Chemical-Mineralogical Selection Criteria For Serpentinite-Based Forsterite Refractories

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Received: 25 Dec 2025 | Received Revised Version: 08 Jan 2026 | Accepted: 26 Jan 2026 | Published: 10 Feb 2026

Volume 08 Issue 02 2026 | Crossref DOI: 10.37547/tajas/Volume08Issue02-06

Abstract

The study examines the chemical-mineralogical composition and phase transformations of serpentinites from the Arvaten and Sultan-Uvays deposits to assess their suitability as local raw materials for forsterite refractories. XRD, SEM and chemical analysis were employed. The main stages of thermal transformations and their relationship to the formation of forsterite-bearing phases were identified. The magnesia-silicate and magnesia-iron modules were considered as suitability criteria. The results show that serpentinites from the Arvaten deposit are a promising feedstock for producing forsterite refractory materials.

Keywords: Serpentinite, refractories, forsterite, chemical-mineralogical composition, X-ray diffraction analysis (XRD), physico-mechanical properties, magnesia–silicate module, magnesia–iron module.

Cite This Article: Kadyrova Zulayho Raimovna, Niyazova Shokhista Mansuraliyevna, Kodirova Umida Aslonovna, Kazakova Munira Narzikulovna, & Kholmurodova Sokhiba Almakhmat kizi. (2026). Chemical-Mineralogical Selection Criteria For Serpentinite-Based Forsterite Refractories. The American Journal of Applied Sciences, 8(2), 51–55. https://doi.org/10.37547/tajas/Volume08Issue02-06

1. Introduction

The modern development of ferrous and non-ferrous metallurgy, the chemical industry, as well as the production of ceramic, glass, and construction materials imposes increasingly stringent requirements on the quality and service life of refractory products. Under exposure to high temperatures, aggressive slags, and severe thermal shocks, refractories must exhibit high refractoriness, thermal shock resistance, corrosion resistance, and slag resistance. According to their chemical-mineralogical nature, refractory materials are classified as acidic (silica-based), basic (magnesia-based), neutral (alumina-, chromite-based, etc.), and special materials (carbon-, zirconia-containing) [1]. The selection of a specific refractory type is determined by slag composition and basicity, the temperature-time regime of the process, and the nature of thermo-mechanical loads. When operating with basic slags at high temperatures, MgO-containing refractories are of particular importance due to their enhanced slag resistance and property stability [2].

Raw materials for the production of forsterite refractories include olivine-bearing rocks, serpentinites, dunites, talc, and other magnesia-silicate rocks [3]. Among them, serpentinites are considered one of the most promising feedstocks; they are hydrated magnesium silicates with the general composition $(Mg, Fe)_3Si_2O_5(OH)_4$. In terms of crystal structure, serpentine-group minerals are complex layered formations built by alternating octahedral and tetrahedral sheets. The serpentine group comprises three main varieties-chrysotile, lizardite, and antigorite–which differ in crystal lattice type and particle morphology, and these differences largely determine their practical applications [4-6].

In Uzbekistan, a significant share of refractory products is currently imported, which increases product cost and strengthens dependence on external suppliers. Therefore, the utilization of serpentinites in refractory manufacturing is highly relevant, as it creates prerequisites for developing a domestic raw-material base, reducing production costs, and implementing resource-saving technologies. Moreover, processing serpentinites makes it possible to obtain materials with an increased forsterite content, characterized by a low coefficient of linear thermal expansion, high thermal shock resistance, and stability in aggressive environments.

Thus, investigations of the mineralogical-chemical composition, thermal behavior, and phase transformations of serpentinites are of considerable scientific and practical importance for substantiating energy- and resource-efficient technologies for producing forsterite refractory materials in Uzbekistan.

2. The Experimental Part

To investigate the physicochemical characteristics of serpentinites from the Arvaten and Sultan-Uvays deposits, modern analytical techniques were employed, including wet-chemical analysis, X-ray diffraction (XRD), and scanning electron microscopy (SEM). The combined use of these methods provided reliable information on the mineralogical composition, phase transformations, degree of crystallinity, and particle morphology of the studied rocks.

In the production of forsterite refractories, the quality of natural magnesian raw materials is conventionally evaluated using the modules MgO/SiO_2 and $MgO/(FeO + Fe_2O_3)$. According to these indicators, the investigated serpentinites are comparable with imported analogues. Since unified quality requirements for serpentinite raw materials have not been established, deposit-specific technical specifications are typically developed.

From a technological standpoint, the key assessment parameters are the ratios MgO/SiO_2 and MgO/Fe_2O_3 an increase in these values generally correlates with higher refractoriness of the raw material. Higher modules reduce the demand for additional MgO required to bind SiO_2 into forsterite and iron oxides into magnesioferrite.

According to literature data [7-9], the technological performance of refractory materials is largely governed by the chemical-mineralogical composition and physicochemical properties of the starting raw materials.

The table presents the results of chemical analysis for serpentinite samples from the Arvaten and Sultan-Uvays deposits. Overall, the chemical analysis of serpentinite samples from the Arvaten and Sultan-Uvays deposits shows that these rocks are characterized by a high content of magnesium oxides (≈34-39 wt.%) and silica (≈42 wt.%), combined with a moderate iron level (Fe_2O_3 ≈6.0-6.8 wt.%) and low concentrations of calcium, sodium, and potassium impurities. The magnesia-silica module (MgO/SiO_2 = 0.81-0.96) is close to the stoichiometric range typical of serpentine-group minerals, which supports attribution of the studied material to the chrysotile-antigorite type. The ratio MgO/Fe2O3 = 4.87-6.51 indicates a relatively low iron content, which is beneficial for the thermal stability and chemical inertness of the material during high-temperature processing.

Table

Chemical composition of serpentinites

Sample ID	Oxide contents (wt.%)										LOI (wt.%)	MgO/SiO_2	MgO/Fe_2O_3
	SiO_2	Al_2O_3	MgO	Fe_2O_3	FeO	CaO	TiO_2	Na_2O	K_2O	SO_3			
ArS-1	42.09	2.29	34.58	6.60	0.10	2.05	0.01	1.04	0.11	0.21	10.91	0.82	5.16
ArS -2	41.85	2.70	34.23	6.89	0.14	2.11	0.08	1.10	0.16	0.27	10.21	0.81	4.87
ArS -3	41.67	2.59	33.98	6.48	0.09	2.02	0.09	1.11	0.19	0.29	11.15	0.82	5.17
ArS (avg.)	41.87	2.53	34.26	6.66	0.11	2.06	0.06	1.08	0.15	0.26	10.79	0.82	5.06
SUS -1	41.35	0.32	38.62	6.36	0.52	0.81	0.05	0.29	0.11	0.12	11.18	0.93	6.07
SUS -2	41.53	0.38	38.84	6.07	0.54	0.83	0.08	0.32	0.14	0.11	11.16	0.94	6.39
SUS -3	40.72	0.36	39.01	5.99	0.50	0.88	0.05	0.38	0.10	0.13	11.88	0.96	6.51
SUS (avg.)	41.20	0.36	38.83	6.14	0.52	0.84	0.06	0.33	0.12	0.12	11.41	0.94	6.32

Therefore, considering the combined chemical-mineralogical characteristics and the calculated quality modules, serpentinites from the Arvaten [10] and Sultan-Uvays [11] deposits can be regarded as promising magnesium-bearing raw components for the development of magnesian refractories, particularly forsterite-based and related refractory materials [12].

The mineralogical composition of the investigated serpentinite samples from the Arvaten and Sultan-Uvays deposits was determined by X-ray diffraction. The corresponding diffractograms are presented in Fig. 1.

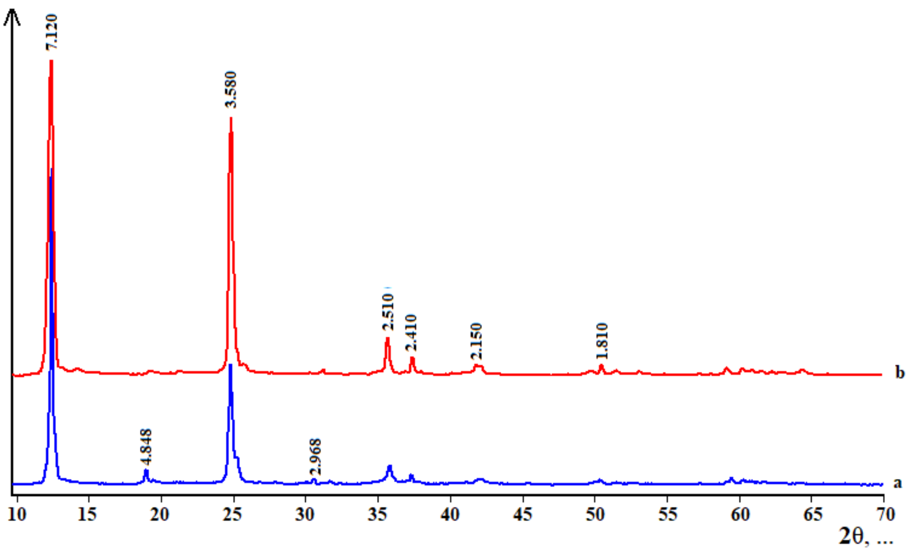
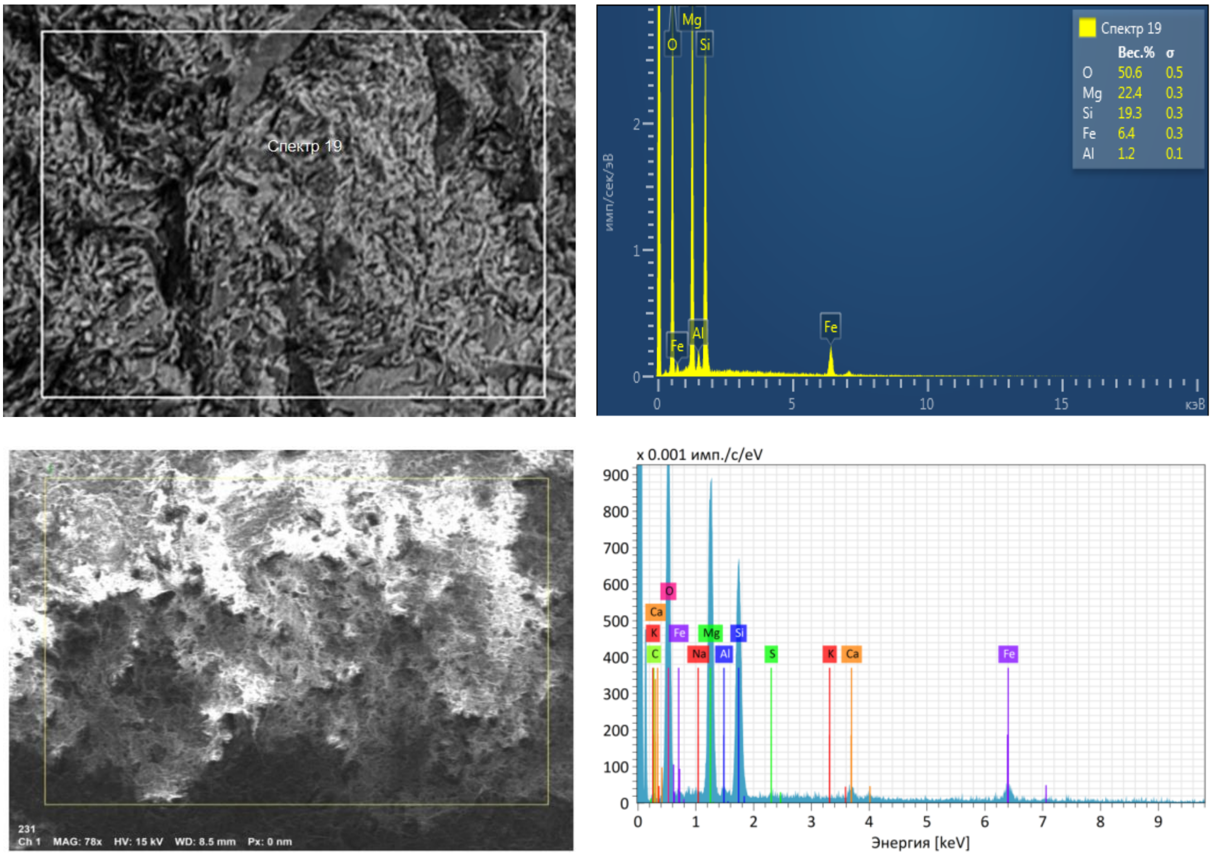


Figure 1: X-ray diffraction pattern of the serpentinite samples from the Arvaten (a) and Sultan-Uvays (b) deposits

The X-ray diffraction (XRD) analysis of the serpentinite samples from the Arvaten and Sultan-Uvays deposits showed that its mineralogical composition is dominated by antigorite, a serpentine-group mineral with the general formula $X_{2\text{-}3}Si_2O_5(OH)_4$ (where X = Mg, Fe^{2+}, Fe^{3+}, Al), characterized by interplanar spacings d = 7.120, 3.580, 2.510, 2.410, 2.150 and 1.810 nm. It was also determined that the X-ray diffraction pattern of the Arvaten serpentinite contains diffraction maxima corresponding to a small amount of the magnetite mineral (d = 4.484, 2.968, 0.251, 0.215 nm). In addition, it was established that the intensity of the diffraction maxima attributed to the antigorite mineral in the X-ray pattern of the Arvaten sample is relatively low.

SEM-EDS analysis of selected surface areas of serpentinite samples from the Arvaten and Sultan-Uvays deposits revealed that the most intense peaks in the spectra are predominantly associated with oxygen, silicon, and magnesium. In addition, peaks of comparatively lower intensity corresponding to iron were identified (Fig. 3).



a

b

Figure 3: SEM micrographs and EDS spectra of serpentinite samples: (a) Arvaten deposit; (b) Sultan-Uvays deposit

Besides the major elements, weak signals attributable to aluminium were also observed, which may indicate the presence of minor clay-related impurities and aluminosilicate phases (e.g., feldspars). Overall, the elemental composition of the studied serpentinites is governed by the Mg-Si-O system, with iron present in subordinate amounts.

The SEM and energy-dispersive spectroscopy (EDS) results for serpentinites from the Arvaten and Sultan-Uvays deposits fully corroborate the findings of chemical analysis and X-ray diffraction (XRD).

3. Conclusion

Serpentinites from the Arvaten and Sultan-Uvays deposits are characterized by high MgO and SiO_2 contents, confirming their suitability as magnesian-silicate raw materials. The quality modules MgO/SiO_2 = 0.81-0.96 and MgO/Fe_2O_3 = 4.87-6.51 indicate a favorable magnesia-silica balance and relatively low iron content, which contribute to enhanced thermal stability and chemical inertness during high-temperature processing. XRD data show that the mineralogy is dominated by antigorite (serpentine group) with minor magnetite, while quartz, chlorite, and talc may occur as accessory phases. SEM-EDS results confirm the predominance of the Mg-Si-O system with subordinate Fe and trace Al-bearing components, consistent with chemical analysis and XRD identification. Overall, the studied serpentinites can be regarded as promising domestic raw materials for the development of magnesian refractories, including forsterite-based and related refractory compositions.

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