

# OIB and E-MORB petrogenesis investigated with machine learning

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## 1. Introduction:

- Oceanic basalts provide an invaluable window into evolutionary processes governing spatial and temporal chemical heterogeneity in the mantle.
- Ocean island basalts (OIB) and enriched mid-ocean ridge basalts (E-MORB) are powerful tracers of mantle melting and crust-mantle recycling processes.
- Whether the elemental and isotopic variations observed in both E-MORB and OIB are derived from similar mechanisms, however, remains under debate.
- We implemented a novel machine learning approach complemented by mantle mixing models to highlight compositional differences between E-MORB and OIB and further investigate the significance of the best elemental discriminators.

## 2. Methods:

- OIB and E-MORB data were compiled from GEOROC database and Gale et al. (1) (Fig. 1).
- Our compilation was filtered for data quality and to eliminate samples affected by fractional crystallization.

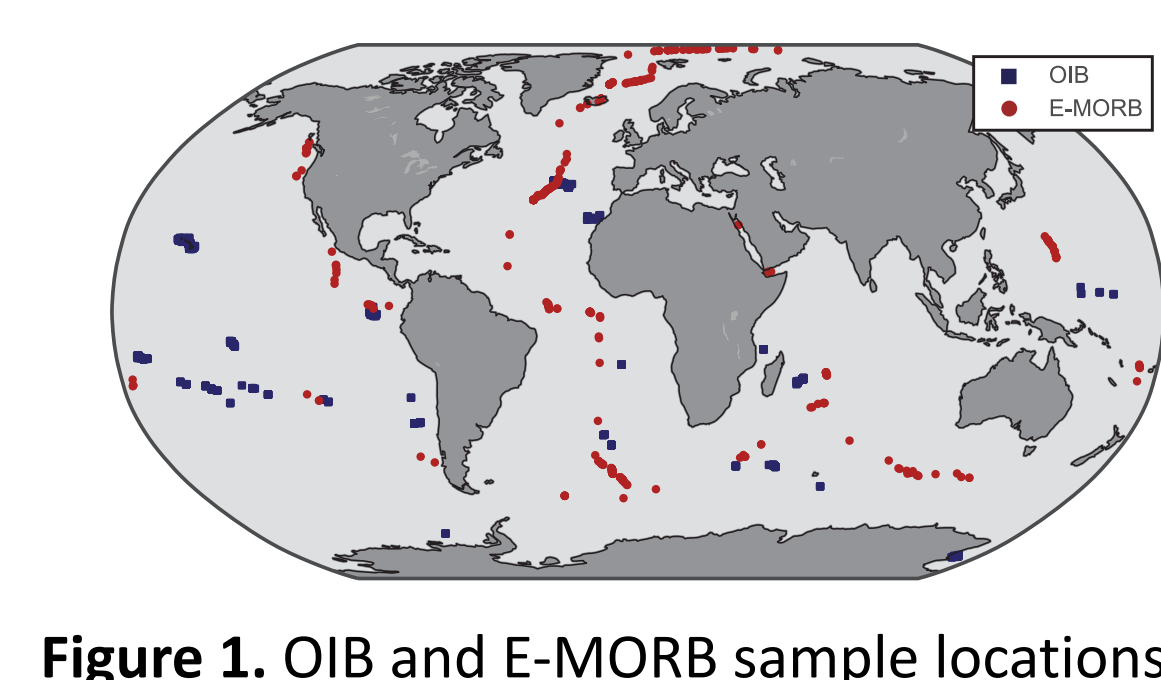


Figure 1. OIB and E-MORB sample locations.

### Machine learning approach:

- Random Forest (RF) modeling was implemented to identify the best elemental predictors.
- Probabilistic OIB/E-MORB discriminant diagrams were constructed using the best RF elemental predictors as inputs into Gaussian process (GP) discrimination models.

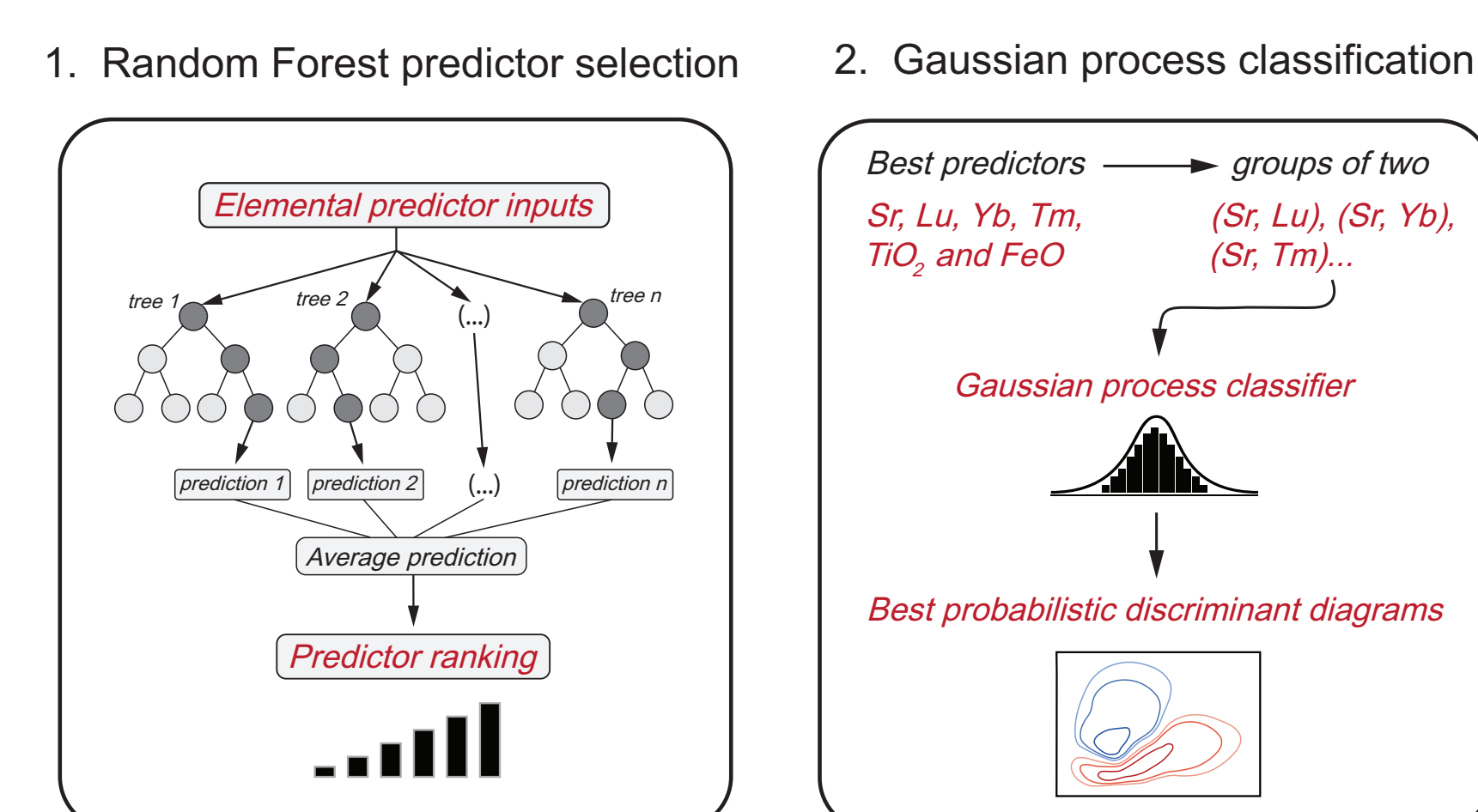


Figure 2. Machine learning recipe implemented here.

### Trace element modeling approach:

- OIB and E-MORB sources were inversely modeled considering median OIB and E-MORB.
- We varied the proportions of depleted mantle (DM), low-degree slab melt (melt), and recycled oceanic crust (ROC) to identify possible source compositions and successful parameter combinations (Table 1).

	OIB source	E-MORB source
$X_{DM}$	0.85 - 1.00	0.98 - 1.00
$X_{melt}$	0 - 0.15	0 - 0.02
$X_{ROC}$	0 - 0.15	-
$F_{slab}$	0 - 0.03	0 - 0.03
$F_{source}$	0.01 - 0.10	0.08 - 0.2

Table 1. Parameter ranges considered in OIB and E-MORB mixing models.

## 3. Results:

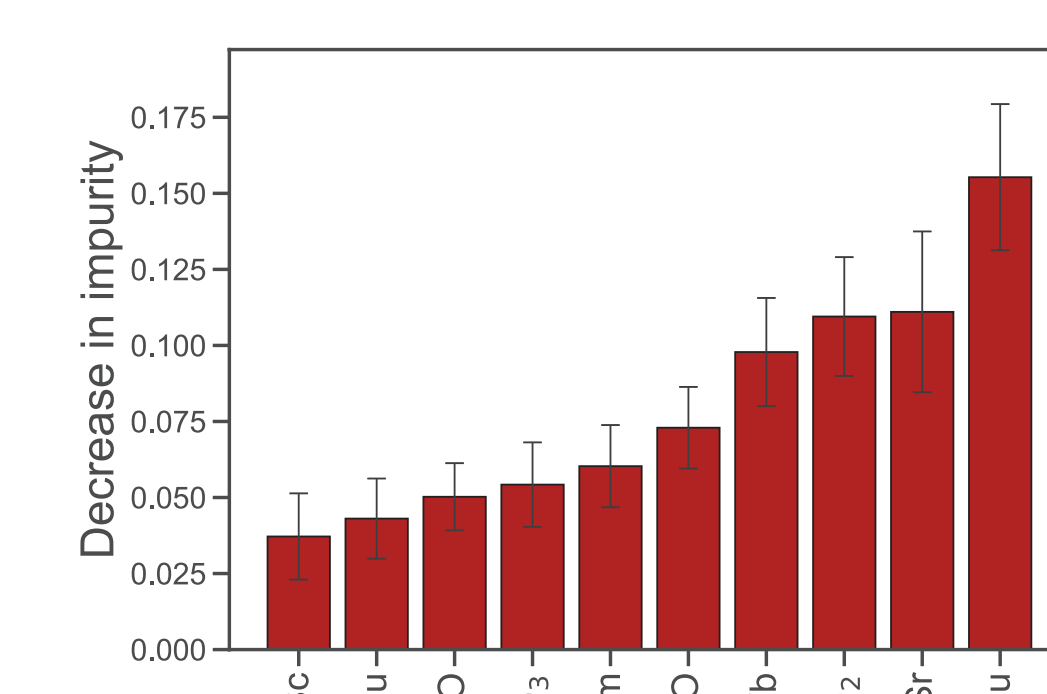


Figure 3. (above) Ten best predictors from RF modeling.

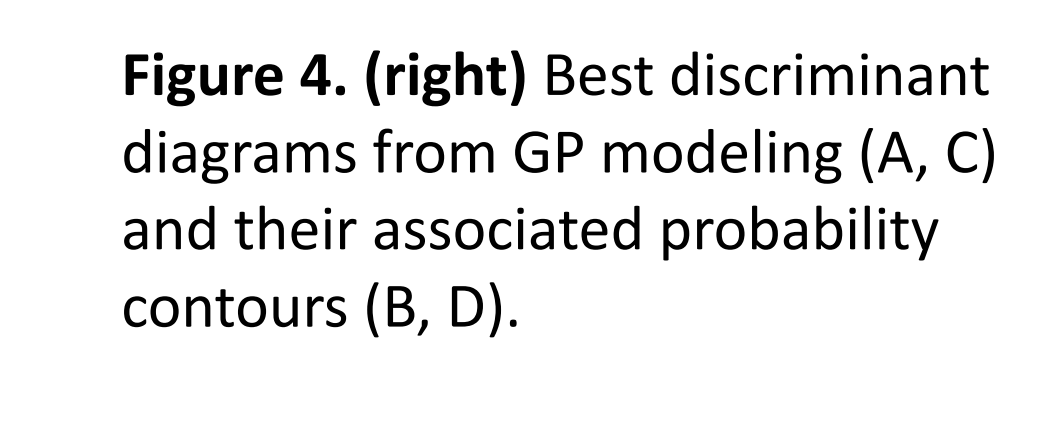


Figure 4. (right) Best discriminant diagrams from GP modeling (A, C) and their associated probability contours (B, D).

- TiO<sub>2</sub> versus Lu and Sr versus FeO are the two best discriminant diagrams to differentiate OIB and E-MORB, with F1 scores better than 97% (Fig. 4).

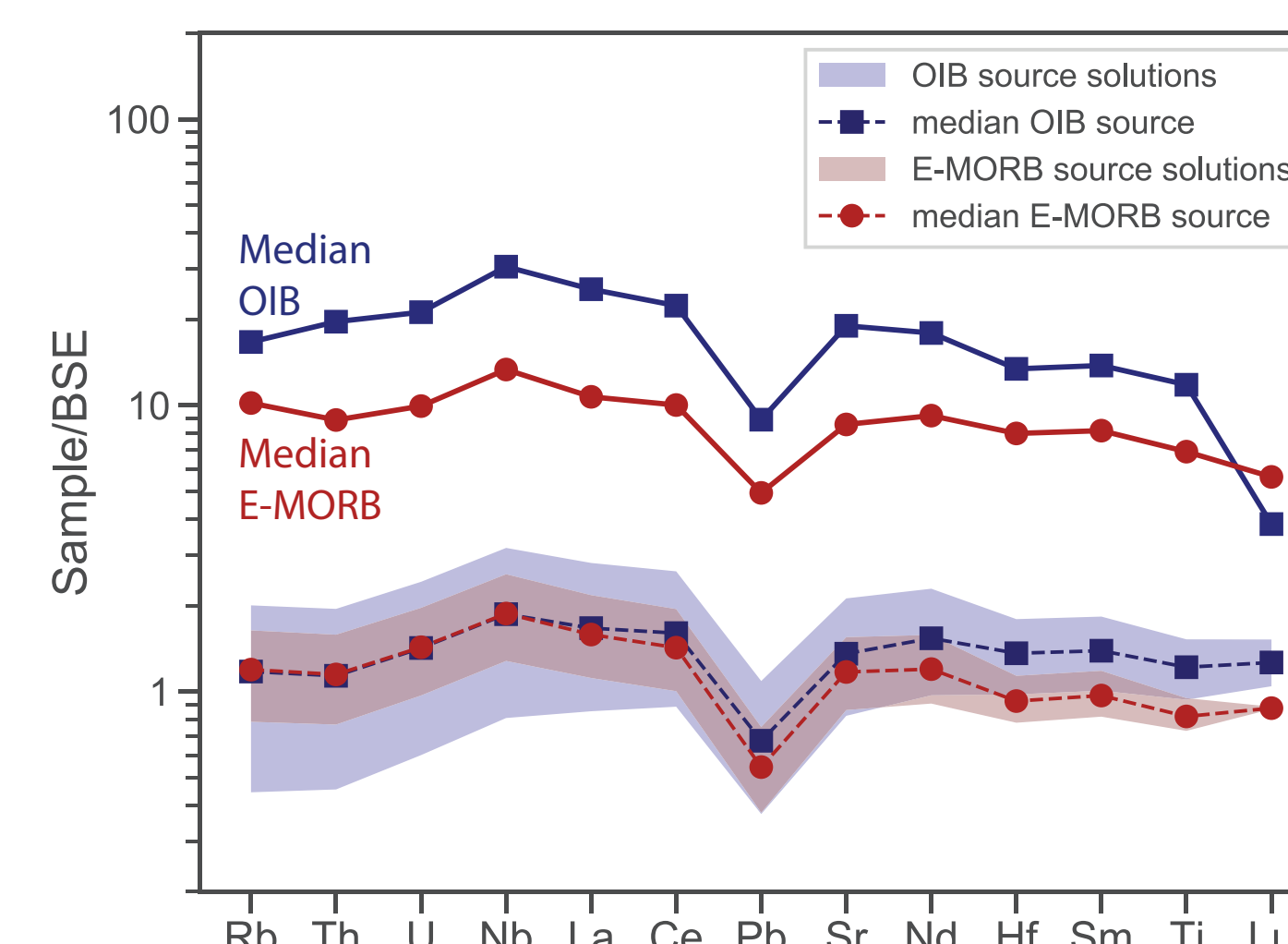


Figure 5. Compositional ranges of calculated OIB and E-MORB sources.

- OIB sources range from depleted to slightly enriched, while E-MORB sources are exclusively enriched (Fig. 5).
- Median OIB and E-MORB sources have indistinguishable highly incompatible element concentrations (Fig. 5), but OIB sources are more enriched in moderately incompatible elements (e.g., Sr, Nd, Hf, Sm, Ti, Lu) (2).

- OIB sources require both ROC and low-degree eclogite melt.
- Progressively more enriched sources (made by increasing  $[X_{ROC} + X_{melt}]$  or  $X_{melt}$ , or by decreasing  $F_{slab}$ ) require higher  $F_{source}$  values to successfully model median OIB and E-MORB (Figs. 6A and 6C).
- The median values of  $F_{slab}$  and  $X_{melt}$  for E-MORB and OIB sources are similar (Figs. 6b and 6d), indicating that E-MORB and OIB sources do not require metasomatic fluids of different compositions.

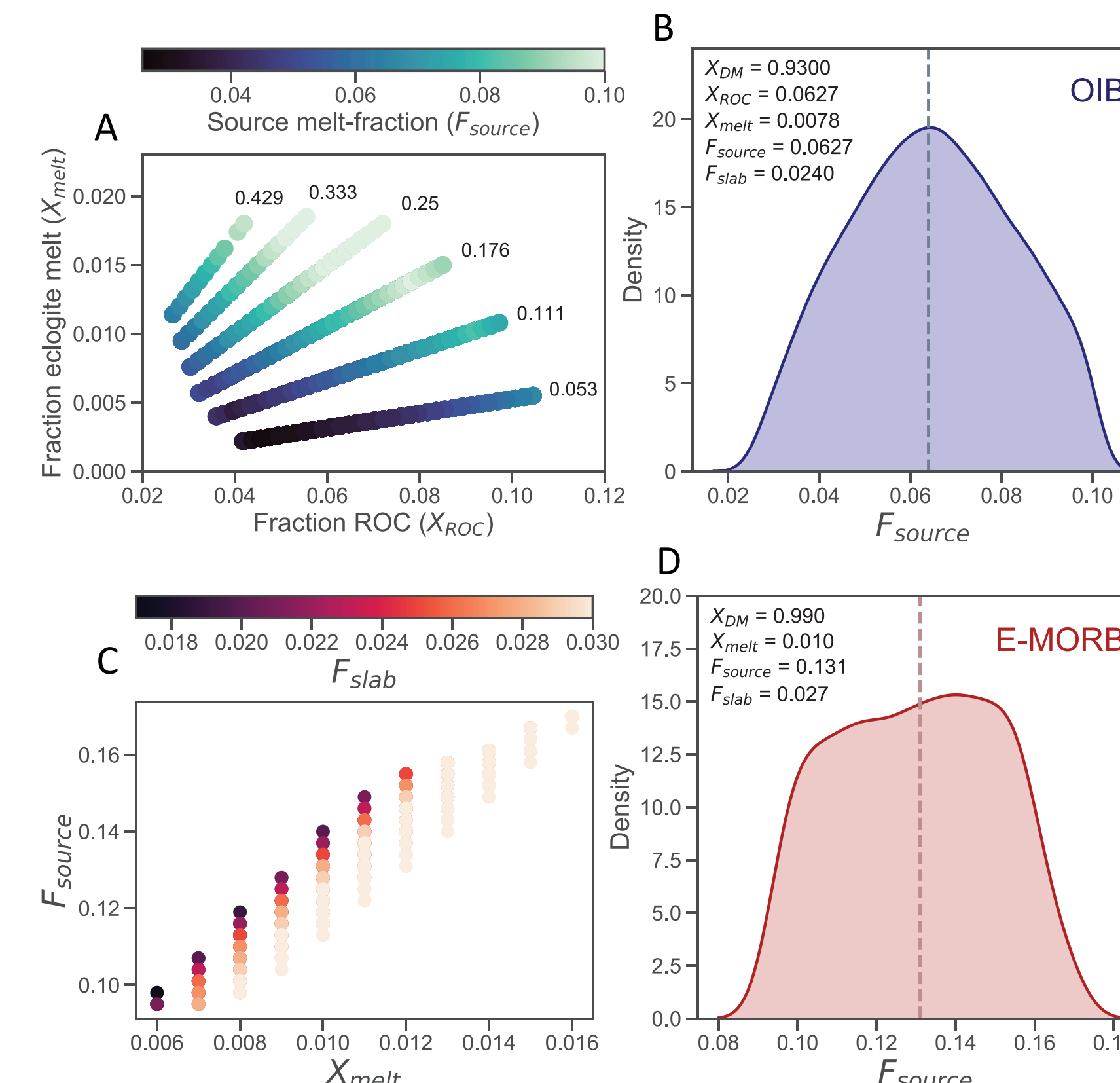


Figure 6. Successful parameter combinations for calculated OIB and E-MORB sources; median values for each modeling parameter are listed in panels B and D.

## 4. Discussion:

- The best elemental discriminators (TiO<sub>2</sub>, Lu, Sr, and FeO) are all sensitive to degree of melting (F) and depth/pressure of melting.
- OIB have higher FeO and TiO<sub>2</sub> and lower Lu than E-MORB because OIB melts form at higher P.
  - The TiO<sub>2</sub> effect may be exacerbated by relative enrichment in the OIB source (Fig. 5) (2).
- Sr may also be sensitive to P, because it behaves more incompatibly with increasing garnet in the source (Fig. 7).

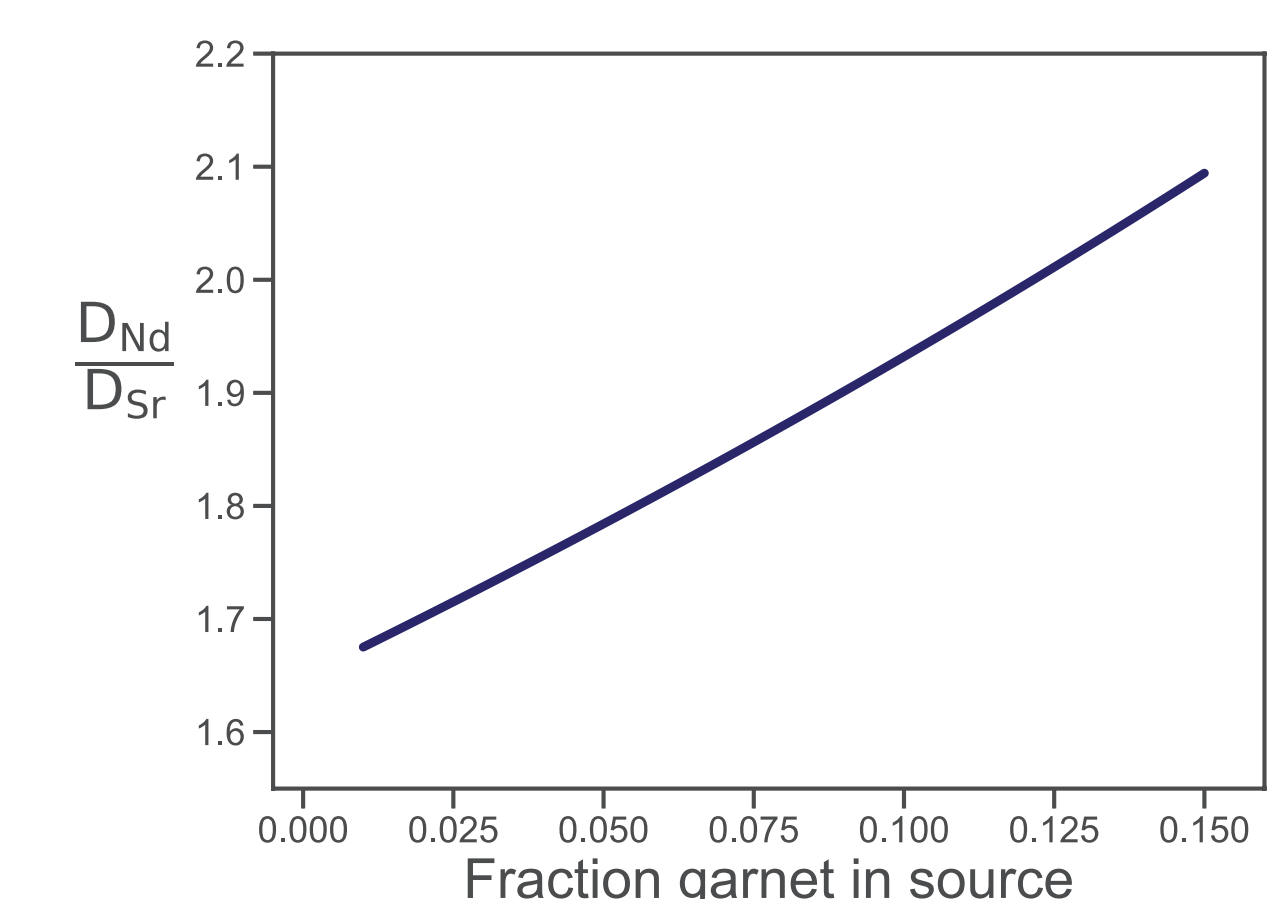


Figure 7. Ratio of bulk Nd and Sr partition coefficients (D) with increasing garnet in the mantle source.

### Joint petrogenetic model:

- A simple, joint model for E-MORB and OIB petrogenesis is proposed after Donnelly et al. (3): Low-degree partial melts of subducting slabs metasomatize the depleted mantle producing a re-fertilized mantle (RM). RM is randomly sampled at mid-ocean ridges to produce E-MORB; upwelling plumes sample both RM and ROC, yielding OIB (Fig. 8).

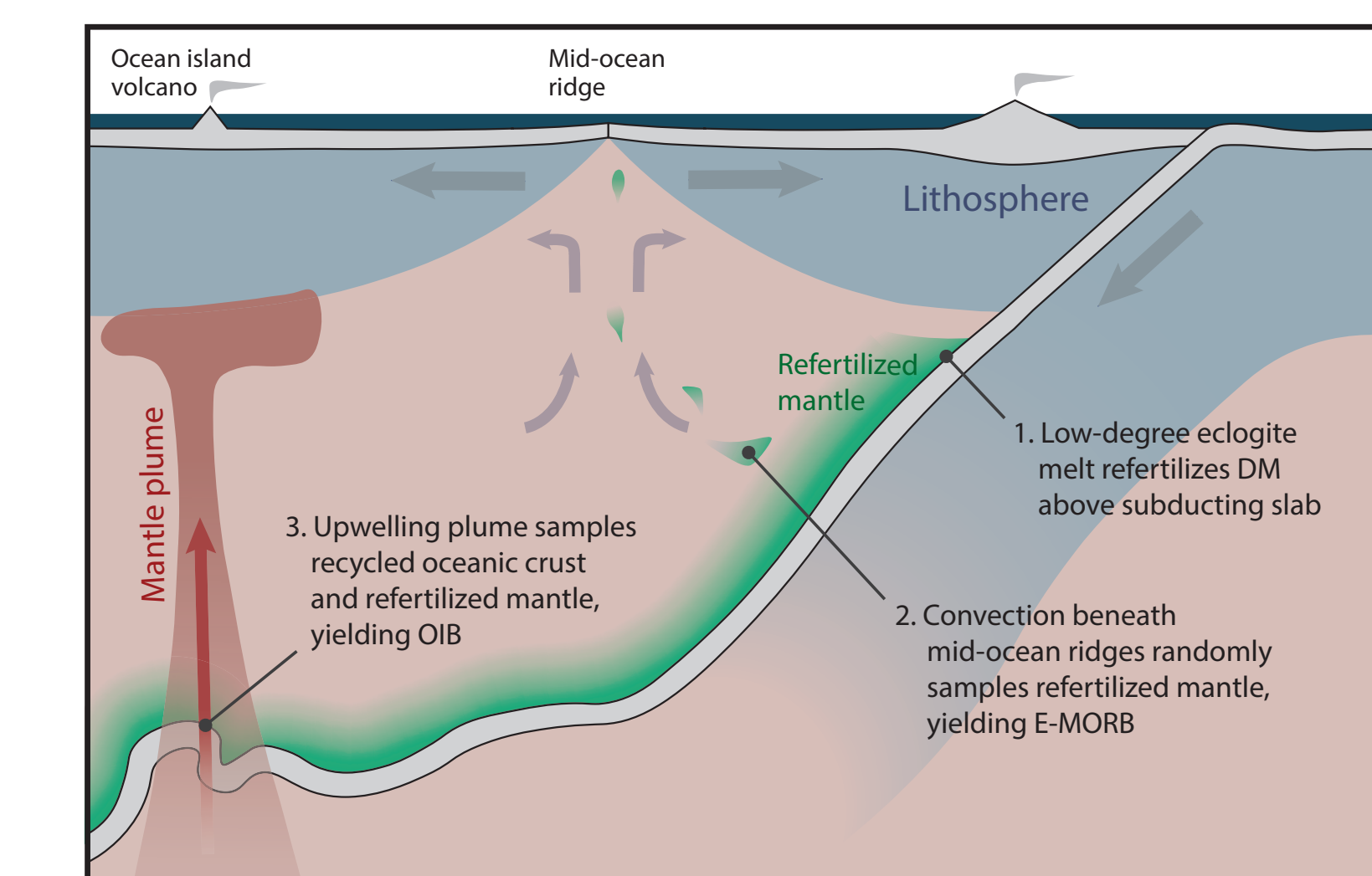


Figure 8. Joint petrogenetic model for OIB and E-MORB.

## 5. Conclusions:

- GP classification is a powerful ML algorithm to produce probabilistic geochemical discriminant diagrams
- The best discriminators between OIB and E-MORB are elements sensitive to pressure and degree of melting (TiO<sub>2</sub>, Lu, Sr, and FeO).
- E-MORB and OIB sources are compositionally similar, but OIB sources are more enriched in moderately incompatible elements due to the influence of ROC.
- OIB and E-MORB sources can be modeled through the same mechanism, involving low-degree melting of a subducting slab and subsequent metasomatism.

## References:

[1] Gale, A. et al. (2013). *Geochim. Geophys. Geosyst.* 14, 489–518. [2] Prytulak, J. and Elliott, T. (2007). *Earth and Planetary Science Letters* 263, 388–403. [3] Donnelly, K.E. et al. (2004). *Earth and Planetary Science Letters* 226, 347–366.