Determination of the composition of the Zinelbulak talc-magnesite deposit rock using modern physicochemical methods

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Abstract. In this study, the elemental and oxide composition of talc-magnesite raw materials obtained from the Zinelbulak deposit, located in the Sultan Uvays mountain range of Uzbekistan, were investigated using X-ray fluorescence analysis. The results revealed the presence of the following compounds in mass percentages relative to the total mass: talc ($3MgO{\cdot}4SiO_2{\cdot}H_2O$) 60.97%, magnesite ($MgCO_3$) 27.74%, dolomite ($MgCO_3{\cdot}CaCO_3$) 2.90%, chlorite ($5MgO{\cdot}5FeO{\cdot}Al_2(SiO_3)_3{\cdot}H_2O$) 8.01%, and calcite ($CaCO_3$) 0.38%. The results of the IR spectral analysis of the sample confirm the findings of the X-ray fluorescence and X-ray phase analyses. To further study the composition of the raw material, differential thermal analysis and thermogravimetry methods were employed. A quantitative analysis of particle size during the grinding process of the talc-magnesite raw material from the Zinelbulak deposit was also conducted. The research results indicate the potential for utilizing these new raw material sources in the production of talc and magnesite.

1 Introduction

Uzbekistan possesses abundant raw material reserves essential for producing modern materials across various industries. Notably, the Kulatau clay deposit, the Tuproqqal'a dune sands, the Sulton Uvay feldspar deposit, the sandstone, kaolin, and phosphorite deposits in the Xo'jakul raw material zone, and the Zinelbulak talc-magnesite resources serve as primary raw material bases for diverse industrial productions. Among Central Asian countries, the Zinelbulak talc-magnesite deposit holds particular significance due to its substantial reserves, extensive distribution, feasibility of open-pit mining, and ease of processing. Developing modern technologies for processing the minerals from this deposit could simultaneously facilitate the extraction of talc and magnesite, which are critically needed in many sectors of the national economy [1-5].

Talc is the softest of minerals and is widely used in industry due to its numerous beneficial technological properties. Notably, its white color, high melting point, greasy feel, chemical inertness, ease of grinding, high absorbent properties, fluxing characteristics, fire resistance, as well as excellent heat and electrical insulation capabilities are particularly valued. Talc is

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primarily utilized in soap production, the paper industry, plastics and ceramic manufacturing, rubber technology, paint and roofing material production, cosmetics and pharmaceuticals, refractory material production, the chemical industry, metallurgy, cosmetics, baby powder production, and even in the food industry [6, 7].

Magnesite, due to its unique physical and chemical properties, is a highly sought-after material utilized across various industries. Primarily, it is used in the production of refractory materials, special cements, and fire-resistant paints. Additionally, magnesite is employed in the manufacturing of jewelry. Beyond these applications, magnesite plays a role in pulp and paper production, serves as an additive in animal feed, and is used in the production of fertilizers. In recent years, this mineral has been used in the production of new-generation construction boards. These boards offer high sound and thermal insulation, resistance to moisture and cold, and are considered environmentally friendly [8, 9].

In this scientific work, the properties of minerals from the Zinelbulak deposit have been studied using modern physicochemical analysis methods to establish a new raw material base for the critically important and unparalleled talc and magnesite needed in the aforementioned industries. It is known that China, India, Russia, and Brazil are leaders in processing talc-magnesite mineral raw materials. Scientific sources and practical data indicate that during the extraction of talc from talc-magnesite, valuable by-products such as magnesite and chlorite are also obtained [6, 8, 9]

In the central part of the Sultan Uvays mountain range, there is a talc-bearing field composed of ultrabasic, basic, acidic, and alkaline intrusive rocks, forming part of the Paleozoic basement exposed at the surface. The talc deposits of the Sultan Uvays mountains are conventionally divided into three areas: Qizilsoy, Qazg‘ansoy, and Zinelbulak[1, 10].

The Zinelbulak deposit occupies the western and southwestern sections of these talc-bearing zones. n this study, the talc-magnesite from the Zinelbulak deposit, located within the Sultan Uvays mountain range, was selected as the research object. The total reserves of raw materials in this deposit are estimated at 23.47 million tons, with 7.74 million tons classified under categories A+B+C1 and 15.73 million tons under category C2 [1, 10, 11]. Additionally, some scientific sources report the reserves as 2.01 million tons (B), 4.77 million tons (C1), totaling 6.78 million tons (B+C1), and 15.73 million tons (C2) [11].

2 Methods

In the analyses, X-ray phase, X-ray fluorescence, infrared spectroscopy, and SEM methods were primarily used. X-ray fluorescence analyses were conducted using the highly efficient Rigaku NEX CG EDXRF spectrometer from Japan. X-ray diffraction (XRD) patterns were obtained using the XRD-6100 powder diffractometer (Shimadzu, Japan), with CuKα radiation, and were computer-controlled. The diffraction patterns of the samples were analyzed based on the ASTM American database and tables of X-ray diffraction indices compiled by Giller and Mikheev [12, 13].

Infrared spectrometric analyses were performed on an "IRTracer-100" Fourier spectrometer (Shimadzu Corp., Japan, 2017), with a spectral range of wavenumbers from 4000 to 400 cm^{-1}, a signal-to-noise sensitivity ratio of 60,000:1, and a scanning speed of 20 spectra per second. The obtained spectrometric indicators were compared and analyzed based on tables of mineral spectrometric indices [14]. The particle size of the crushed samples was determined by laser diffraction using the Shimadzu SALD-7500 (WingSALD II: Version 3.4.1) device [15].

3 Results and discussion

In the initial stage of the research, SEM analyses were conducted on samples obtained from the Zinelbulak talc-magnesite deposit to investigate their microstructure and surface morphological changes, and the analyses were interpreted (Figure 1).

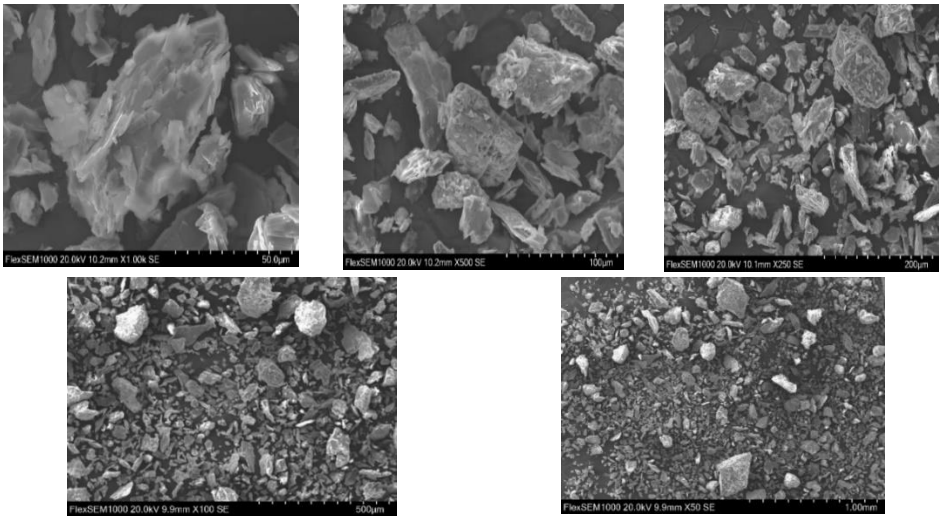

Fig. 1. SEM images of the raw material sample at various magnifications.

In the SEM images, sample particles magnified by 50, 100, 250, 500, and 1000 times can be observed. At the 1000x magnification, large leaf-like or plate-like particles are visible in the center. Additionally, the images clearly show distinct layers. As the magnification decreases, smaller fractions ranging between 10-50 microns appear, which also exhibit layered and coarse, uneven granular or cubic shapes. This indicates the presence of silicates, such as talc and chlorite, which form “layered” structures. The coarse and irregular granular, cubic-like particles in the images are likely associated with magnesite or other hard phases. Based on the SEM images, various morphological characteristics on the sample surface were identified. In particular, signs of strong erosion caused by chemical changes over time were observed on the surfaces of magnesite grains. The presence of talc layers along the boundaries of these grains suggests that, as a result of evolutionary processes and metamorphic changes, thin talc fragments developed around the coarse magnesite grains, partially transforming the magnesite into talc.

In the subsequent stages of research, this raw material was further analyzed using an expanded X-ray fluorescence spectrometer (Figure 2).

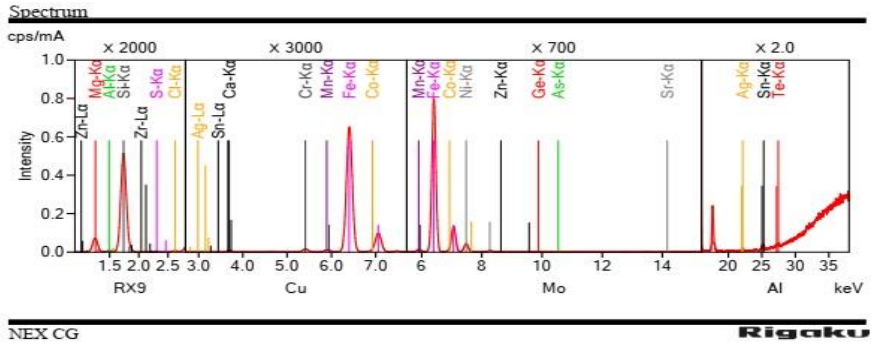

Fig. 2. Comprehensive analysis of Zinelbulak talc-magnesite using an X-ray fluorescence spectrometer.

According to the analysis results, the chemical composition of the talc-magnesite raw material, expressed in mass percentages, is as follows: SiO_2 – 37.6%; MgO – 29.10%; Fe_2O_3 – 5.90%; Al_2O_3 – 1.05%; CaO – 1.00%; SO_3 – 0.08%; MnO – 0.13%; ZrO_2 – 0.15%; NiO – 0.20%; Cr_2O_3 – 0.14%; and loss on ignition – 18.84%. The Zinelbulak talc-magnesite is distinguished from talc ores of other deposits by its higher mass fraction of MgO.

To further investigate the composition of this raw material, X-ray phase analysis was conducted. The results are presented in Figure 3.

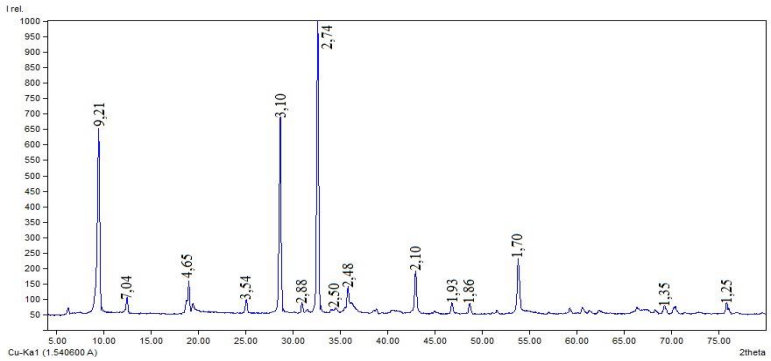

Fig. 3. X-ray diffraction pattern (XRD) of Zinelbulok talc-magnesite raw material.

According to the X-ray diffraction pattern, the peaks with the highest intensity correspond to magnesite at 2.74 d,Å and to talc at 3.10 and 9.21 d,Å. The analysis also identified talc ($3MgO{\cdot}4SiO_2{\cdot}H_2O$) with peaks at 1.65, 1.68, 1.70, 2.08, 2.10, 2.45, 2.48, 2.59, 2.60, 3.54, and 4.65 d,Å. The chlorite compound ($5MgO{\cdot}5FeO{\cdot}Al_2(SiO_3)_3{\cdot}H_2O$) was identified with peaks at 14.21, 7.04, and 4.71 d,Å, while the iron-rich talc compound (minnesotite) showed a peak at 9.59 d,Å.

The magnesite ($MgCO_3$) peaks were identified at 1.70, 1.77, 1.93, 2.10, 2.32, and 2.50 d,Å. Calcite ($CaCO_3$) was observed with peaks at 1.98, 1.86, 1.74, and 2.49 d,Å, while dolomite ($MgCO_3{\cdot}CaCO_3$) exhibited peaks at 1.25, 2.00, 2.54, 2.65, and 2.88 d,Å.

Based on the results of the X-ray phase analysis, the mineralogical quality and quantitative composition of the samples were determined using the BGMN/Profex Rietveld software package. The composition (%) of the analyzed sample is as follows: talc – 60.97%, magnesite – 27.74%, chlorite – 8.01%, dolomite – 2.90%, and calcite – 0.38%.

The IR spectrometric analysis results of the sample also confirmed the above-mentioned X-ray fluorescence and X-ray phase analysis results (Figure 4).

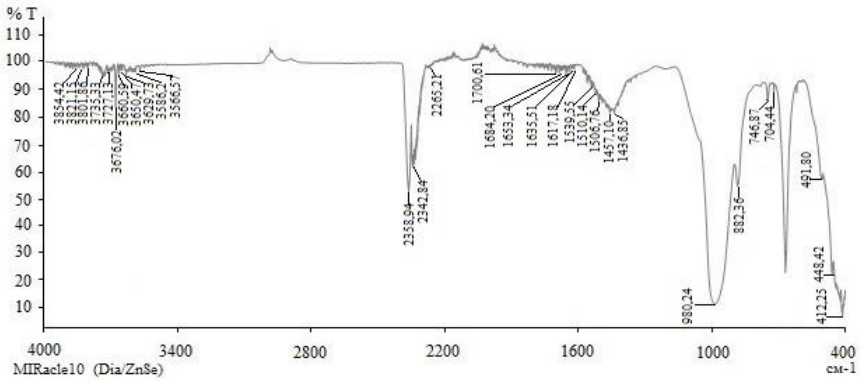

Fig. 4. Infrared spectroscopy analysis of talc-magnesite raw material.

In the IR spectral analysis, the talc crystal lattice Si-O bonds were identified in the low-intensity absorption bands at 980-920 cm^{-1}. Medium-intensity absorption bands at 1700-1600 cm^{-1} were associated with Si-O-Si bonds, while low-intensity bands at 480-450 cm^{-1} corresponded to the metal-oxygen bonds of talc and magnesite, represented by Si-O-Me and Mg-O. This confirms the layered silicate structure of talc.

The asymmetric valence vibrations of CO_3^{2-} ions associated with magnesite, dolomite, and calcium carbonate appeared in high-intensity spectral bands at 1436.85 and 1457.10 cm^{-1}, representing the main spectral region of magnesite. Deformation vibrations were observed in the low-intensity absorption frequencies in the range of 764-746 cm^{-1}, which indicate carbonate structures.

The analysis also revealed strong absorption frequencies for the hydroxyl layers of talc (OH^- ions) in the range of 3000-3700 cm^{-1}. Asymmetric valence vibrations were identified at absorption frequencies of 3676.02, 3660.59, and 3650.47 cm^{-1}, corresponding to the 3Mg, $2Mg+Fe^{2+}$, and $Mg+2Fe^{2+}$ bonds, respectively. The X-ray phase and IR spectroscopic data mutually confirmed each other.

In subsequent research, thermal (TG-DTA) analyses were conducted to further clarify the analysis results, as well as to study the thermal stability and decomposition processes of the raw material (Figure 5).

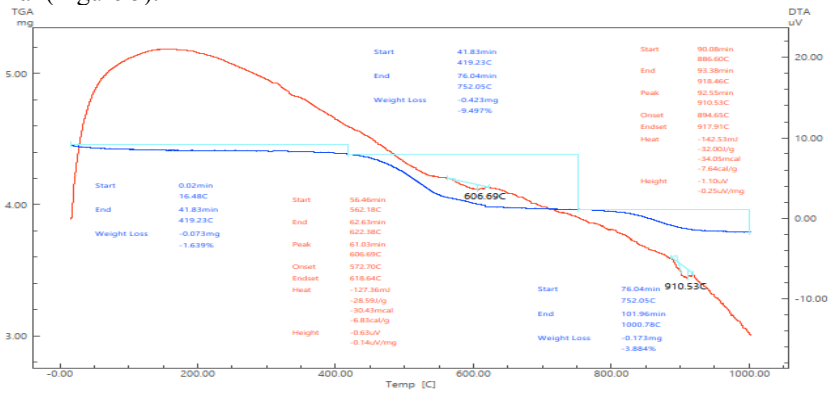

Fig. 5. TG-DTA analysis of talc-magnesite raw material.

TG-DTA analyses indicated that the changes occurred mainly in three stages. Stage 1 was observed at temperatures ranging from 16.46 to 419.32°C. This stage is associated with the release of free and bound water from the raw material sample, resulting in a weight loss of 1.639%, which corresponds to 0.0739 mg. Stage 2 occurred between 419.32 and 752.05°C.

During this phase, the sample lost 0.42 mg, or 9.497% of its weight. The first endothermic process was observed at 606.69°C, corresponding to the thermal decomposition of $MgCO_3$ and the release of CO_2. Stage 3 took place between 752.05 and 1001.78°C. The sample lost 0.1773 mg, or 3.884% of its weight. The second endothermic process was observed at temperatures between 910.53 and 917.63°C, indicating the breakdown of the talc structure and the formation of magnesium silicate (MgSiO), silicon dioxide (SiO_2), and water. This stage corresponds to the release of water and the reformation of crystal lattices.

The TGA curve in the analysis results showed a decrease consistent with the stages, indicating a total mass loss of up to 15%.

When studying the application areas of the raw material, particle size distribution is of particular importance, especially when subjected to mechanical processing and grinding. The particle size distribution of the raw material samples was determined using laser diffraction with the Shimadzu SALD-7500 (WingSALD II: Version 3.4.1) device (Figure 6).

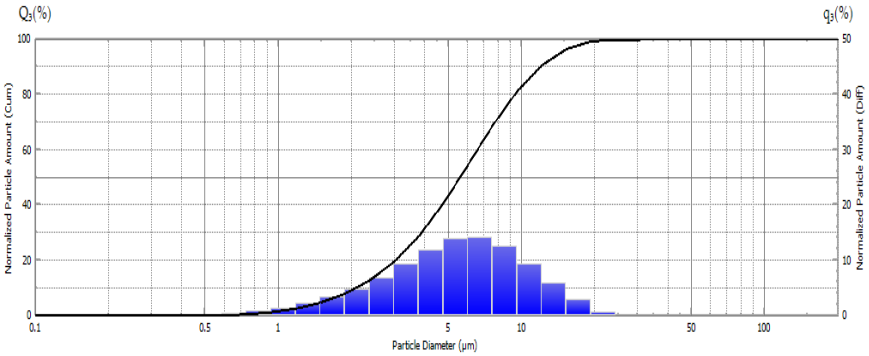

Fig. 6. Histogram of the particle size distribution analysis of ground talc-magnesite raw material.

In this histogram, the X-axis represents the particle diameter, while the Y-axis shows the cumulative distribution. The curve illustrates the percentage of particles smaller than a certain size. It is known that in ceramics and glass production, the material particle size requirement is typically 4-10 μm, while for the paint coating industry, plastics, and rubber manufacturing, the particle size requirement is 5-8 μm.

According to the histogram data, 50% of the crushed talc-magnesite raw material particles are smaller than 7-8 μm, and 90% of them are smaller than 15-20 μm. The proportion of particles smaller than 1 μm and larger than 20 μm is very low. These indicators demonstrate that the raw material meets the GOST 21235-75 standards.

4 Conclusion

The composition of minerals from the Zinelbulak talc-magnesite deposit was determined using modern physicochemical methods. The microstructure and surface morphological changes of the composition were studied using a scanning electron microscope (SEM). The obtained data indicated that the mineral mainly consists of two phases – talc and magnesite. Additionally, minor quantities of minerals such as serpentine, enstatite, quartz, hematite, and magnetite were observed. However, distinct morphological features of these minerals were not detected in SEM images, likely due to their minimal quantity or their fine dispersion across the surface.

A detailed chemical composition analysis using an X-ray fluorescence spectrometer revealed the following composition by percentage: SiO_2 – 37.6%; MgO – 29.10%; Fe_2O_3 – 5.90%; Al_2O_3 – 1.05%; CaO – 1.00%; SO_3 – 0.08%; MnO – 0.13%; ZrO_2 – 0.15%; NiO – 0.20%; Cr_2O_3 – 0.14%; and loss on ignition – 18.84%. Based on X-ray phase analysis, the

mineralogical quality and quantitative composition of the raw material were determined as follows (%): talc – 60.97%, magnesite – 27.74%, chlorite – 8.01%, dolomite – 2.90%, and calcite – 0.38%.

In XRD analysis, talc exhibited strong peaks at 3.10 and 9.21 d,Å and lower intensity peaks at 1.65, 1.68, 1.70, 2.08, 2.10, 2.45, 2.48, 2.59, 2.60, 3.10, 3.54, and 4.65 d,Å. IR spectroscopic analysis confirmed the presence of hydroxyl layers (OH^- ions) with absorption frequencies in the range of 3000-3700 cm^{-1}. TG analysis indicated a 1.639% mass loss due to water release in the temperature range of 16.46–419.32°C, confirming the presence of talc.

The presence of magnesite was established through XRD analysis with a high-intensity peak at 2.74 d,Å and moderate-intensity peaks at 1.70, 1.77, 1.93, 2.10, 2.32, and 2.50 d,Å. Comparative analysis using IR spectroscopy and TG-DTA revealed that CO_3^{2-} groups were identified at 1436-1485 cm^{-1} and 2358-2524 cm^{-1} absorption frequencies. The TG-DTA analysis confirmed that magnesite underwent decarbonization in the temperature range of 600-750°C, releasing CO_2 and resulting in a 9.49% total mass loss, leading to the formation of MgO.

Due to talc's low hardness of 1 on the Mohs scale, 90% of the particles in the crushed samples were reduced to sizes smaller than 15-20 μm. This particle size distribution confirms that Zinelbulak talc-magnesite raw materials are suitable for use in ceramics, rubber, plastics, and paint materials production.

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