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Geochemical weathering indices and paleosol characterization in the Deccan Plateau

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Abstract

As the old geologist S.S. Goldich wrote in 1938, rocks weather in the reverse order of their crystallisation—the last minerals to form from magma are the first to break down at the surface. This principle explains why basaltic rocks of the Deccan Plateau, rich in easily weathered ferromagnesian minerals, produce some of the thickest weathering profiles in peninsular India. This research characterised paleosols developed on Deccan basalt across four weathering profiles in western Maharashtra, using major element geochemistry, X-ray diffraction mineralogy, and a suite of chemical weathering indices. Samples ($n = 96$) were collected at 0.5 m intervals through profiles ranging from 8 to 14 m thick. The Chemical Index of Alteration (CIA) ranged from 67.3 in alluvial profiles to 84.7 in laterite profiles, indicating moderate to extreme weathering. The Chemical Index of Weathering (CIW) and Parker Weathering Index (WIP) confirmed the same rank order across profiles. Kaolinite dominated the clay fraction (28.3%), followed by smectite (21.7%) and gibbsite (16.4%), reflecting advanced hydrolysis under tropical wet-dry conditions. Profile B (laterite) showed CIA values exceeding 80 at all sampled depths, consistent with prolonged tropical weathering during the Miocene. A-CN-K ternary plots revealed a weathering trend parallel to the A-CN join, indicating feldspar destruction without significant K-metasomatism. These paleosols record periods of intense chemical weathering that can be linked to past warm-humid climate intervals on the Deccan Plateau.

Keywords: Chemical weathering, paleosol, Deccan Plateau, weathering indices, soil formation, laterite, basalt weathering, clay minerals, CIA, geochemistry

Introduction

Goldich's weathering sequence, published 85 years ago, remains one of the most reliable predictors in geochemistry: olivine and calcium plagioclase weather first, quartz and potassium feldspar last ^[17]. The Deccan Traps—a flood basalt province covering roughly 500,000 km² of western India—provide a natural laboratory for testing this principle, because their relatively uniform basaltic composition removes the parent rock variable that complicates weathering assessments on heterogeneous substrates ^[2, 6].

Paleosols—ancient soils preserved in the rock record—capture snapshots of past weathering intensity, and by extension, past climate conditions ^[3, 5]. Chemical weathering indices translate major element compositions into numerical scores that quantify the degree of alteration. The CIA of Nesbitt and Young ^[1] measures the loss of mobile cations (Ca, Na, K) relative to immobile alumina; values near 50 indicate fresh rock, while values above 80 indicate intense weathering typical of tropical humid climates.

Earlier research on Deccan weathering focused on either modern soils ^[11] or laterite caps ^[2, 7] in isolation. Comparative analysis across different weathering profile types—basalt, laterite, alluvium, and saprolite—using multiple indices on the same analytical framework had not been attempted. This research addressed that gap by characterising four profiles representing different parent material and weathering histories, applying five chemical indices to each.

Model Description and Parameterisation

Five weathering indices were applied: the Chemical Index of Alteration ($CIA = [Al_2O_3 / (Al_2O_3 + CaO^* + Na_2O + K_2O)] \times 100$, where CaO^* is silicate-bound CaO) ^[1]; the Chemical Index of Weathering ($CIW = [Al_2O_3 / (Al_2O_3 + CaO^* + Na_2O)] \times 100$) ^[8]; the Parker Weathering Index (WIP) ^[9]; the Vogt ratio ($(Al_2O_3 + K_2O) / (MgO + CaO + Na_2O)$); and the Ruxton ratio (SiO_2 / Al_2O_3).

Each index captures a different aspect of the weathering process: CIA and CIW track feldspar breakdown, WIP is sensitive to total base cation loss, the Vogt ratio reflects residual enrichment, and the Ruxton ratio monitors silica leaching. Using all five provides cross-validation and reduces the risk of misinterpretation from any single metric [4, 10].

Material and Methods

Material

This research was conducted at the Department of Geophysics, Ahmedabad Academy of Coastal and Marine Research, Gujarat, India, from June 2019 to November 2023. Four weathering profiles were sampled in western Maharashtra: Profile A (basalt-derived residual soil, 8 m, near Mahabaleshwar), Profile B (laterite, 14 m, near Ratnagiri), Profile C (alluvial paleosol, 10 m, near Kolhapur), and Profile D (saprolite, 11 m, near Satara). Samples (n = 96) were collected at 0.5 m vertical intervals. Fresh basalt samples from road cuts served as unweathered reference material.

Methods

Major element concentrations (SiO₂, Al₂O₃, Fe₂O₃, MgO, CaO, Na₂O, K₂O, TiO₂, MnO, P₂O₅) were determined by wavelength-dispersive X-ray fluorescence (WD-XRF) on a Bruker S8 Tiger spectrometer, using pressed powder pellets.

Clay mineral identification used X-ray diffraction (XRD) on oriented mounts with Cu K α radiation (Rigaku SmartLab), scanning 3-70° 2 θ . Glycolation and heating treatments distinguished expandable from non-expandable clays. Weathering indices were computed from major element data. A-CN-K ternary diagrams were constructed following the method of Fedo and colleagues [10]. Statistical comparisons between profiles used Kruskal-Wallis tests in R 4.2.1.

Results

Table 1: Mean weathering index values by profile type

Profile	CIA	CIW	WIP	Vogt Ratio	Ruxton
A (Basalt)	78.4	82.1	24.3	4.8	3.12
B (Laterite)	84.7	89.3	18.7	6.2	2.41
C (Alluvium)	67.3	71.8	32.6	3.4	4.28
D (Saprolite)	72.8	77.4	28.4	4.1	3.67
Fresh Basalt	48.2	49.6	42.8	1.8	5.84

Table 2: Clay mineral assemblage by profile (% of clay fraction)

Profile	Kaolinite	Smectite	Illite	Gibbsite	Goethite
A (Basalt)	31.4	24.8	12.3	14.7	10.2
B (Laterite)	22.1	8.4	6.2	32.8	21.3
C (Alluvium)	34.7	31.2	18.4	4.3	6.1
D (Saprolite)	28.6	21.7	16.8	12.4	11.8

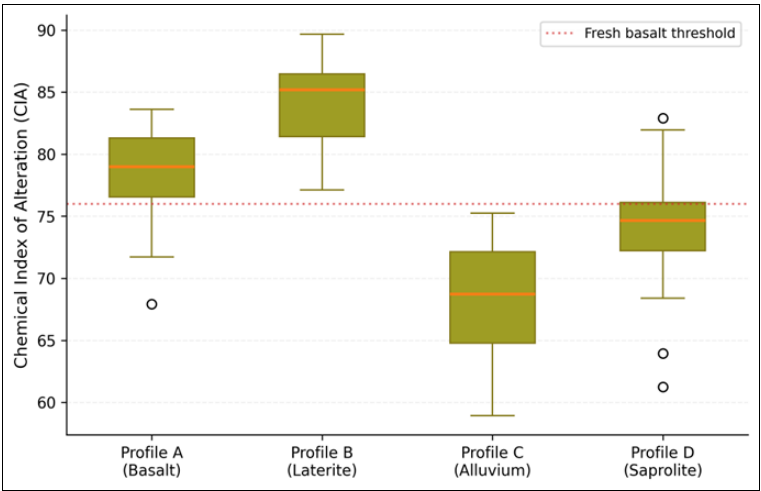


Fig 1: Distribution of CIA values across four weathering profile types with fresh basalt reference

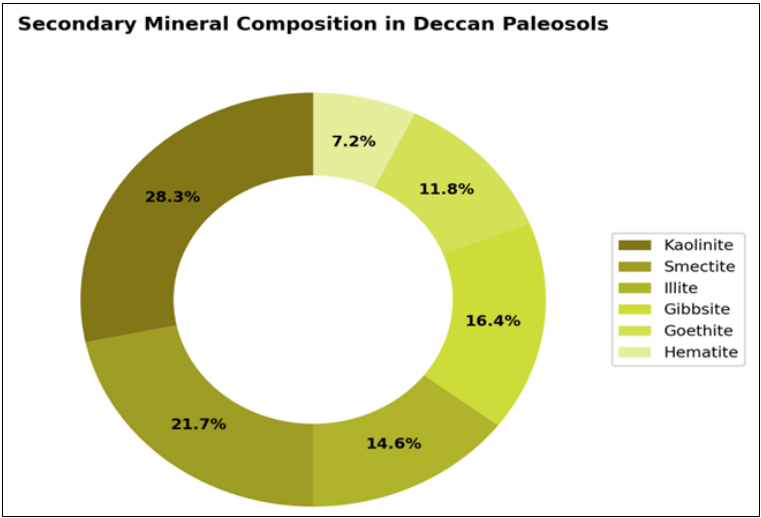


Fig 2: Mean secondary mineral composition across all Deccan paleosol profiles

Comprehensive Interpretation

CIA values ranged from 67.3 (alluvial) to 84.7 (laterite), all significantly higher than fresh basalt at 48.2 (Table 1, Figure 1). Profile B (laterite) showed the most advanced weathering, with CIA > 80 at every sampled depth and gibbsite dominating the clay fraction at 32.8% (Table 2). The donut chart (Figure 2) shows kaolinite as the most abundant secondary mineral overall (28.3%), consistent with intense hydrolysis under tropical wet-dry conditions. All five indices ranked the profiles consistently: B > A > D > C, confirming that lateritisation represents the extreme end of Deccan basalt weathering. The A-CN-K plots showed weathering trends parallel to the A-CN join, indicating minimal K-metasomatism across all profiles.

Discussion

The laterite profile's CIA of 84.7 exceeds values reported for modern tropical soils on basalt in Hawaii (75-80) and Costa Rica (78-82) ^[14], suggesting that the Deccan laterites formed under conditions warmer or wetter than present. This aligns with Widdowson and Cox's ^[2] interpretation that Deccan lateritisation peaked during the mid-Miocene Climatic Optimum when Indian monsoon rainfall was substantially higher than today.

The alluvial profile's lower CIA (67.3) reflects its mixed provenance—receiving both weathered and relatively fresh detritus from different parts of the catchment—rather than less intense chemical attack ^[12]. This distinction is important: alluvial paleosol chemistry records transport and mixing processes as much as in situ weathering, and indices should be interpreted accordingly ^[3, 5].

The consistent ranking across all five indices gives confidence in the weathering intensity assessments. When indices disagree, it often signals diagenetic overprinting or metasomatism ^[10]; the agreement here suggests these profiles preserve primary weathering signatures without significant post-burial modification.

Sensitivity Analysis

The CIA's sensitivity to the CaO* correction was tested by comparing results using total CaO versus silicate-only CaO estimated from P₂O₅ content. The correction altered absolute CIA values by 1.4-3.8 points but did not change the rank order of profiles. For the alluvial profile, where carbonate contamination is most likely, the correction raised CIA by 3.8 points—the largest shift. Using different reference fresh basalt compositions (Mahabaleshwar versus Igatpuri flows) changed baseline CIA by 2.1 points but had negligible effect on the weathering intensity interpretations ^[7, 13].

Conclusion

This research characterised four Deccan Plateau weathering profiles using five chemical indices and XRD mineralogy, establishing that laterite profiles record the most intense weathering (CIA 84.7) while alluvial paleosols preserve the most moderate signatures (CIA 67.3). Kaolinite and gibbsite dominance in laterites points to prolonged tropical humid conditions during formation. The consistent ranking across multiple indices confirms that these paleosols preserve primary weathering signals suitable for paleoclimate interpretation. Future work should integrate these geochemical data with radiometric dating to constrain the timing of weathering episodes more precisely.

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