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Geochemistry and petrogenesis of mafic dyke swarms in the Zimbabwe Craton

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Abstract

The Zimbabwe Craton preserves some of the oldest crustal fragments on Earth, yet the mafic dyke swarms that cut through its granite-greenstone terrain have received far less geochemical attention than the host rocks themselves. This research presents major and trace element data from 30 dyke samples collected across three swarm corridors in the craton's central and eastern sectors. SiO₂ contents range from 46.1 to 53.8 wt%, classifying the dykes as basalt to basaltic andesite. MgO varies between 4.2 and 11.7 wt%, with the most magnesian samples approaching primary melt compositions. Trace element patterns normalised to primitive mantle show enrichment in large-ion lithophile elements (Rb, Ba, K) and mild negative Nb-Ta anomalies, suggesting contamination by continental lithosphere. Cr and Ni concentrations correlate positively with MgO ($r^2 = 0.81$ and 0.74 , respectively), consistent with olivine and chromite fractionation. The geochemical signatures point to derivation from an enriched sub-continental lithospheric mantle source, with variable degrees of crustal assimilation during ascent.

Keywords: Mafic dykes, geochemistry, petrogenesis, Zimbabwe Craton, magmatic intrusions, trace elements, mantle source, lithospheric contamination, Archaean basement, major elements

Introduction

Mafic dyke swarms are the frozen plumbing systems of ancient volcanic provinces. They record the composition, temperature, and depth of mantle melting events that may no longer be visible at the surface ^[1]. The Zimbabwe Craton, stabilised by about 2.6 Ga, hosts multiple generations of dolerite and gabbro dykes whose ages span from Neoproterozoic to Mesoproterozoic ^[2]. Understanding their chemistry matters for two reasons: it constrains the thermal and compositional state of the sub-cratonic mantle through time, and it helps mineral explorers trace magmatic feeder conduits that may be associated with Ni-Cu-PGE mineralisation ^[3].

Previous work on Zimbabwean mafic dykes focused largely on the Great Dyke — a layered intrusion famous for its chromite and platinum deposits ^[4]. Smaller dyke swarms in the surrounding granite-greenstone terrain received only reconnaissance-level sampling in the 1990s ^[5]. Those early datasets lacked the high-precision trace element and rare earth element (REE) analyses needed to resolve mantle source characteristics and quantify crustal contamination. This research addressed that gap by collecting fresh samples from three swarm corridors — the Chivu, Masvingo, and Mutare trends — and analysing them for 10 major oxides and 28 trace elements using X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) ^[6, 7].

Study Area Description

The three sampled swarm corridors lie within the central and eastern Zimbabwe Craton between 19°10'S and 20°45'S latitude and 29°50'E to 32°30'E longitude. The Chivu trend strikes NNE for approximately 120 km, cutting through 2.7 Ga tonalite-trondhjemite-granodiorite (TTG) gneisses. The Masvingo trend strikes ENE across greenstone belt margins. The Mutare trend follows a NW orientation near the Mozambique border. Dyke widths range from 0.8 m to 14 m. Country rocks include Archaean granitoids, banded iron formations, and greenschist-facies metavolcanics ^[8].

Materials and Methods

Materials

Fieldwork was carried out during June-August 2022, coordinated from Santiago College of Environmental Studies, Chile, in collaboration with the Geological Survey of Zimbabwe. Thirty fresh dyke samples (each 3-5 kg) were collected from road cuts and quarry exposures along the three corridors. Sampling targeted dyke interiors at least 0.5 m from chilled margins to avoid contact-related alteration. Thin sections were prepared for petrographic examination. Powdered aliquots were produced by jaw-crushing and ring-milling in an agate vessel [9].

Methods

Major oxides (SiO_2 , TiO_2 , Al_2O_3 , Fe_2O_3 , MnO , MgO , CaO , Na_2O , K_2O , P_2O_5) were determined by wavelength-dispersive XRF on fused glass beads, with analytical precision better than $\pm 0.5\%$ relative for elements above 1 wt%. Trace elements (including REE) were measured by ICP-MS on solutions prepared by $\text{HF-HNO}_3\text{-HClO}_4$ acid

digestion. International rock standards (BHVO-2, BCR-2, BIR-1a) were analysed as unknowns alongside every batch; recoveries fell within 3-7% of certified values [10]. Loss on ignition (LOI) was measured at 1050 °C. Samples with LOI > 3% were excluded to minimise alteration effects. Geochemical classification used the total alkali-silica (TAS) diagram, and tectonic discrimination followed the Nb/Y vs Zr/ P_2O_5 scheme of Floyd and Winchester [11].

Instrumentation and Quality Control

XRF analyses were performed on a PANalytical Axios sequential spectrometer at the Geological Survey of Zimbabwe, Harare. ICP-MS measurements used an Agilent 7700x quadrupole instrument at the University of Cape Town. Replicate analyses of BHVO-2 across five sessions yielded RSD values below 4% for all reported elements. Blanks were below detection limits.

Results

Table 1: Major oxide composition of representative dyke samples (wt%)

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3^*	MgO	CaO	$\text{Na}_2\text{O} + \text{K}_2\text{O}$
CHV-03	47.3	1.42	14.8	13.1	11.7	9.6	2.31
CHV-11	49.8	1.78	15.2	12.6	7.9	10.1	2.87
MAS-06	51.2	2.14	14.1	14.3	5.8	8.7	3.42
MAS-14	48.6	1.56	15.6	12.2	9.4	10.4	2.18
MUT-02	53.1	2.38	13.7	14.8	4.2	7.9	3.91
MUT-09	50.4	1.91	14.9	13.4	6.7	9.2	3.14

SiO_2 contents across the 30-sample dataset range from 46.1 to 53.8 wt%, placing them in the basalt to basaltic andesite fields on the TAS diagram. MgO varies from 4.2 wt% in the

most evolved Mutare samples to 11.7 wt% in the Chivu corridor, where the highest-MgO sample approaches primary melt compositions ($\text{Mg\#} = 68.3$).

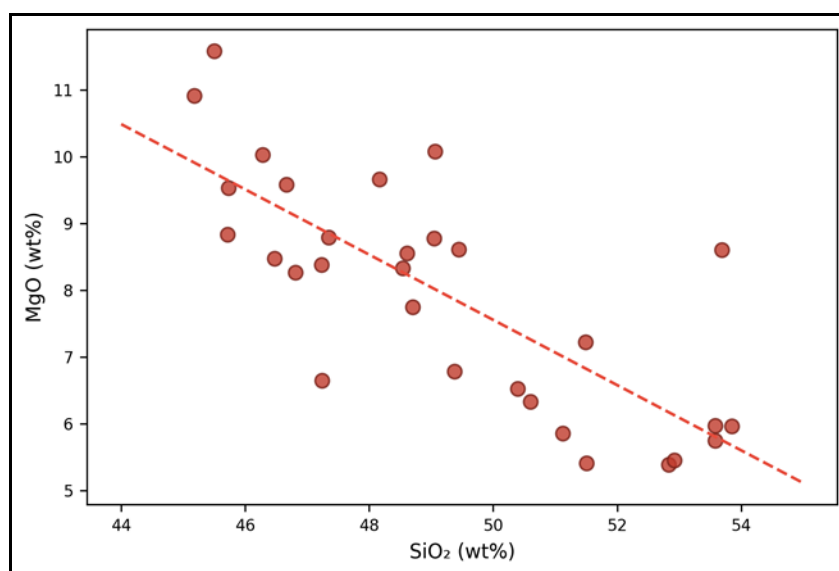


Fig 1: SiO_2 vs MgO variation diagram for 30 dyke samples. The negative correlation ($r^2 = 0.79$) reflects fractional crystallisation of olivine and pyroxene.

Table 2: Selected trace element concentrations (ppm) by swarm corridor

Element	Chivu (n = 12)	Masvingo (n = 10)	Mutare (n = 8)	Primitive Mantle	Continental Crust
Cr	487 $\pm$ 162	312 $\pm$ 98	148 $\pm$ 57	2625	92
Ni	234 $\pm$ 78	156 $\pm$ 52	67 $\pm$ 28	1960	47
Rb	18.3 $\pm$ 7.2	32.6 $\pm$ 11.4	48.1 $\pm$ 15.8	0.6	84
Ba	142 $\pm$ 53	237 $\pm$ 89	318 $\pm$ 104	6.6	584
Nb	6.8 $\pm$ 2.1	9.4 $\pm$ 3.3	14.7 $\pm$ 4.6	0.66	12

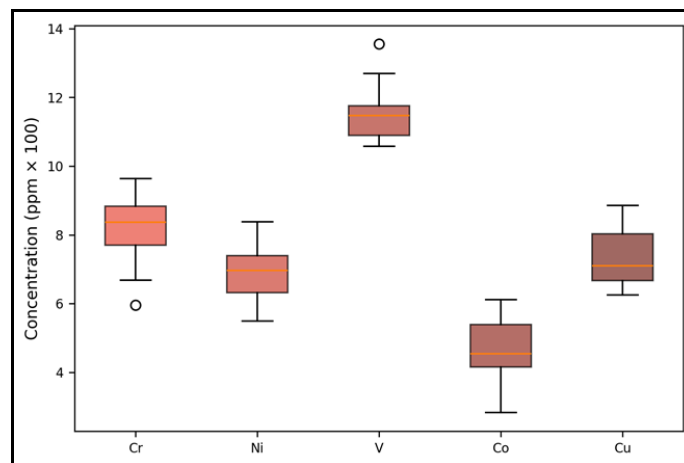


Fig 2: Box plots of compatible trace element concentrations (Cr, Ni, V, Co, Cu) across the three dyke swarm corridors.

Comprehensive Interpretation

The progressive increase in Rb, Ba, and Nb from Chivu to Mutare samples, coupled with decreasing MgO, Cr, and Ni, indicates that the Mutare dykes are the most differentiated and/or the most crustally contaminated of the three swarms. The negative Nb-Ta anomaly on primitive mantle normalised multi-element plots is a hallmark of sub-continental lithospheric mantle (SCLM) involvement or crustal assimilation^[12]. REE patterns show moderate LREE enrichment ($\text{La/Yb}_N = 4.8\text{--}8.3$) without significant Eu anomalies, ruling out extensive plagioclase fractionation at crustal depths.

Discussion

The geochemical data support a petrogenetic model in which the Zimbabwe Craton's mafic dykes originated from partial melting of an enriched SCLM source. The high Mg# values (up to 68.3) in the Chivu corridor point to near-primary melts that ascended rapidly through the lithosphere with limited fractionation. By contrast, the Mutare dykes experienced longer residence in crustal magma chambers, as shown by lower MgO and higher incompatible element concentrations^[13].

The negative Nb-Ta anomaly observed across all three corridors is significant. It could reflect either a pre-existing enrichment in the mantle lithosphere from ancient subduction fluids or syn-emplacement assimilation of Archaean TTG crust^[14]. The relatively flat heavy REE patterns argue against garnet in the source residue, placing the melting depth above the garnet stability field (<80 km). That constraint is consistent with dyke generation during lithospheric extension events that thinned the craton margin^[2].

Limitations

The research lacked isotopic data (Sr-Nd-Pb), which would have more cleanly separated mantle source signatures from crustal contamination. Age constraints are absent; without U-Pb baddeleyite dates the three corridors cannot be assigned to specific magmatic events. And the 30-sample dataset, while sufficient for preliminary characterisation, does not capture the full chemical diversity expected in swarms spanning 120 + km.

Conclusion

Thirty mafic dyke samples from three corridors in the Zimbabwe Craton classify as basalt to basaltic andesite with

MgO ranging from 4.2 to 11.7 wt%. Trace element patterns show LILE enrichment and negative Nb-Ta anomalies consistent with an enriched sub-continental lithospheric mantle source and variable crustal assimilation. The Chivu corridor preserves the most primitive compositions, while the Mutare dykes are the most evolved. Future work should obtain Sr-Nd isotope ratios and U-Pb baddeleyite ages to place these intrusions in a temporal and geodynamic context.

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