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

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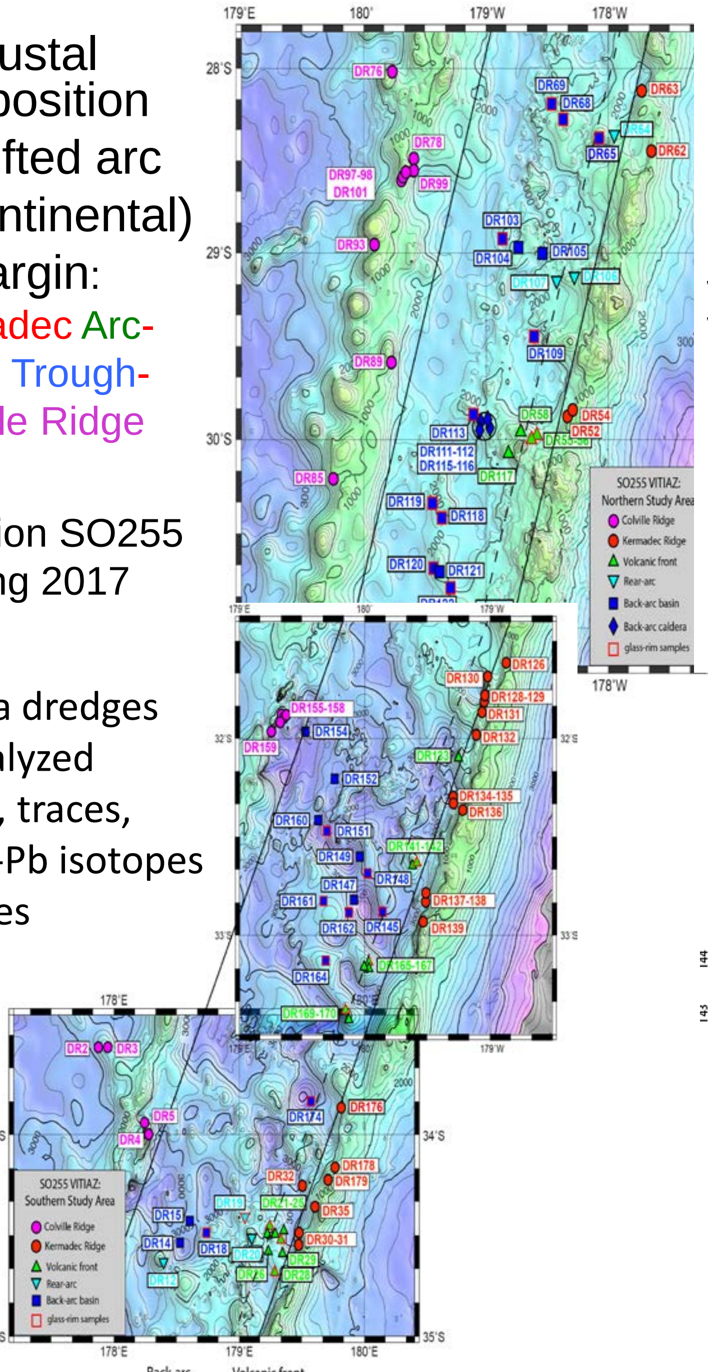
A perspective from 50 years work in Fiji-Tonga (not discussed today),
35 years in Izu-Marianas,
10 years in Kermadec
and their surrounding backarc basins.

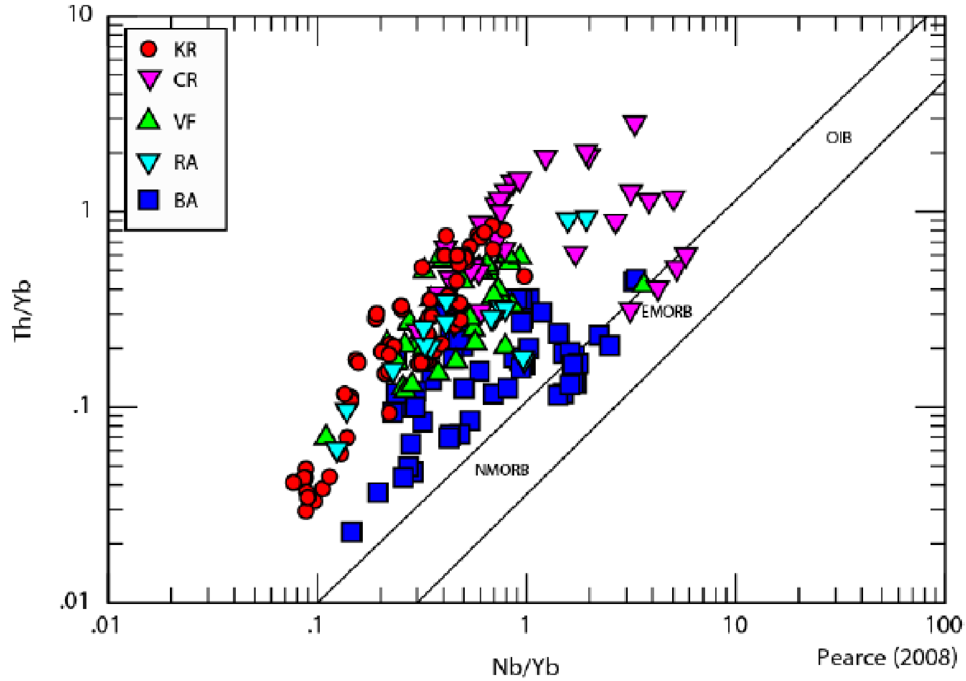
With help from Matthias Witte, Ina Simon, Oli Jagoutz,
Philipp Brandl, and Gene Yogodzinski

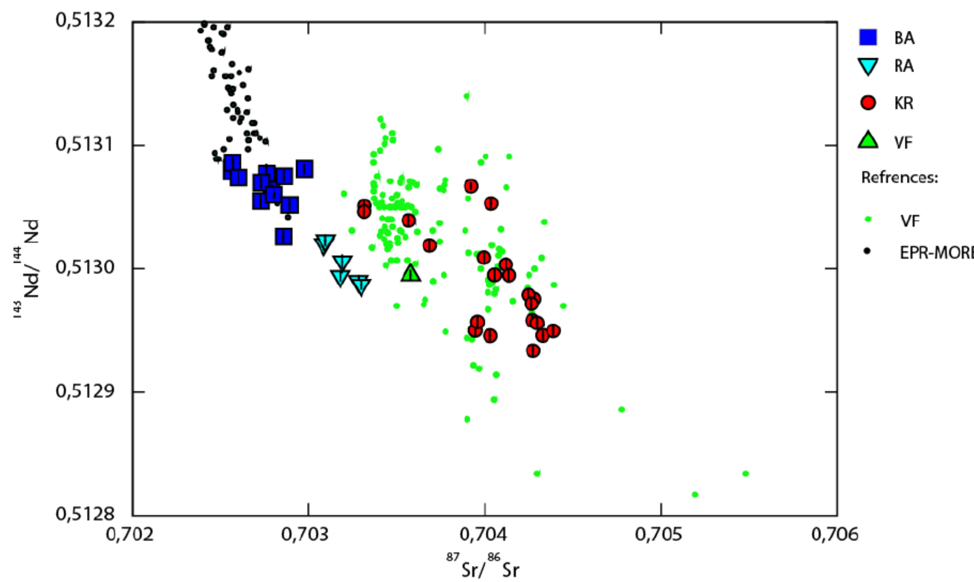
Crustal composition of a rifted arc (not continental) margin:
Kermadec Arc-
Havre Trough-
Colville Ridge

Expedition SO255
Spring 2017

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



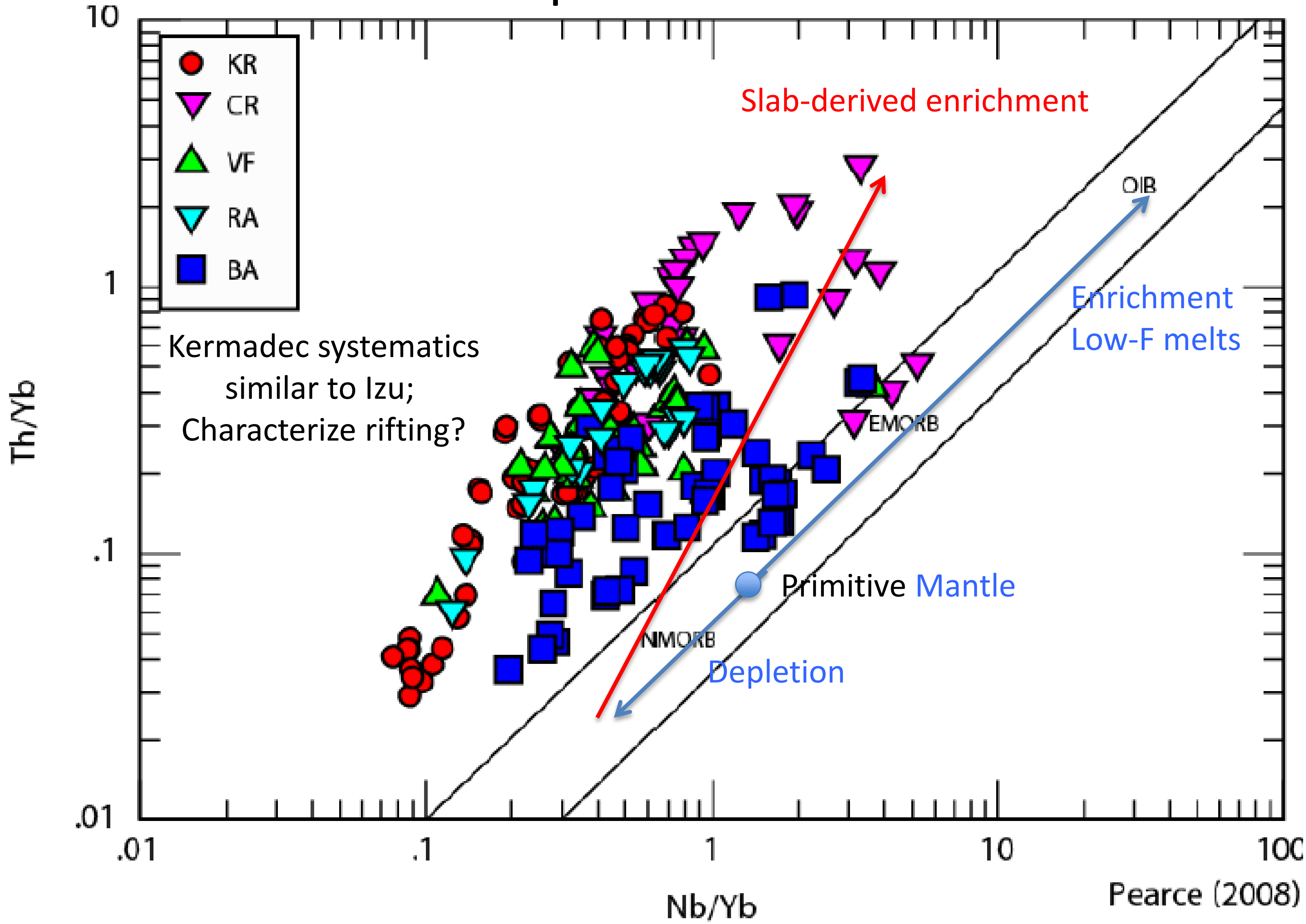




Ina Simon and Matthias Witte, GEOMAR

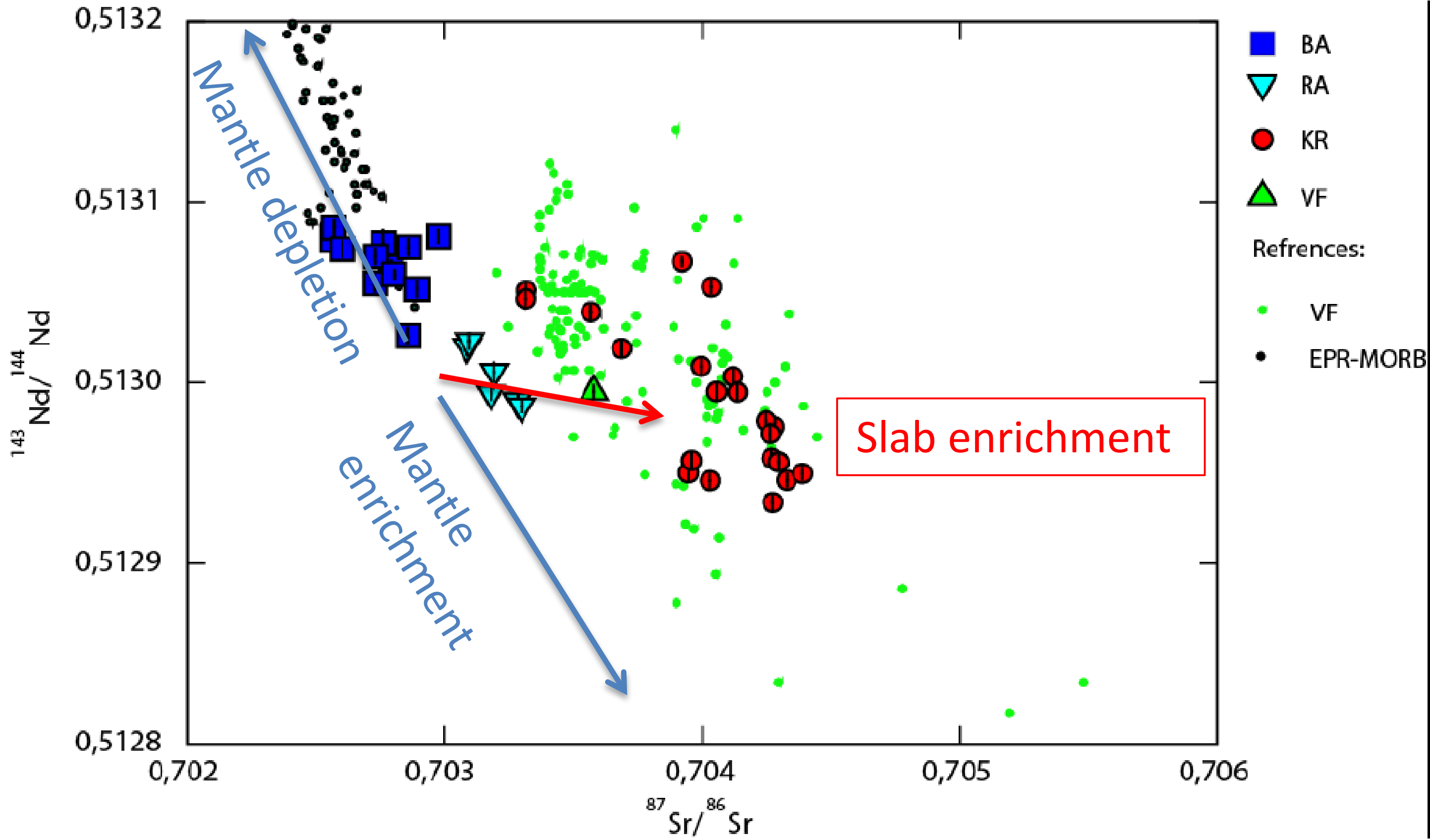
What does "*enrichment*" mean?

1. Incompatible trace elements



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).

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).

(Jakes and White 1969, 1972).

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).

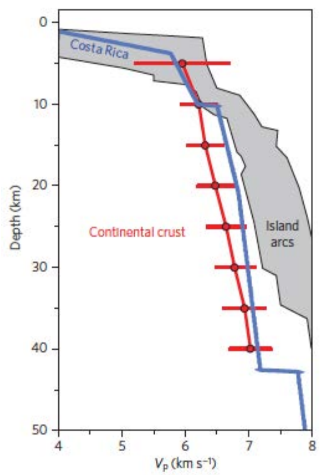
IATS is part of a chemical continuum from FAB to BABB to IATS.

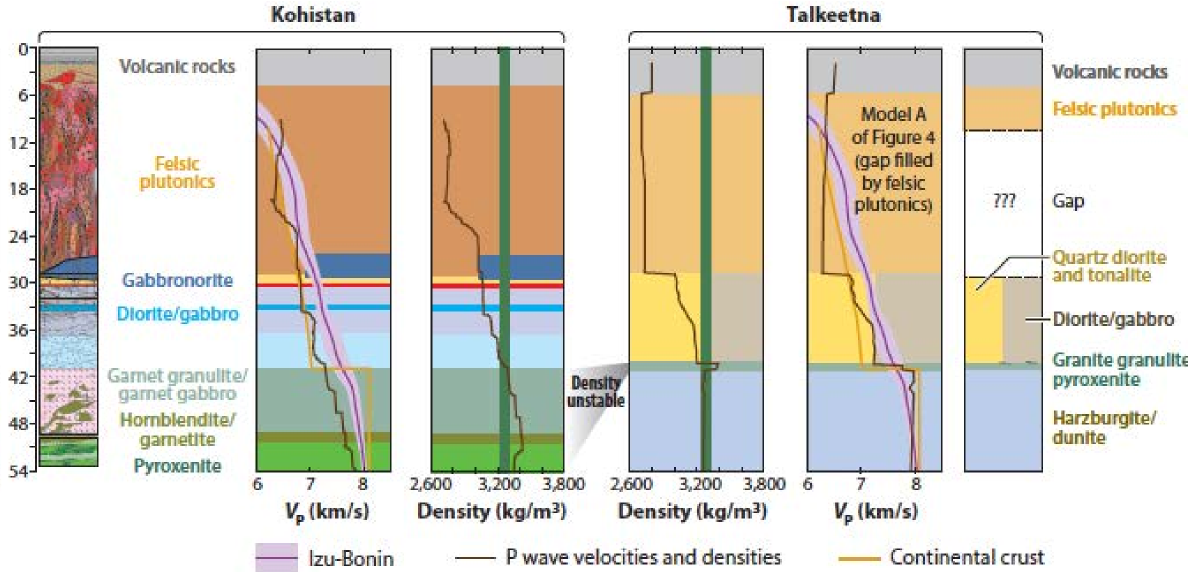
Non-basaltic parental magmas (boninite, high-Mg andesite, adakite) are exceptional. They and shoshonites require non-steady state conditions.

"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…

Gazel et al. (2015)



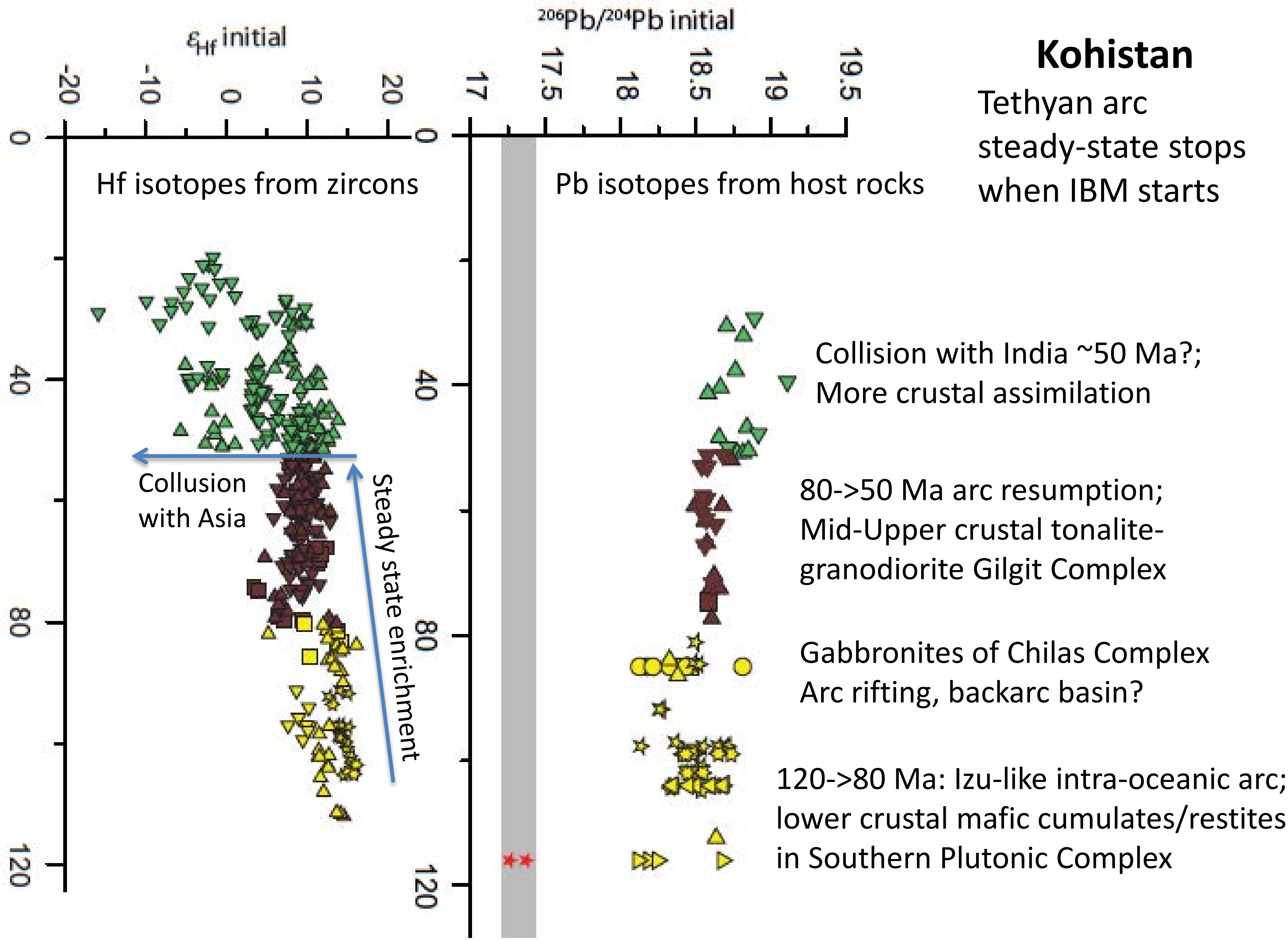


Jagoutz and Keleman (2015) Ann. Rev.Earth Pkanet.Sci 43:363-404; Jagoutz and Behn (2013) Nature 504: 131-134

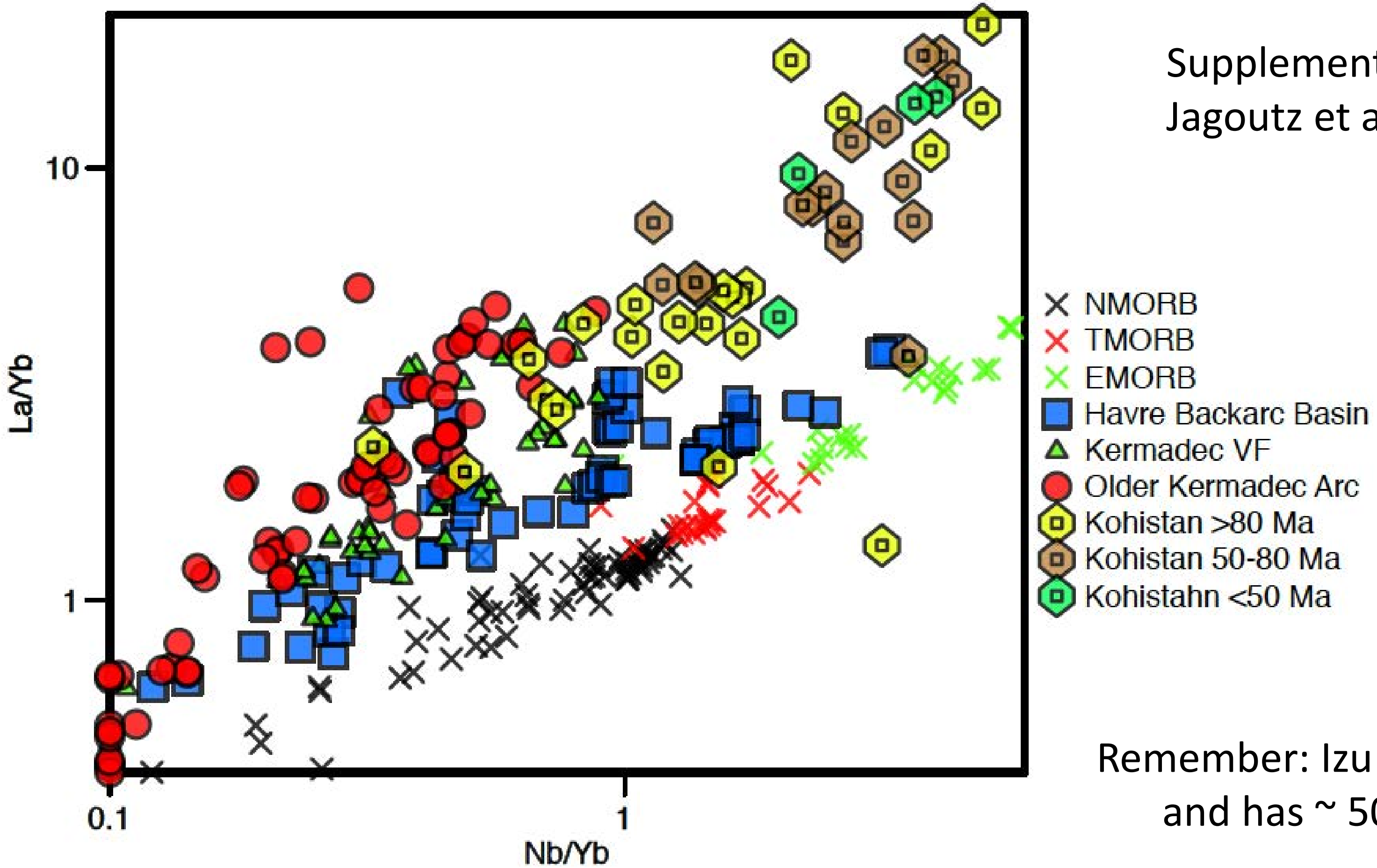
- Kohistan has similar velocity structure/petrology/geochem as Izu.
- No clear seismic Moho in either.
- No vestage of a beginning in exhumed arcs; new arc crust replaces everything.
- If most parental arc magma is basaltic, then ~ 2/3 of arc crust must get lost.
- Losing it requires thick hot crust (>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 km^3/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.

Kohistan

Tethyan arc steady-state stops when IBM starts



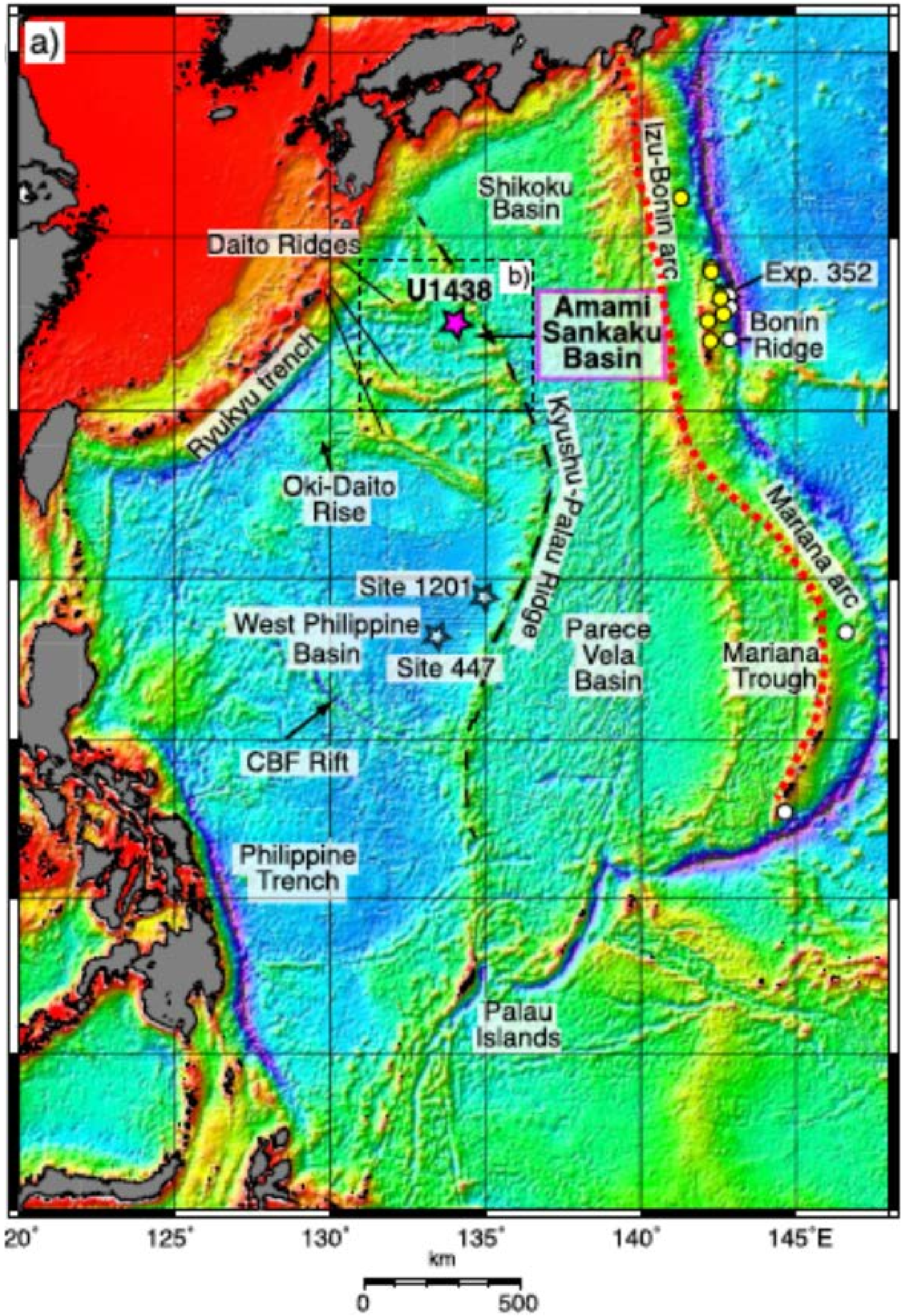
Jagoutz et al. (2018) Geol.Soc.Lond.Spec.Pr 483



Supplemental Data from Jagoutz et al. (2018)

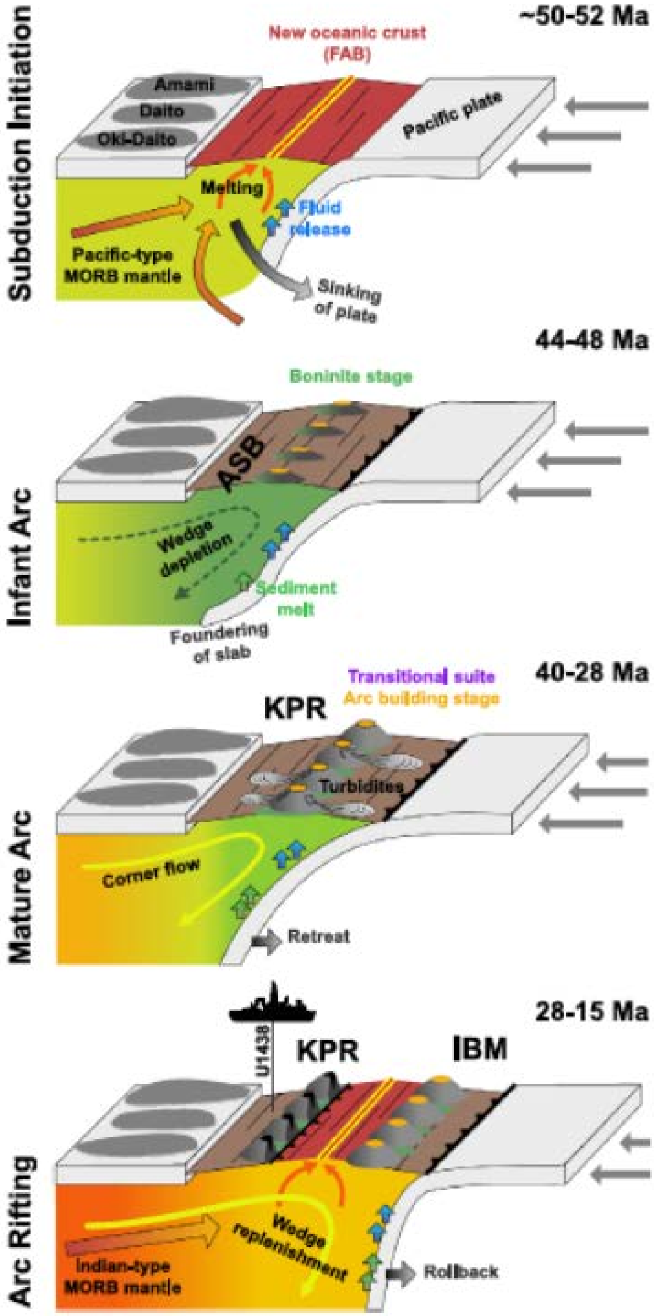
Remember: Izu is like Kermadec and has ~ 50m.y. history.

- 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.

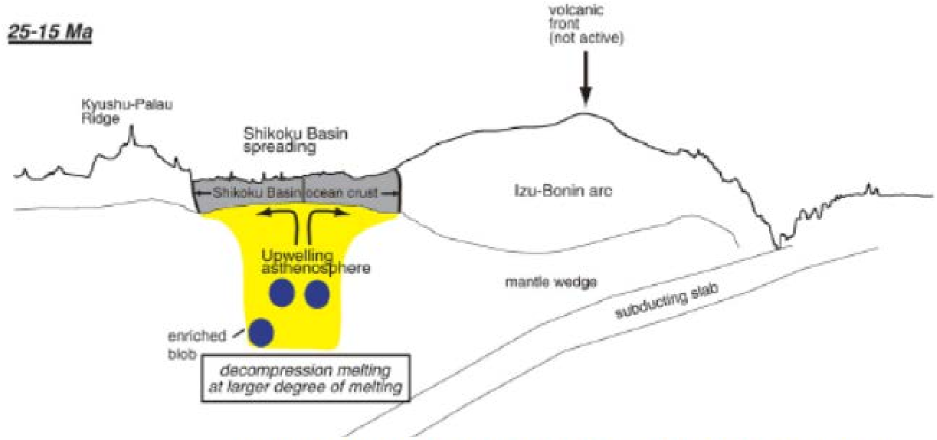


IBM Story
(especially Izu)

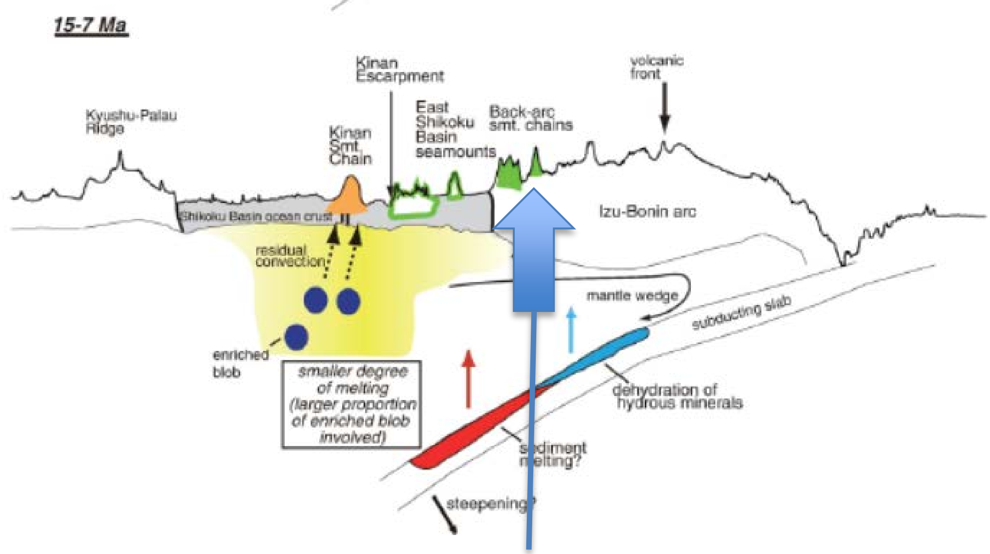
Best studied Cenozoic arc:
- lots of active seismic control (Kodaira)
- lots of dredging results
- lots of drilling results (Reagan, DeBari, Straub, me)
- 50 m.y. history built on even older arcs
- Two arc rifting ± backarc spreading episodes.
- Even though a MARGINS focus site, still lacks “synthesis and integration”.



P.A. Brandl et al. / Earth and Planetary Science Letters 461 (2017) 73–84

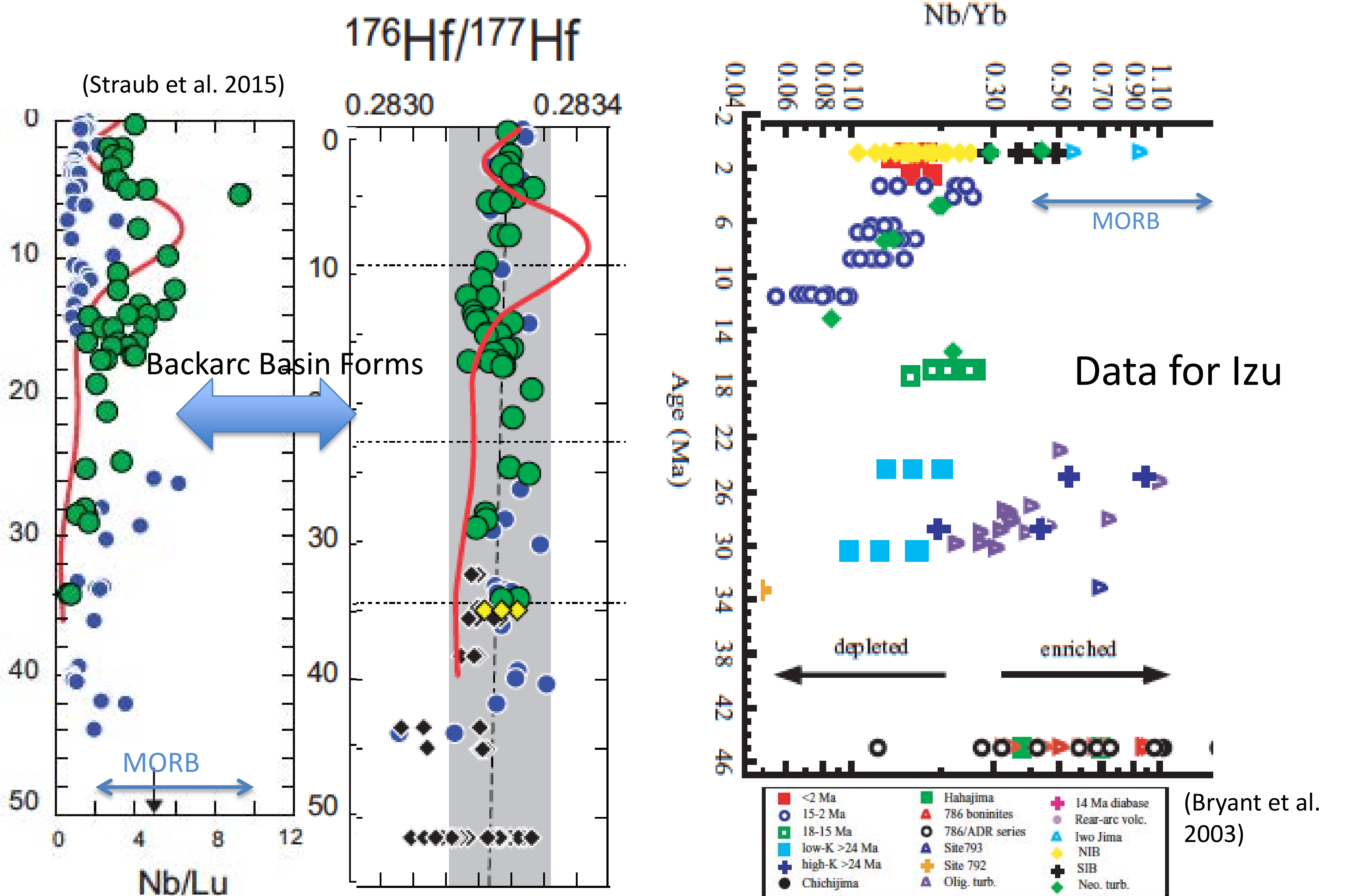


O. Ishizuka et al. / Chemical Geology 266 (2009) 283–305



IODP Exp350 discovered IATS
beneath ± between CA backarc seamount chains

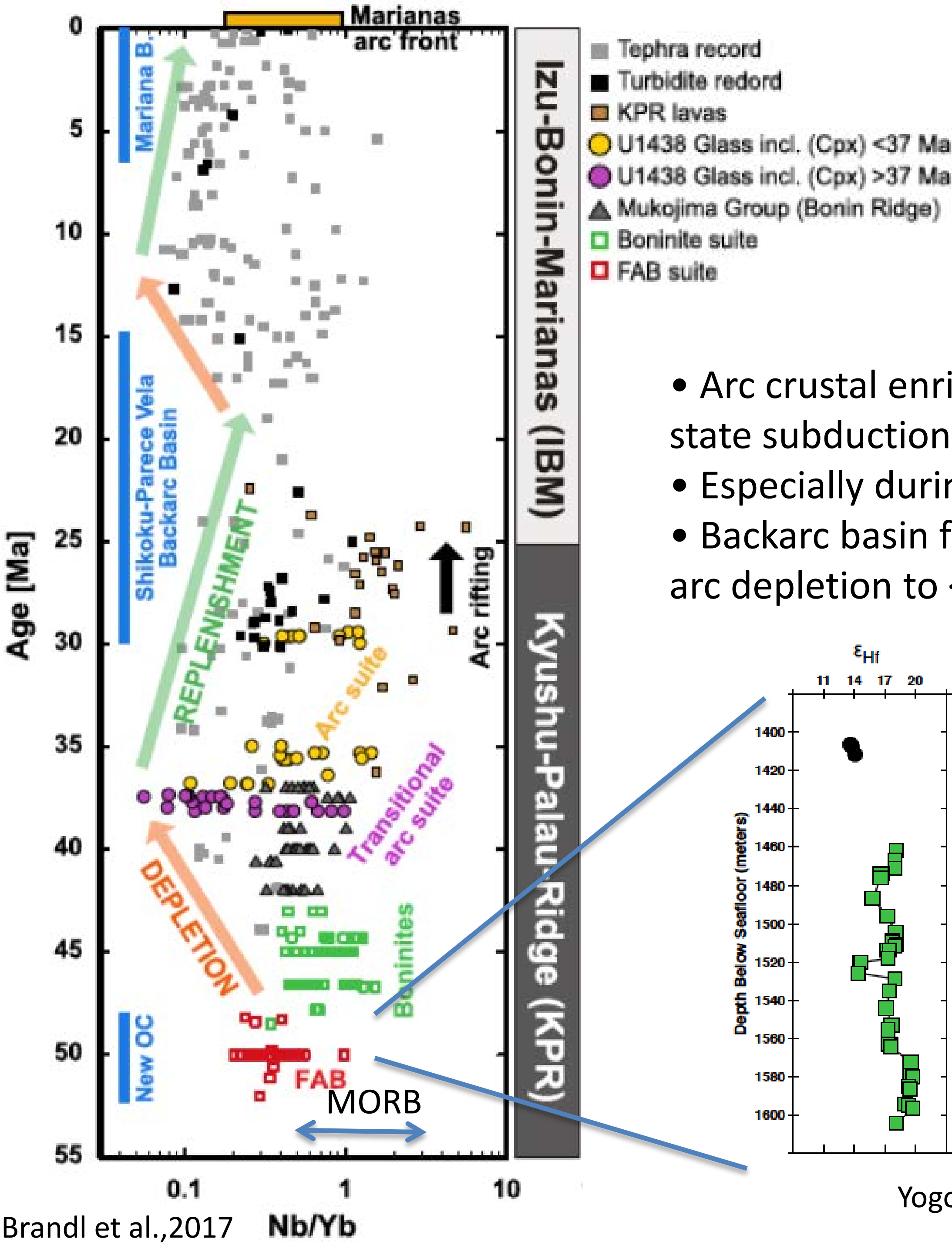
Mariana arc (green data) versus Izu. Difference attributed to arrival of OIB-related AOC and sediment in Marianas.



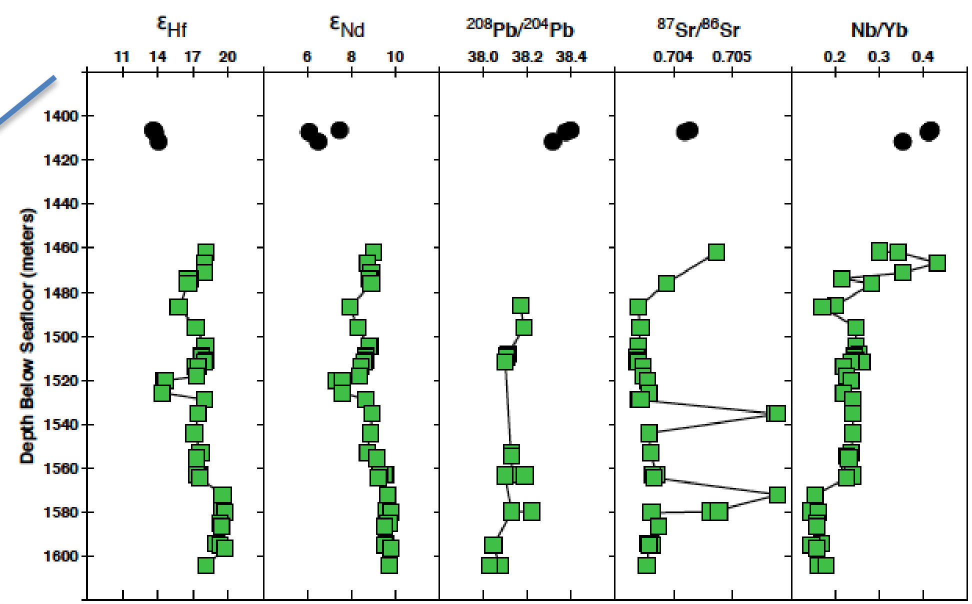
Izu Arc Maturation

- Multiple sampling strategies: drilling; dredging; vclastics; 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.

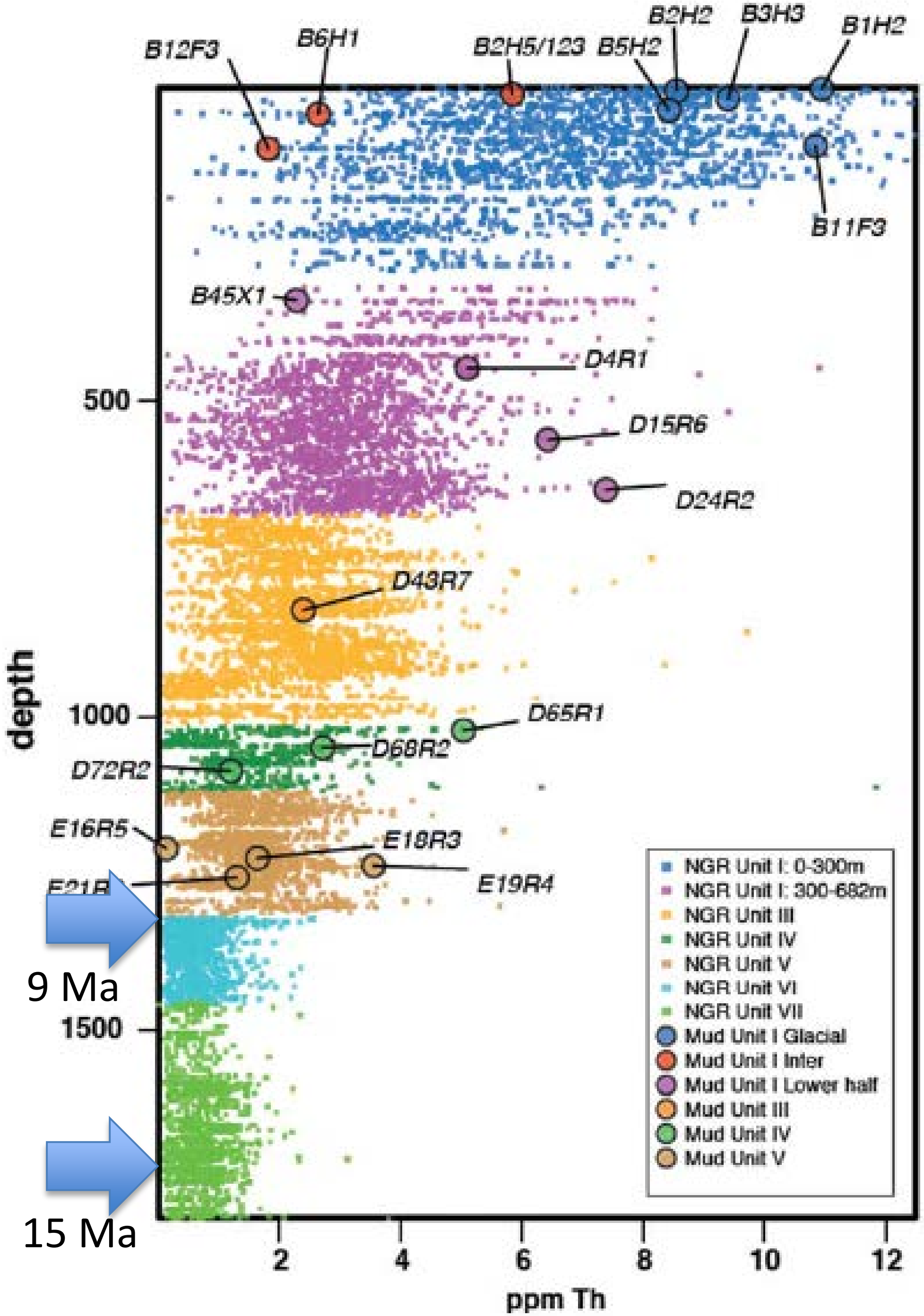


Brandl et al.,2017

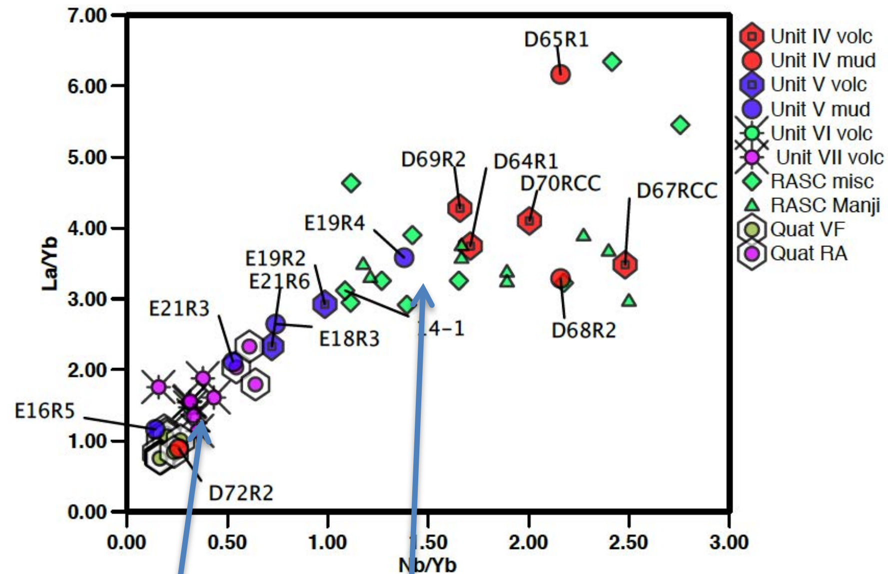


Yogodzinski et al. and Hickey-Vargas et al., 2018)

IODP Exp350 Izu reararc



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.

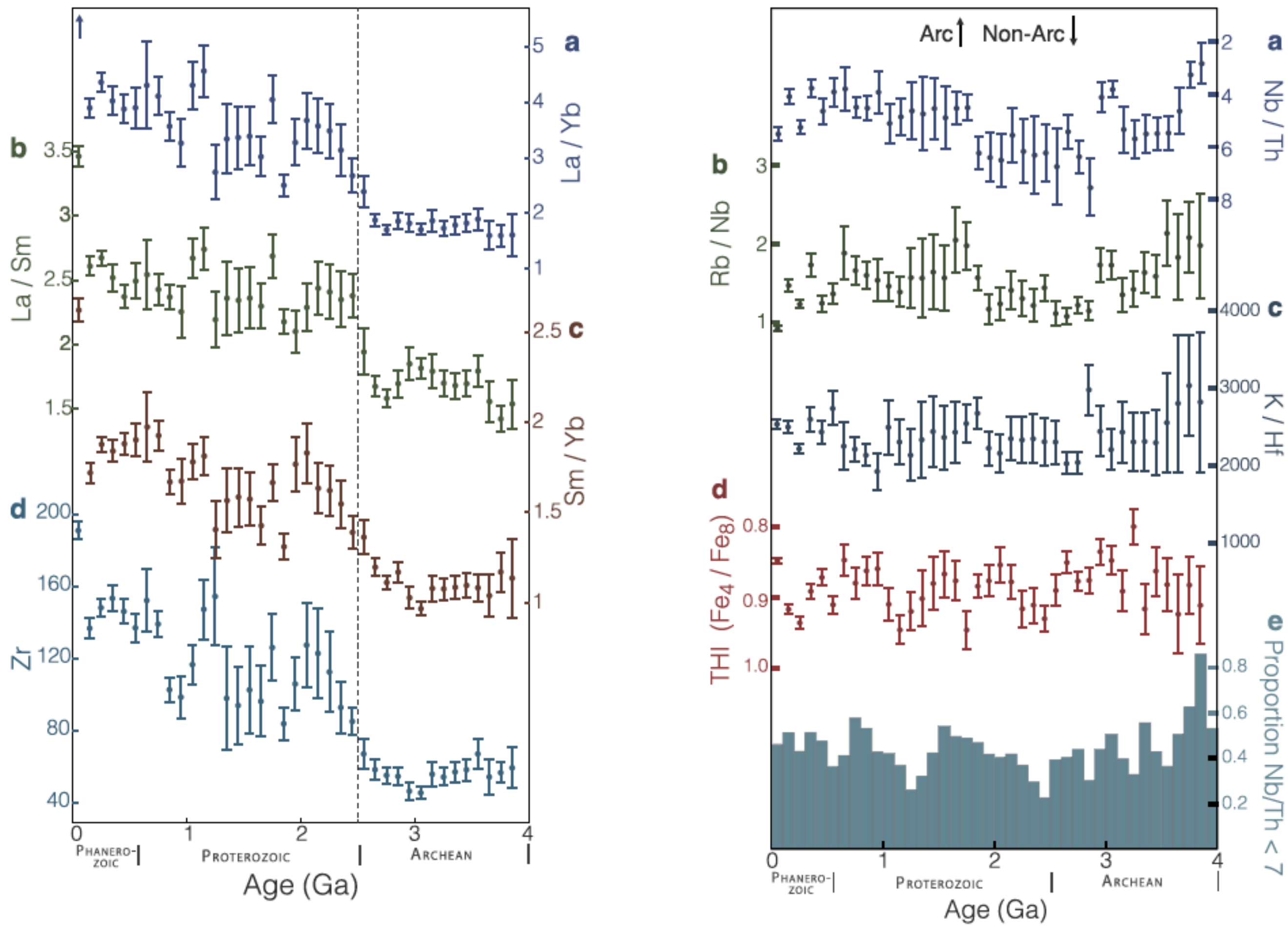
Start of reararc seamount volcanism (CA) ~ 9 Ma.

Clasts, tuff, mud all have simliar 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 2σ for >30,000 analyses binned at 100 My intervals.