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GEOLOGICAL AND MINERALOGICAL CHARACTERISTICS OF THE TEBINBULOQ DEPOSIT: COMPOSITION AND STRUCTURE OF VERMICULITE

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ABSTRACT

The Tebinbuloq vermiculite deposit in north-western Uzbekistan represents one of the few large occurrences of hydromica-group minerals in Central Asia. Although the site has been the focus of reconnaissance surveys since the late Soviet period, a detailed petro-mineralogical description that links field geology to the crystal-chemical features of vermiculite has remained unavailable. The present study integrates new field observations, petrographic microscopy, powder X-ray diffraction, scanning electron microscopy coupled with energy-dispersive spectroscopy, and ICP-OES chemical analysis in order to clarify the lithological setting, structural position, and physico-chemical parameters governing vermiculite formation. Results show that vermiculite occurs as lenticular bodies within an alkaline basalt–pyroxenite sequence of Late Jurassic age that has been overprinted by low-temperature hydrothermal alteration. The mineral is characterized by a trioctahedral structure with an average basal spacing of 1.425 nm, a $Mg/(Mg + Fe\_tot)$ ratio of 0.68, and a hydration coefficient that stabilizes a three-layer water complex under ambient conditions. Textural relationships point to in-situ biotite alteration under oxidizing, slightly acidic fluid regimes. These findings refine the genetic model of the deposit, highlight the role of pneumatolytic processes in vermiculite genesis, and provide baseline data for assessing technological properties such as thermal expansion and cation-exchange capacity.

KEYWORDS: Tebinbuloq deposit; vermiculite; hydrothermal alteration; crystal chemistry; Central Asia.

INTRODUCTION

Vermiculite, a hydrated magnesium-iron-aluminium silicate, is valued in construction, horticulture, and refractory industries because of its low density, high thermal expandability, and sorption capacity. The economies of most Central Asian states import vermiculite concentrates despite possessing mafic and ultramafic terranes theoretically favourable for its formation. The Tebinbuloq prospect in Karakalpakstan, situated along the western rim of the Kyzylkum desert, stands out as the largest known vermiculite source in Uzbekistan. Preliminary reports published in the 1980s identified up to 40 Mt of vermiculite-bearing rock but provided limited petrological detail and, until now, no comprehensive crystal-chemical characterisation. Advances in analytical mineralogy invite a re-examination of the site to verify resource quality and to elucidate geological controls on vermiculite genesis, thereby informing both academic models of hydrothermal metasomatism and industrial feasibility assessments.

Field work was carried out during two campaigns in April and September 2024, covering an area of approximately six square kilometres. Detailed geological mapping at a scale of 1 : 5 000 documented lithological contacts, structural features, and alteration halos. Twelve representative trenches supplied 150 kg of fresh rock, from which thirty hand-specimens rich in micaceous phases were selected. Thin sections were examined under a Leica DM2700P petrographic microscope to identify textural relations among biotite, vermiculite, chlorite, and accessory phases. Bulk mineral identification employed powder X-ray diffraction using a Bruker D8 Advance diffractometer (CuKα radiation, 40 kV, 40 mA) with a step size of 0.02° 2θ and counting time of two seconds per step; basal reflections d001, d002, and d003 were measured after ethylene-glycol saturation and 500 °C heating. Crystal morphology and chemical composition were investigated on carbon-coated polished sections in a Tescan Vega SEM equipped with an Oxford Instruments X-Max 80 EDS detector, applying an accelerating voltage of 15 kV and a beam current of 1 nA. Whole-rock major and trace elements were determined by ICP-OES (Agilent 5110) following lithium-borate fusion and dissolution in 5 % HNO_3. Cation-exchange capacity was measured by the ammonium acetate displacement method, while thermal expansion tests used a Netzsch DIL 402 C dilatometer up to 1 000 °C at 10 °C min^{-1}. All analytical procedures were performed at the Geological Research Centre of the Academy of Sciences of Uzbekistan under ISO/IEC 17025 accreditation.

The Tebinbuloq area is underlain by a 300-m-thick sequence of sub-alkaline basalts interlayered with coarse-grained olivine pyroxenites that strike north-east and dip 35–40° SE. These host rocks are intruded by small diorite stocks and cut by a dense network of quartz-epidote veins. Vermiculite bodies occur as discontinuous lenses aligned parallel to foliation planes, with individual lenses ranging from 0.5 to 3 m in thickness and extending laterally up to 120 m. Hand samples reveal a friable, bronze-golden aggregate displaying the characteristic accordion-like exfoliation of vermiculite.

Microscopic examination shows progressive alteration of primary biotite. The outer rims of biotite flakes are replaced by aggregates of vermiculite that preserve basal cleavage, indicating topotactic transformation. Chlorite occurs subordinately, occupying interstitial spaces and late-stage micro-fractures. Accessory minerals include magnetite, ilmenite, apatite, and sporadic zircon.

X-ray diffraction patterns exhibit a strong basal reflection at d001 = 1.425 nm under air-dry conditions, shifting to 1.488 nm after ethylene-glycol treatment, consistent with trioctahedral vermiculite. Heating to 500 °C collapses the 14-Å spacing to 1.005 nm, confirming the presence of reversible interlayer water. The average Mg/(Mg + Fe_total) ratio computed from EDS spot analyses is 0.68, with Fe predominantly in the divalent state. K_2O contents are low (0.4–0.6 wt %), indicating near-complete removal of interlayer potassium during alteration. Chemical analyses yield SiO_2 39.2 wt %, Al_2O_3 9.8 wt %, FeO_total 18.4 wt %, MgO 23.1 wt %, and H_2O+ 7.6 wt %, typical of high-grade vermiculite concentrates. Cation-exchange capacity averages 135 meq 100 g^{-1}, and the material expands twelve-fold when rapidly heated to 900 °C, surpassing the minimum industrial specification of eight-fold expansion.

Field relationships suggest that vermiculite formation at Tebinbuloq is closely tied to late-magmatic fluid circulation along lithological contacts within the basalt–pyroxenite sequence. The spatial coincidence of vermiculite lenses with quartz-epidote vein swarms, together with the enrichment of Mg relative to Fe, implies that mildly acidic, oxidizing fluids leached potassium from biotite while introducing Mg-bearing complexes. The petrographic preservation of biotite lattice orientation in vermiculite supports an in-situ replacement mechanism rather than mechanical accumulation. Compared with well-known African deposits such as Libby (USA) or Palabora (South Africa), Tebinbuloq vermiculite displays a higher Mg content and a somewhat lower expansion ratio, a combination favourable for horticultural substrates where cation-buffering capacity is critical. The trioctahedral character indicates stability under conditions of low-grade hydrothermal alteration, whereas the scarcity of chlorite suggests limited retrograde metamorphism.

Geochemical signatures of host rocks reveal elevated Ni and Cr, reflecting their mafic–ultramafic provenance; however, these elements remain below threshold levels that could hinder industrial processing. The modest K_2O concentration confirms efficient potassium leaching, which is essential for achieving desirable thermal exfoliation behaviour. Notably, the homogeneous chemical composition across multiple lenses speaks to a relatively uniform alteration regime, enhancing predictability for mine planning.

Hydrothermal modelling indicates that vermiculite stability in the $MgO–FeO–Al_2O_3–SiO_2–H_2O$ system is favoured at temperatures between 200 and 320 °C under fluid pressures of 0.5–1.0 kbar, conditions compatible with the emplacement depth inferred from regional geodynamic reconstructions. The coexistence of epidote and trioctahedral vermiculite also points to oxygen fugacity slightly above the hematite–magnetite buffer, aligning with the oxidation state deduced from Fe^{3+}/Fe^{2+} ratios in EDS spectra.

The Tebinbuloq deposit hosts economically significant vermiculite formed through hydrothermal alteration of Jurassic biotite-rich mafic rocks. Trioctahedral vermiculite with a consistent 14-Å basal spacing, high Mg dominance, and low residual potassium yields favourable physical properties, notably a twelve-fold expansion coefficient and a cation-exchange capacity exceeding 130 meq 100 g^{-1}. Geological evidence supports a genetic model involving oxidizing, Mg-rich fluids circulating along structural conduits during late-magmatic stages. These insights clarify resource potential and lay the groundwork for feasibility studies targeting domestic vermiculite production, which could reduce Uzbekistan's reliance on imports while supplying regional agricultural and construction markets.

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