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PHYSICOCHEMICAL BASIS OF THERMAL ACTIVATION OF DOLOMITE RAW MATERIAL FROM KARAKALPAKSTAN FOR THE SYNTHESIS OF COMPOSITE BUILDING MATERIALS

Amina Zhanabayevna Abilova [1], Rysgul Zhiyemuratovna Bekbosinova [1], Abat Azatovich Saypov [1], Zhenis Zhanabayevich Abilov [1], Bakhtiyar Muratbaevich Ismailov [2]

[1] Research Institute of Natural Sciences, Karakalpak Branch of the Academy of Sciences of the Republic of Uzbekistan, Nukus, Uzbekistan

[2] Berdakh Karakalpak State University, Nukus, Uzbekistan

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Abstract

This study presents the results of a comprehensive investigation of the physicochemical characteristics, phase composition, and kinetics of thermal activation of natural dolomite from the Jamansay deposit in the Republic of Karakalpakstan. Energy-dispersive X-ray fluorescence spectroscopy (EDXRF), X-ray diffraction (XRD), and Fourier-transform infrared spectroscopy (FTIR) were used to determine the chemical and mineralogical composition of the raw material, which is characterized by a predominance of magnesium–calcium carbonate components and a relatively low content of silicate impurities. Differential thermal and thermogravimetric analysis (DTA-TG) was employed to identify the main stages of thermal decomposition and decarbonization of dolomite. It was established that the most intensive decomposition of the magnesium-bearing component occurs within the temperature range of 730–750 °C, where a reactive magnesia phase, predominantly active MgO, is formed, while the calcium-bearing component is mainly preserved in carbonate form. Scanning electron microscopy (SEM) revealed changes in surface morphology, development of porosity, and structural rearrangement of the material during thermal activation. The obtained results substantiate a rational selective calcination regime and demonstrate the potential of thermally activated dolomite for producing magnesia-based binders, composite, and refractory building materials with controlled properties. The practical significance of the study lies in expanding the raw material base of the construction industry through the utilization of local mineral resources and creating prerequisites for the development of energy-efficient and environmentally safe composite materials.

Keywords: *dolomite raw material; thermal activation; calcination; decarbonization; phase transformations; caustic dolomite; reactive MgO; composite building materials; magnesia-based binders*

Introduction

The current development of the construction industry is driven by the need for rational use of natural resources, expansion of the raw-material base, and the development of new composite materials with specified performance properties. In this context, carbonate rocks are of particular interest, as they are widely distributed in nature and can be used to produce various types of mineral binders and functional components of building materials. Their prospects for application stem from their capacity for directed physicochemical transformations during thermal treatment, accompanied by changes in phase composition and the formation of new reactive compounds (Walling & Provis, 2016).

Among natural carbonate minerals, dolomite – a double carbonate of calcium and magnesium with the composition $CaMg(CO_3)_2$ – is of particular scientific and practical importance. The combination of calcium and magnesium components determines the possibility of its use as a complex mineral raw material. As a result of directed thermal treatment, dolomite can be transformed into products containing reactive oxide and residual carbonate phases, the properties of which are determined by the calcination conditions. Recent studies have shown that dolomite raw material can serve as a source of reactive MgO and can be used in the production of magnesia-based and other composite binder systems (Zhang et al., 2025).

One of the main factors determining the efficiency of dolomite utilization is its thermal activation regime. Heating induces sequential decarbonization processes of the magnesium and calcium components, accompanied by changes in the crystal structure, development of porosity, and formation of oxide phases. Insufficient calcination temperature or duration may lead to incomplete decomposition of the initial mineral, whereas excessive thermal treatment can cause sintering and a decrease in the reactivity of the resulting products. Therefore, selecting rational calcination parameters requires investigation of the kinetics of thermal decomposition, phase transformations, and microstructural changes specific to a given raw material (Ruan et al., 2017).

The possibility of selective thermal activation of dolomite plays a special role, whereby conditions are created for the preferential decomposition of the magnesium component with the formation of active MgO while a significant proportion of the calcium component is retained in the form of $CaCO_3$. This approach makes it possible to control the phase composition of the calcination product and to obtain caustic dolomite with a specified reactivity. In recent studies, partial calcination is considered a promising method for producing highly reactive dolomite components for building materials and composite binders (Qin et al., 2024).

Products obtained through thermal activation can be used in various magnesia-based and composite systems. The reactivity of MgO significantly affects subsequent hydration, phase-formation, and structure-formation processes, while the presence of residual carbonate phases can alter the density and character of the developing structure. This confirms the need to establish the relationship between the conditions of thermal treatment of dolomite and the functional properties of its activation products. Magnesia-based binders represent a distinct class of materials whose properties are largely determined by the characteristics of the initial MgO and by the chemical patterns governing the formation of hydrate phases (Bikaeva et al., 2023).

Studies by the Russian researchers R. A. Ibragimov, Yu. V. Bikaeva, and I. D. Tverdov (Bikaeva et al., 2024; Ibragimov & Bikaeva, 2025) have shown that the properties of magnesia stone strongly depend on the degree of activation of caustic dolomite. Additional activation intensifies hydration processes, alters the state of MgO, and promotes the formation of a denser structure of magnesia stone. These results confirm that controlling the reactivity of the magnesium-containing component is an important condition for improving the efficiency of composite building materials.

A separate line of research is concerned with assessing the quality of dolomite calcination products. Specialists from Kazan National Research Technological University have proposed approaches for determining the degree of calcination and the activity of caustic dolomite. These studies confirm that the choice of temperature–time regime

must take into account the mineralogical and structural features of the specific raw material (Khuziakhmetov, 2025a, 2025 b).

For the Republic of Karakalpakstan, this line of research is of particular relevance. The region's mineral resource base is characterized by considerable diversity of natural resources, creating favorable conditions for the development of a regional building-materials industry. Carbonate rocks occupy a special place in the mineral resource base, represented by industrial deposits of limestone, marble, marl, chalk, and dolomite. The presence of a substantial raw-material base for building materials creates opportunities for expanding production based on local natural resources and reducing dependence on imported raw materials. Significant reserves of mineral raw materials for the production of building materials – including limestone, structural and decorative stone, gypsum, and other non-metallic raw materials – have been identified in the Republic of Karakalpakstan (Turemuratov et al., 2025).

The aim of the study is to establish the physicochemical regularities of thermal activation of dolomite raw material from Karakalpakstan and to determine the effect of calcination parameters on the phase composition, structure, and reactivity of the thermal-treatment products for their subsequent use in the synthesis of composite building materials.

Materials and Methods

Among the carbonate deposits of the Republic of Karakalpakstan, the Jamansay deposit is of particular importance, distinguished by thick strata of high-purity natural dolomite. Unlike calcitic rocks, which are based on calcium carbonate ($CaCO_3$), dolomite is an ordered double calcium–magnesium carbonate with the composition $CaMg(CO_3)_2$. This crystal-chemical structure determines its potential as a high-technology mineral raw material for producing magnesia-based binders and composite building materials.

The main object of the present study was natural dolomite raw material from the Western Jamansay deposit of dolomitized rocks. The area of the studied site is 72.18 hectares. Administratively, the deposit is located in the Karauzyak district of the Republic of Karakalpakstan, 110 km southeast of the district center – the urban settlement of Karauzyak – and 12 km east of the settlement of Karatau. The distance from the deposit's industrial zone to the city of Nukus is approximately 85 km in the northwest direction.

The geological structure of the Western Jamansay area is highly complex and is represented by a heterogeneous complex of metamorphic and igneous formations. The formation of dolomitized rocks under these geological conditions necessitates a comprehensive study of their chemical composition, structural and mineralogical features, and the character of their thermal transformations. Accordingly, the main focus of this work is on the processes of decarbonization and structural transformation of natural dolomite during thermal activation.

Representative samples of natural dolomite from the Western Jamansay deposit were selected for the study. Prior to physicochemical analysis, the raw material was crushed and ground. The prepared samples were used to determine the chemical composition, investigate structural features, and study the patterns of thermal decomposition.

The chemical composition of the raw material was determined by energy-dispersive X-ray fluorescence spectroscopy (EDXRF), which made it possible to establish the content of the main rock-forming elements and impurity components. Fourier-transform infrared spectroscopy (FTIR) was used to study the structural and chemical features of the initial dolomite and changes in its carbonate structure.

The processes of thermal decomposition and decarbonization were studied using simultaneous thermal analysis (DTA–TG). Joint analysis of thermal effects and mass changes in the samples made it possible to establish the sequence of physicochemical transformations and the temperature intervals of decomposition of the magnesium–calcium carbonate system. Particular attention was given to the interval of 740–750 °C, in which the most intense dissociation of the magnesium component was observed while the calcium-containing framework remained stable.

Morphological and microstructural changes in the initial and thermally activated dolomite were studied by scanning electron

microscopy (SEM). The resulting micrographs were used to assess the evolution of the porous structure, surface character, and features of the formation of magnesium oxide crystalline particles during thermal activation.

Thus, the combined application of EDX-RF, FTIR, DTA–TG, and SEM methods made it possible to trace the relationship between the composition and structure of the initial dolomite raw material, the sequence of its thermal decomposition, and the formation of reactive calcination products. This approach provided the basis for substantiating the rational temperature interval for thermal activation of dolomite and for assessing the prospects for its use in the synthesis of composite building materials.

Results and Discussion

Within the studied elevation, a complex of rocks of various genesis and composition is distributed, including magnesium–calcium carbonates, porphyrites, and siliceous shales. The presence of such rocks forms a promising mineral resource base for the production of various types of building materials. Among these varieties, the dolomite raw material of the Jamansay deposit, represented by magnesium–calcium carbonate rocks, is of particular interest. Its practical significance is due to the simultaneous presence of calcium and magnesium components, which determines the possibility of purposefully modifying the properties of the raw material during thermal treatment and obtaining reactive products.

To substantiate the feasibility of using the studied dolomite as a raw material for the synthesis of composite building materials, an assessment of its main physicochemical characteristics was carried out. Particular attention was paid to the content of magnesium- and calcium-containing components, as well as the amount of impurity oxides and loss on ignition, since these indicators determine the character of subsequent decarbonization processes and the formation of thermal-activation products. The basic physicochemical and structural-technological characteristics of the dolomite raw material from the Jamansay deposit are presented in Table 1.

Table 1. *Chemical composition of dolomite from the Jamansay deposit*

Sample	MgO	CaO	Fe_2O_3	Al_2O_3	SiO_2	SO_3	MnO	LOI	Σ
Dolomite	24.1	25.7	2.14	1.03	2.18	0.428	0.12	43.98	99.803

Source: author's data (energy-dispersive X-ray fluorescence analysis, EDXRF, 2025)

The results of the chemical analysis indicate a predominance of magnesium and calcium oxides in the composition of the studied raw material, with contents of 24.10% and 25.70%, respectively. Their combined content reaches 49.80%, confirming the pronounced magnesium–calcium character of the studied carbonate raw material. At the same time, the contents of silica, iron oxide, and aluminum oxide are 2.18%, 2.14%, and 1.03%, respectively, indicating the presence of accompanying mineral components in the natural raw material.

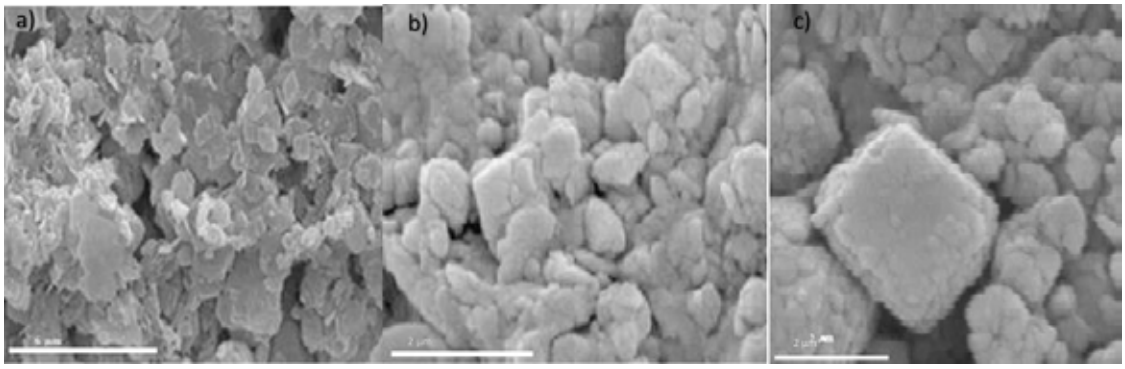
The morphological features of particles of the isolated fractions and changes in the microstructure of the dolomite raw material during thermal treatment were studied by scanning electron microscopy (SEM) using a JEOL JSM-T210 scanning electron microscope under high-vacuum conditions. Fresh fracture surfaces of the initial and thermally treated samples were analyzed to study the microstructure. Imaging was carried out at magnifications corresponding to scale bars of 6 and 2 μm, allowing assessment of particle morphology, the state of grain boundaries, surface character, and the development of pore space.

Comparative analysis of the electron-microscopic images made it possible to trace the morphological transformations occurring during thermal activation. Particular attention was paid to changes in the shape and size of structural elements, the appearance of microcracks, and pore formation. These changes were considered in relation to decarbonization processes accompanied by the release of gaseous products and the re-

organization of the initial material structure. The development of porosity may contribute to an increase in the accessible surface area and an enhancement of the reactivity of the thermal-activation products.

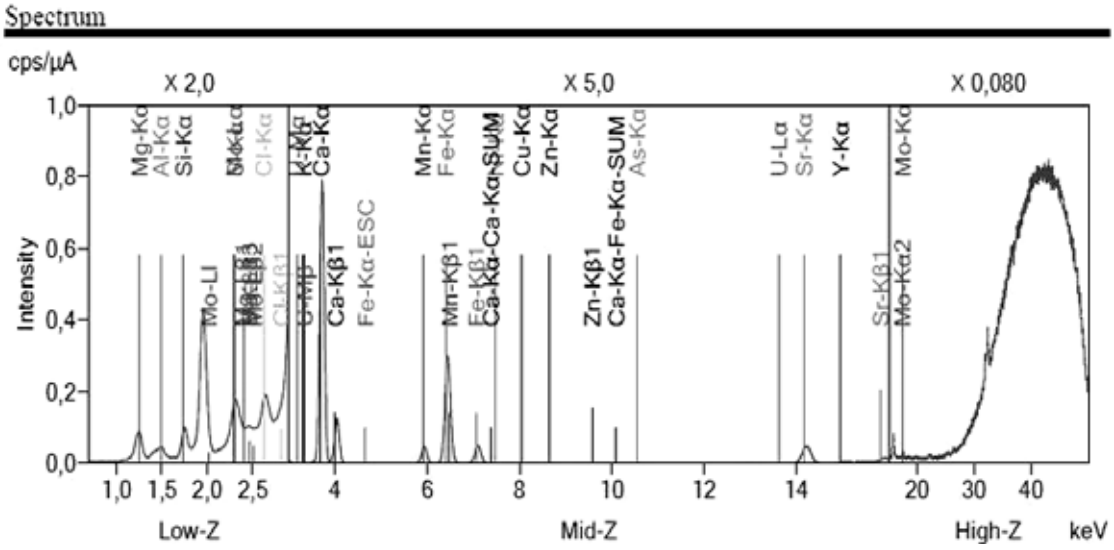
The SEM results were compared with the thermal and chemical analysis data, allowing a comprehensive assessment of the physicochemical and microstructural transformations of the dolomite raw material. Electron-microscopic images of fracture surfaces of the initial and thermally treated samples, obtained at scales of 6 and 2 μm, are presented in Figure 1.

Figure 1. *Electron-microscopic images of fracture surfaces of the initial and thermally treated samples*



Quantitative elemental analysis of the dolomite raw material was performed by energy-dispersive X-ray fluorescence spectrometry using a Rigaku NEX DE (EDXRF) benchtop analyzer. The method is based on recording the energy and intensity of the characteristic secondary X-ray fluorescence radiation arising from the interaction of primary X-ray radiation with the sample. The obtained spectra were used to determine the qualitative and quantitative elemental composition of the dolomite raw material, including the content of the main and impurity components (Fig. 2).

Figure 2. *X-ray fluorescence analysis of dolomite*



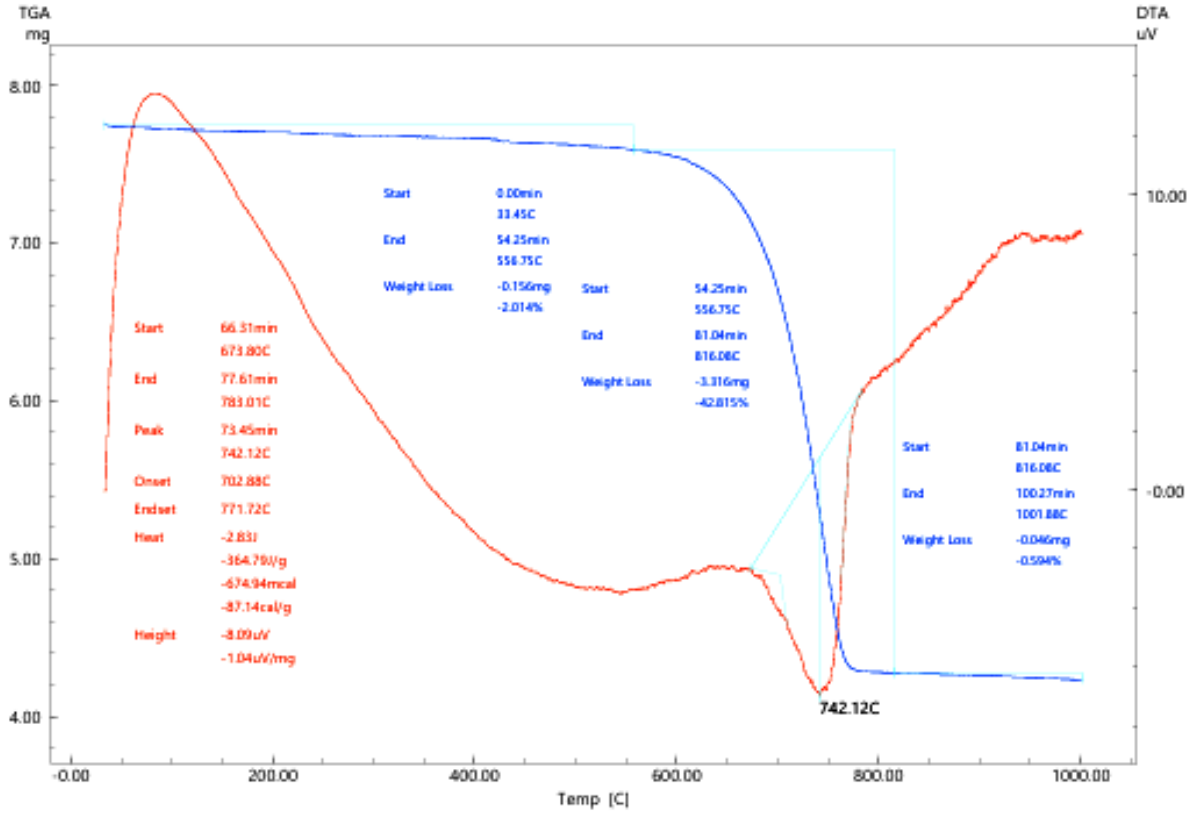
To confirm the mineral-phase composition of the studied raw material, X-ray diffraction (XRD) analysis was additionally performed. Based on the set of diffraction maxima, a predominance of the crystalline dolomite phase was established, with a characteristic intense reflection recorded in the region of 2θ = 33.7°. Along with the main dolomite reflections, the diffractogram may also show accompanying maxima corresponding to the calcite phase ($CaCO_3$), indicating the presence of calcium carbonate in

the composition of the studied raw material. The combined use of EDXRF and XRD made it possible to comprehensively assess the elemental and mineral-phase composition of the natural dolomite and to use the obtained results for the subsequent interpretation of its thermal-activation processes.

The results of differential thermal and thermogravimetric analysis established that heating of the dolomite raw material is accompanied by the sequential occurrence of several physicochemical processes, reflected in the DTA and DTG curves as endothermic effects and changes in sample mass (Fig. 3). Overall, the thermal behavior of the studied material can be divided into three characteristic stages: removal of physically adsorbed moisture and volatile substances, intensive decomposition of the magnesium-containing carbonate component, and subsequent thermal dissociation of the more stable residual carbonate phases with the formation of an oxide product.

At the first stage, in the temperature range of 33–557 °C, a relatively small decrease in sample mass is recorded. This process is mainly associated with the removal of hygroscopic and adsorbed moisture, as well as other weakly bound volatile components. More significant changes are observed with a further increase in temperature. In the interval of 557–816 °C, intensive decarbonization of the dolomite raw material occurs, accompanied by the release of CO_2 and a substantial decrease in mass. This temperature range characterizes the active breakdown of the carbonate structure, primarily of the magnesium component, with the formation of a reactive magnesia phase. At temperatures above 816 °C, further decomposition of the thermally more stable calcium-containing carbonate compounds is observed, along with the formation of a predominantly oxide residue.

Figure 3. *Thermogram of dolomite*



The pronounced endothermic effect recorded on the DTA curve in the high-temperature region indicates a significant intensity of the thermal destruction processes affecting the initial crystal structure. Of particular interest is the temperature interval of 730–750 °C, within which, according to the thermal analysis data, the maximum inten-

sity of selective decomposition of the magnesium component of dolomite is achieved. The formation of a reactive magnesia phase within this interval allows this regime to be regarded as the most promising for directed thermal activation of the studied raw material. At the same time, the calcium component is still predominantly retained in carbonate form, which provides the possibility of obtaining a partially calcined dolomite product with a specified ratio of active magnesia and residual carbonate phases.

Thus, the DTA and DTG results show that thermal activation of dolomite from the Jamansay deposit has a stepwise character and is determined by the sequential removal of adsorbed components, decarbonization of the magnesium fraction, and subsequent decomposition of the more thermally stable calcium-containing component. The established interval of 730–750 °C is a rational region for obtaining a reactive calcination product with predominant formation of active Mg O. This creates prerequisites for the further use of thermally activated dolomite in the development of magnesia-based binders and composite building materials.

Thus, the overall body of results obtained in studying the chemical, physicochemical, mineralogical, and physico-mechanical state of the initial dolomite raw material and its thermal-activation products indicates the promise of using carbonate rocks from the Jamansay deposit as a mineral basis for the synthesis of magnesia-based binder systems. The resulting heat-treatment products can be regarded as promising components for the development of composite building and refractory materials with adjustable performance properties.

Conclusion

The conducted study made it possible to establish the main regularities of thermal activation of natural dolomite from the Western Jamansay deposit of the Republic of Karakalpakstan. It was established that the raw material is characterized by a high content of magnesium–calcium carbonate components and a low content of silicate impurities. According to DTA–TG data, a stepwise character of decarbonization was determined, with the most intensive selective decomposition of the magnesium component occurring at 730–750 °C, resulting in the formation of reactive MgO while the calcium component is predominantly retained in carbonate form. SEM data confirmed the development of porosity and structural reorganization of the material during thermal activation. The obtained results substantiate a rational regime of selective calcination and confirm the prospects for using thermally activated Jamansay dolomite for producing magnesia-based binders, composite, and refractory building materials.

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Contact: abilova.amina@aknuk.uz; saypov.abat@aknuk.uz; bekbosinova.rusgul@aknuk.uz; abilov.jenis@aknuk.uz; ismailov_b@karsu.uz