

Original Article

Characterization of Bentonite Clay from the Krantau and Beshtyube Deposits and their Physicochemical Investigation

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Abstract - Nowadays, the production and utilization of traditional chemical fertilizers are associated with a series of issues, such as high resource consumption, significant energy expenditure, and severe environmental pollution, which have brought about non-negligible negative impacts on the growth of green plants and the ecological environment. This document presents a comprehensive study on the characterization and physicochemical investigation of bentonite clay from the Krantau and Beshtyube deposits in Karakalpakstan. The research focuses on utilizing bentonite in the production of complex mixed fertilizers. The study outlines the chemical composition, physicochemical properties, and mineralogical composition of bentonite clays from these deposits. The research employs various analytical techniques to investigate the bentonite samples. Technologies such as Energy-Dispersive X-ray Spectroscopy (EDS), Scanning Electron Microscopy (SEM), Thermogravimetric Analysis (TGA), Fourier-Transform Infrared spectroscopy (FT-IR), and Optical Emission Spectrometry utilizing Inductively Coupled Plasma (ICP-OES) are among these. The findings show that the Krantau bentonite clay is largely made up of sodium montmorillonite, with illite, kaolinite, hydromica, and feldspar also present. The study shows several unique and interesting insights. To begin, the Krantau deposit in Karakalpakstan has a substantial advantage, with bentonite discovered between glauconite layers and projected reserves of approximately 5 million tons. This co-occurrence of bentonite and glauconite may result in more efficient extraction and usage of both minerals. Second, the study underlines bentonite's potential for increasing the effectiveness of mineral fertilizers due to its large specific surface area and high cation exchange capacity. Finally, the study emphasizes the value of indigenous mineral resources in Uzbekistan and Karakalpakstan for agricultural uses, which might reduce reliance on imported fertilizers while also boosting sustainable farming practices in the area.

Keywords - Global bentonite reserves, Soil agrochemical properties, Krantau deposit, Beshtyube deposits, Bentonites montmorillonite physico - chemical properties, Agriculture industrial applications.

1. Introduction

On a global scale, land degradation is considered one of the most serious challenges to the sustainable development of human society, as it negatively affects the amount of arable land, food production, water security, economic development, and environmental stability [1]. These days, the production and use of conventional chemical fertilizers are linked to a number of problems, including high resource consumption, high energy costs, and serious environmental pollution, which have had detrimental effects on the ecological environment and the growth of green plants [2]. In addition to addressing the drawbacks of conventional fertilizer application techniques, research on slow-release fertilizers also advances

green, sustainable development and the enhancement of the ecological environment, which is vital for boosting hydroponic plant growth.

Against this background, improving the efficiency of mineral fertilizer utilization in agriculture is of great importance. Statistical statistics show that, under typical conditions, fertilizers are only used 25-40% of the time for nitrogen, 10-25% of the time for phosphorus, and 30-50% of the time for potassium [3]. The low utilization efficiency of fertilizers not only leads to resource losses but also contributes to environmental pollution. In this regard, compared with conventional fertilizers, slow-release fertilizers significantly



improve nutrient use efficiency and minimize nutrient losses [4]. The production of slow-release fertilizers is being gradually industrialized [5-8]; however, most commercially available slow-release fertilizers are based on coatings made from thermoplastic and thermosetting resins, which are expensive, difficult to degrade, and may damage soil structure during long-term application [9]. At the moment, slow-release fertilizer research is mostly concentrated on nitrogen-based formulations [10, 11], with few studies on phosphorus, potassium, and micronutrients, resulting in a restricted variety of slow-release fertilizer products on the market.

To overcome these issues, the utilization of natural mineral raw materials, notably bentonite, offers a possible alternative. Bentonite has stable chemical characteristics that prolong the fertilizer's useful life and preserve structural integrity under a range of environmental circumstances. Bentonite is suited for large-scale applications because of its low cost and abundance of resources. It satisfies the standards for green plants and is non-toxic and eco-friendly. Bentonite also improves the mechanical strength of the particles and is easy to shape, which makes it perfect for creating core particles. Bentonite is a perfect material for the primary component of core particles because of its benefits, which include adsorption capacity, slow-release characteristics, stability, cheap cost, environmental friendliness, and ease of processing [12].

The main constituent of bentonite, a mineral clay, is montmorillonite [13]. High water absorption capacity, robust adsorption activity, and exceptional expandability are some of the special qualities of bentonite [14], allowing it to enhance diverse soil conditions via distinct processes. Crop development is encouraged when bentonite is added to aeolian sand because it improves soil organic matter content and plant nutrient usage efficiency [15]. Additionally, bentonite supports sustainable agricultural production in semi-arid environments by increasing soil moisture retention [16], improving drought tolerance [17], and increasing millet yield [18].

The term "bentonite" comes from the fact that it was initially found in the Fort Benton area of Montana, USA. When dissolved in water, it produces colloidal particles and is mostly composed of montmorillonite group minerals [19]. Over 10 billion tons of bentonite are stored worldwide, with roughly 45% of that amount found in China, 15% in the United States, and 7% in Turkey [20]. Greece, Russia, India, and the CIS nations are among the other nations possessing substantial reserves. The majority of bentonite deposits are of the alkaline earth metal kind, with the greatest alkaline bentonite deposits being in the Dash-Salakhly area of Azerbaijan, the Resadiye region of Turkey, and Wyoming, USA. The output of bentonite has been growing quickly in recent years. Bentonite is a fine-grained clay with great binding ability, high plasticity, and noticeable thixotropic characteristics.

The chemical formula for bentonite is $\text{Si}_2\text{Al}_4\text{O}_{22}(\text{OH})_4 \cdot n\text{H}_2\text{O}$. Bentonite is a fine-grained, extremely elastic clay with good binding, thixotropic, and sorption characteristics. Bentonite considerably enhances the agrochemical and agrophysical characteristics of soil. Bentonite's structural characteristics give it a high cation exchange capacity and a large specific surface area, which improves the long-term effectiveness of mineral fertilizers. Bentonite also includes a variety of macro- and micro-elements. Bentonite reduces groundwater pollution by mineral salts by limiting the leaching of mineral fertilizers from the land. Additionally, bentonite may absorb a variety of dangerous contaminants from soil.

Over 200 bentonite deposits and occurrences have been found in Uzbekistan and the Republic of Karakalpakstan, with an estimated total reserve of more than 2 billion tons. When compared to similar deposits across the world, some of these deposits are thought to be of higher grade. The highest bentonite reserves are found in the deposits of Krantau Beshtyube in Karakalpakstan and Navbahor, Lagan, Khauidak, Azkamar, Kattakurgan, and Akhangaran, in Uzbekistan where montmorillonite makes up the majority of the mineral composition-up to 70% in certain cases. Bentonite significantly increases crop output, particularly when used in conjunction with mineral fertilizers.

2. Materials and Methods of Research

The methods described in references were used to evaluate the phosphate rock, glauconite, and bentonite samples' physico-mechanical characteristics, such as bulk density, angle of repose, and flowability [21, 22]. The moisture content was determined following the procedure described by [22]. For the analysis of $\text{CuK}\alpha$ radiation, the XRD-6100 diffractometer (Shimadzu, Japan) was employed, with settings of 30 mA and 30 kV for tube current and voltage, respectively, and a β -filter of Ni. The detector rotated at a speed of 4° per minute, covering a scanning angle range from 4° to 80° .

During scanning, the samples were rotated at a speed of 30 rpm. The qualitative and quantitative phases of the samples were identified using the MATCH! Figure out the phase using Powder Diffraction program (Crystal Impact GbR, Bonn, Germany, 2026) [23]. A thermal study of Karakalpakstan agro-ores (phosphate rock, bentonite, and vermiculite) was performed using a Shimadzu DTG-60 equipment fitted with a K-type thermocouple (Low RG Silver) and porcelain crucibles. Every experiment was carried out with an argon flow rate of 80 mL/min in an inert nitrogen atmosphere.

The rate at which temperatures rose was 10°C per minute, and the intended temperature range had been between 25 and 900 degrees Celsius. The standard material Indium (In) was used to calibrate the measurement device. Shimadzu

LabSolutions TA Start Window software was used to evaluate the data and produce graphical results [24, 25]. The microstructure and morphology of the individual fertilizer granule surfaces and sections thereof were examined using an electron microscope with scanning electrons (SEM-EVO MA 10, Carl Zeiss, Germany).

This equipment is intended for the microanalysis of the structure and surface defects of inorganic materials, such as microparticles and surface microfeatures. Elemental analysis of raw and enriched glauconite samples from the Krantau deposit was carried out using an OPTIMA 2100DV instrument equipped with inductively coupled argon plasma (ICP-OES). Samples were produced using Berghof's SPEEDWAVE MWS-3+DAP-60+ microwave digestion apparatus. An analytical balance was used to weigh 0.05-0.5 g of the sample, which was then transferred to Teflon autoclaves. The autoclaves were then loaded with 3 mL of strong nitric acid (chemically pure) and 2 mL of hydrogen peroxide. The containers were sealed and placed in a Berghof microwave digesting system (or an analogous model) for processing, which was controlled using the MWS-3+ software. Infrared (IR) spectroscopy was widely employed in this investigation. The examination of IR absorption spectra obtained during the transmission of infrared light through the test substance enables the detection of selective energy absorption associated with the distinctive vibrational frequencies of the material. These frequencies are related to the positional diversity of atoms inside the material, molecular

rotational speeds, and crystalline structural vibrations. Each substance has a unique vibration spectrum. The quantity, intensity, shape, and activity of the absorption lines in the spectrum are determined by the molecular structure and chemical composition of the substance. This enables both qualitative and quantitative studies of compounds in various aggregation states using IR spectroscopy.

3. Results

The current study focuses on bentonite's utilization in the manufacturing of high-quality complex fertilizers. This is accomplished by including enhanced bentonite powder into the mixture, resulting in fertilizer granules with maximum mechanical strength, limited porosity, and a decreased interior surface area. Industrial-scale manufacture of such fertilizers with bentonite additions may be carried out at agricultural production firms utilizing high-capacity units, with minimal equipment changes and the ability to quickly achieve the needed high-efficiency compound fertilizers. The Krantau deposit in the Republic of Karakalpakstan has a significant advantage in that bentonite is found between the glauconite strata, with estimated reserves of around 5 million tons. In this context, the physico-chemical and physico-mechanical characteristics, as well as the composition of bentonite clay, were investigated in order to advance the development of a technique for generating complex fertilizers from Karakalpakstan's agro-ores.

Table 1. Chemical composition of Bentonite from Krantau and Beshtobe deposits

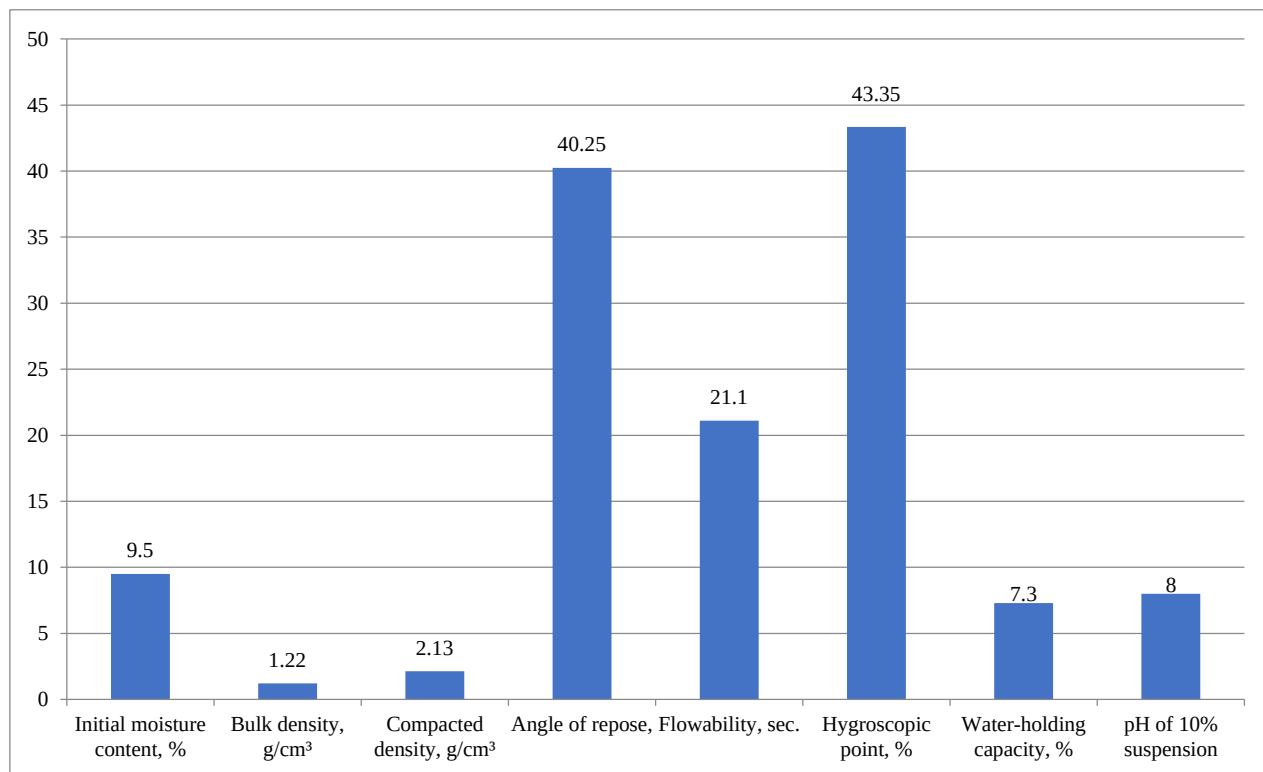
“Component Content (wt %)”	“Deposit Samples”	
	<i>Krantau</i>	<i>Beshtobe</i>
SiO ₂	66,42	62,63
Al ₂ O ₃	10,91	14,21
Fe ₂ O ₃	6,91	4,31
TiO ₂	0,42	0,36
MgO	1,17	1,12
MnO	0,01	-
Na ₂ O	2,01	2,1
K ₂ O	2,54	2,94
CO ₂	0,30	0,20
SO ₃	0,52	0,58
P ₂ O ₅	0,09	0,09
H ₂ O	3,27	2,68
∑	3,93	6,39
∑ %	99,62	98,55

The primary physicochemical and physico-mechanical properties of bentonite clays are as follows: composition and structural features, moisture content, density, angle of repose, flowability, pH level, moisture adsorption capacity (hygroscopicity), and water-holding capacity (moisture capacity) Thermogravimetry, electron microscopy, and X-ray diffraction were employed to perform a comprehensive

mineralogical composition analysis (Figure 1). The X-ray diffractogram was obtained with an XRD-6100 diffractometer (Shimadzu, Japan). CuK α radiation has been employed with an uninterrupted sensor rotational rate of 4 degrees per minute and scanned angles between 4 degrees and 80 degrees (with Nickel β -filter, tubing frequency Thirty mA, tube voltage of 30 kV).

Table 2. Physicomechanical properties of Krantau bentonite clay

“Deposit”	“Parameters”							
Krantau	Initial moisture content, %	Bulk density, g/cm ³	Compacted density, g/cm ³	Angle of repose,	Flowability, sec	Hygroscopic point, %	Water-holding capacity, %	pH of 10 % suspension
	9,5	1,22	2,13	40°25	21,10	43,35	7,3	8,00

**Fig. 1 Physicomechanical properties of krantau bentonite clay**

The presented diffractogram of natural bentonite shows distinctive peaks that can be utilized to determine the mineralogical composition. Peaks in an X-ray diffractogram usually correlate to certain crystallographic planes of the minerals present. The tallest and sharpest peak often reflects the sample's primary mineral component.

The Krantau deposit bentonite clay sample is mostly made up of sodium montmorillonite, according to the experimental results. The presence of strong lines typical of montmorillonite (Figure 2) suggests that it is the primary rock-forming material. Along with montmorillonite lines, reflections suggest the presence of illite. (1.0090, 0.445, 0.3795, 0.3235, 0.2971, 0.1639, and 0.1502 nm), feldspar (0.3236, 0.2330, and 0.1502 nm), hydro-mica (0.4566, 0.3607, 0.2592, 0.1767, and 0.1559 nm), and kaolinite (0.716, 0.2592, and 0.1502 nm). The d_{001} reflection at 1.236 nm confirms that

montmorillonite is in its sodium form. Thermogravimetric examination of milled bentonite clays was conducted using a Shimadzu DTG-60 thermal analysis apparatus equipped with a K-type thermocouple (Low RG Silver) and porcelain crucibles.

Every test was conducted with an argon flow rate of 80 milliliters per minute in an inert nitrogen atmosphere. With a heating rate of 10 °C per minute, the temperature ranged from 25 to 900 °C. As the standard reference, Indium (In) was used to calibrate the system. To analyze data and create graphs, the Shimadzu LabSolutions TA Start Window software package was utilized. The thermogram of Krantau bentonite clay in Figure 3 does not exhibit any endothermic or exothermic peaks, indicating that there is no material liquefaction upon heating, bond breaking, or functional group separation.

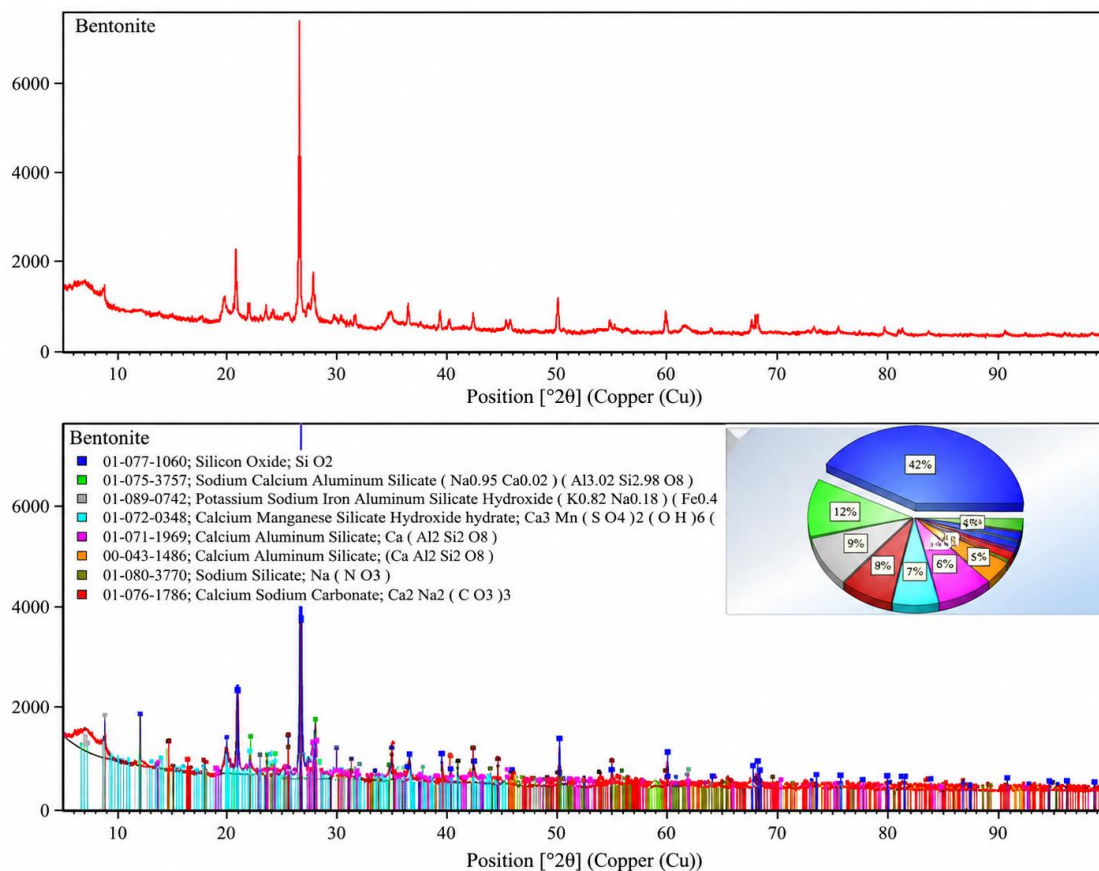


Fig. 2 X-ray Diffractogram of Krantau bentonite clay

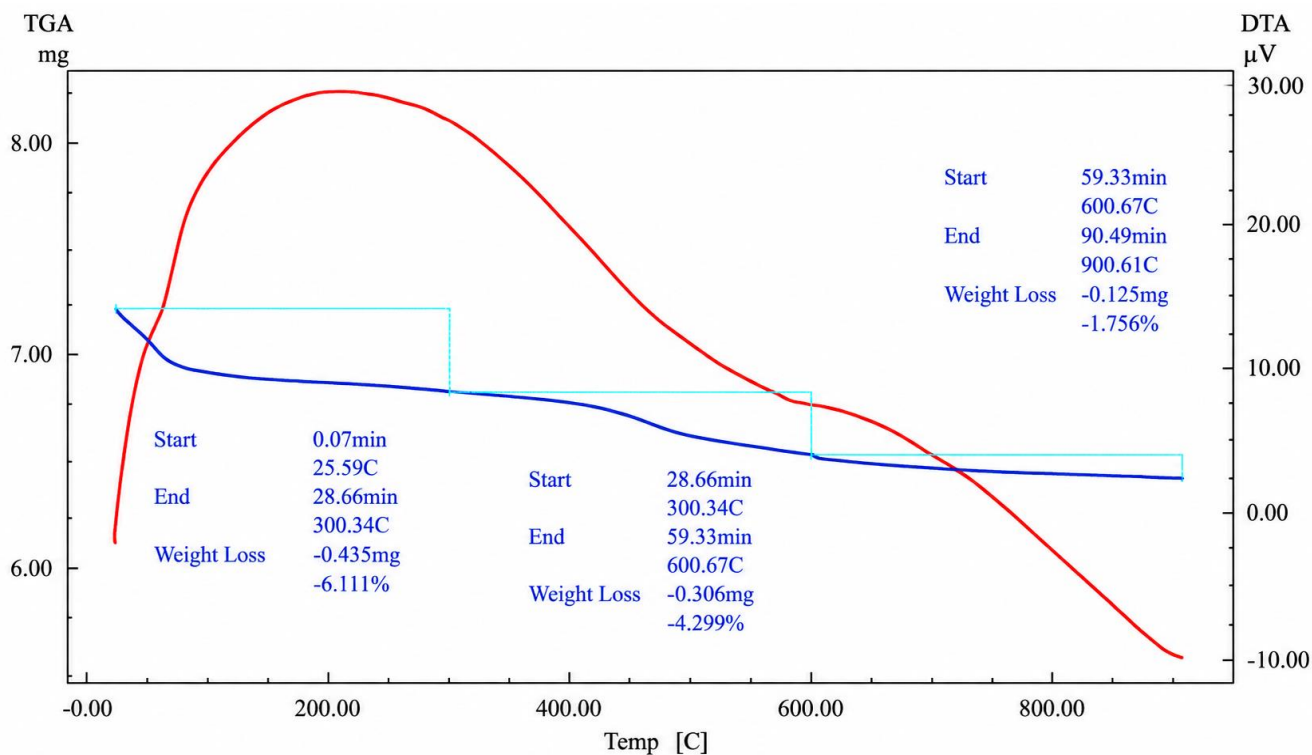


Fig. 3 TGA-DSC analysis of Krantau bentonite clay

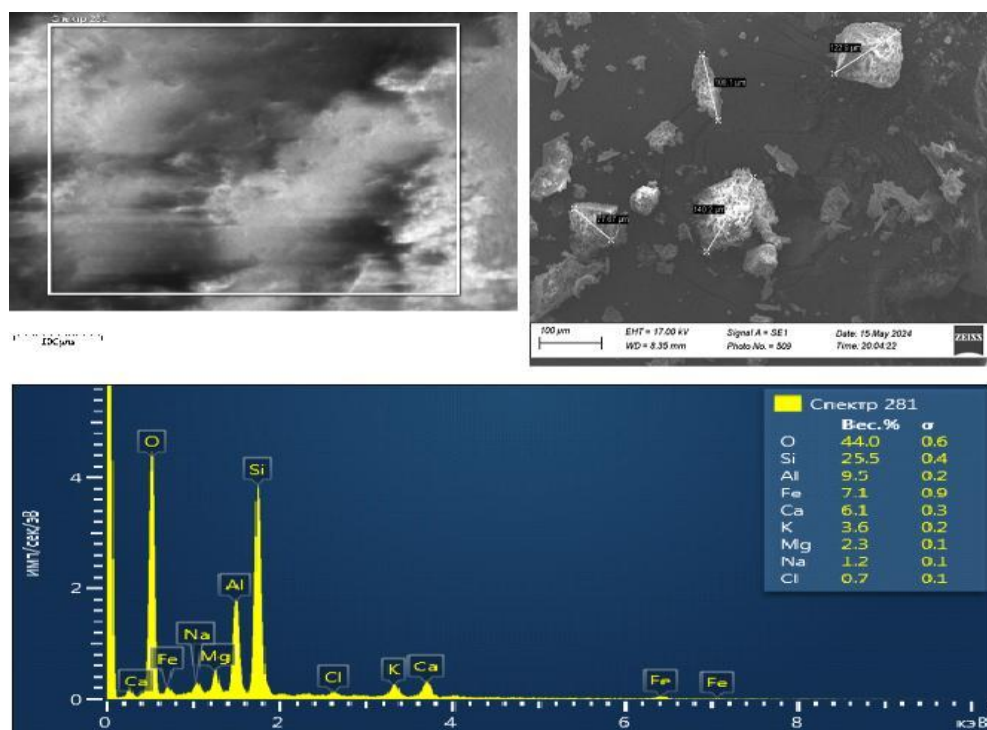


Fig. 4 Electron micrographs and EDS analysis of Krantau bentonite clay

A scanning electron microscope was used to analyze powdered Krantau bentonite clay samples. The elemental composition of the sample was concurrently examined using an INCA system (Oxford Instruments, UK) and Energy-Dispersive X-ray Spectroscopy (EDS).

From Figure 4, the energy-dispersive spectrum of the analyzed bentonite clay shows the following elements with their corresponding weight percentages:

Oxygen (O): 44.0 % Silicon (Si): 25.5 % Aluminum (Al): 9.5 % Iron (Fe): 7.1 % Calcium (Ca): 6.1 % Potassium (K): 3.6 % Magnesium (Mg): 2.3 % Sodium (Na): 1.2 % Chlorine

(Cl): 0.7 % The SEM images (Figure 4) of bentonite clay from the Krantau deposit reveal, at a magnification corresponding to a 100 nm scale bar, fine crystalline particles located within pore spaces. The previously disclosed elemental distribution data were obtained concurrently using Energy-Dispersive X-Ray Spectroscopy (EDS).

Table 3 shows the findings of optical emission spectrometry using an inductively coupled argon plasma. These results show that the glauconite clay from the Krantau deposit has the greatest amounts of K, Li, Na, Al, Ca, and other elements.

Table 3. Results of Optical emission spectrometry by ICP-OES

“Element Names and their Concentrations (mg/10 g)”							
Li 670.784	Al 396.153	Cu 327.393	Fe 238.204	Mg 285.213	P 213.617	K 766.490	Ca 317.933
0,036	396,248	0,332	203,893	56,656	3,731	57,742	11,328
“Element Names and their Concentrations (mg/10 g)”							
Cr 267.716	Mn 257.610	B 249.677	Mo 202.031	Ba 233.527	Na 589.592	V 292.464	Zn 206.200
0,402	0,564	0,572	0,069	0,852	94,695	0,433	0,282
“Element Names and their Concentrations (mg/10 g)”							
Sb 206.836	Co 228.616	Ni 231.604	Sn 283.998	Si 251.611	S 181.975	Sr 407.771	
0,128	0,028	0,164	0,238	1,047	1,892	3,041	

4. Discussion

A Thermo Scientific Nicolet iS50 FT-IR Spectrometer was used to perform Fourier-Transform Infrared (FT-IR)

spectroscopy on clay powder samples in the 400-4000 cm^{-1} range. To conduct spectral measurements, materials were dried and crushed into a fine powder. The stretching vibrations

of the Si-O and O-H groups are represented by the most visible absorption bands in the FT-IR spectra. Bands measured at 984.86 cm^{-1} , 911.22 cm^{-1} , and 693.01 cm^{-1} . The wide, strong peaks are ascribed to Si-O-Si stretching vibrations of the SiO_4 tetrahedral structure as well as Al-OH stretching and Al-O-Si bending vibrations in raw clays. Despite being extremely hydrophobic molecules in a liquid with little polarity, the two clays showed adsorption. Reports indicate interactions with many species, both ionic and non-ionic, even though interaction with cations is preferred in clays. Van der Waals forces and interactions with uncharged, nonpolar molecules. Furthermore, the interaction between clays and organic molecules is facilitated by the hydrophobic sites (-Si-O-Si-) on the surface of the tetrahedral sheets [26]. Bands measuring 517.71 cm^{-1} and 413.65 cm^{-1} . These properties are related to the deformation (bending) modes of Me-O (where Me = metal) or Si-O-Al bonds. Absorption in the $517.71\text{--}645.42\text{ cm}^{-1}$ region. This region depicts the Si-O-Si ring vibrations of connected SiO_4 tetrahedra. Overall, the FT-IR data supports the presence of comparable phyllosilicates anticipated for the

Krantau bentonite, as well as montmorillonite-type clay minerals with characteristic Al-OH and Si-O-Si vibrational bands. There was significant doubt when the absorption band at $795.64\text{--}777.29\text{ cm}^{-1}$ was identified as a doublet. Beidelite, a montmorillonite mineral, exhibits this doublet; however, quartz absorption may also be correlated with it. There have been attempts to analyze soil's contribution to the total potential for global warming, despite the lack of a standard method to account for it. Soil changes following a change in land management may be estimated using a variety of emission factors and datasets from the literature, the most popular of which being the Intergovernmental Panel on Climate Change emission factor approach [27]. The stretching and bending vibrations of free and adsorbed water, as well as the O-H stretching vibrations in kaolinite, montmorillonite, and muscovite, are represented by the bands at $3619.53\text{--}3409.00\text{ cm}^{-1}$ and 1634.50 cm^{-1} [28]. According to the FT-IR analysis of the clay samples, the minerals quartz, muscovite, glauconite, illite, kaolinite, opal, and montmorillonite are present.

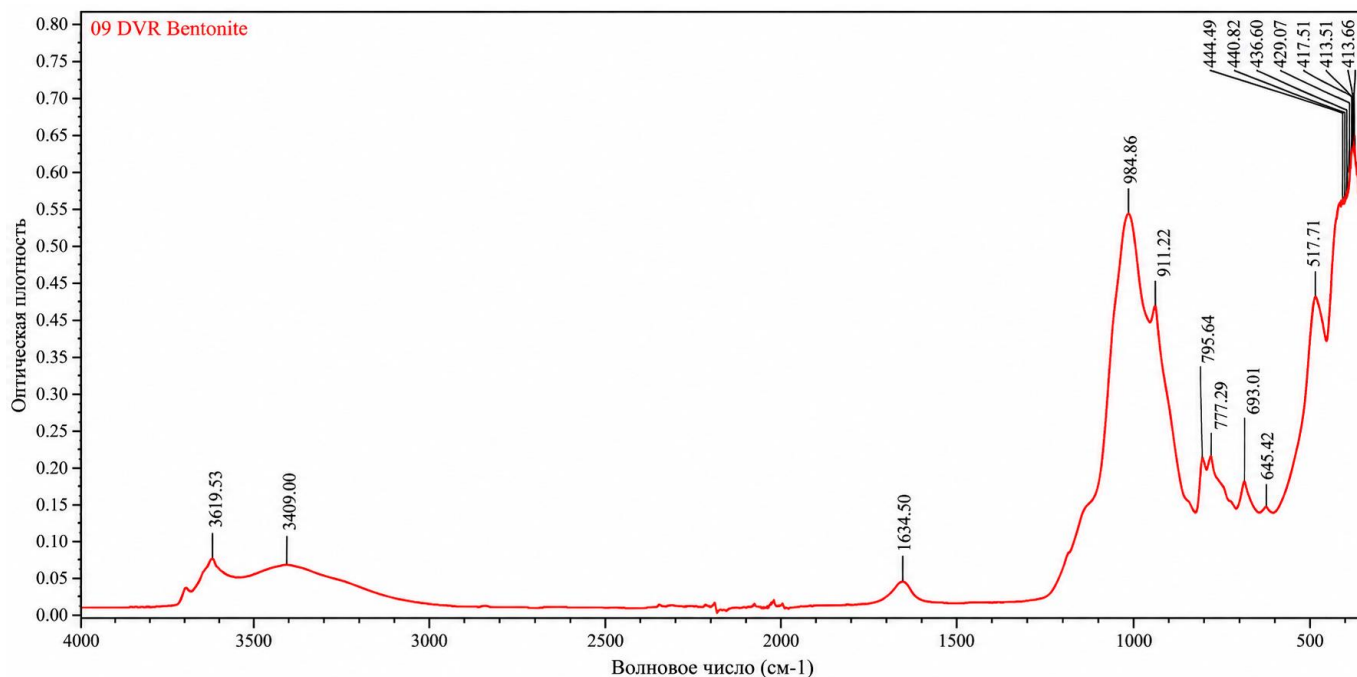


Fig. 4 FT-IR spectra of Krantau bentonite clay

5. Conclusion

Bentonite clays from the Krantau and Beshtyube deposits in the Republic of Karakalpakstan are thoroughly characterized physicochemically and physicommechanically in this study, which also shows how promising they are for application in the creation of complex mineral fertilizers. Krantau bentonite is mostly made of sodium montmorillonite, with notable proportions of illite, kaolinite, hydro-mica, feldspar, quartz, glauconite, and related clay minerals, according to the findings of chemical, mineralogical, and structural investigations. For industrial fertilizer granulation

and application, bentonite's advantageous physicommechanical characteristics-such as its strong hygroscopic behavior, high water-holding capacity, superior flowability, and appropriate bulk density-are crucial. The stability, structural integrity, and rich elemental content of the bentonite samples were confirmed by sophisticated analytical methods such as XRD, TGA-DSC, SEM-EDS, ICP-OES, and FT-IR spectroscopy. While SEM imaging showed a fine porous microstructure favorable to nutrient retention and progressive release, the thermal analysis verified the lack of detrimental phase transitions within the working temperature range. A major

benefit for integrated mineral extraction and processing is the Krantau deposit's advantageous position, where bentonite occurs between glauconite strata with estimated reserves of about 5 million tons. With little alteration to current industrial infrastructure, this geological feature allows for the development of economical, locally derived fertilizer manufacturing methods. Overall, the results show that bentonite from the Krantau and Beshtyube deposits is a very

promising natural resource for boosting soil qualities, decreasing nutrient losses, increasing fertilizer efficiency, and promoting sustainable agricultural development in the Republic of Karakalpakstan and Uzbekistan. The use of these local mineral resources can significantly reduce dependence on imported fertilizers and contribute to the long-term environmental and economic sustainability of the agricultural sector.

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