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Petrogenesis of Granitoids in the Birimian Terrane, SW Ghana: Constraints from Oxygen Isotope and Bulk Rock Geochemistry

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1 INTRODUCTION

• Previous Nd, Sr, and Hf isotope studies indicated that Birimian granitoids were derived predominantly from juvenile crust but could not distinguish whether the magmas originated from juvenile arc lower crust, arc-derived metasedimentary rocks, or a heterogeneous arc-built crustal column, as these potential sources cannot be readily discriminated using radiogenic isotope systems alone. Consequently, the magma sources and the petrogenetic relationship between Belt- and Basin-hosted granitoids remained unresolved.

Whole-rock $\delta^{18}O$ is a robust tracer of magma sources, capable of distinguishing contributions from the mantle, juvenile lower crust, and sedimentary crust beyond the resolving power of conventional radiogenic isotope systems. When integrated with whole-rock major- and trace-element geochemistry, it provides a powerful framework for constraining granitoid petrogenesis.

This study presents the first systematic whole-rock $\delta^{18}O$ dataset for Birimian granitoids, integrated with whole-rock geochemistry and previous radiogenic isotope studies, to resolve the magma sources, petrogenesis, and genetic relationships of Belt- and Basin-hosted granitoids in southern Ghana.

2 STUDY AREA — BIRIMIAN TERRANE, GHANA

BELT-TYPE · 2.17 – 2.13 Ga

Tonalite – Granodiorite

Ashanti & Sefwi Volcanic Belts

Qtz + Pl + Kfs + **Bt + Hbl + Ttn**

A/CNK = 0.97–1.02 | Mg# = 44–46

Magnesian | εNd(t) = +1 to +4

→ **I-type | Calc-alkaline arc**

BASIN-TYPE · 2.10 – 2.05 Ga

Monzogranite – Leucogranite

Cape Coast & Kumasi Basins

Qtz + Kfs + Pl + **Bt ± Ms (Hbl absent)**

A/CNK = 1.02–1.28 | Mg# = 27–42

Ferroan | εNd(t) = −2 to +2

→ **S-type | Crustal melting**

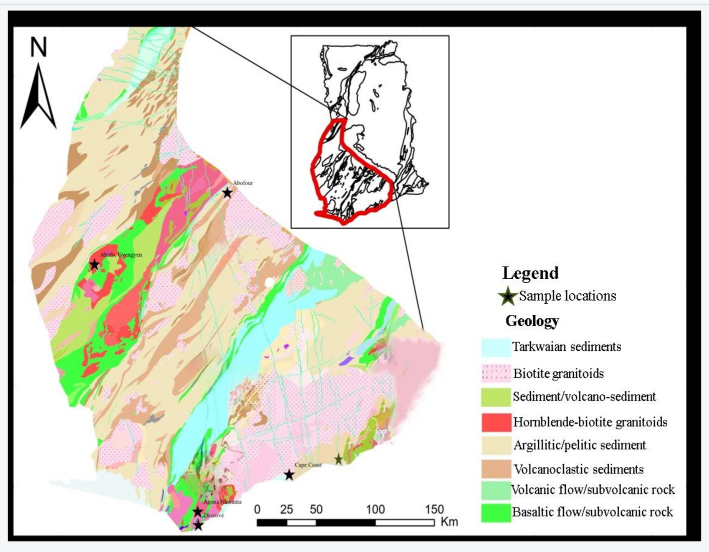

Figure 1. Geological map of Ghana (Modified after Taylor and McLennan, 1992).

3 OBJECTIVES

i. Characterise whole-rock $\delta^{18}O$ of Belt- and Basin-hosted granitoids with major- and trace-element geochemistry

ii. Evaluate juvenile crustal contribution and reworking during the Eburnean Orogeny via a multi-proxy approach

iii. Distinguish petrogenetic evolution of Belt I-type, Basin S-type, and Basin I-type granitoids

iv. Develop an integrated petrogenetic model for Birimian granitoid evolution and its broader implications for Paleoproterozoic arc-built crust

4 METHODS

1. **Field Sampling**

Field mapping for fresh outcrops: 32 specimens (geochemistry); 28 for $\delta^{18}O$ (LOI < 2.0 wt%). Kwapia MMEs sampled separately.

2. **Whole-Rock Geochemistry**

ALS Geochemistry, Vancouver: Majors by ICP-AES (ME-ICP06); trace+REE by ICP-MS (ME-MS81), $LiBO_2$ fusion. Precision ±2% (majors), ±10% (trace).

3. **Oxygen Isotope Analysis**

QFIR, Canada: BrF_5 fluorination, DeltaPlusXP IRMS, vs. V-SMOW. NBS-28 = 9.6±0.4‰ (n=9). LOI <2.0 wt% filter.

5 PETROGRAPHY

Belt-hosted granitoid: I-type

hornblende–biotite–plagioclase assemblage; magmatic titanite present (~1 vol%)

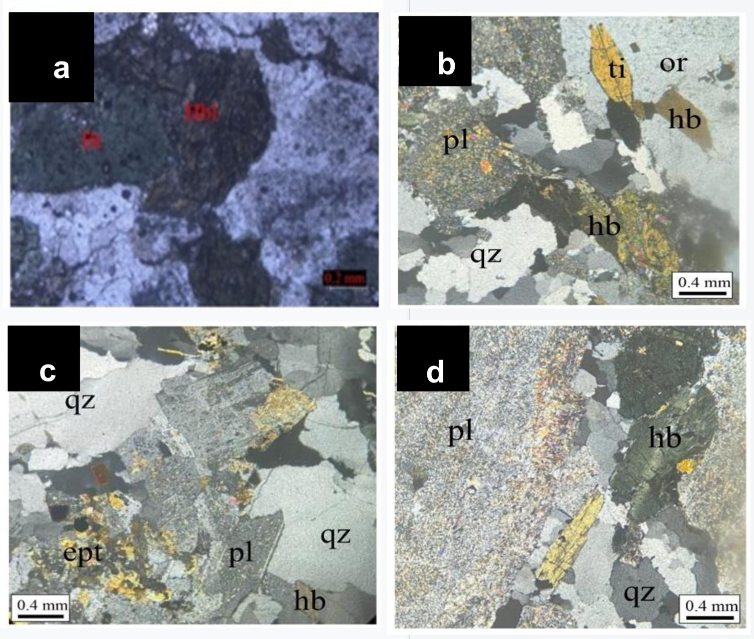

Figure 2. Photomicrographs of Belt-type granitoids. (a) Qz–biotite (bt) intergrowth. (b) Titanite (ti), hornblende (hb), pl, or, qz (c) Epidote (ept) with pl, qz, hb (d) Pl–hb–qz intergrowth..

Basin-hosted granitoid:

Basin-hosted S-type granitoids
Two-mica (muscovite + biotite) assemblage.
Titanite absent (ilmenite-series affinity).

Basin-hosted I-type granitoids
Biotite-dominated assemblage.
Titanite present (similar to belt-hosted I-type granitoids).

Kwapia MMEs:
fine-grained basaltic-andesite; titanite 3–4 vol%; early apatite

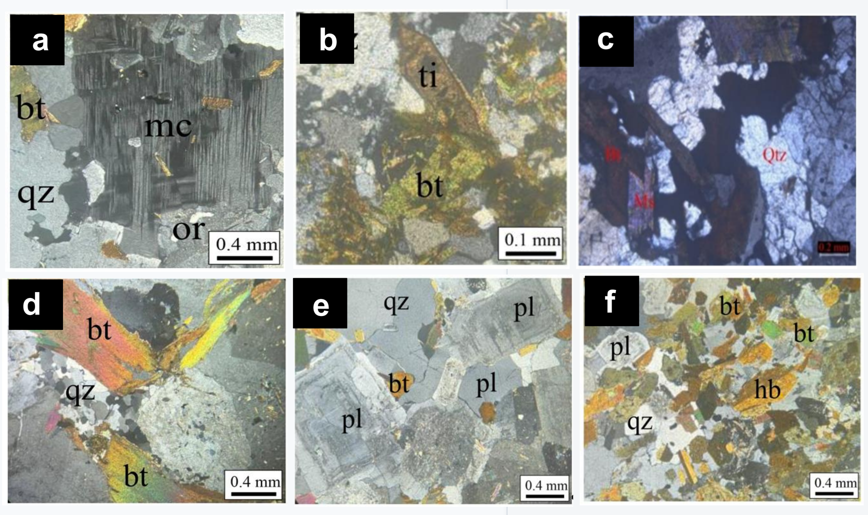

Figure 3. Photomicrographs of Basin-type granitoids. (a) Microcline (mc) with tartan twinning, qz, bt, or. (b) Titanite (ti) with bt. (c) Qz, bt, muscovite (ms). (d) Pleochroic bt in qz matrix. (e) Twinned plagioclase (pl), qz, bt. (f) Pl–qz–bt–hornblende (hb) assemblage. *Abbreviations: bt = biotite, hb = hornblende, mc = microcline, ms = muscovite, or = orthoclase, pl = plagioclase, qz = quartz, ti = titanite.*

6 WHOLE-ROCK GEOCHEMISTRY

Classification: TAS and QAPF

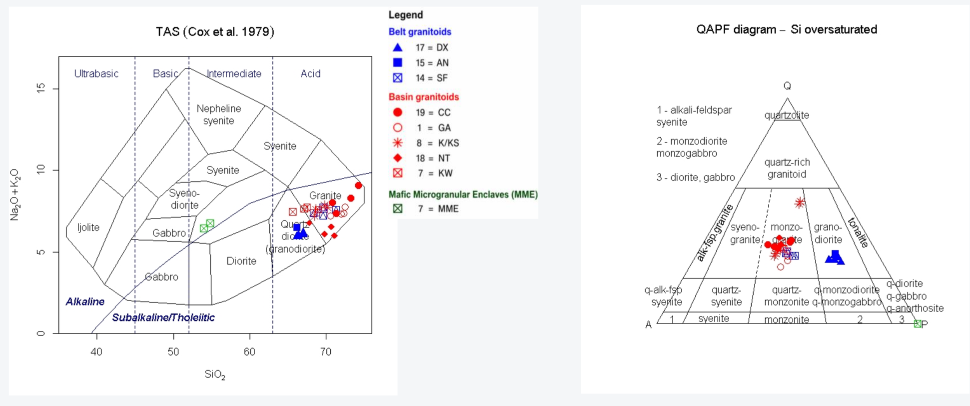

Figure 4. TAS (Cox et al. 1979) and QAPF. Belt and Basin granitoid. The legend is the same for all plots

Oxidation State, Alkalinity & REE Patterns

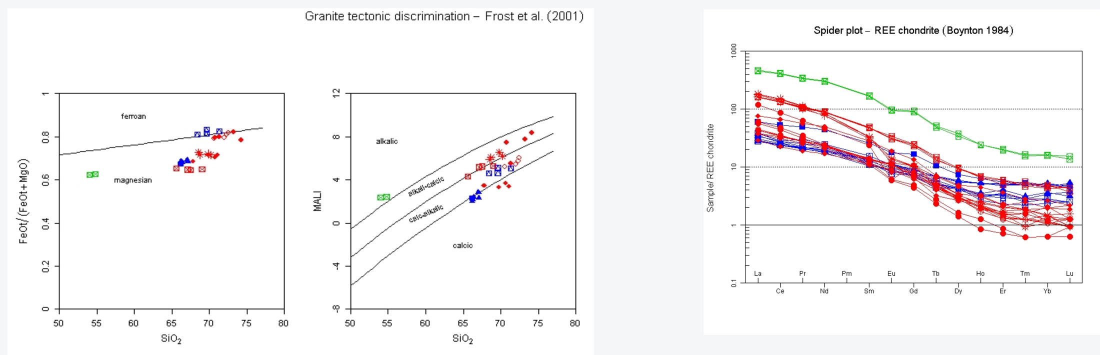

Figure 5. Frost et al. (2001): both suites are magnesian, calc-alkalic to alkali-calcic — matching metaluminous Belt (A/CNK 0.93–1.02) and peraluminous Basin (1.09–1.22). REE (Boynton 1984)

7 HARKER VARIATION DIAGRAMS

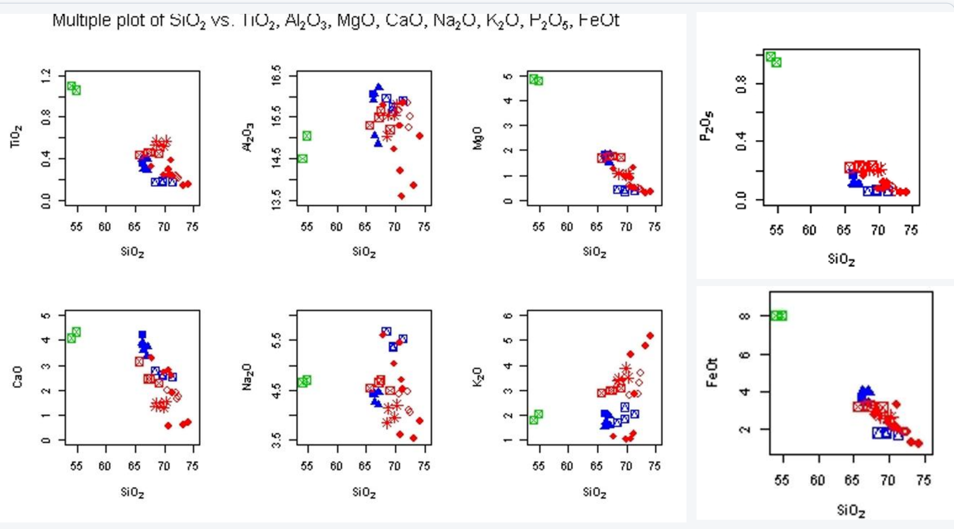

Figure 6. Harker diagrams (SiO_2 vs. major oxides). TiO_2, MgO, CaO decline with SiO_2 → fractional crystallisation

Key Trends

SiO_2: Belt 64.2–69.6 wt%; Basin 69.8–74.2 wt%

TiO_2, MgO, CaO decline with SiO_2 → hornblende + plagioclase fractionation

Basin: high K_2O, Al_2O_3 → crustal-melt signature

P_2O_5 scatter → apatite-controlled Th in MMEs

8 OXYGEN ISOTOPE GEOCHEMISTRY

Belt-Hosted I-Type	Basin-Hosted S-Type
+8.5 ± 0.7‰	**+9.6 ± 0.9‰**
n=8 +7.5 to +9.4‰	n=11 +7.9 to +11.5‰

Basin-Hosted I-Type	Kwapia MMEs
+9.08 ± 1.35‰	**+8.25‰**
n=7 +7.0 to +10.9‰	n=2 +7.9 to +8.6‰

$\delta^{18}O$ vs. A/CNK — The Central Discriminatory Observation

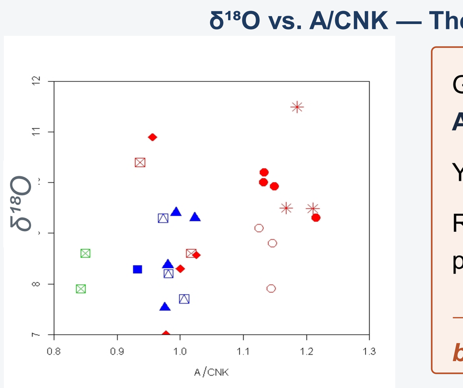

Figure 7. $\delta^{18}O$ vs. A/CNK

Gomoa Assin (GA) is unambiguous S-type:
A/CNK = 1.09–1.11

Yet $\delta^{18}O$ = +7.9–9.1‰ falls within the Belt I-type field

Rules out direct metapelite anatexis (pure-sediment melting predicts $\delta^{18}O$ > +10‰)

→ S-type magmas derived from a heterogeneous, arc-built crustal column

GOMOA ASSIN DECOUPLING: S-type A/CNK (1.09–1.11) paired with Belt-range $\delta^{18}O$ (+7.9–9.1‰) rules out direct metapelite anatexis.

9 FOUR-TRACER CONVERGENCE ON SOURCE HETEROGENEITY

$\delta^{18}O$, K_2O, Rb and Ba/Th co-vary: Abofor → Cape Coast → Gomoa Assin. No $\delta^{18}O$–SiO_2 correlation — source heterogeneity, not differentiation, is the principal control.

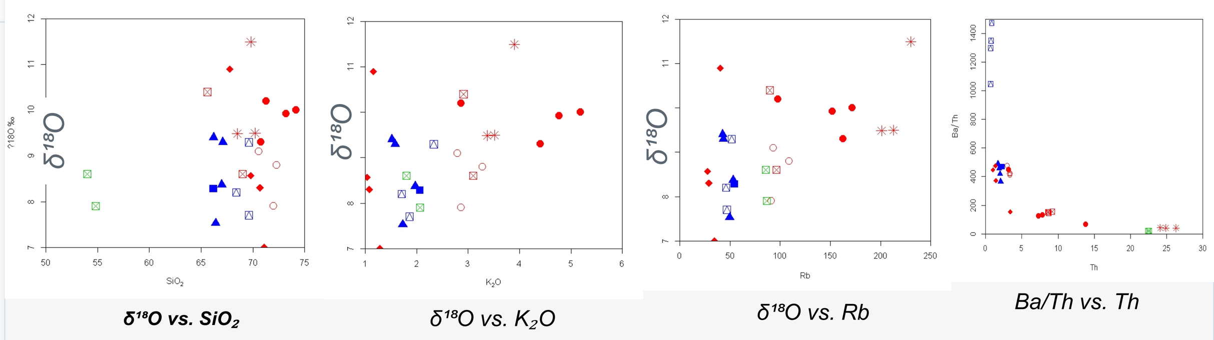

Figure 8. $\delta^{18}O$ vs. SiO_2, K_2O and Rb. No $\delta^{18}O$–SiO_2 correlation (r = −0.149) rules out differentiation/alteration; $\delta^{18}O$, K_2O and Rb decrease together from Abofor → Cape Coast → Gomoa Assin — a coherent spatial gradient

10 TECTONIC DISCRIMINATION

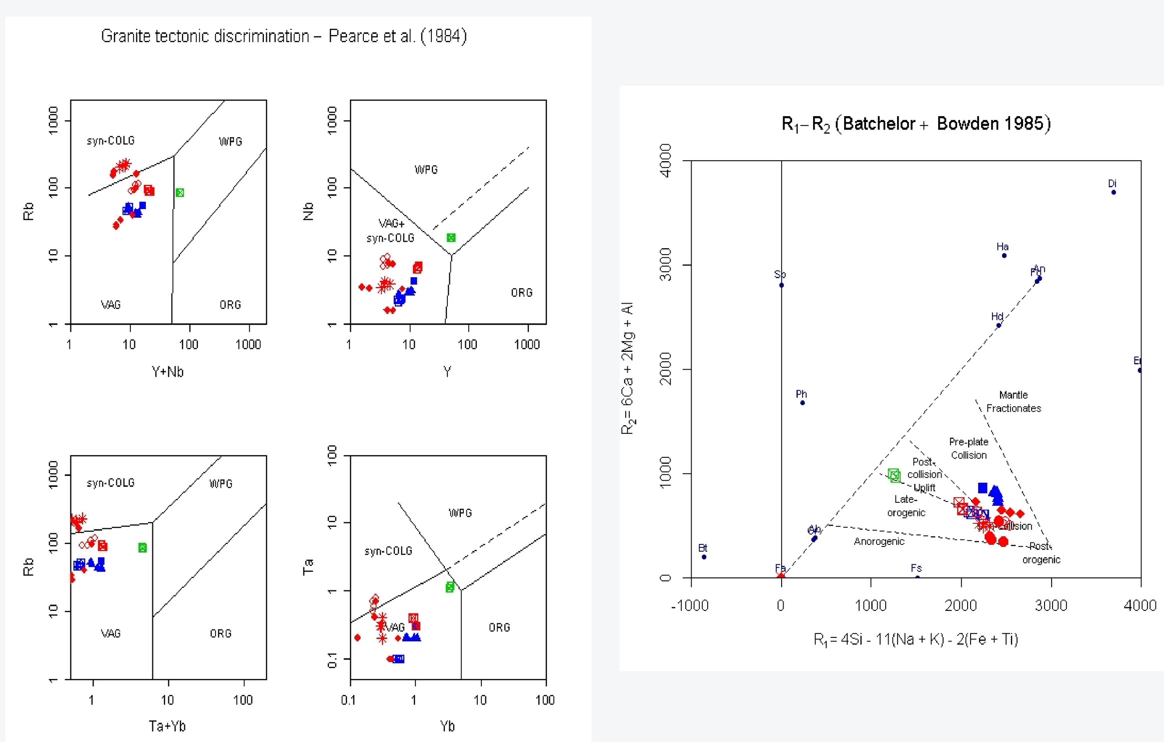

Figure 9. Granite tectonic discrimination. Left: Pearce et al. (1984) — Belt I-type → VAG/pre-plate collision; Basin S-type → syn-COLG; Basin I-type → overlap (collision). Right: Batchelor & Bowden (1985) R1–R2 diagram, corroborating the trend.

11 INTERPRETATION

Integrated Interpretation

The combined $\delta^{18}O$, whole-rock geochemistry and petrographic datasets define a three-stage tectono-magmatic evolution during the Eburnean Orogeny.

Key findings

- Stage 1 – Juvenile arc lower-crust melting generated Belt-hosted I-type granitoids.
- Stage 2 – Syn-collisional crustal thickening produced Basin-hosted S-type granitoids through melting of a heterogeneous arc-built crustal column.
- Stage 3 – Mafic recharge, magma mixing and crustal assimilation generated Basin-hosted I-type granitoids and Kwapia MMEs.

12 PETROGENETIC MODEL

Three-Stage Eburnean Tectono-Magmatic Evolution

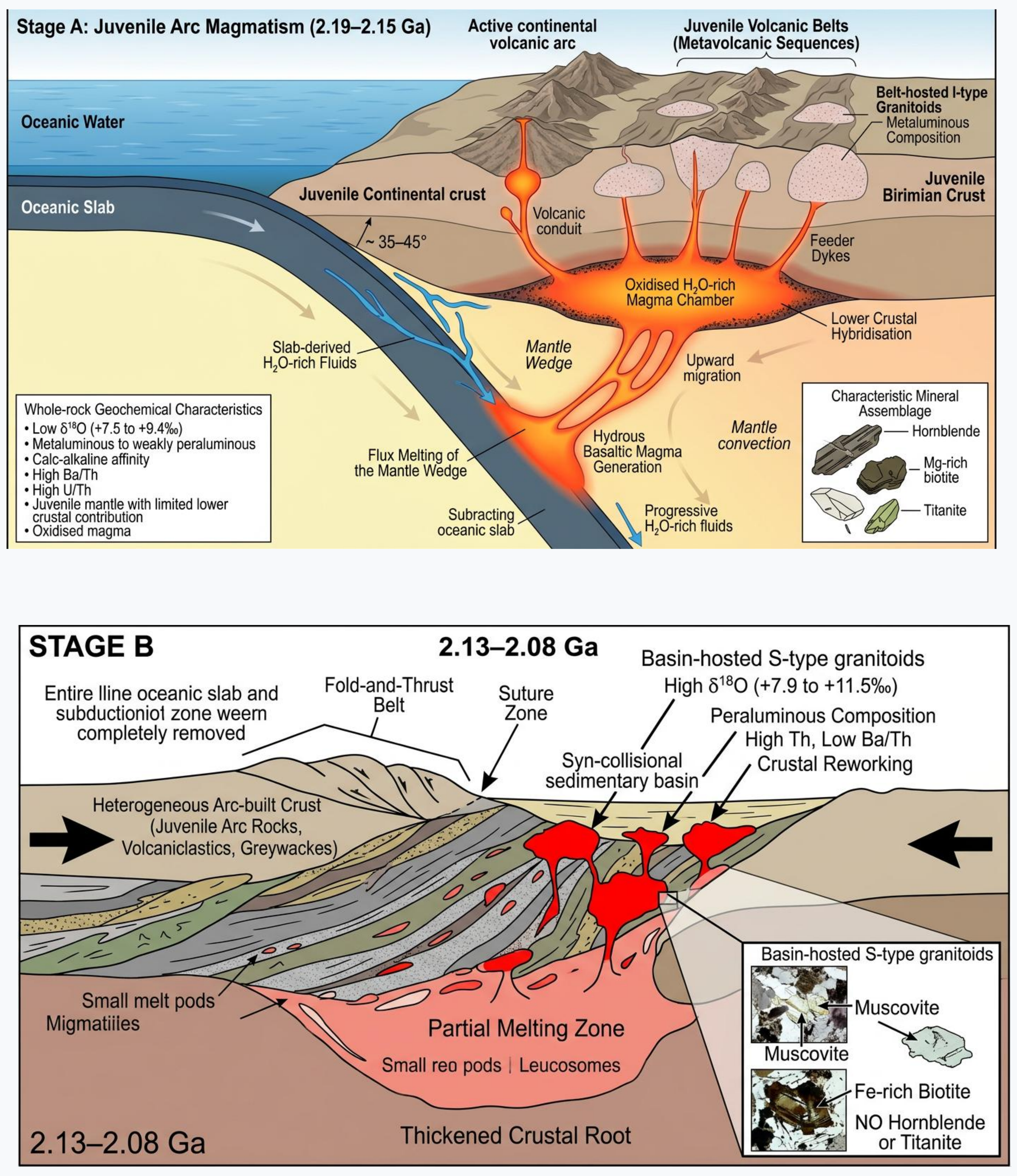

Figure 10. Stages A–B: Pre-collision Belt I-type arc magmatism to syn-collision Basin S-type crustal reworking through a heterogeneous arc-built crustal column.

Stage C — Open-System Basin Magmatism (~2.12–2.10 Ga)

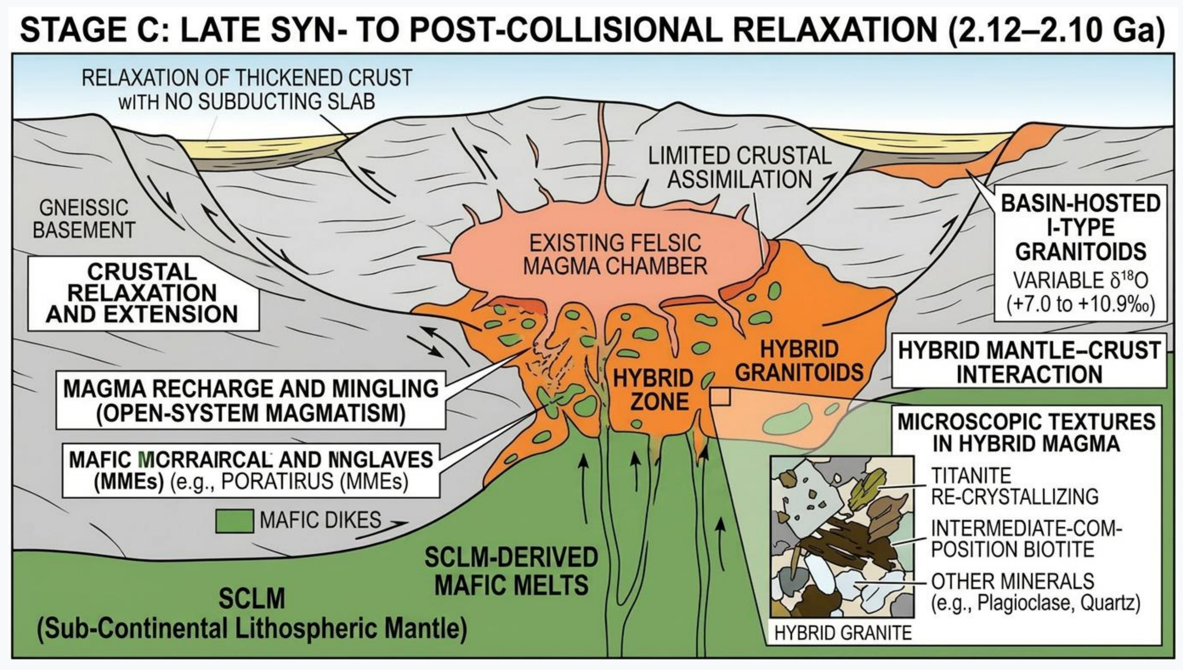

Figure 11. Stage C: Mafic recharge into basin — enclave equilibration records a mingling-to-mixing continuum in an open-system basin.

13 BROADER IMPLICATIONS

- Whole-rock $\delta^{18}O$ resolves crustal architecture beyond the capability of conventional radiogenic isotope systems
- Birimian S-type granitoids formed through melting of a heterogeneous arc-built crustal column, not simple metasedimentary anatexis — a framework applicable to other Paleoproterozoic juvenile arc-built terranes

14 CONCLUSIONS

1. Belt-hosted I-type granitoids were generated from an isotopically homogeneous juvenile arc lower crust during early Eburnean arc magmatism
2. Basin-hosted S-type granitoids formed through melting of a heterogeneous arc-built crustal column, rather than direct metasedimentary anatexis
3. The Gomoa Assin $\delta^{18}O$–A/CNK decoupling provides the strongest evidence against the classical pure-sediment S-type model
4. Basin-hosted I-type granitoids and Kwapia MMEs record open-system magma evolution through mafic recharge, mixing and crustal assimilation
5. Whole-rock $\delta^{18}O$, integrated with geochemistry, establishes a new petrogenetic framework for granitoid evolution in the Ghanaian Birimian and comparable terranes

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