Structural And Morphological Studies Of Magnesia Raw Materials Of Uzbekistan

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Abstract

The development of refractory materials based on local magnesia–silicate resources of Uzbekistan is a promising approach for resource conservation and import substitution. In this study, a comparative assessment of serpentinites from the Sultan-Uvays (Republic of Karakalpakstan) and Arvaten (Jizzakh region) deposits was carried out as a raw-material base for producing magnesia refractories of the MgO-SiO_2 system. The chemical composition and impurity components were analyzed, and the structural and morphological features of the samples were investigated using FTIR spectroscopy and SEM-EDS. According to the SEM-EDS results, the spectra are dominated by O-Si-Mg signals, while Fe peaks show relatively low intensity and only trace impurities are detected. The FTIR spectra exhibit characteristic bands of the serpentine structure (ν(OH) ~3565-3675 cm^{-1}, Si-O ~954-1069 cm^{-1}, and Si-O-Mg/Mg-O modes ~734-400 cm^{-1}). The obtained results confirm the potential of serpentinites from both deposits as local magnesia-silicate raw materials and substantiate their use for producing MgO-SiO_2 refractory materials, including forsterite-type compositions.

Keywords: Serpentinite; magnesia-silicate raw materials; Sultan-Uvays; Arvaten; chemical composition; SEM-EDS; FTIR; refractories; MgO-SiO2 system.

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1. Introduction

Technological and service characteristics of materials used in the national economy, including refractories, are largely determined by the composition, structure, and properties of the starting raw components [1]. In this regard, the development of magnesia-based refractory materials using local mineral resources is one of the priority areas of resource conservation and import substitution in the ceramic and metallurgical industries. Under the increasing requirements for thermal and slag resistance of lining materials, magnesia–silicate rocks capable of serving as a raw-material base for producing forsterite refractories and other materials of the MgO-SiO2 system are of particular interest [2]. Among such rocks, serpentinites occupy an important place; they are widespread in several regions of Uzbekistan and are characterized by a high content of MgO and SiO2, which potentially determines their suitability for synthesizing magnesia-bearing refractory phases [3].

Serpentinites are natural polymineral formations in which, along with serpentine minerals, accessory phases such as magnetite, chlorite, talc, carbonates, and other minerals may be present. Such a multiphase nature, as well as variations in chemical composition, leads to differences in the behavior of the raw material during heat treatment and subsequent sintering. From a technological standpoint, the decisive factors include the MgO/SiO2 ratio, the contents of iron and calcium, the loss on ignition (LOI), and the distribution of impurity elements, which affect phase formation, the degree of forsterite formation, and the development of the microstructure of refractory products [4-6].

A modern assessment of the suitability of serpentinites as magnesia-bearing raw materials should rely not only on chemical analysis, but also on a comprehensive investigation of their structure and morphology [7]. Informative approaches include IR spectroscopy, which makes it possible to identify features of the silicate matrix and hydroxyl groups [8-10], as well as scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM-EDS) [11], which provides insight into microstructural characteristics, particle size and agglomeration behavior, and the local distribution of elements. Taken together, these methods allow the chemical and mineralogical characteristics of the raw material to be correlated with its reactivity and technological potential for producing magnesia–silicate materials.

In view of the above, a comparative study of serpentinites from the Sultan-Uvays and Arvaten deposits of Uzbekistan is relevant, as these rocks represent promising magnesia-bearing raw materials. Comparing their chemical composition, structural features based on IR spectroscopy, and morphology determined by SEM–EDS makes it possible to identify key differences, determine the factors that limit or enhance the suitability of the raw material, and develop scientifically grounded recommendations for its targeted use in refractory technology.

2. The Experimental Part

The Sultan-Uvays serpentinite deposit is located in the Beruniy District of the Republic of Karakalpakstan, on the southern slope of the Sultan-Uvays Mountains. Geographically, the site is confined to the vicinity of the A380 “Tuya-Muyin–Nukus” highway and lies approximately 4.5 km north of the 686-km marker. According to preliminary estimates, the serpentinite reserves are about 5.0 million tonnes, which makes this deposit an economically promising source of magnesia–silicate raw materials in the medium term.

The Arvaten serpentinite occurrences are situated in the Jizzakh Region, approximately 9 km northwest of the Jizzakh limestone plant and about 1.5 km from the settlement of Kuyabash. From a structural and geographic viewpoint, the serpentinite body is associated with the northeastern slopes of the Northern Nurata Mountains; the coordinates of the area are 40°09′ N, 67°43′ E. Historically, interest in the Arvaten serpentinites was first noted during geological appraisal surveys: in 1961, A.A. Popovich and co-authors preliminarily described them as igneous rocks of potential interest for producing materials by stone casting methods [12]. Subsequently, based on the results of a full-scale geological exploration carried out in 1965 by V.S. Badaev and co-authors [13], the deposit was characterized as a large geological massif composed predominantly of serpentinites. The thickness of the serpentinite sequence is estimated at 90-125 m, while the massif extends for 1300–1400 m, confirming the substantial resource potential of the Arvaten area and its practical value as a raw-material base.

The table summarizes the chemical composition of serpentinite samples collected from the Arvaten and Sultan-Uvays deposits. The results indicate that both raw materials are characterized by an elevated MgO content (about 34-39 wt.%) with an almost constant SiO2 level (around 42 wt.%). The iron content is moderate (Fe2O3 ~6.0-6.8 wt.%), whereas CaO, Na2O, and K2O occur only as minor impurities. The calculated magnesia–silica modulus, MgO/SiO2 (0.81-0.96), falls within the range typical of serpentine-group minerals and suggests that the studied material can be attributed to the chrysotile–antigorite type. The MgO/Fe2O3 ratio (4.87-6.51) points to relatively low iron enrichment, which may favorably affect the thermal stability and chemical resistance of the material during high-temperature processing. The chemical composition and physico-technical characteristics of of Serpentinites from the Arvaten and Sultan-Uvays Deposits are given in Table.

Table

Chemical Composition and Physical-Technical Characteristics of Serpentinites from the Arvaten and Sultan-Uvays Deposits

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

To assess the microstructure and the distribution of the major elements in the serpentinites, SEM-EDS analysis was performed; the SEM micrographs and EDS spectra are presented in Fig. 1.

SEM observations show that the serpentinites from the Sultan-Uvays and Arvaten deposits exhibit a heterogeneous microstructure and well-developed aggregate textures (Fig. 1a,c). The micrographs reveal densely packed fine particles together with areas characterized by a rough, highly developed surface, which reflects the natural polymineral character of the rocks and differences in the structural ordering of the serpentine matrix. Locally, contrast variations (brighter and darker regions) are observed, which can be associated with compositional and/or phase-density heterogeneity.

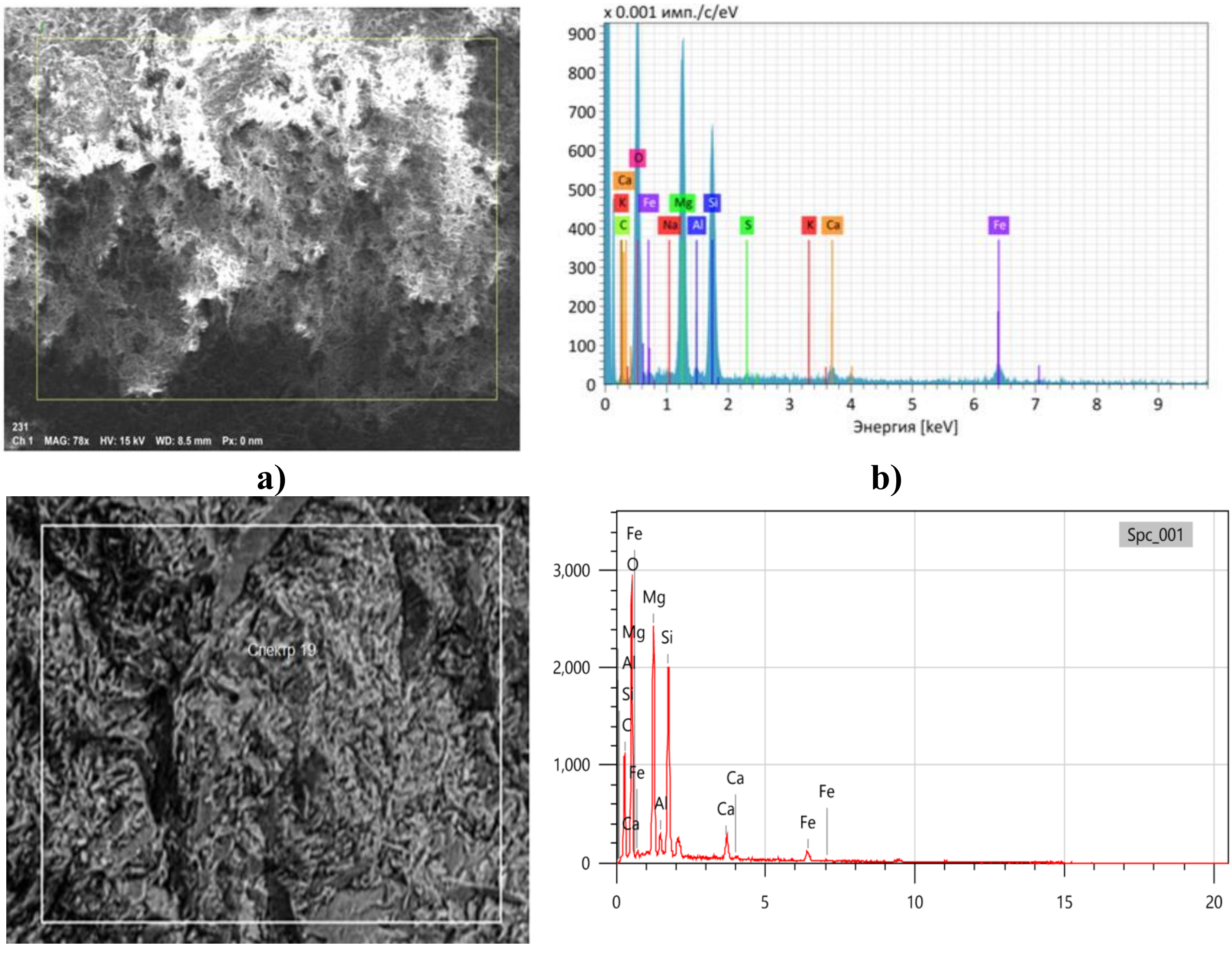
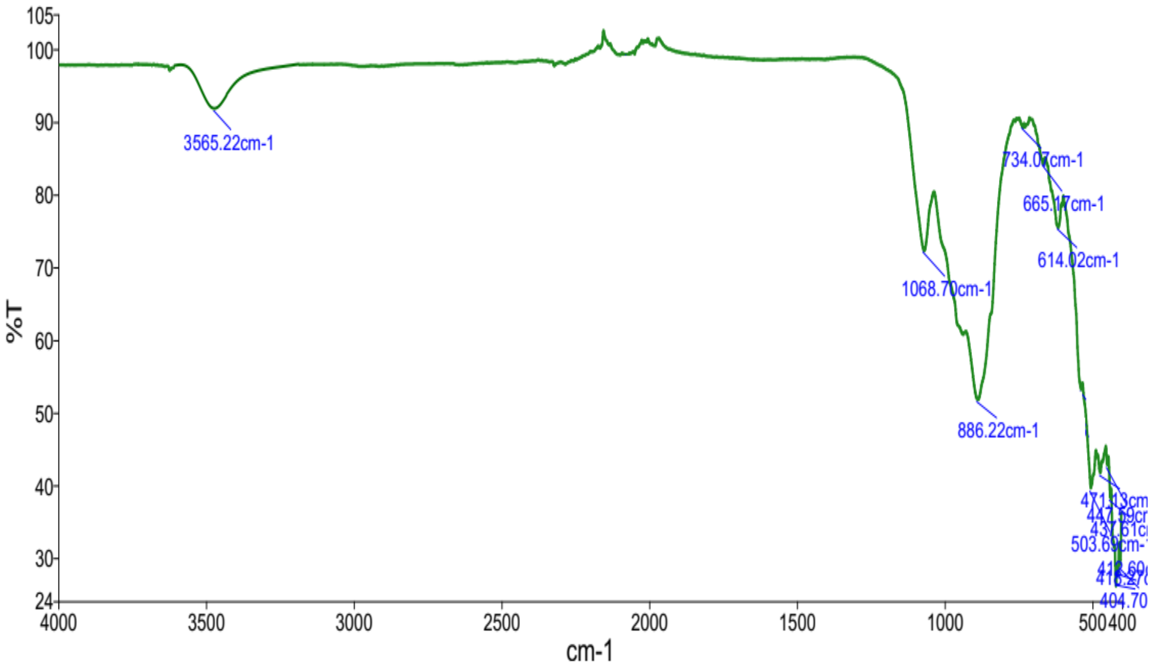


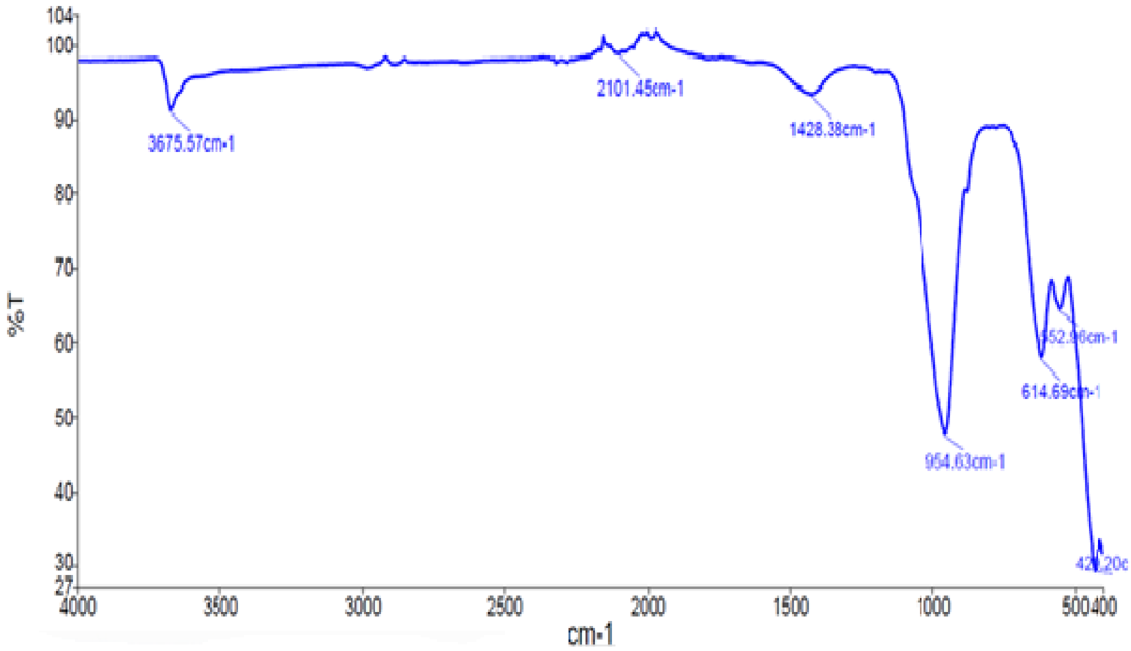
Fig. 1. SEM micrographs (a,c) and EDS spectra (b,d) of serpentinite samples from the Sultan-Uvays and Arvaten deposits

EDS analysis of selected surface areas indicates that the spectra of both samples are dominated by signals of oxygen, silicon, and magnesium, confirming the magnesia–silicate nature of the raw materials (Fig. 1b,d). In addition to the major elements, iron-related peaks are detected, but with noticeably lower intensity, consistent with the moderate Fe content obtained from bulk chemical analysis. Weak signals of aluminum and minor alkaline/alkaline-earth elements (Ca, Na, K) are also present, suggesting trace impurity phases (e.g., clay- or feldspar-related components and/or carbonates). Overall, the combined SEM-EDS results support that serpentinites from both deposits represent promising magnesia–silicate raw materials with a relatively low level of impurity elements, which is potentially favorable for subsequent high-temperature processing in refractory compositions.

To assess the structural features of the serpentinites, IR spectroscopy was performed; the obtained spectra are presented in Fig. 2.



a)



b)

Fig. 2. FTIR spectra of serpentinite samples from the Sultan-Uvays (a) and Arvaten (b) deposits

The FTIR spectra of serpentinites from the Sultan-Uvays and Arvaten deposits exhibit a set of diagnostic absorption bands typical of serpentine-group minerals, confirming the predominance of a magnesia–silicate phase in the investigated raw materials (Fig. 2). In the high-frequency region, O-H stretching bands ν(OH) are observed at ~3565-3675 cm^{-1}, indicating the presence of structurally bound hydroxyl groups within the layered framework of serpentine minerals. The presence and intensity of these bands suggest that the hydroxyl component characteristic of natural serpentines is retained and may serve as an indicator of the degree of structural ordering.

In the mid-frequency region, intense bands appear in the ~954-1069 cm^{-1} range and are assigned to Si-O stretching vibrations in the tetrahedral sheets of the silicate matrix. This region is characteristic of layered magnesian silicates and reflects the structural features of the tetrahedral units as well as possible variations in the crystallochemical environment of silicon. In the low-frequency region, bands are detected within ~734-614 cm^{-1} and ~552-400 cm^{-1}, corresponding to bending vibrations and lattice modes involving Si-O-Mg and Mg-O linkages, which are typical of the serpentine structure. Taken together, these bands confirm the magnesia–silicate nature of the samples and are consistent with the results of bulk chemical analysis and SEM-EDS characterization.

Overall, the physico-chemical investigations showed that serpentinites from the Sultan-Uvays and Arvaten deposits are promising raw materials and are suitable for the production of magnesia-based refractory materials.

3. Conclusion

Comprehensive physico-chemical studies (chemical analysis, SEM–EDS, and IR spectroscopy) indicate that serpentinites from the Sultan-Uvays and Arvaten deposits are promising magnesia–silicate raw materials for refractory applications. The samples show high MgO (≈34–39 wt.%) and SiO2 (≈42 wt.%) with moderate Fe2O3 (≈6.0-6.8 wt.%) and low CaO, Na2O, and K2O contents; the MgO/SiO2 ratio (0.81-0.96) is typical of serpentine-group minerals. SEM-EDS confirms a heterogeneous microstructure and the dominance of O-Si-Mg with minor Fe, while IR spectra display characteristic ν(OH), Si-O, and Si-O-Mg/Mg-O bands. Overall, the results support the suitability of both serpentinites as local feedstock for MgO-SiO2(forsterite-type) refractory materials.

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