration of silicate and aluminosilicate minerals was observed. This finding is of significant scientific and practical importance for developing technologies for the beneficiation of glauconite-rich raw materials and their potential use in producing mineral fertilizers or pigment materials.

The elemental composition of the magnetic fraction obtained during magnetic separation was also studied using energy-dispersive X-ray spectroscopy (EDS/XRF). The spectral results showed a high concentration of Fe in this fraction. In particular, the Fe-Kα and Fe-Kβ lines located in the range of 6.40 keV and 7.06 keV were recorded as the most intense peaks. This confirms that the magnetic fraction is enriched in iron-bearing minerals.

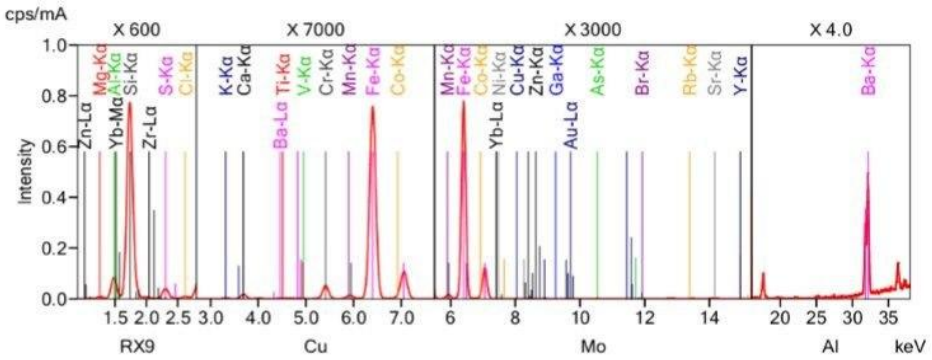

Figure 4. **EDS spectrum of magnetic fraction.**

The spectral diagram reveals the presence of Si-Kα (1.74 keV), Al-Kα (1.49 keV), and K-Kα (3.31 keV) peaks. The detection of these elements indicates that the aluminosilicate framework of glauconite is partially preserved within the magnetic fraction. In addition, the relatively high intensity of Fe peaks confirms the effective enrichment of iron-bearing phases during the magnetic separation process.

Minor peaks corresponding to Mn, Ti, Cr, and V were also identified, which may be associated with iron oxides and Fe-Mn mineral phases. Furthermore, low-intensity signals of Zn, Cu, Ni, and Ba were detected, indicating their presence as trace impurities.

Overall, the spectral analysis demonstrates that magnetic separation efficiently concentrates iron-rich components in the studied fraction. The results also suggest the potential application of this fraction in the production of iron-based pigments, mineral additives, or functional materials with magnetic properties. The efficiency of the separation process is further confirmed by the significant increase in the intensity of Fe-related peaks.

DISCUSSION. The compounds present in glauconite from the Changi deposit are shown in Table 3. The results of magnetic separation indicate the selective separation of iron-bearing phases within the glauconitic raw material.

According to spectral analysis data, the intensity of Fe-Kα and Fe-Kβ lines significantly increased in the magnetic fraction, whereas the non-magnetic fraction was dominated by peaks corresponding to Si and Al elements.

Table 3. ***Compositional analysis of natural glauconite mineral***

№	Component	Result	Unit	Stat.Err	LLD	LLQ
1	Cl	0.0133	mass%	0.0002	0.0002	0.0006
2	MgO	3.28	mass%	0.0338	0.0467	0.140

3	Al_2O_3	6.25	mass%	0.0290	0.0236	0.0707
4	SiO_2	34.4	mass%	0.0295	0.0066	0.0198
5	SO_3	0.308	mass%	0.0026	0.0014	0.0041
6	K_2O	1.20	mass%	0.0183	0.0072	0.0215
7	CaO	5.94	mass%	0.0308	0.0186	0.0557
8	TiO_2	0.148	mass%	0.0047	0.0100	0.0301
9	Cr_2O_3	(0.0102)	mass%	0.0013	0.0037	0.0110
10	MnO	0.206	mass%	0.0031	0.0055	0.0165
11	Fe_2O_3	47.8	mass%	0.0231	0.0367	0.110
12	Co_2O_3	0.0857	mass%	0.0036	0.0125	0.0375
13	CuO	0.0031	mass%	0.0004	0.0009	0.0028
14	ZnO	0.0078	mass%	0.0004	0.0005	0.0015
15	As_2O_3	0.0121	mass%	0.0003	0.0004	0.0011
16	Rb_2O	0.0066	mass%	0.0003	0.0007	0.0020
17	SrO	0.0061	mass%	0.0002	0.0002	0.0006
18	ZrO_2	0.344	mass%	0.0005	0.0007	0.0020
19	Y_2O_3	0.0028	mass%	0.0001	0.0002	0.0006
20	BaO	0.0317	mass%	0.0016	0.0028	0.0083
21	WO_3	0.0144	mass%	0.0010	0.0018	0.0055
22	ReO_2	(0.0055)	mass%	0.0007	0.0020	0.0059
23	PbO	(0.0031)	mass%	0.0006	0.0017	0.0052
24	U_3O_8	0.0029	mass%	0.0002	0.0009	0.0026

This phenomenon can be explained by the concentration of iron-rich minerals under the influence of a magnetic field, while silicate and aluminosilicate phases remain in the non-magnetic fraction. The results confirm that magnetic separation exhibits a selective behavior in the beneficiation of glauconitic ores.
The increase in the intensity of Fe peaks in the magnetic fraction indicates the enrichment of iron oxides and iron-bearing silicate minerals (Table 4). Since Fe^{2+} and Fe^{3+} ions in glauconite possess magnetic susceptibility, they are effectively separated under the influence of a magnetic field. In addition, the detection of Mn, Ti, and Cr elements suggests the presence of additional iron–manganese and titanium-bearing mineral phases within the magnetic fraction.

Table 4. ***XRF Analysis of the magnetic fraction***

№	Component	Result	Unit	Stat.Err	LLD	LLQ
1	Cl	0.0213	mass%	0.0002	0.0002	0.0006
2	Br	(0.0005)	mass%	0,0001	0.0004	0.0013
3	MgO	2.09	mass%	0.0317	0.0434	0.130
4	Al_2O_3	8.20	mass%	0.0276	0.0227	0.0682
5	SiO_2	30.2	mass%	0.0280	0.0079	0.0236
6	SO_3	0.484	mass%	0.0023	0.0011	0.0033
7	K_2O	1.31	mass%	0.0166	0.0224	0.0672
8	CaO	4.55	mass%	0.0262	0.0316	0.0949
9	TiO_2	0.356	mass%	0.0064	0.0132	0.0396

10	V_2O_5	0.0495	mass%	0.0029	0.0075	0.0226
11	Cr_2O_3	2.94	mass%	0.0091	0.0087	0.0261
12	MnO	0.437	mass%	0.0053	0.0143	0.0430
13	Fe_2O_3	48.7	mass%	0.0134	0.0037	0.0110
14	Co_2O_3	0.117	mass%	0.0061	0.0085	0.0255
15	ZnO	0.0081	mass%	0.0004	0.0007	0.0020
16	Ga_2O_3	(0.0013)	mass%	0.0002	0.0005	0.0015
17	As_2O_3	0.0196	mass%	0.0004	0.0003	0.0009
18	Rb_2O	0.0060	mass%	0.0002	0.0006	0.0017
19	SrO	0.0318	mass%	0.0003	0.0003	0.0010
20	ZrO_2	0.237	mass%	0.0045	0.0074	0.0223
21	Y_2O_3	0.0021	mass%	0.0001	0.0002	0.0006
22	BaO	0.223	mass%	0.0041	0.0059	0.0177
23	Au_2O	0.0311	mass%	0.0066	0.0011	0.0033
24	Yb_2O_3	0.0348	mass%	0.0018	0.0033	0.0099

This indicates that the magnetic separation process is capable of partially concentrating not only iron but also associated heavy elements. The dominance of Si, Al, and K elements in the non-magnetic fraction suggests that the aluminosilicate structure of glauconite is partially preserved (Table 5). In particular, the presence of potassium indicates that this product retains its agronomic value.

Table 5. ***XRF Analysis of the Non-Magnetic Fraction***

№	Component	Result	Unit	Stat.Err	LLD	LLQ
1	Cl	0.0148	mass%	0.0002	0.0002	0.0006
2	MgO	2.53	mass%	0.0338	0.0467	0.140
3	Al_2O_3	9.78	mass%	0.0290	0.0236	0.0707
4	SiO_2	37.6	mass%	0.0295	0.0066	0.0198
5	SO_3	0.608	mass%	0.0026	0.0014	0.0041
6	K_2O	2.14	mass%	0.0183	0.0072	0.0215
7	CaO	7.25	mass%	0.0308	0.0186	0.0557
8	Cr_2O_3	0.0321	mass%	0.0014	0.0032	0.0096
9	MnO	0.377	mass%	0.0030	0.0034	0.0102
10	Fe_2O_3	38.2	mass%	0.0105	0.0181	0.0542
11	Co_2O_3	0.143	mass%	0.0050	0.0166	0.0497
12	ZnO	0.0122	mass%	0.0004	0.0005	0.0015
13	Ga_2O_3	(0.0007)	mass%	0.0003	0.0004	0.0013
14	As_2O_3	0.0333	mass%	0.0044	0.0002	0.0006
15	SrO	0.0251	mass%	0.0003	0.0003	0.0009

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16	ZrO_2	0.344	mass%	0.0005	0.0007	0.0020
17	Ag_2O	0.0024	mass%	0.0066	0.0004	0.0012
18	SnO_2	0.0066	mass%	0.0010	0.0005	0.0016
19	BaO	0.853	mass%	0.0005	0.0058	0.0173
20	WO_3	0.0311	mass%	0.0066	0.0011	0.0033
21	PbO	(0.0040)	mass%	0.0010	0.0014	0.0042
22	Bi_2O_3	0.0062	mass%	0.0005	0.0003	0.0010
23	U_3O_8	0.0029	mass%	0.0002	0.0009	0.0026

The results of magnetic separation demonstrate the selective partitioning of iron-bearing phases within the glauconitic raw material. Spectral analysis indicates a significant increase in the intensity of Fe-Kα and Fe-Kβ lines in the magnetic fraction, whereas the non-magnetic fraction is dominated by peaks corresponding to Si and Al elements. This phenomenon can be explained by the concentration of iron-rich minerals under the influence of a magnetic field, while silicate and aluminosilicate phases remain predominantly in the non-magnetic fraction. The results confirm that magnetic separation exhibits a selective behavior in the beneficiation of glauconitic ores.

The increase in Fe peak intensity in the magnetic fraction indicates enrichment of iron oxides and iron-bearing silicate minerals (Table 4). Since Fe^{2+} and Fe^{3+} ions in glauconite exhibit magnetic susceptibility, they are effectively separated under magnetic field influence. In addition, the presence of Mn, Ti, and Cr suggests the occurrence of secondary iron-manganese and titanium-bearing mineral phases within the magnetic fraction. This further indicates that magnetic separation is capable of partially concentrating not only iron but also associated heavy elements.

In contrast, the non-magnetic fraction is characterized by the dominance of Si, Al, and K elements, indicating partial preservation of the aluminosilicate structure of glauconite (Table 5). In particular, the presence of potassium confirms that this fraction retains its agronomic value. Given that glauconite is a potassium-bearing layered aluminosilicate mineral, the non-magnetic fraction can be considered a promising material for use as a slow-release fertilizer. Moreover, the high silicate content suggests its potential application as a sorbent or soil structure-improving agent.

The obtained results are consistent with previous investigations on glauconite beneficiation and agricultural utilization. Franzosi et al. (2014) reported that beneficiation of glauconitic sandstone increases its suitability as an alternative potassium fertilizer by improving the concentration of potassium-bearing mineral phases [8]. Likewise, Karimi et al. (2012) demonstrated that glauconitic materials can effectively supply potassium to plants under agricultural conditions, supporting their application as slow-release fertilizers [9]. In the present study, magnetic separation enriched the aluminosilicate fraction while preserving potassium within the non-magnetic product, suggesting that this fraction may represent a promising raw material for environmentally friendly potassium fertilizer production. Furthermore, the mineralogical interpretation presented here is consistent with the nomenclature and classification criteria recommended by Guggenheim et al. (2007), which emphasize the importance of correctly identifying glauconite as a mica-group clay mineral

when evaluating its technological properties [18]. Collectively, these findings confirm that the integrated application of grinding and magnetic beneficiation represents a promising approach for upgrading Uzbek glauconite for sustainable agricultural use.

However, it should be noted that the applied spectral technique is mainly semi-quantitative and does not provide complete information on the crystalline structure of mineral phases. Therefore, further investigations using X-ray diffraction (XRD), scanning electron microscopy with energy-dispersive spectroscopy (SEM-EDS), and thermal analysis methods are recommended. These approaches would allow a more detailed understanding of phase transformations occurring during magnetic separation.

CONCLUSION

In this study, a comprehensive investigation of the granulometric composition, chemical structure, and behavior of glauconite-bearing raw material from the Changi deposit during magnetic separation was conducted. Based on the obtained results, the following conclusions were drawn.

After drying and crushing processes, the glauconite sample demonstrated significant fragmentation into fine fractions. The highest mass yield was observed in the −0.150 +0.075 mm fraction (39.60%), indicating that the mineral possesses a fragile and easily degradable structure.

The results of the granulometric analysis confirmed that the bulk of the glauconite raw material is transformed into a fine dispersed state, which is technologically important for subsequent beneficiation processes. XRF/EDS analyses revealed the predominance of Fe, Si, Al, and K elements in the sample, confirming the typical aluminosilicate nature of glauconite and the presence of iron-rich phases within its structure.

Magnetic separation resulted in the concentration of iron-rich minerals in the magnetic fraction, while silicate components (quartz and feldspar) were predominantly accumulated in the non-magnetic fraction. This demonstrates the efficiency of magnetic separation as a physical beneficiation method for glauconite-bearing raw materials. The results further indicate that the efficiency of magnetic separation increases with decreasing particle size, confirming that the degree of mineral liberation plays a critical role in the beneficiation process.

Overall, the combined application of granulometric classification and magnetic separation represents an environmentally friendly and energy-efficient technological approach for the primary beneficiation of glauconite-bearing raw materials.

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