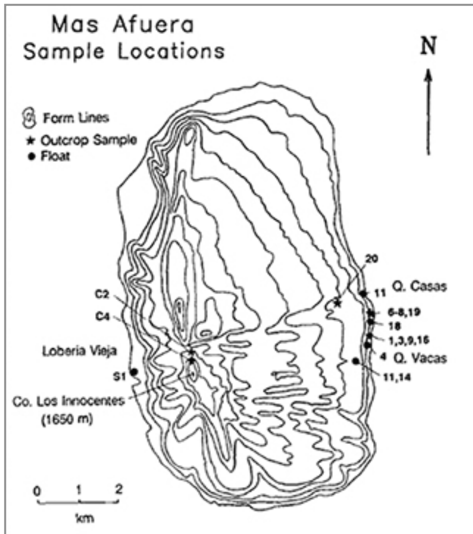
Geochemistry of Juan Fernandez Lavas Reveal Variable Contributions from a High-$^{3}He/^{4}He$ Mantle Plume

Thi B. Truong[1*,2]
Paterno R. Castillo[2]
David R. Hilton[2]
James M.D. Day[2]

1. College of Earth, Ocean, and Atmospheric Sciences, OSU, Corvallis, OR, USA
2. Scripps Institution of Oceanography, UCSD, La Jolla, CA, USA
* Current

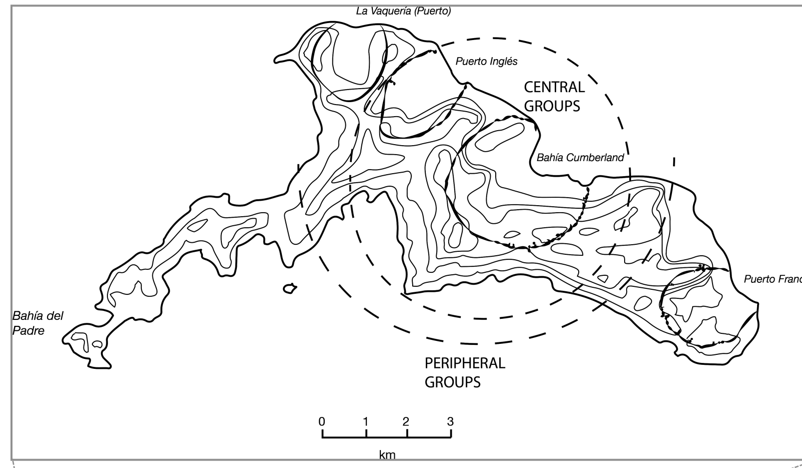
Juan Fernandez Islands, SE of Chile

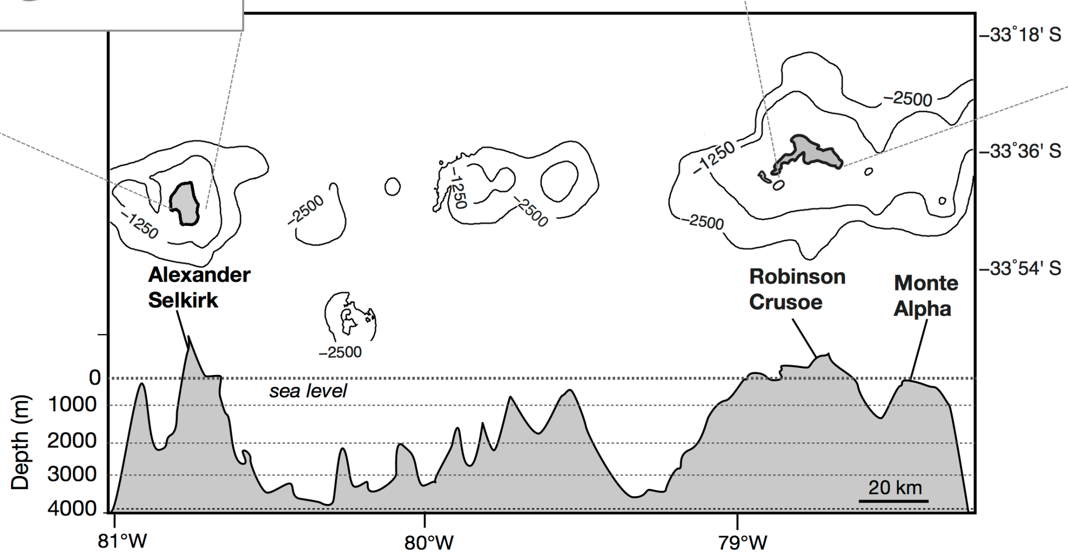
Alexander Selkirk (*Mas Afuera)*
K/Ar: 2.5-0.85 Ma



Group III alkali basalts and olivine tholeiite basalts,

Robinson Crusoe *(Mas a Tierra)*
K/Ar: 5.8-3.1 Ma





Group I alkali basalts and olivine tholeiite basalts
Group II basanites

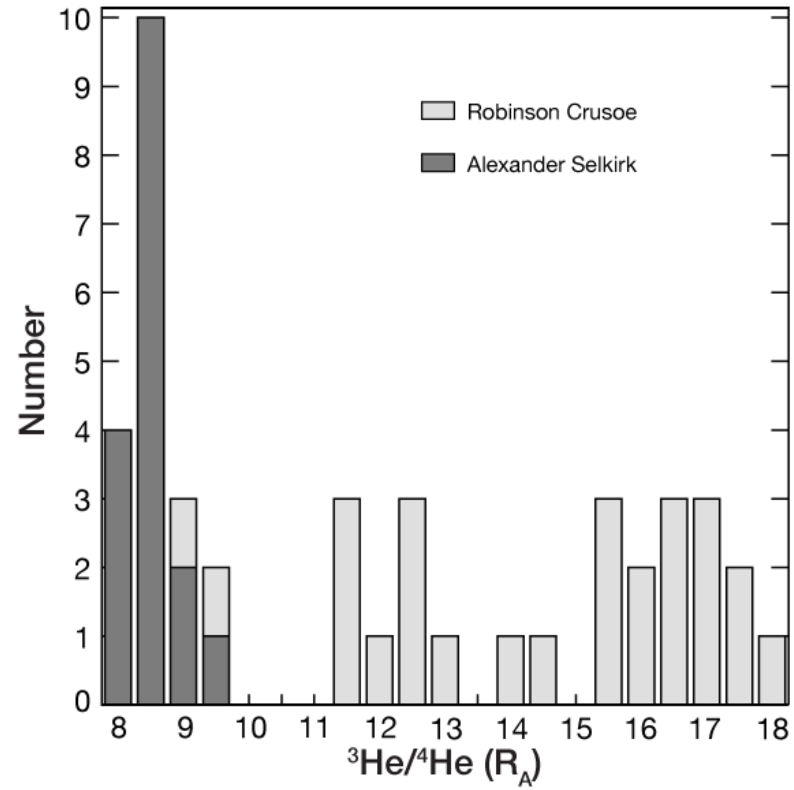
Situating Juan Fernandez in Global OIB Studies

Juan Fernandez notable among other high-$^3He/^4He$ OIBs for range in ratios.

- Despite this range, has relatively limited, nearly homogeneous range of Sr-Nd isotopic signature.

Natland (2003) proposed shallow-level disequilibrium, complex history of magmatic differentiation with “xenocryst” olivines decoupled $^3He/^4He$

Juan Fernandez is an important case study for Helium isotopic variations



Age-progressive volcanism ✔ + High-$^3He/^4He$ (>9 R_A) ✔? = **Mantle plume** ??

Juan Fernandez Study

Major Questions:

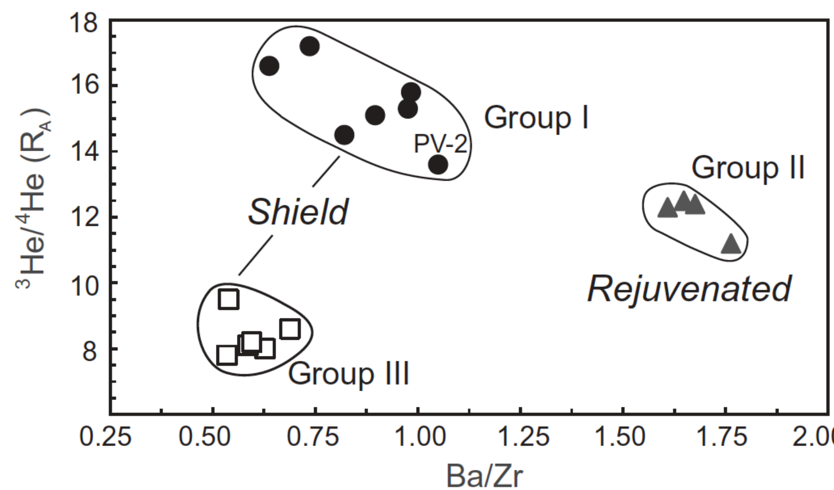
① What is the relationship between He-Sr-Nd-Pb isotopes and major, trace elements?

- Integrated results of $^{3}He/^{4}He$ with radiogenic isotopes and trace elements allow us to evaluate the contribution of mantle source

② Does the volcanic evolution of Juan Fernandez reflect decreasing input of a high-$^{3}He/^{4}He$ mantle plume with time?

- Group I→II→III
- Other source components?

③ Stages of volcanic evolution? Representative of OIB?



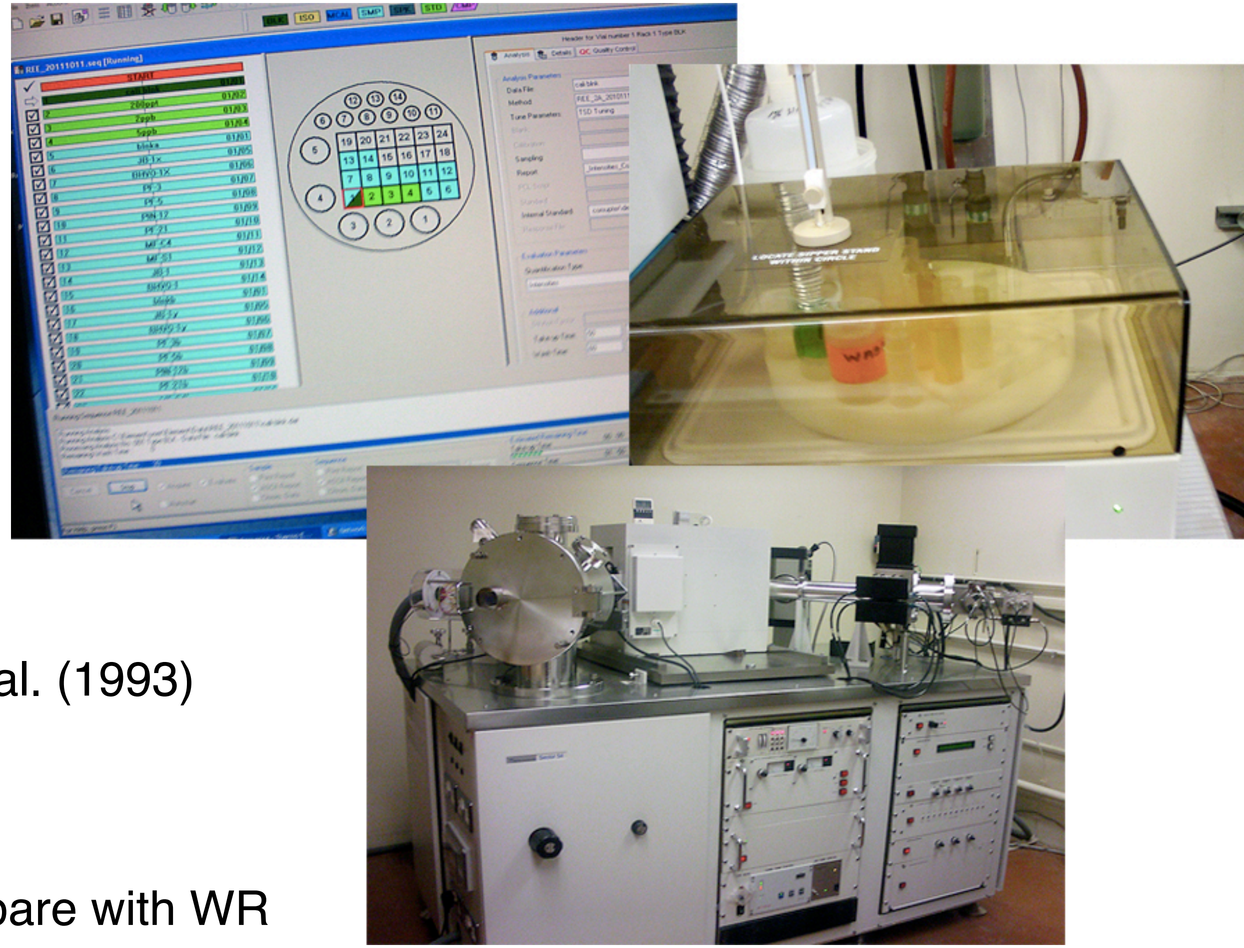
Sample Suite

Collected on Leg 1 of SIO HYDROS Expedition in 1988 with R/V Melville

17 mafic lavas analyzed as whole rock + 5 olivine separates

Bias toward picritic compositions (> 13.5 wt% MgO) due to preferential sampling of olivine-accumulative rocks for He isotope work

Analytical Methods



<u>ICP-MS</u>
Whole rock:
(n=17) Trace elements (Rb, Sr, Y, Ba, Pb, Th, REE, HFSE

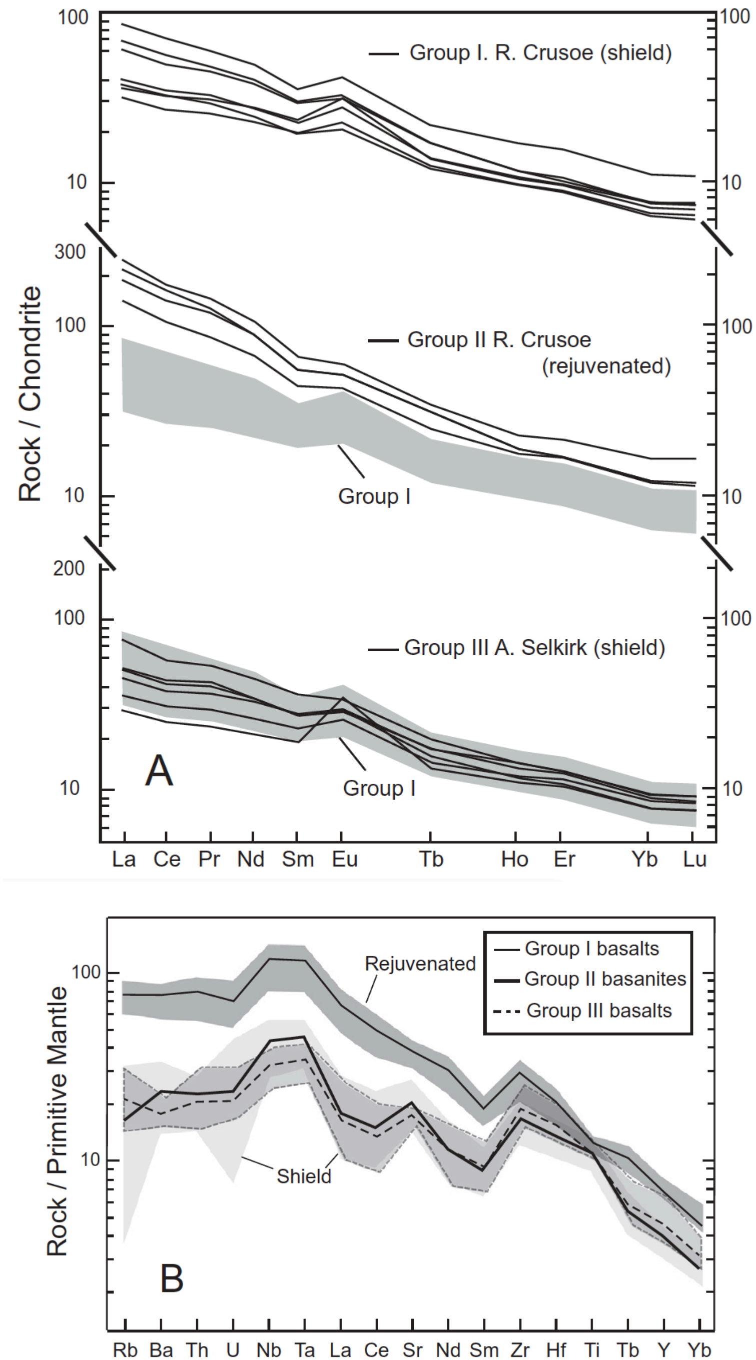
<u>TIMS</u>
Whole rock:
(n=4) Sr-Nd isotopes
- 1 to replicate Farley et al. (1993)
- 3 without previous data

(n=17) Pb isotopes
Olivine:
(n=5) Nd isotopes to compare with WR

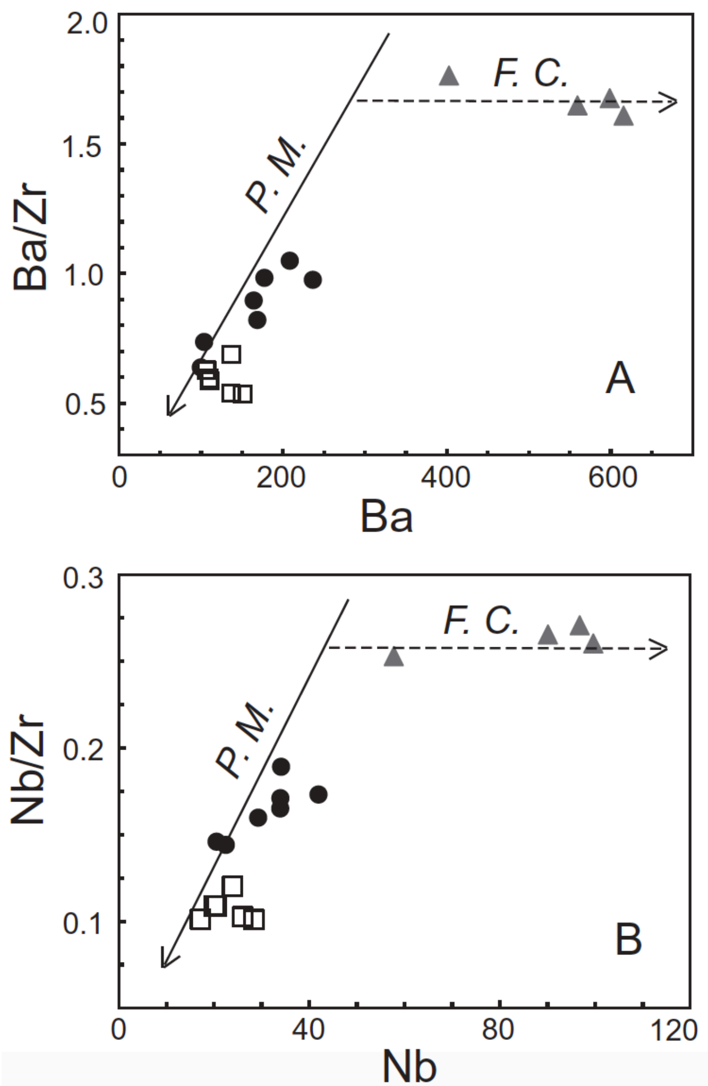
Results: Incompatible Trace Elements, REEs

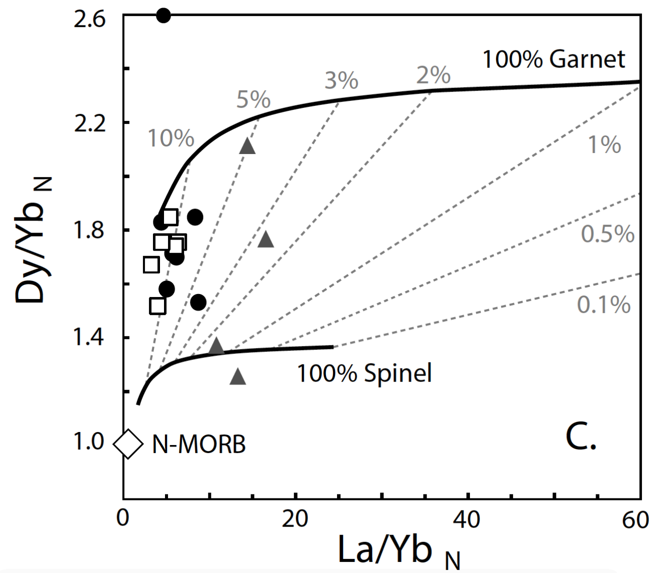
1. Trace element data confirm/strengthen previous classification groups I, II, III
2. Sub-parallel incompatible trace element concentration patterns.
   - R. Crusoe **group I** basalts and A. Selkirk **group III** basalts similar slopes (La/Sm)
   - R. Crusoe **group II** basalts most fractionated suite, with (La/Yb_N) = 20.2

Trace elements suggest origin from a **common, though slightly heterogeneous mantle source**.



Results: Trace Elements and Magmatic Process Identification





- **Group III** basalts produced by the largest degree of partial melting
- **Group II** basanites: smallest degree of partial melting. F.C. also accounts for trace elements

Trace element variations indicate different degrees of partial melting of a common, slightly heterogeneous mantle source

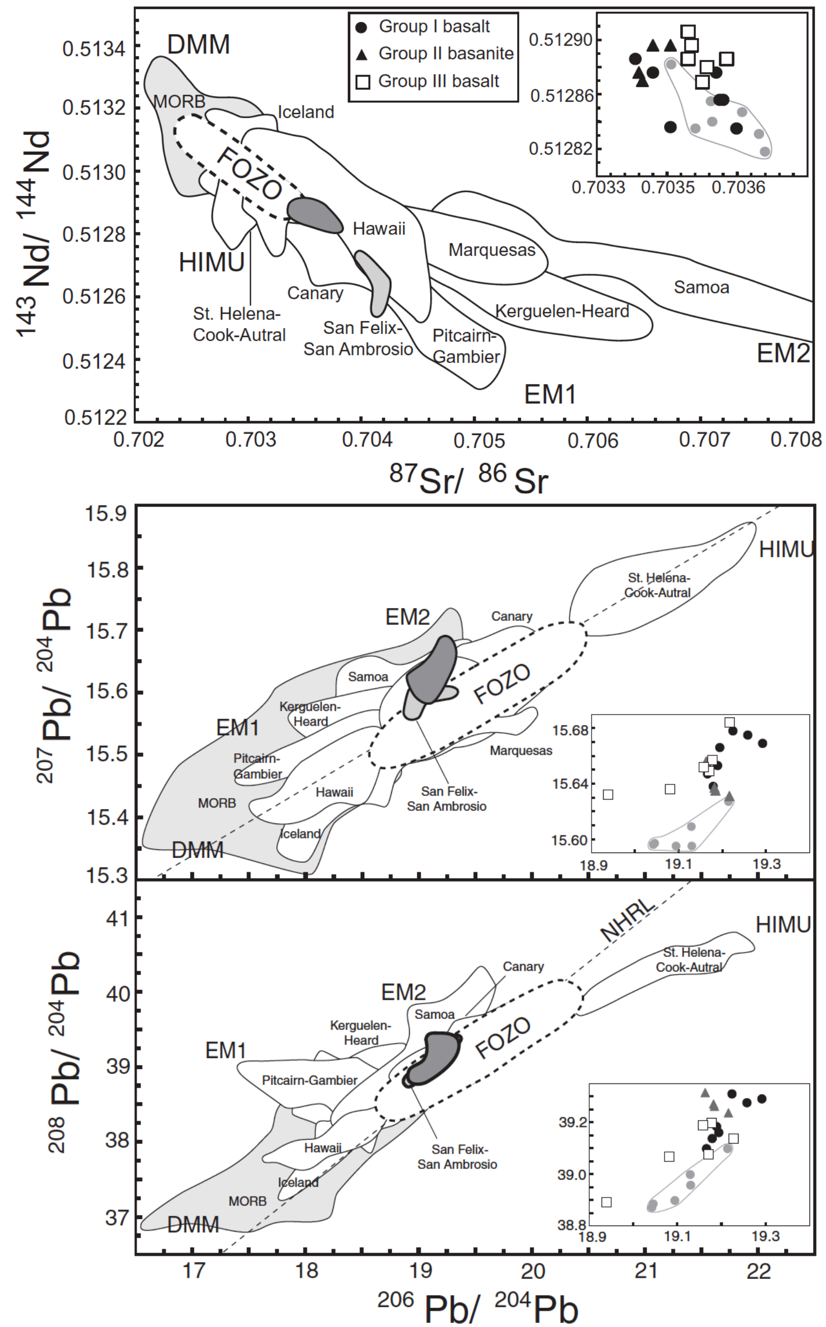
Results: Sr-Nd-Pb Radiogenic Isotopes

Narrow Sr and Nd isotopic range, but indicates ~binary mixing

- Group I is relatively the most isotopically heterogeneous in terms of Sr and Nd isotopic composition.

Narrow Pb isotopic range, but indicates ~binary mixing

- $^{207}Pb/^{206}Pb$ may demonstrate EM1 – FOZO binary mixing.



Modeling $^4He^*$ in low-$^3He/^4He$ ratios

Can we model the growth of $^4He^*$ in group I magma to produce the lower $^3He/^4He$ ratios of group II during the 1 Myr hiatus between shield to post-shield?

$$^4He^* = 2.80 \times 10^{-8}\{[U](4.35 + \frac{Th}{U})\}T(\mathrm{cm^3\ STP\ g^{-1}})$$

Equation from Graham et al. (1987)

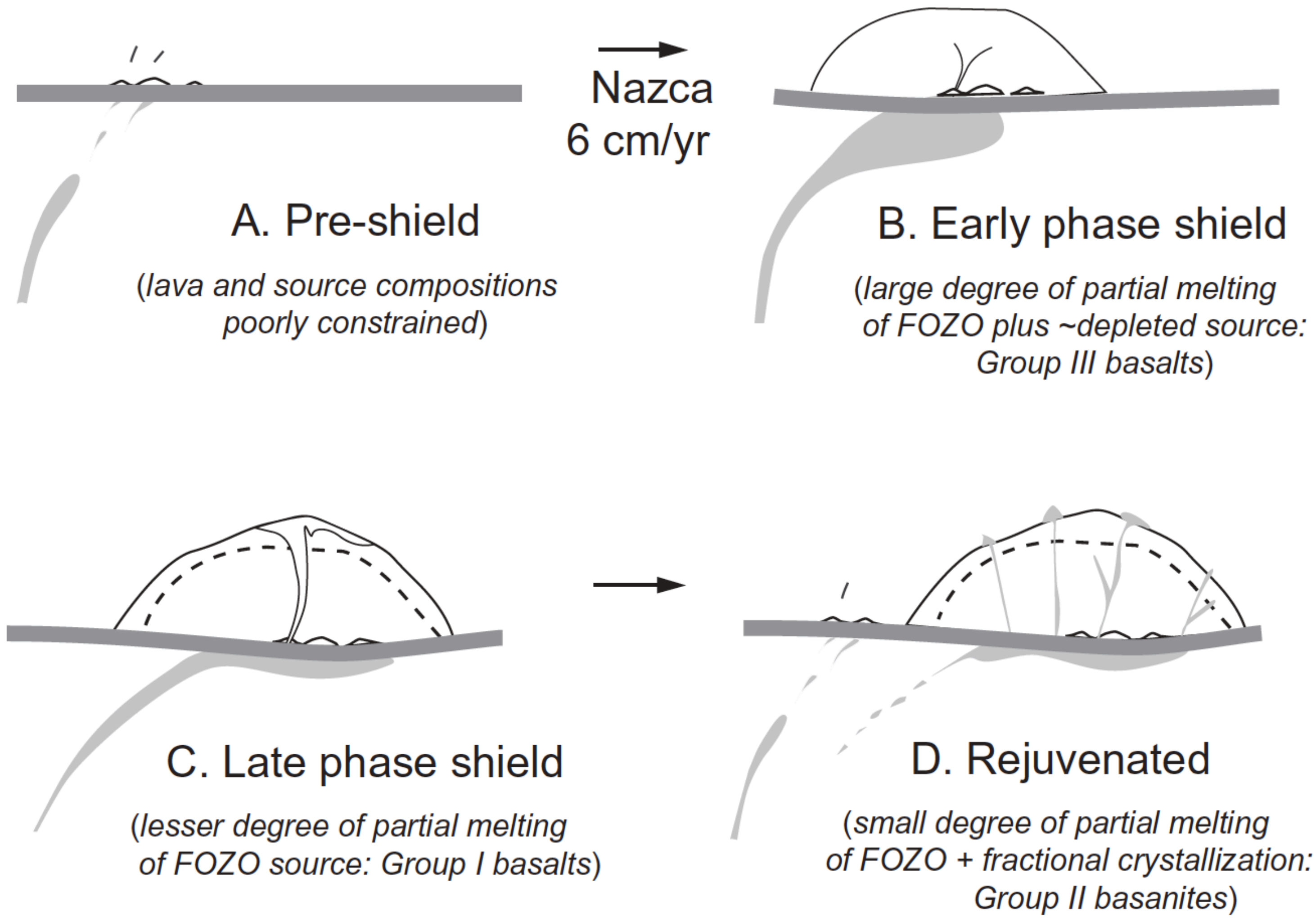
Table 2
Per cent ^4He from Group I basalt needed to produce Group II $^3He/^4He$ after 1 M.y. hiatus.

$^3He_{PIN\text{-}8}$	$[He]_{PIN\text{-}8}$	[He*]	$^3He/^4He$	% He*
cc/g	cc/g	(cc/g)	(R/R_A)	Needed
5.65E − 13	2.69E − 08	3.75E − 07	12.5	1.5
5.65E − 13	2.69E − 08	3.75E − 07	11.2	2.5

Modeling shows the inclusion of <3% radiogenic $^4He^*$ from *in situ* ingrowth of a basalt with initial $^3He/^4He$=17.2 R_A matches observed $^3He/^4He$ ratios in group II basanites $^3He/^4He$=11.2-12.5 R_A.

Proposed Geologic Evolution

Geochemistry consistent with temporal evolution of Juan Fernandez volcanoes



Major Conclusions

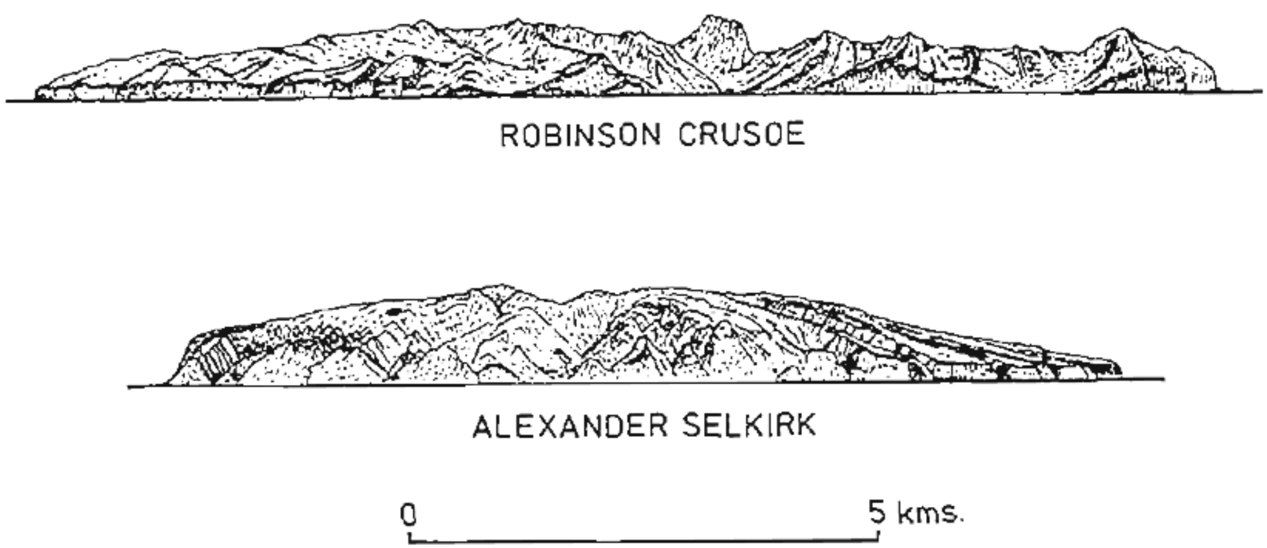
- Limited range of radiogenic isotopes indicates **parental magmas derived from common source,** though it is slightly heterogeneous.
- Variations in major and trace element composition controlled by **differences in degrees of partial melting** of common mantle source.
- Contributions to OIB from **high-$^{3}He/^{4}He$ mantle sources vary** spatially (m to km length) and temporally (10^{2}-10^{6} years)
  - Helium may not be strongly correlated to radiogenic lithophile isotope systematics.

① Geochemistry is consistent with a **mantle plume**

② Juan Fernandez is unlike other high-$^{3}He/^{4}He$ OIB linear volcanic island chains with the **dominance of the FOZO component** in the mantle plume source

Thank you for your attention, Volc-OR!

Questions?



Acknowledgements: Special thanks to Chris MacIsaac, Kate Durkin, Ken Farley, Captain Dave for guiding me through the lab work, presentation of results, and sharing memories from their field experience.

See Truong et al. (2018) *Chemical Geology* for details and complete references