Assigned Topic:
How does the composition of island arc crust evolve as the convergent plate boundary matures?

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A perspective from 50 years work in Fiji-Tonga (not discussed today),
35 years in Izu-Marianas,
10 years in Kermadec
and their surrounding backarc basins.

With help from Matthias Witte, Ina Simon, Oli Jagoutz, Philipp Brandl, and Gene Yogodzinski
Crustal composition of a rifted arc (not continental) margin: Kermadec Arc-Havre Trough-Colville Ridge

Expedition SO255 Spring 2017

~100 lava dredges
~300 analyzed
- majors, traces, Sr,Nd-Hf-Pb isotopes
ArAr dates

Ina Simon and Matthias Witte, GEOMAR
What does “enrichment” mean?

1. Incompatible trace elements

- Slab-derived enrichment
- Enrichment Low-F melts
- Primitive Mantle
- Depletion

Kermadec systematics similar to Izu; Characterize rifting?
2. Fe-enrichment is called *tholeiitic*; depletion is *calcalkaline*.

3. *Isotope enrichments* also can be from either the mantle or slab:

Maturation of Kermadec frontal arc crust during rifting:
- more mantle enrichment (higher Nb, but also higher $^{143}/^{144}$Nd);
- less slab enrichment (lower $^{87}$Sr/$^{86}$Sr ± less Th).

![Graph showing isotope enrichment trends](image-url)
It was once thought that arcs “matured” from:

- **island arc tholeiitic series** (IATS: Jakes and Gill, 1970)): depleted in most mantle and slab trace element and isotope ratios, but enriched in Fe; evolved to
- **calcalkaline series** (the opposite); evolved to
- **shoshonitic series** (enrichments on steroids).


Although this has long been considered inconsistent (Gill, 1981), and missed the FAB and boninites of IBM (Reagan et al., 2010; Ishizuka et al. 2011), increasing mantle ± slab enrichment may nevertheless characterize “maturation” during steady-state subduction, and inflections may signify non-steady state events (e.g., arc rifting, backarc basin opening, arc rupture, flat slabs, collisions).

IATS is part of a chemical continuum from FAB to BABB to IATS.

Non-basaltic parental magmas (boninite, high-Mg andesite, adakite) are exceptional. They and shoshonites require non-steady state conditions.

“Mature crust” may be like some baby-boomers-- enriched, entitled, and forgetful—but with interesting non-linear stories when asked.
What Oli might have said...

- Kohistan has similar velocity structure/petrology/geochem as Izu.
- No clear seismic Moho in either.
- No vestage of a beginning in exhumed arcs; new arc crust replaces everything.
- If most parental arc magma is basaltic, then ~2/3 of arc crust must get lost.
- Losing it requires thick hot crust (>30 km; >900°C) and non-steady-state events like arc rifting or collision.
- If that much crust is lost, then arc magma production rates are high (~200 km³/km/My) and arc geochemical enrichments (e.g., Th) must come from AOC as well as sediment, or OIB components in the slab or mantle wedge.

120->80 Ma: Izu-like intra-oceanic arc;
lower crustal mafic cumulates/restites in Southern Plutonic Complex

Gabbronites of Chilas Complex
Arc rifting, backarc basin?

80->50 Ma arc resumption;
Mid-Upper crustal tonalite-granodiorite Gilgit Complex

Collision with India ~50 Ma?;
More crustal assimilation

120->80 Ma: Izu-like intra-oceanic arc;
lower crustal mafic cumulates/restites in Southern Plutonic Complex
Supplemental Data from Jagoutz et al. (2018)

- Older Kohistan samples (120-80 Ma) overlap modern arcs but never as depleted. Mostly Chilas (85 Ma, rifting?) gabbronorites. IATS.
- Intermediate age felsic plutonics more enriched than even modern reararcs to Nb/Yb=10, La/Yb=40. CA.
- Youngest felsic plutonics very enriched to Nb/Yb=40, La/Yb=40 with very low HREE: anatectic (SH?).
- More mature means plutons increasingly enriched in K, LREE, and Hf-Nd-Pb isotopes, especially after collision. Both mantle and slab-sourced enrichments.

Remember: Izu is like Kermadec and has ~ 50m.y. history.
IBM Story
(especially Izu)

Best studied Cenozoic arc:
- lots of active seismic control (Kodaira)
- lots of dredging results
- lots of drilling results (Reagan, DeBari, Straub, me)
- 50 m.y. history built on even older arcs
- Two arc rifting ± backarc spreading episodes.
- Even though a MARGINS focus site, still lacks “synthesis and integration”.
IODP Exp350 discovered IATS beneath ± between CA backarc seamount chains.
Mariana arc (green data) versus Izu. Difference attributed to arrival of OIB-related AOC and sediment in Marianas.

(Bryant et al. 2003)

(Straub et al. 2015)
Izu Arc Maturation

- Multiple sampling strategies: drilling; dredging; volcanics; melt inclusions
- IODP Exp351 Site 1438 results.
- Arc crustal enrichment (replenishment) during steady state subduction. Both mantle and slab enrichments.
- Especially during initial arc rifting.
- Backarc basin formation (actual spreading) results in arc depletion to <DMORB levels.

Brandl et al., 2017
Arc maturation may be traced most completely by clastic sediments that integrate magmatic inputs.

Resumption of reararc volcanism (IATS) after backarc spreading stops ~15 Ma.

Start of reararc seamount volcanism (CA) ~ 9 Ma.

Clasts, tuff, mud all have similar ratios.
Conclusions about arc maturation

• Tectonic history is essential to identify steady-state versus “other”, and what “other” is. Therefore, include arc rifting in RIE syntheses.
• Arc rifting plays a big role in the evolution of arc crustal maturation. Therefore, include arc rifting in RIE syntheses.
• Even the best studied exhumed arcs are hard to compare with Cenozoic ones (cf. plutonic versus volcanic rocks, much less melt inclusions; fewer tectonic constraints).
• Steady-state and initial rifting usually lead to mantle ± slab enrichments in arc crust; backarc spreading leads to crustal depletion; collisions enrich.
• Synthesis is hard work, needs big data ± AI, and dedicated funding. There may now be enough data for IBM and Tonga-Fiji. Biggest gap is geochronology.
• Expeditionary science is still essential (e.g., NZ, Aleutians).
  Germans mapped and dredged; Americans only drilled.
• I hope that your generation maintains momentum and loses neither hope nor ambition. Science has goals but rarely has endings.
• Becoming mature (i.e., getting old) can be good, at least for awhile, for crust as well as people.
• Even basalts on continents have been arc-like forever: calcalkaline; Nb-depleted; and Th- and LREE-enriched (especially after 2.7 Ga).

• Data are means and $2\sigma$ for $>30,000$ analyses binned at 100 My intervals.