*Geochemistry Geophysics Geosystems*

Supporting Information for

# Assessing origins of end-Triassic tholeiites from Eastern North America using hafnium isotopes

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## Additional Supporting Information (Files uploaded separately)

Table S4 (Mantle Wedge Calculator model)
Caption for Table S4

## Introduction

The Supporting Information for this manuscript includes supporting figures showing trace element and isotope compositions for samples from this study. It also includes three supporting tables with modeling parameters for all of the calculations and models described in the main text. An additional supporting table, Table S4, is the metasomatized mantle evolution model calculator from this study, provided as a user-enabled spreadsheet.

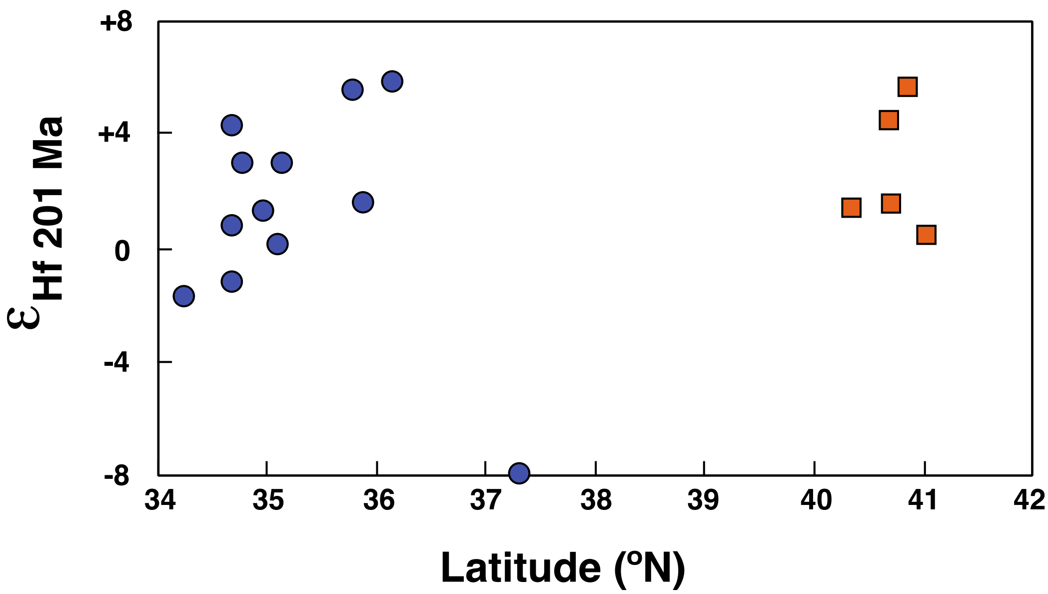


**Figure S1.** Age-corrected $\varepsilon_{Hf}$ vs. latitude for ENA tholeiites from this study, including samples from the southern ENA region and the northern Newark basin. All symbols as in Figure 2.

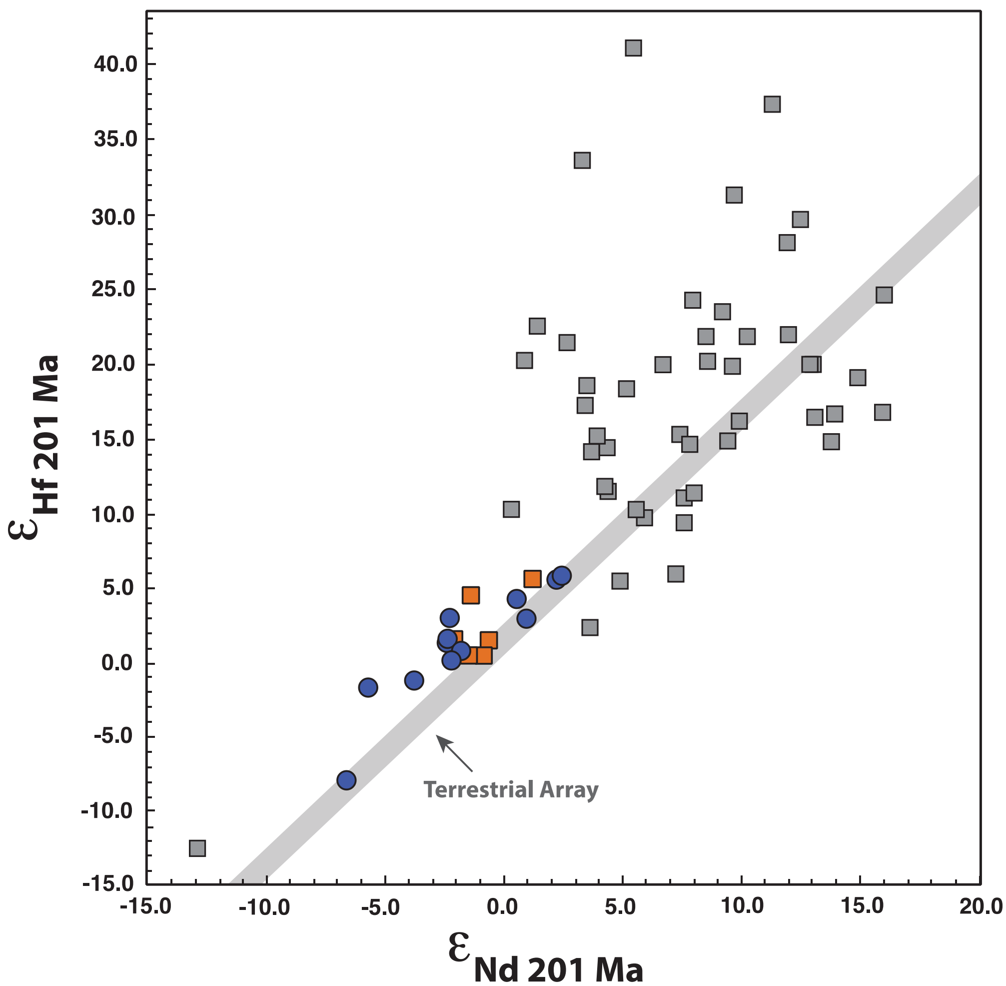


**Figure S2.** $\varepsilon_{Hf}$ vs. $\varepsilon_{Nd}$ showing samples from this study (symbols as in Figure 2) with globally representative SCLM-derived xenolith samples from Jordan, China, Morocco, and France (Choi et al., 2008; Shaw et al., 2007; Wittig et al., 2010) (gray squares).

| | Lu (ppm) | Hf (ppm) | Sm (ppm) | Nd (ppm) | U (ppm) | Pb (ppm) | $\epsilon_{Hf}$ | $\epsilon_{Hf,201\ Ma}$ [a] | $\epsilon_{Nd}$ | $\epsilon_{Nd,201\ Ma}$ [b] | $^{206}Pb/^{204}Pb$ | $^{206}Pb/^{204}Pb_{201\ Ma}$ [c] | $^{207}Pb/^{204}Pb$ | $^{207}Pb/^{204}Pb_{201\ Ma}$ [d] | References |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DMM solid source** | 0.63 | 0.20 | 0.27 | 0.71 | 0.005 | 0.023 | +18.2 | +16.7 | +9.4 | +8.5 | - | - | - | - | Salters & Stracke, 2004; Klein et al., 2004 |
| **DMM partial melt (MORB)** | - | 2.9 | - | 6.1 | - | 0.2 | +18.2 | +16.7 | +9.4 | +8.5 | - | - | - | - | |
| **DMM alternate composition** | | | | | | | +16.8 | +14.3 | +9.8 | +8.4 | 18.28 | 17.93 | 15.49 | 15.47 | Workman & Hart, 2005 |
| **EM1 solid source** | 0.1 | 0.4 | 0.54 | 1.67 | 0.04 | 0.23 | -5.8 | -5.7 | -5.8 | -5.8 | 17.77 | 17.34 | 15.49 | 15.47 | Eisele et al., 2002; Jackson & Dasgupta, 2008; Willbold & Stracke, 2006; Woodhead & Devey, 1993 |
| **EM1 partial melt** | - | 9.3 | - | 60.0 | - | 5.5 | -5.8 | -5.7 | -5.8 | -5.8 | 17.77 | 17.34 | 15.49 | 15.47 | |
| **EM2 solid source** | 0.1 | 0.4 | 0.53 | 1.55 | 0.02 | 0.1 | -5.9 | -6.1 | -6.6 | -6.9 | 19.56 | 19.17 | 15.66 | 15.64 | Jackson & Dasgupta, 2008; Jackson et al., 2007; Salters et al., 2011; Willbold & Stracke, 2006; Workman et al., 2004 |
| **EM2 partial melt** | - | 5.6 | - | 42.3 | - | 6.6 | -5.9 | -6.1 | -6.6 | -6.9 | 19.56 | 19.17 | 15.66 | 15.64 | |
| **Upper continental crust:** | | | | | | | | | | | | | | | |
| **Carolina terrane** | - | 2.0 | - | 65.0 | - | 25.9 | - | -8.6 [e] | - | -6.3 | - | 17.4 | - | 15.6 | Whalen et al., 2015, and references therein |
| **Lower continental crust:** | | | | | | | | | | | | | | | |
| **Michigan mafic granulite** | 0.27 | 1.2 | 2.1 | 9.0 | 0.12 | 3.3 | -0.2 | +0.14 | -13.0 | -11.4 | 17.74 | 17.67 | 15.71 | 15.70 | Zartman et al., 2013 |
| **Markt mafic granulite** | - | - | - | - | 0.5 | 2.5 | - | - | - | - | 16.9 | 16.5 | 15.4 | 15.3 | Huang et al., 1995 |
| **Intermediate granulite** | 0.79 | 20.0 | 33.4 | 131.0 | - | - | -21.5 | -17.0 | -13.0 | -7.1 | - | - | - | - | Schmitz et al., 2004 |
| **Average subducted sediment [f] (GLOSS)** | 0.41 | 4.06 | 5.80 | 27.0 | 1.68 | 19.9 | +2.0 | -0.07 | -8.8 | -9.67 | 18.91 | 19.1 | 15.67 | 15.68 | Plank and Langmuir, 1998; Chauvel et al., 2008 |

[a] $^{176}Hf/^{177}Hf$ isotope ratios corrected to an age of 201 Ma using a $^{176}Lu$ decay constant of $1.867 \times 10^{-11}\ a^{-1}$ (Söderland et al., 2004). $\epsilon_{Hf}$ values were determined using an age-corrected CHUR value of $^{176}Hf/^{177}Hf = 0.282659$, calculated using present-day CHUR values of $^{176}Hf/^{177}Hf = 0.282785$ and $^{176}Lu/^{177}Hf = 0.0336$ (Bouvier et al., 2008).

[b] $^{143}Nd/^{144}Nd$ isotope ratios corrected to an age of 201 Ma using a $^{147}Sm$ decay constant of $6.539 \times 10^{-12}\ a^{-1}$ (Begemann et al., 2001). $\epsilon_{Nd}$ values were determined using an age-corrected CHUR value of $^{143}Nd/^{144}Nd = 0.512374$, calculated using present-day values of $^{143}Nd/^{144}Nd = 0.51263$ and $^{147}Sm/^{144}Nd = 0.196$ (Bouvier et al., 2008).

[c] $^{206}Pb/^{204}Pb$ isotope ratios corrected to 201 Ma using a $^{238}U$ decay constant of $1.551 \times 10^{-10}\ a^{-1}$ (Jaffey et al., 1971).

[d] $^{207}Pb/^{204}Pb$ isotope ratios corrected to 201 Ma using a $^{235}U$ decay constant of $9.8485 \times 10^{-10}\ a^{-1}$ (Jaffey et al., 1971).

[e] $\epsilon_{Hf}$ for Carolina terrane upper crust was calculated using the age-corrected $\epsilon_{Nd}$ value shown and the average terrestrial array best fit relationship after Vervoort et al. (2011).

[f] Subducted sediment isotope values determined using average subducted sediment compositions (GLOSS) with a calculated age of 170 Ma, chosen to represent subducted Paleozoic sediments in the CAMP melt region (i.e., sediments subducted around 370 Ma and later sampled by CAMP melting at 201 Ma), after Merle et al. (2011).

**Table S1.** Composition of source reservoirs and partial melts used for mixing and EC-AFC calculations.

| Parameter [a] | Magma | Mafic LCC | Intermediate LCC | UCC | Units |
|---|---|---|---|---|---|
| $T_{liquidus}$ | 1380 | 1100 | 1000 | 1000 | ºC |
| $T_{initial}$ | 1380 | 600 | 600 | 300 | ºC |
| $T_{solidus}$ | - | 950 | 850 | 700 | ºC |
| $T_{equilibrium}$ | 1100 | 1100 | 1100 | 1100 | ºC |
| $C_p$ | 1484 | 1388 | 1380 | 1370 | J/kg K |
| $H_{crystallization}$ | 396,000 | - | - | - | J/kg |
| $H_{fusion}$ | - | 350,000 | 300,000 | 270,000 | J/kg |
| $D_{Hf}$ [b,c,d] | 0.05 | 0.14 | 1.23 | 0.05 | |
| $D_{Nd}$ | 0.04 | 0.14 | 0.17 | 0.09 | |
| $D_{Pb}$ | 0.002 | 0.14 | 0.14 | 0.2 | |

[a] Liquidus and solidus temperatures, specific heat ($C_p$) values, and enthalpies estimated using values after Callegaro et al. (2017), Heinonen et al. (2016), and Bohrson and Spera (2001).

[b] Magmatic partition coefficients were determined using mineral/melt partition coefficients by McKenzie and O'Nions (1991) and fertile spinel peridotite modes of 60% olivine, 20% clinopyroxene, and 20% orthopyroxene.

[c] Mafic lower crust assimilant partition coefficients were determined using lower crustal granulite mineral modes after Zartman et al. (2013) and mineral/melt partition coefficients estimated from ranges compiled in the GERM Earthref catalog. Intermediate lower crust assimilant partition coefficients were determined for a granulite with 14% quartz, 42% garnet, 34% plagioclase, 3% clinopyroxene, 0.1% apatite, 0.1% zircon, and 1% rutile. This composition is comparable to intermediate granulite xenoliths measured by Schmitz et al. (2004) and Zartman et al. (2013). In the absence of accessory minerals, $D_{Hf} = 0.12$, $D_{Nd} = 0.10$, and $D_{Pb} = 0.13$.

[d] Upper crust assimilant partition coefficients were determined using average upper crust compositions after Taylor and Maclennan (1995) and Wedepohl (1995), which were used to calculate a stable upper crustal assemblage of 21% clinopyroxene, 38% quartz, 4% muscovite, 9% orthoclase, and 28% plagoclase; and mineral/melt partition coefficients estimated from ranges compiled in the GERM Earthref catalog.

**Table S2.** Model parameters used for EC-AFC calculations, after Bohrson and Spera (2001) and Spera and Bohrson (2001).

**Table S3.** Model parameters used for calculating the composition of residual metasomatized mantle (see Table S4).

| | U | Th | Pb | Rb | Sr | Sm | Nd | Lu | Hf | References |
|---|---|---|---|---|---|---|---|---|---|---|
| **DMM** | 0.005 | 0.01 | 0.02 | 0.09 | 9.8 | 0.3 | 0.7 | 0.06 | 0.2 | Salters & Stracke, 2004 |
| **GLOSS** | 1.7 | 6.9 | 19.9 | 57.2 | 327 | 5.8 | 27 | 0.4 | 4.1 | Plank & Langmuir, 1998 |
| **Altered Ocean Crust (AOC)** | 0.3 | 0.01 | 0.7 | 13 | 180 | 2.6 | 6.7 | 0.4 | 1.9 | Staudigel et al., 1996 |
| **Partition coefficients, $D_i$:** | | | | | | | | | | |
| **Bulk peridotite/melt** [a] | 0.0065 | 0.0044 | 0.0012 | 0.0012 | 0.0071 | 0.041 | 0.020 | 0.61 | 0.065 | McKenzie & O'Nions, 1991; Salters et al., 2002 |
| **Bulk sediment/melt** [b] | 1.0 | 1.2 | 1.0 | 1.1 | 0.6 | 2.9 | 3.0 | 5.5 | 2.4 | Johnson & Plank, 2000 |
| **Bulk sediment/fluid** [c] | 3.1 | 4.5 | 0.8 | 1.7 | 0.7 | 2.0 | 2.4 | 2.5 | 2.1 | Johnson & Plank, 2000 |
| **AOC Mobility coefficients** [d] | 0.3 | 0.4 | 0.9 | 0.6 | 0.4 | 0.1 | 0.31 | 0.01 | 0.01 | Kogiso et al., 1997 |

| | $\frac{^{206}Pb}{^{204}Pb}$ | $\frac{^{207}Pb}{^{204}Pb}$ | $\frac{^{207}Pb}{^{204}Pb}$ | $\frac{^{87}Sr}{^{86}Sr}$ | $\frac{^{143}Nd}{^{144}Nd}$ | $\frac{^{176}Hf}{^{177}Hf}$ | References |
|---|---|---|---|---|---|---|---|
| **DMM** | 18.4 | 15.5 | 37.8 | 0.70254 | 0.51315 | 0.28317 | Salters & Stracke, 2004 |
| **GLOSS** | 18.9 | 15.7 | 38.9 | 0.7173 | 0.51218 | 0.2824 | Plank & Langmuir, 1998 |
| **Altered Ocean Crust (AOC)** [e] | 18.4 | 15.5 | 37.8 | 0.70458 | 0.51308 | 0.28320 | Salters & Stracke, 2004; Staudigel et al., 1996 |

[a] Peridotite/melt partition coefficients were calculated using a fertile garnet peridotite composition with 59% olivine, 8% clinopyroxene, 21% orthopyroxene, and 12% garnet. Mineral/melt partition coefficients were drawn from experiments RD1097-1 and RD1097-5 of Salters et al. (2002) and calculated values of McKenzie and O'Nions (1991).

[b] Sediment/melt partition coefficients are averaged from experiments PC 36 and PC 39 of Johnson and Plank (2000).

[c] Sediment/fluid partition coefficients are averaged from experiments PC 38 and PC 47 of Johnson and Plank (2000).

[d] Mobility coefficients for AOC are shown as percent mobilities, after Kogiso et al (1997).

[e] Trace element concentrations for AOC are derived from Atlantic drilling site 417/418 (Staudigel et al., 1996).

**Table S4.** Metasomatized mantle evolution calculator (download as .xlsx file).