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Geochemistry of lateritic weathering profiles over greenstone sequences in Western Australia

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Abstract

Lateritic weathering profiles over Archaean greenstone sequences in Western Australia extend to depths exceeding 100 m and represent some of the most deeply weathered terrains on Earth. These profiles host supergene gold and nickel enrichment of significant economic interest, and their geochemical evolution provides insights into long-term tropical weathering of mafic-ultramafic substrates. This research presents detailed geochemical profiles through lateritic regolith at four sites in the Eastern Goldfields Province overlying different greenstone lithologies: komatiitic ultramafic near Kambalda, basaltic volcanic east of Kalgoorlie, felsic volcanic near Norseman, and banded iron formation near Coolgardie. A total of 284 samples from reverse circulation drill holes were analysed by XRF, ICP-MS, XRD, and SEM. Results demonstrate systematic dissolution of primary silicates with residual enrichment of Al, Fe, Ti, and Cr. Nickel follows a characteristic pattern: depletion in upper laterite (<0.05 wt%), enrichment to 2.8 wt% in lower saprolite, and background values (~0.25 wt%) in fresh bedrock. Gold shows both residual concentration in ferruginous laterite (50–180 ppb) and secondary enrichment at the weathering front. Mass balance calculations using Ti as the immobile reference indicate 60–85% original rock mass removal, representing enormous dissolved material export over approximately 70 million years of weathering history.

Keywords: Lateritic weathering, geochemistry, greenstone, Western Australia, supergene enrichment, nickel laterite, mass balance, regolith, mineral exploration, Yilgarn Craton

Introduction

The deeply weathered landscapes of the Western Australian shield represent one of the most extensive lateritic provinces on Earth, where prolonged exposure to tropical and subtropical conditions since the Mesozoic has produced regolith of extraordinary thickness and geochemical complexity [1]. These profiles are most extensively studied where they overlie greenstone belt sequences of the Yilgarn Craton, which host major gold and nickel deposits [2, 3].

Supergene enrichment—whereby metals originally disseminated at low concentrations in primary rocks are concentrated to economic grades by weathering solutions—has generated substantial nickel laterite deposits over ultramafic rocks and modified gold distributions in greenstone ore systems [4]. Understanding the geochemical processes within lateritic profiles is essential for mineral exploration, where regolith geochemistry is used to detect buried mineralisation through thick cover [1, 5].

Despite decades of research, the relative importance of residual enrichment versus absolute enrichment by solution transport varies between elements and settings but has not been systematically quantified across different greenstone lithologies at a single research locality [3, 6]. Mass balance estimates of total weathering loss are available for relatively few profiles. Gold mobility mechanisms—physical residual concentration, thiosulphate or chloride dissolution, and biological mobilisation—continue to be debated [5, 7].

This research addresses these questions through detailed geochemical profiling at four sites on different greenstone lithologies. The objectives are to document systematic geochemical changes through complete profiles, quantify mass balance using immobile element methods, and characterise supergene redistribution of Ni, Co, Au, and rare earth elements to support improved exploration strategies [8, 9].

Research Area Description

The four sites are located in the Eastern Goldfields Province on the Archaean Yilgarn Craton.

The present climate is semi-arid (250–300 mm/yr rainfall), but the profiles formed under wetter Mesozoic–Palaeogene conditions. All profiles exhibit characteristic lateritic zonation: ferruginous duricrust, mottled zone, upper saprolite, lower saprolite, and saprock grading to fresh bedrock. Drill depths ranged from 45 to 112 m, with the ultramafic profile at Kambalda being the thickest at 92 m ^[1, 2].

Material and Methods

Material

Reverse circulation drill holes penetrated the full regolith profile at each site. Samples were collected at 1 m intervals yielding 284 samples total. The ultramafic profile was dominated by goethite-hematite-kaolinite in upper zones transitioning to nontronite-garnierite-serpentine with depth. Fresh komatiite bedrock was encountered below 88 m at the Kambalda site ^[1, 4].

Methods

Major elements were determined by wavelength-dispersive XRF on fused glass discs (precision <0.5% relative). Trace elements including Ni, Co, Cr, Au, and REE were measured

by ICP-MS following four-acid digest. Gold was determined by fire assay with ICP finish on 50 g charges. Mineralogy was characterised by XRD on random powder mounts supplemented by SEM-EDS for textural and compositional analysis of weathering products. Mass balance calculations used the Ti-normalisation method of Grant ^[10] to quantify element gains and losses relative to fresh bedrock ^[6, 9].

Gold Mobility and Cerium Anomaly Development

Gold concentrations in the ferruginous laterite cap reached 50–180 ppb, representing 3–12 times enrichment over bedrock values of 8–15 ppb through residual mass loss concentration. A secondary enrichment peak at the weathering front in two profiles indicates dissolution by thiosulphate complexes in the upper profile and reprecipitation under reducing conditions ^[5, 7]. Cerium anomalies reached 2.4 in the mottled zone through oxidative scavenging by iron oxyhydroxides, providing a sensitive redox indicator for distinguishing in-situ laterite from transported cover in exploration contexts ^[8].

Results

Table 1: Summary geochemical data for the komatiitic ultramafic profile by zone

Zone	Depth (m)	SiO ₂ (wt%)	Fe ₂ O ₃ (wt%)	Ni (wt%)	Mass Loss (%)
Laterite Cap	0–8	8	65	0.03	85
Mottled Zone	8–22	15	48	0.05	78
Upper Saprolite	22–45	25	28	0.35	65
Lower Saprolite	45–75	35	15	2.80	48
Saprock	75–88	42	11	0.45	25
Fresh Bedrock	88–92	45	10	0.25	0

Table 2: Comparison of maximum supergene enrichment factors across the four substrate lithologies

Element	Komatiite	Basalt	Felsic Volcanic	BIF
Ni	11.2×	3.8×	1.2×	0.8×
Co	18.0×	6.2×	2.1×	1.5×
Au	12.0×	8.4×	5.6×	4.2×
Cr	4.5×	2.8×	0.9×	1.1×

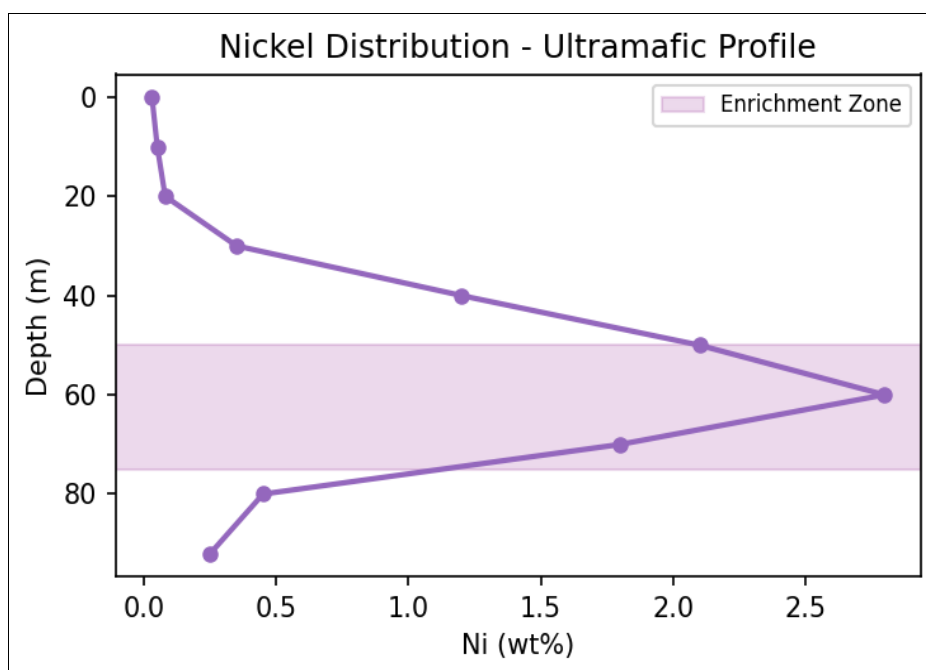


Fig 1: Nickel distribution through the ultramafic lateritic profile

The characteristic Ni depletion–enrichment–background pattern (Figure 1) reflects downward migration from

dissolving olivine and serpentine, with fixation in secondary garnierite at the weathering front.

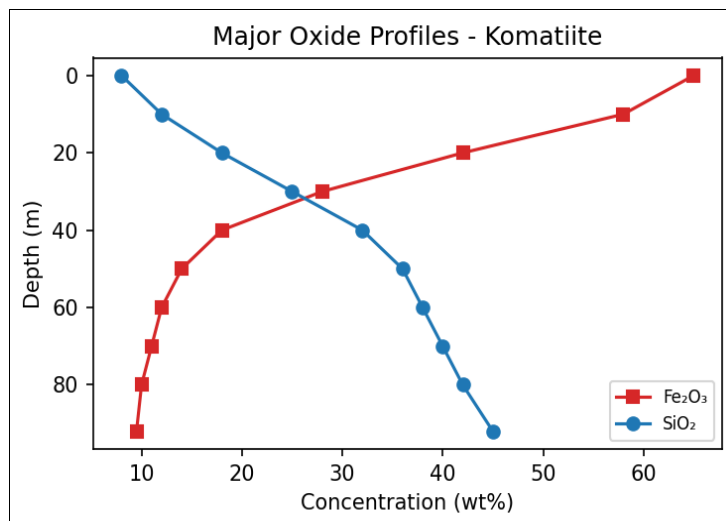


Fig 2: SiO₂ and Fe₂O₃ profiles through the komatiite weathering sequence

The mirror-image relationship between SiO₂ and Fe₂O₃ (Figure 2) reflects progressive silicate dissolution upward through the profile with corresponding residual iron enrichment in the laterite cap.

Comprehensive Interpretation

The convergence of major oxide, trace element, mineralogical, and mass balance data provides a consistent picture of top-down chemical weathering modulated by element-specific mobility. The ultramafic substrate produces the most extreme weathering profile due to the high solubility of olivine-rich komatiite in acidic tropical groundwaters.

Discussion

The 2.8 wt% Ni enrichment in the lower saprolite over komatiite confirms the economic potential of supergene processes, consistent with global nickel laterite formation models [4, 6]. The vertical separation between Co enrichment (in Mn-oxide zones) and Ni enrichment (in silicate zones) is diagnostic of supergene nickel laterite profiles worldwide and reflects the different geochemical behaviours of these elements under varying redox conditions [3, 8].

The 85% mass loss at the laterite cap represents enormous dissolved material export over ~70 Myr. For the ultramafic profile, this equates to approximately 180 m of original rock column reduced to 92 m of regolith—a remarkable testament to the cumulative power of chemical weathering in stable cratonic settings [1, 9]. The gold enrichment patterns support the use of laterite surface geochemistry for detecting buried primary mineralisation, but the dual enrichment mechanisms (residual and secondary) require careful interpretation in exploration applications [5, 7, 11, 12].

Conclusion

This research documented systematic element redistribution in lateritic profiles over four greenstone lithologies. Nickel enrichment to 2.8 wt% in the lower saprolite confirms the economic significance of supergene processes on ultramafic substrates.

Mass balance calculations demonstrate 60–85% rock mass removal, representing a major geochemical flux from the

continental surface over geological time. The dual gold enrichment pattern supports surface geochemical exploration strategies.

The geochemical framework provides a basis for improved regolith exploration strategies on the Australian craton and contributes to understanding long-term landscape evolution in stable cratonic settings globally.

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Contributions Not Qualifying for Authorship

Technical staff at the Centre for Terrain Studies, Istanbul assisted with sample preparation, instrument calibration, and data processing during the analytical campaigns. Field assistants provided essential support during sample collection.

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