

Technological and Global Analysis of Integrated Titanium and Vanadium Extraction from Tebinbulak Deposit Ores

 Matkarimov Sohijjon

Professor, Head of The Department, Tashkent State Technical University, Uzbekistan

 Turdiyeva Aziza

Master Degree Student of Tashkent State Technical University, Uzbekistan

Received: 22 July 2026 | Received Revised Version: 16 August 2026 | Accepted: 06 September 2026 | Published: 29 September 2026

Volume 08 Issue 09 2026 | Crossref DOI: 10.37547/tajas/Volume08Issue09-03

Abstract

This paper presents an in-depth, integrated technological and global analysis of the industrial development of Tebinbulak, one of the largest titanomagnetite ore deposits in Central Asia (located in the Karauzyak District of the Republic of Karakalpakstan, with on-balance ore reserves of ~2.0 billion tons). A comprehensive synthesis of experimental mineralogical and beneficiation test data for representative sample No. 7 of pyroxenite ores was carried out, including three-stage crushing, granulometric classification, dry and wet screening, and manual/laboratory magnetic separation. Optical microscopy was employed to investigate the structural and textural relationships among the ore phases: fine-dispersed exsolution textures of titanomagnetite solid solutions with lamellar ilmenite exsolutions in magnetite, isomorphic vanadium substitution within the magnetite crystal lattice, martitization (hematite replacement), and sulfide inclusions. By integrating advanced global scientific expertise (FactSage thermodynamic modeling, electric smelting reduction of metallized pellets at 1625–1650 °C, hydrochloric acid destruction, and low-temperature synergistic roasting of vanadium converter slag with a binary Na₂C₂O₄/Na₂CO₃ mixture), an end-to-end, energy-efficient, environmentally benign, slime-free comprehensive flow sheet was developed and validated. The thermodynamic conditions preventing the formation of refractory titanium carbides (TiC) were established, achieving overall recoveries exceeding 99.5% for iron into hot metal, 92.6–94.4% for vanadium into commercial hot metal (with subsequent production of 98.73% pure V₂O₅), and selectively partitioning 94.1–99.0% of titanium into high-grade titania slag (42–46% TiO₂) suitable for pigment-grade TiO₂ synthesis.

Keywords: Tebinbulak, titanomagnetite, vanadium, titanium dioxide, magnetic separation, pyrometallurgy, direct reduction, electric furnace smelting, hydrochloric acid leaching, converter slag, vanadium pentoxide, zero-waste technologies.

© 2026 Matkarimov Sohijjon, & Turdiyeva Aziza. This work is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0). The authors retain copyright and allow others to share, adapt, or redistribute the work with proper attribution.

Cite This Article: Matkarimov Sohijjon, & Turdiyeva Aziza. (2026). Technological and Global Analysis of Integrated Titanium and Vanadium Extraction from Tebinbulak Deposit Ores. The American Journal of Applied Sciences, 8(09), 17–28. <https://doi.org/10.37547/tajas/Volume08Issue09-03>

1. Introduction and Strategic Relevance of The Tebinbulak Project

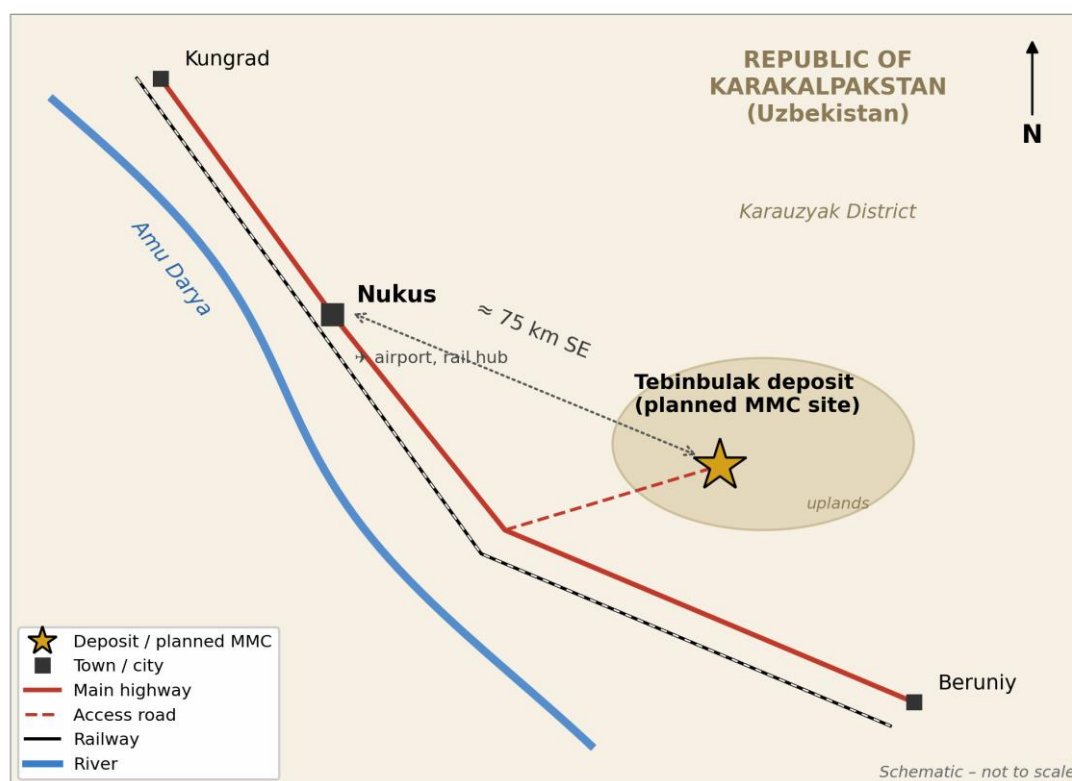
Establishing a resilient, competitive, and self-sufficient

mineral resource base for ferrous and non-ferrous metallurgy is a fundamental priority of industrial and technological modernization in the Republic of Uzbekistan. In accordance with Decree of the President

of the Republic of Uzbekistan No. UP-4947 dated February 7, 2017, 'On the Action Strategy for Further Development of the Republic of Uzbekistan,' Presidential Resolution No. PP-4124 dated January 17, 2019, 'On Measures for Further Improvement of the Mining and Metallurgical Industry,' and strategic national initiatives, the industrial exploitation of major iron ore assets is regarded as a primary catalyst for national re-industrialization. In August 2019, President of Uzbekistan Sh. M. Mirziyoyev conducted an official visit to the Republic of Karakalpakstan to inspect the investment framework for establishing a major mining and metallurgical complex (MMC) based on the world-class Tebinbulak titanomagnetite deposit.

Geographically and administratively, the Tebinbulak deposit is situated in the Karauzyak District of the Republic of Karakalpakstan, approximately 75 km

southeast of the city of Nukus. Geological reserves are estimated at an unprecedented scale of approximately 2.0 billion metric tons of ore, ensuring continuous industrial operation for at least 50–70 years. According to design parameters, the complex is projected for an annual mining and processing throughput of up to 33 million tons of run-of-mine (ROM) ore, yielding over 1.5 million tons of high-grade finished steel products (including rebar, up to 225,000 tons of wire rod, and 375,000 tons of merchant bars and structural shapes—angles and channels). The project ensures fundamental import substitution of rolled steel, generates more than 2,000 highly skilled jobs, and targets approximately 35% of output for export. Renowned international engineering firms DMT-Group Consulting (Germany) and Horst Wiesinger Consulting (Austria) were engaged in the engineering and feasibility evaluations.



[Figure 1: Geographic location and transport logistics infrastructure of the Tebinbulak prospect area (Karauzyak District, Republic of Karakalpakstan)]

From scientific, metallurgical, and geoeconomic perspectives, however, the titanomagnetite ores of Tebinbulak represent far more than ordinary iron ore; they constitute an intricate polymetallic mineral matrix.

Alongside iron oxides (Fe), the ore contains commercially significant concentrations of titanium dioxide (TiO₂) and vanadium pentoxide (V₂O₅). In the context of the global green technology transition,

titanium and vanadium are designated as strategic and critical raw materials. Vanadium is an indispensable microalloying agent for high-strength low-alloy (HSLA) steels and aerospace superalloys, as well as the core electrolyte material for utility-scale Vanadium Redox Flow Batteries (VRFB) deployed in renewable energy storage. Titanium forms the backbone of structural materials in aerospace, marine engineering, chemical machinery, and biomedicine, while its oxide represents the dominant white pigment globally across paint, coatings, plastics, and paper industries.

Conventional single-product processing schemes focused solely on iron recovery face severe technological, economic, and environmental obstacles. During standard blast furnace or classical electric arc furnace smelting, titanium is converted into high-melting carbides and carbonitrides (TiC, Ti(C,N)). This catastrophically elevates slag viscosity (leading to furnace hearth congelation, or 'freezing'), resulting in the irreversible loss of hundreds of thousands of tons of titanium and vanadium in hazardous slag heaps. Consequently, a scientifically sound development model for Tebinbulak must adhere strictly to closed-loop circular economy principles and selective, zero-waste processing, simultaneously recovering three high-value marketable products: commercial steel / vanadium-

bearing hot metal, purified vanadium pentoxide (V₂O₅ / FeV), and pigment-grade titanium dioxide (TiO₂).

2. Chemical Composition and Ore Preparation of Run-Of-Mine Ore

At the Technopark of Navoi State Mining Institute (NSMI) in collaboration with the Central Research Laboratory of NMMC SE, upon the initiative of Professor K. S. Sanakulov, comprehensive laboratory-scale metallurgical testing was conducted on representative bulk sample No. 7 of Tebinbulak ore (total weight: 1,000 kg; initial lump size up to -500 mm, collected by Karakalpak State Geological Survey Expedition SE). Petrographically, the ore is represented by Fe₂O₃-bearing pyroxenites.

Ore preparation comprised three-stage crushing using laboratory jaw crushers coupled with check screening. In the first and second stages, the ore was crushed to -25.0 mm, thoroughly homogenized, and reduced by quartering to a 100 kg bulk sub-sample. Subsequently, a third stage of fine crushing was executed to -2.0 mm, from which representative analytical samples were split for abbreviated chemical, complete silicate, and semi-quantitative emission spectral analyses (Tables 1–3).

Table 1. Chemical composition of the initial technological sample No. 7 of Tebinbulak ore (abbreviated analysis, wt. %)

Fe_tot	Fe ₂₊	Fe ₃₊	V ₂ O ₅	S_tot	S_sulf	C_tot	C_org	CO ₂	As	Sb	Cu	Pb	Zn
22.0	9.4	12.6	0.16	<0.2	<0.2	<0.1	<0.1	<0.1	<0.087	<0.047	<0.047	<0.047	0.004

Table 2. Complete silicate analysis of the initial Tebinbulak ore (wt. %)

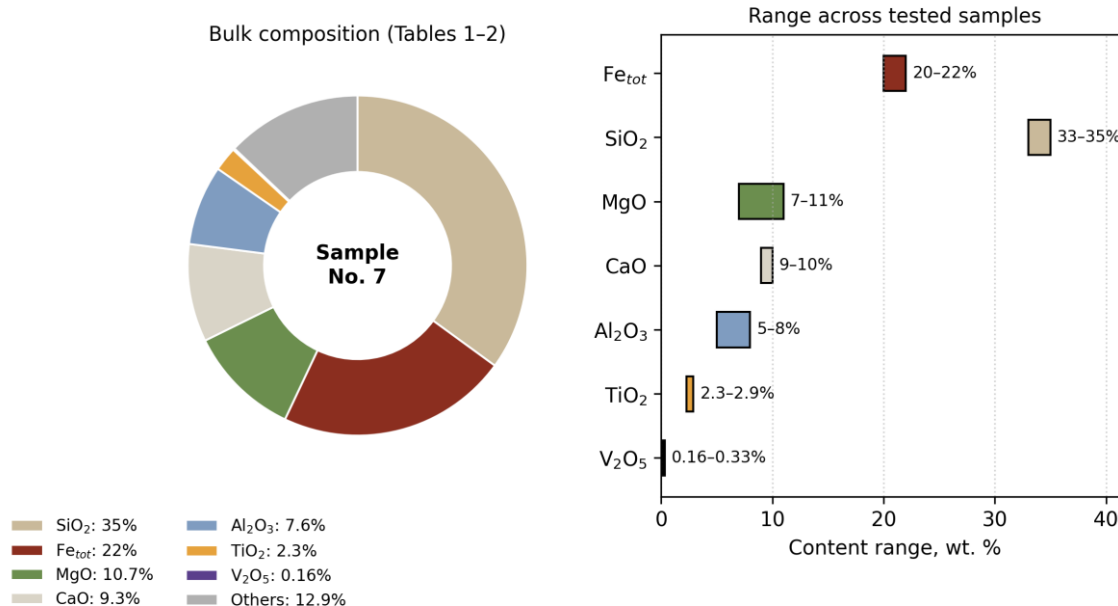
SiO ₂	Al ₂ O ₃	TiO ₂	FeO	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO	LOI
35.0	7.6	2.3	12.1	18.0	9.3	10.7	0.5	0.3	0.26	0.17	0.16

Table 3. Semi-quantitative optical emission spectral analysis of trace elements in initial ore (wt. %)

Element	Co	Ni	Cr	Mo	Yb	Ga	Y	Sr	Zr	Sc	Be	Ba
Grade, %	0.005	0.001	0.05	0.0005	0.0001	0.003	0.001	0.02	0.002	0.001	<0.0001	0.01
Detection limit, %	0.0005	0.0005	0.005	0.0002	0.0001	0.0002	0.001	0.02	0.002	0.001	0.0001	0.01

Spectral analysis confirmed that toxic and volatile elements such as Cd, Bi, Ge, Tl, W, Sn, In, Li, Ta, Hf, and Nb were either completely absent or present below detection limits. The presence of chromium (0.05% Cr), cobalt (0.005% Co), and zirconium (0.002% Zr) confirms the deep magmatic origin of the mafic-

ultramafic intrusion. Furthermore, the exceptionally low contents of sulfur ($S < 0.2\%$) and phosphorus ($P_2O_5 = 0.26\%$) represent a substantial metallurgical advantage, greatly facilitating downstream dephosphorization and desulfurization.



[Figure 2: Major component distribution diagram of Tebinbulak titanomagnetite ore: Fe_{tot} (20–22%), SiO₂ (33–35%), MgO (7–11%), CaO (9–10%), Al₂O₃ (5–8%), TiO₂ (2.3–2.9%), V₂O₅ (0.16–0.33%), Others (12.9%)]

3. Granulometric Analysis and Comparative Evaluation of Dry Vs. Wet Screening

Assessing the sizing characteristics of crushed ore is essential for selecting the optimal classification regime and downstream concentration flowsheet. Crushed material (-2.0+0 mm) was classified using two alternative screening methods: wet and dry screening on

an ASV-500 vibratory sieve shaker. During dry screening, electrostatic agglomeration and mechanical dusting inevitably cause ultra-fine slimes to adhere to coarser particles. In contrast, wet screening provides hydrodynamic shear forces that disperse clay-bearing slimes and clean particle surfaces. Sieve classification and elemental distribution profiles are summarized in Tables 4 and 5.

Table 4. Particle size distribution and elemental partitioning during wet screening of Tebinbulak ore

Size Fraction, mm	Yield, %	Fe _{tot} , %	TiO ₂ , %	V ₂ O ₅ , %	SiO ₂ , %	Fe Dist., %	TiO ₂ Dist., %	V ₂ O ₅ Dist., %
-2.0 + 1.0	31.82	20.2	2.8	0.21	31.8	31.53	32.46	40.94
-1.0 + 0.5	27.09	23.8	2.9	0.15	31.2	31.62	28.62	24.89
-0.5 + 0.315	11.08	21.5	2.6	0.13	33.4	11.68	10.49	8.82

Size Fraction, mm	Yield, %	Fe _{tot} , %	TiO ₂ , %	V ₂ O ₅ , %	SiO ₂ , %	Fe Dist., %	TiO ₂ Dist., %	V ₂ O ₅ Dist., %
-0.315 + 0.074	20.95	19.0	2.6	0.15	35.1	19.52	19.84	19.25
-0.074	9.06	12.7	2.6	0.11	37.8	5.65	8.58	6.11
TOTAL	100.00	20.4	2.7	0.16	33.0	100.00	100.00	100.00

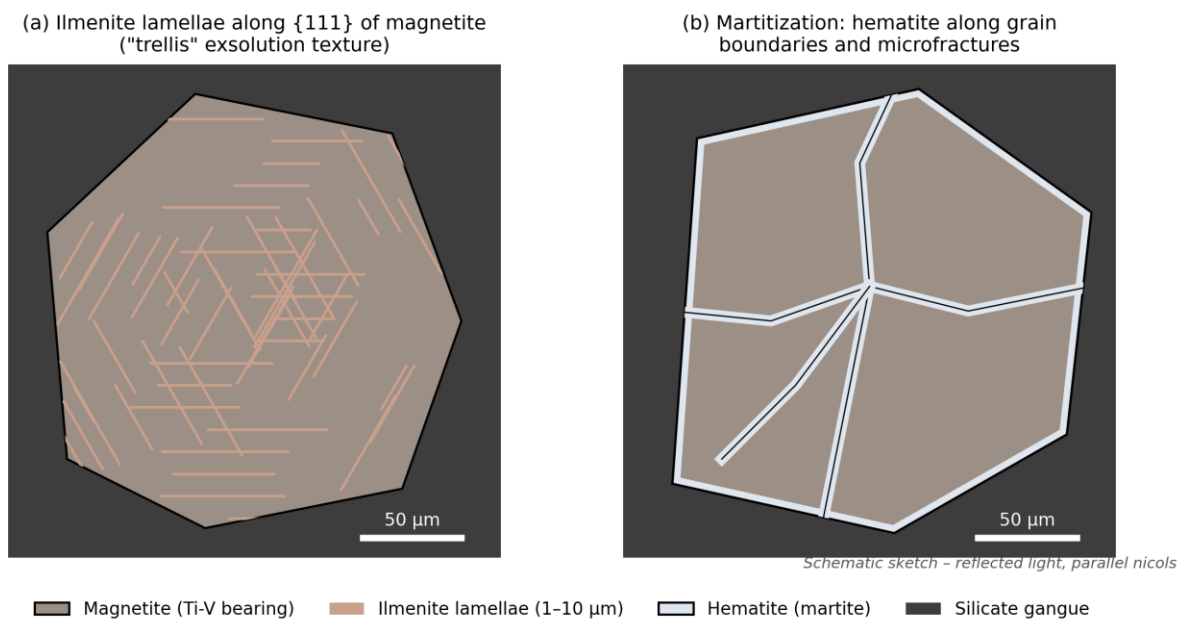
Table 5. Particle size distribution and component partitioning during dry screening of initial ore

Size Fraction, mm	Yield, %	Fe _{tot} , %	TiO ₂ , %	V ₂ O ₅ , %	SiO ₂ , %	Fe Dist., %	TiO ₂ Dist., %	V ₂ O ₅ Dist., %
-2.0 + 1.0	34.86	24.3	2.5	0.17	32.0	37.07	37.37	43.44
-1.0 + 0.5	30.08	24.8	2.2	0.14	33.3	32.64	28.37	30.86
-0.5 + 0.315	7.46	19.5	2.2	0.10	33.3	6.36	7.03	5.46
-0.315	27.61	19.8	2.3	0.10	35.2	23.92	27.23	20.23
TOTAL	100.00	22.9	2.33	0.14	33.4	100.00	100.00	100.00

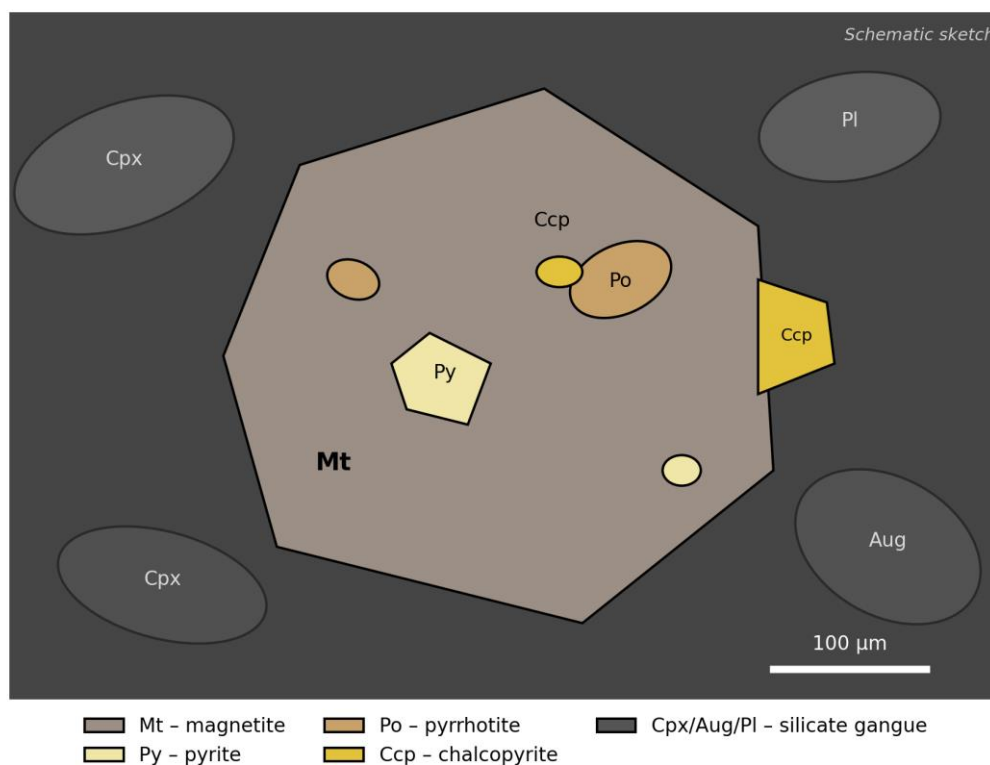
Analysis of the screening data establishes a fundamental metallurgical principle: during wet screening, the fine - 0.074 mm fraction accounts for 9.06% of the mass with a reduced iron content of 12.7% and elevated gangue concentrations (SiO₂ up to 37.8%, Al₂O₃ up to 7.2%). This indicates that brittle aluminosilicates and gangue minerals are selectively slimed under wet hydraulic shear, while valuable ore phases (magnetite, ilmenite) remain concentrated in the -2.0 to +0.074 mm classes. In dry screening, fine gangue dust adheres to coarse ore particles, distorting the apparent yield and impairing the selectivity of dry magnetic separation. Therefore, industrial flowsheets must incorporate wet hydraulic classification and hydrocycloning.

4. Mineralogical Analysis and Structural Intergrowth Patterns

Reflected-light optical microscopy of polished sections of magnetic (MF) and non-magnetic (NMF) fractions (under parallel nicols) revealed the crystallographic and microstructural origins of Tebinbulak ore refractoriness during physical beneficiation. The ore minerals are predominantly magnetite (Fe₃O₄), hematite (Fe₂O₃), and ilmenite (FeTiO₃), with subordinate sulfides (pyrite FeS₂, pyrrhotite Fe_{1-x}S, chalcopyrite CuFeS₂) intimately intergrown with silicate gangue (clinopyroxene, augite, plagioclase).



[Figure 3: Microstructure of magnetic fraction grains: crystallographically oriented solid solution exsolution with ilmenite lamellae hosted in magnetite and secondary hematite replacement (reflected light, parallel nicols)]



[Figure 4: Sulfide mineralization (inclusions of pyrite, pyrrhotite, and chalcopyrite in magnetite) and intergrowth relationships with gangue silicate minerals]

The key micromineralogical constraints are defined as follows:

1. Solid-solution exsolution textures: Magnetite grains exhibit fine micron- and submicron-scale lamellar and lenticular ilmenite segregations oriented strictly along the octahedral (111) crystallographic planes of the host magnetite lattice. This structure formed during magmatic cooling of a titanium-oversaturated melt. Because the thickness of these ilmenite lamellae ranges between 1 and 5–10 μm , physical liberation via mechanical grinding is practically impossible without extensive overgrinding and slimes generation.

2. Isomorphic vanadium substitution: Quantitative spectral and phase analyses confirm that trivalent vanadium (V^{3+} , ionic radius $r = 0.64 \text{ \AA}$) isomorphically substitutes for octahedral trivalent iron (Fe^{3+} , $r = 0.645 \text{ \AA}$) within the magnetite inverse spinel lattice. Vanadium does not form discrete mineral phases; hence, its physical

beneficiation is tied entirely to the magnetite concentrate.

3. Secondary oxidation (martitization): Secondary oxidation along grain boundaries and microfractures replaces magnetite with hematite (Fe_2O_3) and iron hydroxides. This causes a partial loss of magnetic susceptibility, causing oxidized iron to report to non-magnetic tailings.

5. Magnetic Beneficiation and Mineral Liberation Assessment

To investigate magnetic separation kinetics and define technological limits, each size fraction was subjected to magnetic separation using a covered hand magnet (simulating dry and wet regimes). The primary objective was to quantitatively determine the yields of magnetic (MF) and non-magnetic (NMF) fractions, the recoveries of iron, titanium, and vanadium, and the liberation degree across granulometric classes (Tables 6 and 7).

Table 6. Technological indicators of magnetic separation across size fractions of Tebinbulak ore

Size Class, mm	Fraction	Fraction Yield, %	Yield from Ore, %	Fe_tot, %	Fe Recovery, %
-2.0 + 1.0	MF	49.11	15.63	40.4	28.68
	NMF	50.89	16.20	8.1	5.96
-1.0 + 0.5	MF	48.30	13.09	39.0	23.18
	NMF	51.70	14.00	6.3	4.01
-0.5 + 0.315	MF	39.56	4.38	44.1	8.78
	NMF	60.44	6.69	7.5	2.28
-0.315 + 0.074	MF	29.84	6.25	50.9	14.45
	NMF	70.16	14.70	8.1	5.41
-0.074 + 0	MF	12.25	1.11	46.3	2.34
	NMF	87.75	7.95	13.6	4.91
TOTAL	MF + NMF	—	100.00	22.0	100.00

Table 7. Distribution of titanium, vanadium, and rock-forming oxides in magnetic separation products

-2.0 + 1.0	MF	40.4	11.4	5.0	1.10	5.3
	NMF	8.1	6.7	2.2	0.12	5.9

-1.0 + 0.5	MF	39.0	16.8	4.4	0.48	4.7
	NMF	6.3	5.5	1.0	0.08	3.2
-0.5 + 0.315	MF	44.1	17.6	4.8	0.51	2.9
	NMF	7.5	5.6	1.1	0.08	3.7
-0.315 + 0.074	MF	50.9	19.7	5.3	0.32	1.6
	NMF	8.1	6.0	1.7	0.05	4.2
-0.074 + 0	MF	46.3	17.3	4.6	0.24	2.6
	NMF	13.6	7.2	2.3	0.08	7.8
SAMPLE TOTAL	Average	22.0	9.9	2.95	0.33	4.6

Data in Tables 6 and 7 elucidate the mineral liberation dynamics across particle sizes:

In coarse fractions (-2.0+1.0 mm), the magnetic fraction yield is 49.11% with an Fe_{tot} content of 40.4%, indicating pervasive intergrowths of magnetite with host pyroxenes. As particle size is reduced to the optimal narrow range of -0.315+0.074 mm, the magnetic fraction yield declines to 29.84%, while the iron content sharply peaks at 50.9% Fe_{tot}, accompanied by a drop in gangue constituents (Al₂O₃ = 1.6%). Titanium dioxide in the magnetic concentrate reaches 5.0–5.3%, and vanadium pentoxide reaches 0.32–1.10%, experimentally corroborating that Ti and V report directly to the iron concentrate due to micro-structural intergrowths.

6. Thermodynamics and Kinetics of Electric Smelting Reduction: Inhibition of Titanium

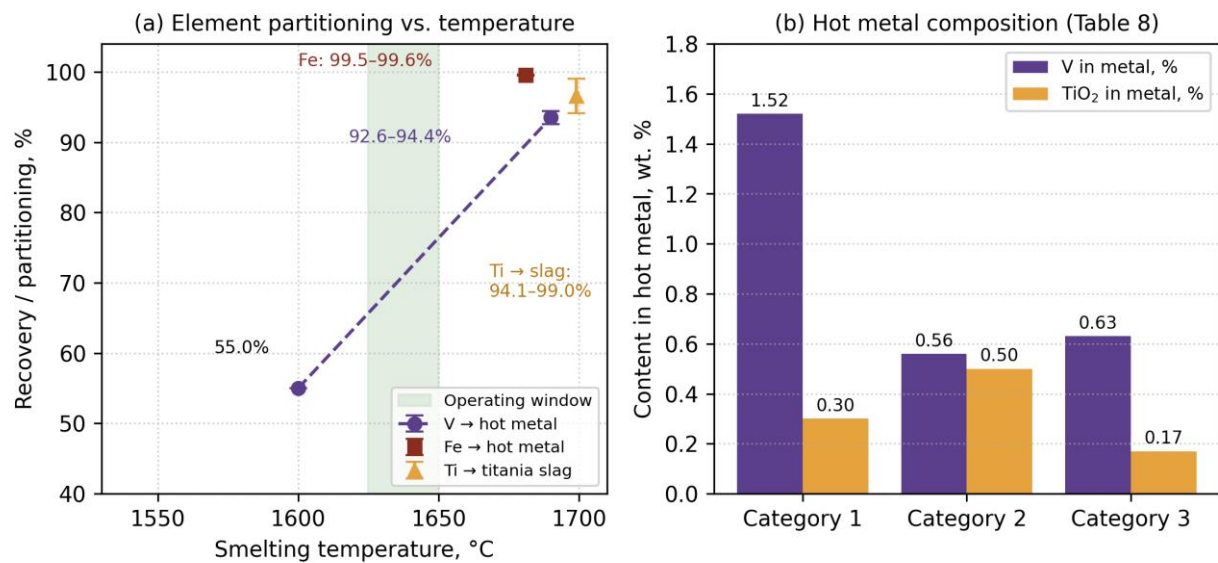
Carbide Formation

Directly smelting titanomagnetite concentrates in conventional blast furnaces leads to severe operational failure due to the reduction of TiO₂ into refractory titanium carbide and carbonitride phases (TiC melting point: 3140 °C), inducing high viscosity, slag foaming, and hearth accretion ('scaffolding'). To resolve this fundamental metallurgical barrier, recent thermodynamic simulations via FactSage and experimental smelting reduction studies of metallized pellets conducted by Z. Guo et al. (2025) were incorporated.

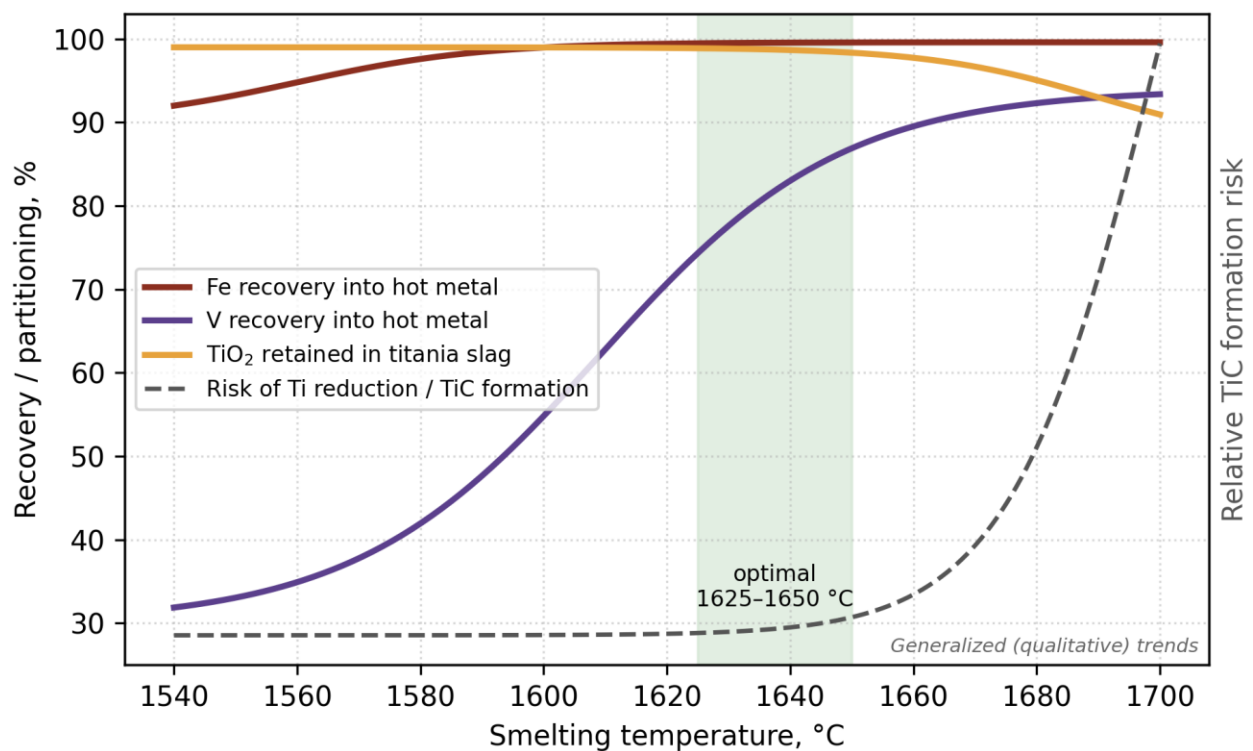
Investigating pellets across varying Ti/V grades at 1540–1690 °C demonstrated that strict temperature regulation and controlled slag-metal redox potential are decisive operational parameters.

Table 8. Chemical composition of the metallic hot metal phase obtained from pellet smelting reduction (after Z. Guo et al.)

Pellet Category	Fe, %	C, %	V, %	TiO ₂ , %	CaO, %	SiO ₂ , %	MgO, %	Al ₂ O ₃ , %	P, %	S, %
Category 1	95.06	2.49	1.52	0.30	0.026	0.20	0.014	0.011	0.015	0.016
Category 2	92.35	5.19	0.56	0.50	0.0034	0.44	0.035	0.040	0.029	0.023
Category 3	94.79	4.07	0.63	0.17	0.0036	0.16	0.013	0.0076	0.0078	0.017



[Figure 5: Experimental separation curves of elements during electric smelting reduction of metallized pellets: effect of temperature on Fe, V, and TiO₂ partitioning into hot metal and slag (Z. Guo et al.)]



[Figure 6: Generalized kinetic relationships of Fe and V partitioning into hot metal and selective TiO₂ concentration into commercial slag]

Smelting trials demonstrate that elevating electric furnace temperature from 1600 °C to 1690 °C causes vanadium recovery into hot metal to increase rapidly from 55.0% to 92.6–94.4%, while iron recovery reaches 99.5–99.6%. Crucially, titanium reduction into the liquid hot metal is effectively inhibited: residual TiO₂ in the metal does not exceed 0.17–0.50%, thereby entirely circumventing TiC precipitation. Concurrently, 94.1–99.0% of total titanium concentrates selectively into commercial titania slag containing 42–46% TiO₂. Extremely low levels of sulfur ($S \leq 0.023\%$) and phosphorus ($P \leq 0.029\%$) guarantee premium-grade vanadium-bearing hot metal.

7. Innovative Technologies for Vanadium Extraction from Converter Slags

Hot metal containing up to 1.52% V is transferred to an oxygen converter for selective devanadization at 1300–1380 °C. Due to vanadium's higher oxygen affinity relative to carbon, a spinel-type vanadium slag (FeO·V₂O₃) containing 12–18% V₂O₅ is formed. Conventional extraction routes utilize high-temperature sodium salt roasting ($T > 850\text{ °C}$) followed by ammonium salt precipitation ((NH₄)₂SO₄, NH₄Cl), generating hazardous ammonia-nitrogen wastewater and incurring high thermal costs.

To ensure environmental compliance and high yield, the Tebinbulak project incorporates the low-temperature synergistic co-roasting technology developed by Z. Li et al. (Chemical Engineering Science, 2026):

1. Low-temperature spinel lattice breakdown: Utilizing a binary sodium oxalate and sodium carbonate mixture (Na₂C₂O₄ : Na₂CO₃ = 3 : 7) lowers eutectic melting temperatures, enabling complete decomposition of the vanadium spinel structure at 750 °C (100 °C lower than conventional roasting).
2. Energy-efficient water leaching: Roasted calcine is leached in water at room temperature (70 °C lower than baseline processes) for 50 minutes, achieving 96.26% vanadium dissolution.

3. Superior selectivity and eco-efficiency: Co-dissolution of toxic chromium impurities is decreased by 16.51 percentage points. Ammonium salts are completely eliminated by hydrothermal precipitation at pH = 1.2 in the presence of 10 vol. % ethanol at 225 °C, recovering 99.08% of vanadium as pure VO₂, subsequently oxidized to commercial V₂O₅ at 98.73% purity.

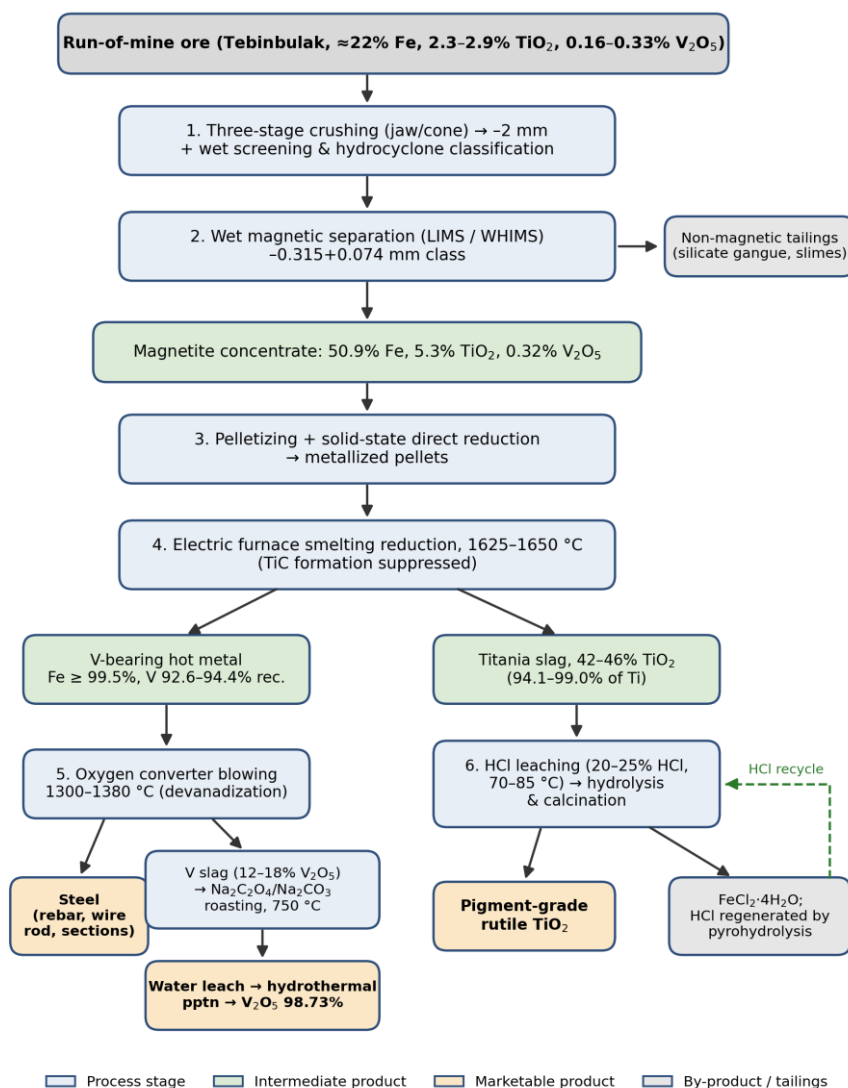
8. Hydrometallurgical Processing of Titania Slag and Pigment TiO₂ Production

Commercial titania slag (42–46% TiO₂) produced during electric furnace smelting serves as high-grade feedstock for pigment-grade titanium dioxide synthesis. According to comprehensive studies by G. Maldybayev et al. (Minerals Engineering, 2023), controlling the CaO/MgO basicity ratio during reduction smelting is essential to direct titanium crystallization into anosovite solid solutions (Ti₃O₅), which exhibit superior acid-leaching reactivity.

For the extraction of titanium from Tebinbulak slags, hydrochloric acid hydrometallurgy, as investigated by C. L. Lopano et al. (Hydrometallurgy, 2022) at the US National Energy Technology Laboratory (NETL), offers optimal efficiency. Leaching kinetics in concentrated hydrochloric acid (20–25% HCl) at moderate temperatures (70–85 °C) are chemically reaction-controlled, yielding 91–94% dissolution of titanium and associated critical metals. Upon cooling, iron selectively crystallizes as ferrous chloride tetrahydrate (FeCl₂·4H₂O), while titanium in the purified filtrate is hydrolyzed and calcined into high-grade rutile pigment TiO₂. Spent hydrochloric acid is completely regenerated via pyrohydrolysis, ensuring closed-loop reagent recycling.

9. Comprehensive Principal Flowsheet for Zero-Waste Beneficiation

Integrating analytical, thermodynamic, and metallurgical findings yields an end-to-end flowsheet for Tebinbulak ore processing (Figure 7).



[Figure 7: Comprehensive principal equipment and technological flowsheet for slime-free integrated recovery of Fe, V, and Ti from Tebinbulak ores]

The integrated flowsheet comprises: 1) Ore preparation with 3-stage crushing and wet classification; 2) Wet low- and high-intensity magnetic separation (LIMS/WHIMS) producing high-grade magnetite concentrate (50.9% Fe); 3) Pelletizing and solid-state direct reduction to metallized pellets; 4) Electric furnace smelting at 1625–1650 °C with phase partitioning into vanadium-bearing hot metal and titania slag; 5) Oxygen converter blowing to produce refined steel and vanadium slag, treated via low-temperature roasting and hydrothermal precipitation to yield V₂O₅ (98.73% purity); 6) Hydrochloric acid leaching of titania slag with acid pyrohydrolysis regeneration, producing pigment-grade rutile TiO₂.

10. Conclusions and Scientific-Practical

Recommendations

1. The Tebinbulak titanomagnetite deposit in Karakalpakstan, with on-balance reserves of ~2.0 billion tons of ore, represents a tier-one strategic asset capable of securing the metallurgical independence of the Republic of Uzbekistan in steel, titanium, and vanadium for over 50 years.

2. Mineralogical and process investigations confirmed that submicron exsolution textures (1–10 μm ilmenite lamellae in magnetite) and lattice-bound vanadium preclude complete physical liberation via flotation or gravity separation. Optimal beneficiation requires wet screening and magnetic separation yielding a -

0.315±0.074 mm concentrate grading 50.9% Fe_{tot}, 5.3% TiO₂, and 0.32% V₂O₅.

3. Thermodynamic and experimental evaluations validate electric furnace smelting reduction of metallized pellets at 1625–1650 °C, ensuring 99.5% iron and 92.6–94.4% vanadium recovery into hot metal, eliminating refractory carbide (TiC) formation, and partitioning 94.1–99.0% of titanium into a 42–46% TiO₂ slag.

4. Integrating low-temperature co-roasting with Na₂C₂O₄/Na₂CO₃ (750 °C) and ammonia-free hydrothermal precipitation provides >96% vanadium recovery with 98.73% V₂O₅ purity, while hydrochloric acid hydrometallurgical refining of titania slag achieves high-purity pigment TiO₂ with complete reagent regeneration.

References

1. Decree of the President of the Republic of Uzbekistan No. UP-4947 dated February 7, 2017, 'On the Action Strategy for Further Development of the Republic of Uzbekistan.'
2. Resolution of the President of the Republic of Uzbekistan No. PP-4124 dated January 17, 2019, 'On Measures for Further Improvement of the Mining and Metallurgical Industry.'
3. Report of the State Enterprise 'Scientific Research Institute of Mineral Resources': 'Technological Studies of Titanomagnetite Ore from the Tebinbulak Deposit.' Tashkent, 2014.
4. Guo, Z. Q., Chen, X., Shi, Y., Zhu, D. Q., Pan, J., Yang, C. C., Li, S. W., Xu, J. W., & Wang, X. (2025). Smelting separation behaviors of various reduced vanadium titanomagnetite pellets. Transactions of Nonferrous Metals Society of China. DOI: 10.1016/S1003-6326(25)66918-4.
5. Maldybayev, G., Korabayev, A., Sharipov, R., Al Azzam, K. M., Negim, E.-S., Baigenzhenov, O., Alimzhanova, A., Panigrahi, M., & Shayakhmetova, R. (2023). Processing of titanium-containing ores for the production of titanium products: A comprehensive review. Minerals Engineering, 203, 108492. DOI: 10.1016/j.mineng.2023.108492.
6. Lopano, C. L., Stuckman, M., Bank, T., Verba, C., & Free, M. L. (2022). Extraction kinetics and recovery of titanium and critical elements from complex oxide minerals using concentrated hydrochloric acid systems. Hydrometallurgy, 211, 105884. DOI: 10.1016/j.hydromet.2022.105884.
7. Nikolaeva, N. V., Alexandrova, T. N., & Afanasova, A. V. (2023). Processing of titanium-magnetite ores with extraction of titanium and vanadium. Journal of Mining Institute (Zapiski Gornogo Instituta), 261, 448–458. DOI: 10.31897/PMI.2023.63.
8. Li, Z., Li, C., Jiang, T., Wen, J., An, X., & Zhang, L. (2026). Clean vanadium extraction from vanadium slag via low-temperature co-roasting with sodium oxalate and sodium carbonate. Chemical Engineering Science, 301, 125096. DOI: 10.1016/j.ces.2026.125096.
9. Gazeta.uz News Agency. (2019, August 21). Visit of the President of the Republic of Uzbekistan to Karakalpakstan: The Mining and Metallurgical Complex Project Based on Tebinbulak. <https://www.gazeta.uz/ru/2019/08/21/tebinbulak/>
10. Kommersant.uz Business Portal. A mining and metallurgical complex will be established at the Tebinbulak deposit. <https://kommersant.uz/na-baze-mestorozhdeniya-tebinbulak-poyavitsya-gorno-metallurgicheskij-kompleks/>