Are provenance interpretations from major, trace and rare earth element data accurate? Results from four active margin settings

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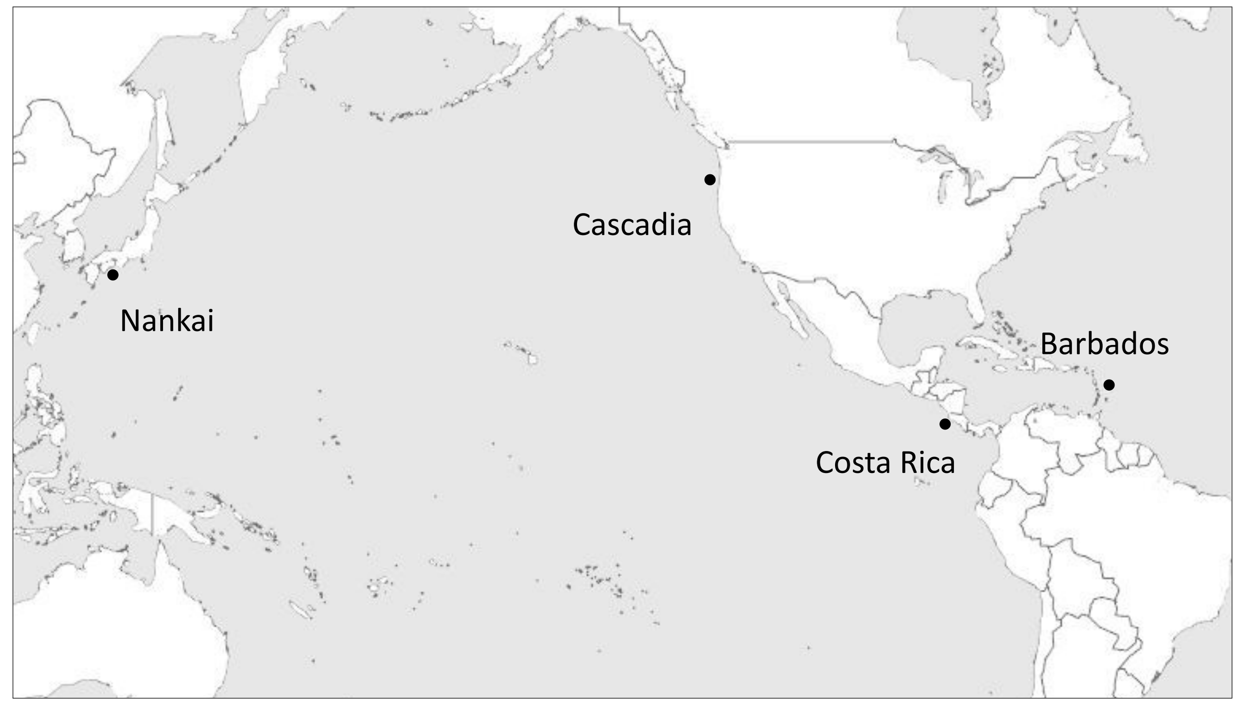
Introduction

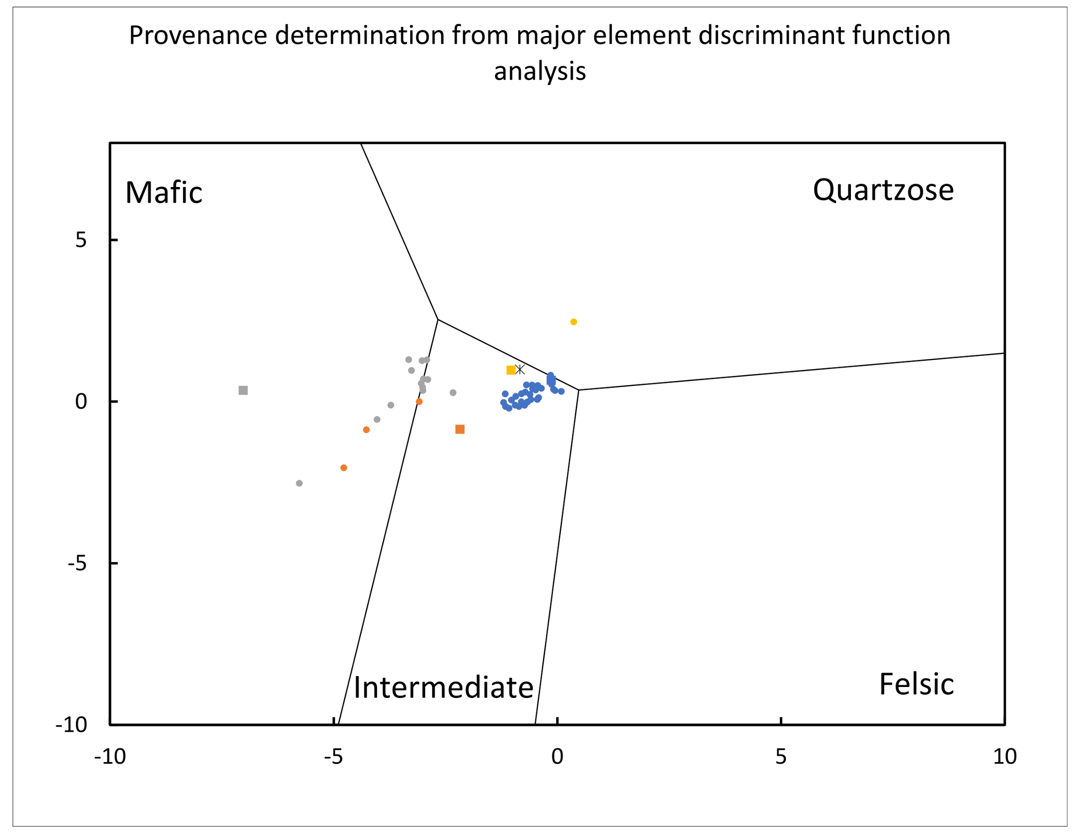
The chemistry of clastic sediments, particularly fine-grained muds, is assumed to be a homogenized representation of the source rocks. It can therefore be used to determine the tectonic setting in which the sediment was deposited. However, there have been some concerns about the accurately of these assumptions, particularly the use of major element discriminant function diagrams and the risk of self-correlation in trace element plots using common denominator ratio pairs. This small study uses samples collected from ODP cores from four subduction zone accretionary wedges: the Nankai Trough (Japan), the northern Barbados Ridge, the Cascadia margin and the Costa Rica accretionary wedge.



Method

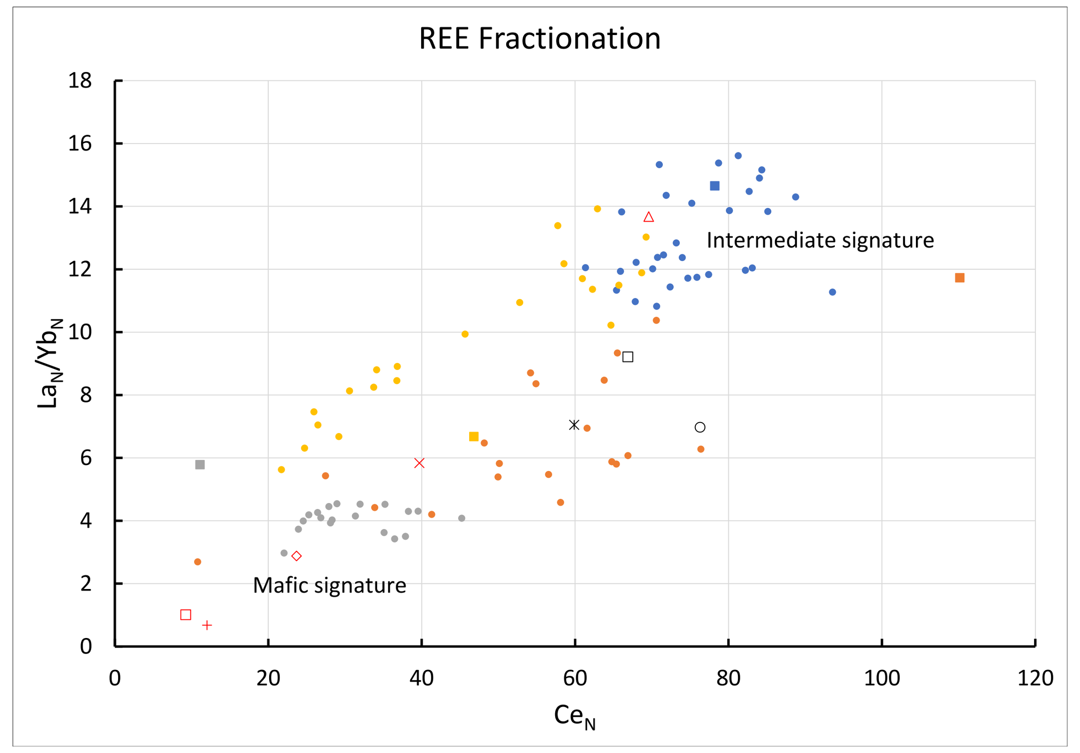
Whole rock samples of hemipelagic muds from each location were powdered and digested in acid before being analyzed by ICP-OES and ICP-MS to determine major, trace and rare earth element concentrations. The data result from several different projects, but rock standards and repeat samples indicate good agreement between the datasets. From these data, provenance interpretations can be made using various established plots. A discriminant function diagram for major elements plots samples in fields representing mafic, intermediate, felsic or quartzose provenance (Roser and Korsch, 1986). Similarly, trace and rare earth element cross plots (Plank and Langmuir, 1998; Cullers, 2002; Totten et al, 2000) help determine mafic versus intermediate signatures and continental versus island arc influences.

Data from this study are plotted as small circles. Published data are included for comparison to assist with interpretation. Averages for these subduction zones (Plank and Langmuir, 1998), upper continental crust (UCC; Taylor and McLennan 1985), North American Shale Composite (NASC; Gromet et al, 1984), global subducting sediment (GLOSS; Plank and Langmuir, 1998), Average mid-ocean ridge basalt (MORB) and average andesite (McLennan, 1989), and typical island arc igneous rocks (Rollinson and Pease 2021 and references therein).

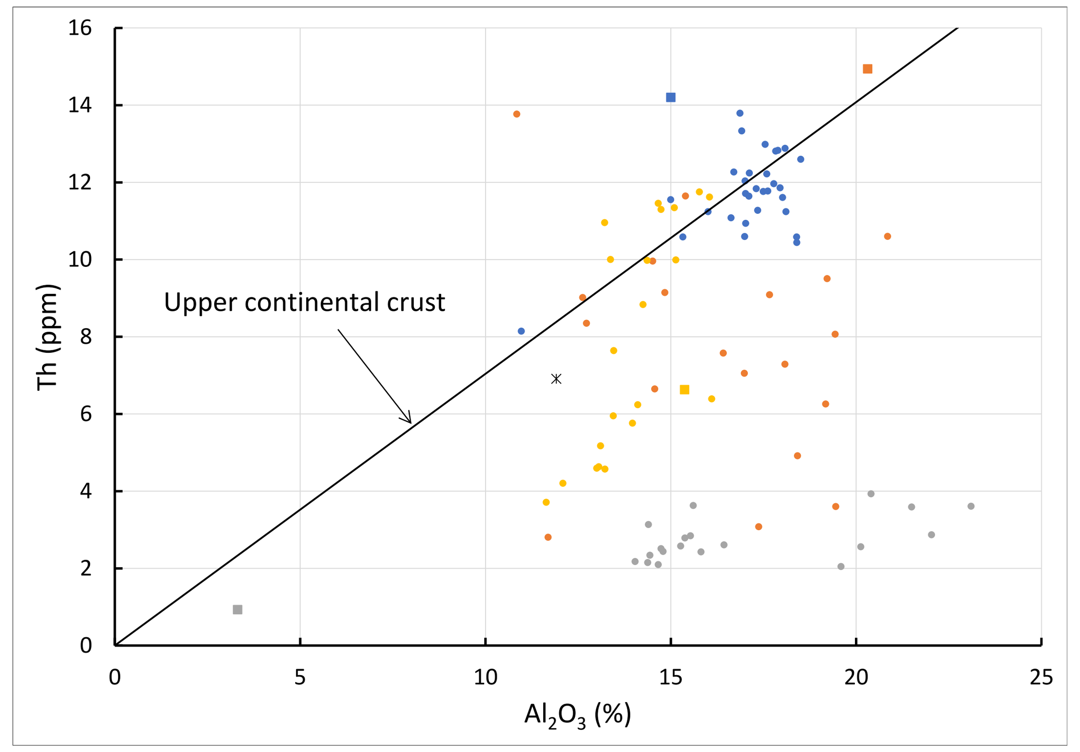


This discriminant function diagram uses major elements (Roser and Korsch, 1986). Other authors have found it good for island arcs, less so for continental arcs (Rollinson and Pease 2021).

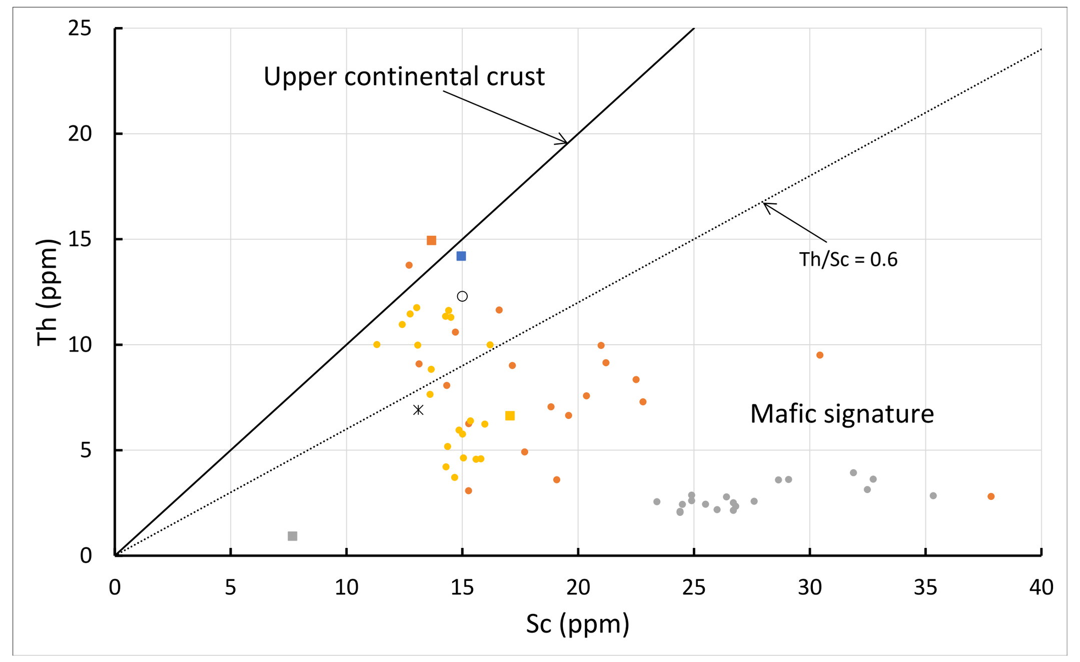
Nankai samples all plot in the intermediate field. Costa Rica samples plot in both mafic and intermediate fields. Previous work on Barbados and Cascadia did not include TiO_2 analysis, so there are not enough samples to draw any conclusions for these sites.



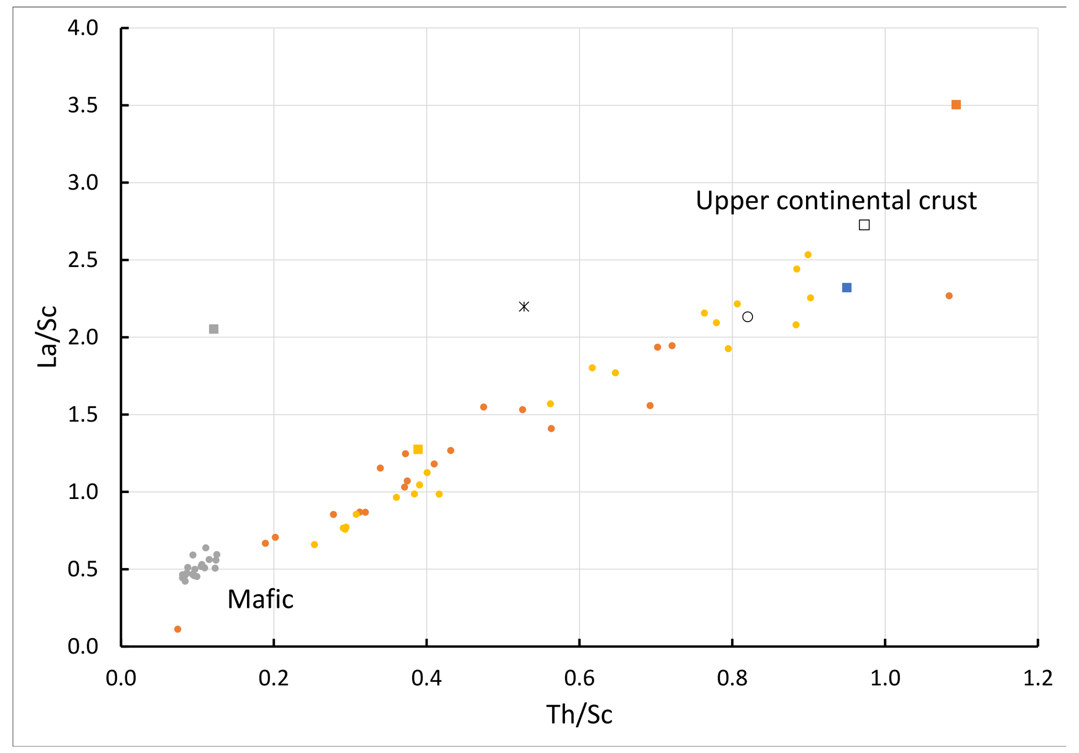
This diagram shows the degree of fractionation of rare earth elements (REE). Nankai samples all have an intermediate signature, while Costa Rica samples all have a mafic signature. Cascadia samples follow the trend line between mafic and intermediate, with Site 891 being more intermediate and Site 892 more mafic. Barbados samples are scattered; many lie below the general trend and show no obvious correlation with site or sedimentary unit.



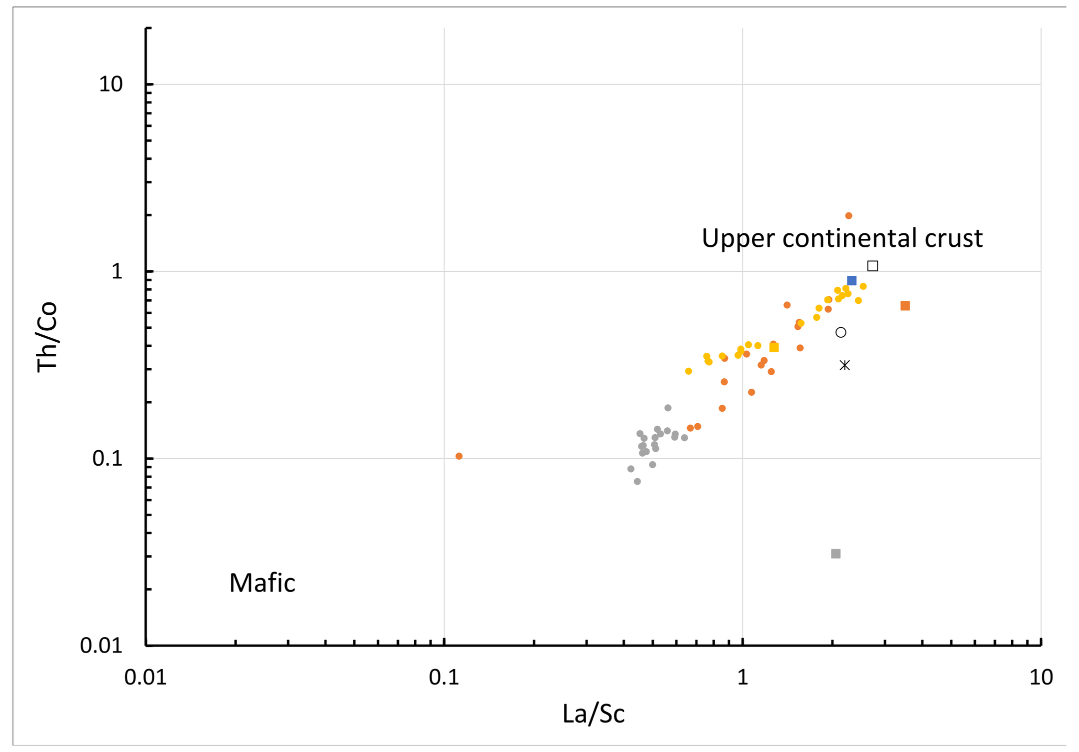
The trendline in this diagram shows the ratio of average UCC (Taylor and McLennan 1985). Samples plotting below this have lower Th concentrations, typical of an increasing mafic signature. Nankai samples plot close to UCC, as do some Barbados and Cascadia, while others from these sites are scattered between the UCC and a more mafic signature. All Costa Rica samples have a clearly mafic signature.



Th is enriched in silicic rocks (incompatible), while Sc is enriched in mafic rocks (compatible). The UCC shows a Th/Sc ratio of 1, and rocks with a Th/Sc ratio below 0.6 are considered mafic (Totten et al, 2000). Costa Rica Samples are clearly mafic, while Barbados and Cascadia samples are again scattered between intermediate and mafic. Sc was not measured in Nankai samples.



Samples plot along a trendline illustrating the mixing of a continental source enriched in La and Th, and a mafic source enriched in Sc (Totten et al, 2000). While this type of ratio plot risks spurious correlation (Rollinson and Pease, 2021), the agreement in provenance signatures with other plots suggests that this is not an issue here. Costa Rica samples are again strongly mafic, while Barbados and Cascadia samples are more diverse.



Cross plot of ratios of elements enriched in silicic rocks (incompatible Th and La) to elements enriched in mafic rocks (compatible Co and Sc). Samples display similar trends to previous plots for all locations. Sc and Co were not measured in Nankai samples.

This study

- Nankai
- Barbados
- Costa Rica
- Cascadia

Published data

- Nankai
- Southern Antilles
- Central America
- Cascadia
- UCC
- NASC
- GLOSS
- Average MORB
- Basaltic andesite (island arc)
- Average Andesite
- Andesite (Antilles)
- Andesite (Andes)

Conclusions

Nankai samples consistently show an intermediate provenance with UCC signature on all plots for which data is available. This is consistent with a mature island arc.

Barbados samples show a scattered distribution between intermediate/UCC and strongly mafic signatures. On closer inspection, there is no correlation between site or lithology and provenance. This suggests that volcanic ash from individual eruptions may influence the provenance signature, representing the diverse compositions of volcanoes in the southern Antilles Arc (Macdonald et al, 2000).

Costa Rica samples consistently show a mafic provenance over all plots using trace elements, but the major element diagram shows a mixed source.

Cascadia samples show a consistent trend between mafic and intermediate, with Site 891, which is further offshore, being more intermediate and Site 892 more mafic.

Future work

While all of the different geochemical interpretations of provenance yield similar results, these data sets are incomplete. For example, Sc and Co were not available for any Nankai samples, and TiO_2 for most Cascadia and Barbados samples. These are currently being reanalyzed to complete the datasets.

Acknowledgements

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