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A viable Labrador Sea rifting origin of the Northern Appalachian and related seismic anomalies

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ABSTRACT

The Northern Appalachian Anomaly (NAA) is a prominent low-seismic-velocity zone, ∼400 km in diameter, in the asthenosphere beneath New England (northeastern USA). Previous studies interpreted this shallow feature, occurring at a depth of ∼200 km, as a thermal anomaly tied to edge-driven convection along the North American continental margins. Those studies recognized, however, that upwelling here is highly unusual given that the passive margin has been tectonically quiescent for ∼180 m.y. We propose an alternative model, based on geologic observations, geotectonic reconstructions, and geodynamic simulations, that the anomaly instead represents a Rayleigh-Taylor instability linked to the breakup of the distant Labrador Sea continental margin. A Labrador Sea origin at breakup, ca. 85–80 Ma, would imply the migration of a chain of Rayleigh-Taylor instabilities at a rate of ∼22 km/m.y., close to expected rates from geodynamic models. A migrating-instability origin for the anomaly can reconcile its spatial characteristics, depth profile, and position near a long-inactive continental margin. A corollary is that the north-central Greenland anomaly, a mirror-image of the NAA, also potentially originated at the time of breakup. Further, The Central Appalachian Anomaly may fit this model if it represents an early-stage instability linked to rifting onset in the Labrador Sea. The NAA and other associated anomalies viably represent a legacy of continental rifting and breakup along the distant Labrador Sea margins.

INTRODUCTION

The Northern Appalachian Anomaly (hereafter, NAA) is a contemporary thermal anomaly located in New England (northeastern USA), centered beneath New Hampshire (Fig. 1A). The NAA is defined by the presence of low-degree partial melt interpreted to result from localized asthenospheric upwelling in response to edge-driven convection (Menke et al., 2016). Earthquake tomographic modeling suggests it is a slow-seismic-velocity anomaly at a depth of ∼200 km (Menke et al., 2016; Schmandt and Lin, 2014; Pollitz and Mooney, 2016) or shallower (i.e., ∼100 km; Brunsvik et al., 2024). Seismic models indicate that it is 350–400 km in diameter and elongated in a NE-SW or NNE-SSW direction (Fig. 1). The maximum shear velocity contrast at 200 km depth is as much as ∼4%, with a compressional-to-shear velocity perturbation ratio close to 1, supporting a thermal origin (Menke et al., 2016). This magnitude of anomaly likely corresponds to a ∼100–150 °C thermal perturbation, based on the mantle Vs-temperature relationship developed by Faul and Jackson (2005), and falls within the range imaged by both regional and global tomography models, which typically show shear wave speed reductions of 1%–4% in this region (e.g., Porter et al., 2016; Brunsvik et al., 2024; Long, 2024). Such an anomaly may have contributed to recent uplift in this part of North America (Fernandes et al., 2019), potentially shaping the Cenozoic tectono-thermal evolution of the Appalachian Mountains. The NAA may be linked to a slightly weaker anomaly ∼650 km to the south, the Central Appalachian Anomaly (CAA) (Byrnes et al., 2019; Long et al., 2021), and while our primary focus is on the NAA, we evaluate this possibility.

Edge-driven convection occurs where there is downwelling of asthenospheric mantle near lithospheric discontinuities (King and Anderson, 1998; King and Ritsema, 2000). However, as noted by Menke et al. (2016) and Carrero Mustelier and Menke (2021), upwelling beneath the NAA is unexpected and highly unusual given its location below the continental side of an ancient passive continental margin (Fig. 1B), which presumably has been inactive since continental breakup along the Central Atlantic margins at ca. 183 Ma. Although near the Great Meteor hotspot track (see Tao et al., 2021), the NAA neither parallels it nor crosses the cratonic margin, suggesting these features are unrelated (Menke et al., 2016). The NAA lies beneath relatively thick lithosphere (100–150 km; Fig. 1B; Afonso et al., 2019), although it may locally be as thin as ∼60–80 km (Espinal et al., 2024; Fig. S1 in the Supplemental Material[1]). Nevertheless, some studies have questioned whether the lithosphere is thinned sufficiently to promote edge-driven convection (Carrero Mustelier and Menke, 2021). Farther seaward of the NAA, the lithosphere thickens to ∼150 km for several hundred kilometers, with only a subtle thinning gradient seen at the continent-ocean boundary (COB; Fig. 1B). The NAA is thus enigmatic, leading to suggestions that it represents an unusual case of persistent, vigorous convection along the edges of the Laurentian craton (Menke et al., 2016; Brunsvik et al., 2024).

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[1]Supplemental Material. Lithospheric thickness sections and modeled origination times, incorporating uncertainty in migration rates. Please visit https://doi.org/10.1130/GEOL.S.29448404 to access the supplemental material; contact editing@geosociety.org with any questions.

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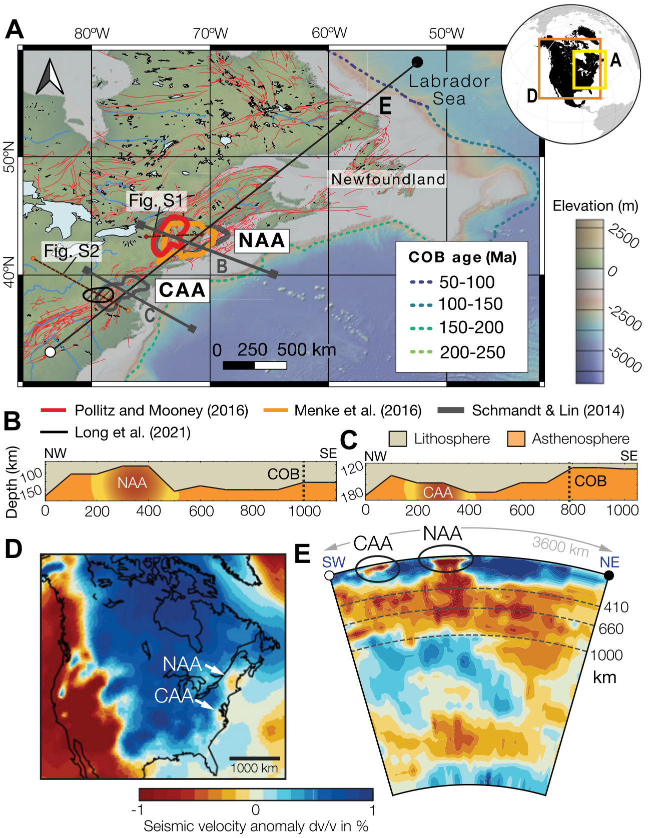

Figure 1. (A) Map of eastern North America (yellow box in global inset map) showing modeled locations of Northern Appalachian Anomaly (NAA) and Central Appalachian Anomaly (CAA) (Schmandt and Lin, 2014; Pollitz and Mooney, 2016; Menke et al., 2016; Long et al., 2021) relative to continent-ocean boundaries (COBs; from Müller et al., 2019); thin red lines show mapped faults from U.S. Geological Survey's Geologic Map of North America (https://ngmdb.usgs.gov/gmna/). (B–C) Cross sections (see A for lines of section) traversing NAA and CAA using LithoRef18 global reference model (Afonso et al., 2019) (see Figs. S1 and S2 [see footnote 1] for other thickness models). (D) Seismic tomography depth slice at 200 km beneath North America (red box in global inset map), averaged across 16 models, extracted using SubMachine (Hosseini et al., 2018). (E) Seismic tomography cross section (see A) based on UU-P07 global model (Amaru, 2007).

A ROLE FOR CONVECTIVE INSTABILITIES?

We examine whether the NAA represents a Rayleigh-Taylor instability, as proposed by Long et al. (2021) for the CAA, but suggest instead that the instability migrated over time along the continental roots from a more distant, now-extinct rift system. We stress that this scenario complements—rather than replaces—earlier models, given that all previous seismic observations of this feature remain valid and are simply interpreted in a new light.

Recent thermo-mechanical models have shown that continental rifting and breakup can generate a chain of Rayleigh-Taylor instabilities that propagate inboard of the rift over time (Gernon et al., 2023, 2024). These convective instabilities cause delamination by exploiting the density and strength contrast between the colder lithosphere and the hotter asthenosphere across the thermal boundary layer. This process bears similarities to small-scale convection and lithospheric dripping, which have been proposed as drivers of plateau uplift in eastern Anatolia (Göğüş and Pysklywec, 2008) and lithospheric erosion of the Wyoming craton (west-central USA; Dave and Li, 2016). However, in those cases, the mantle reorganization is linked to plate collisions, whereas in the NAA context, the convective instability may originate from rift-induced edge-driven convection. Specifically, the first delamination event occurs near the rift and is triggered by a perturbation of the lithospheric root by edge-driven convection, generating a family of sequential Rayleigh-Taylor instabilities. Such instabilities migrate continentward at a rate of $\sim 20 \pm 5$ km/m.y., removing the thermal boundary layer and driving adiabatic upwelling of convective mantle and kimberlite volcanism (in cratonic contexts; Gernon et al., 2023). Convective erosion of keels can promote isostatic uplift and denudation across "stable" cratons, leading to the formation of elevated plateaus (Gernon et al., 2024).

A key aspect of this model is that convective instabilities may represent a legacy of continental rifting and breakup that persists in the mantle for many tens to more than a hundred million years. A propagating instability could easily be misinterpreted as an isolated edge-driven convective cell because at any given time it appears spatially fixed—and its occurrence along ancient continental margins may be coincidental rather than causal. However, over geologic time scales, these chains of instabilities are dynamic and mobile, slowly and sequentially migrating along the continental root. The previously assumed causal linkage with the adjacent Central Atlantic margin thus warrants re-evaluation.

ATLANTIC RIFT SYSTEMS

The margins of the Central Atlantic rift system and its northern extension to the Labrador-Greenland Sea form a complex network of boundaries that were active at different times (Fig. 2), complicating the task of categorically tying instabilities to a single boundary. The North American continental margin commenced rifting at 240 Ma, with breakup occurring ca. 185–182 Ma (Brune et al., 2016). Meanwhile, the COB in the Labrador Sea is much younger,

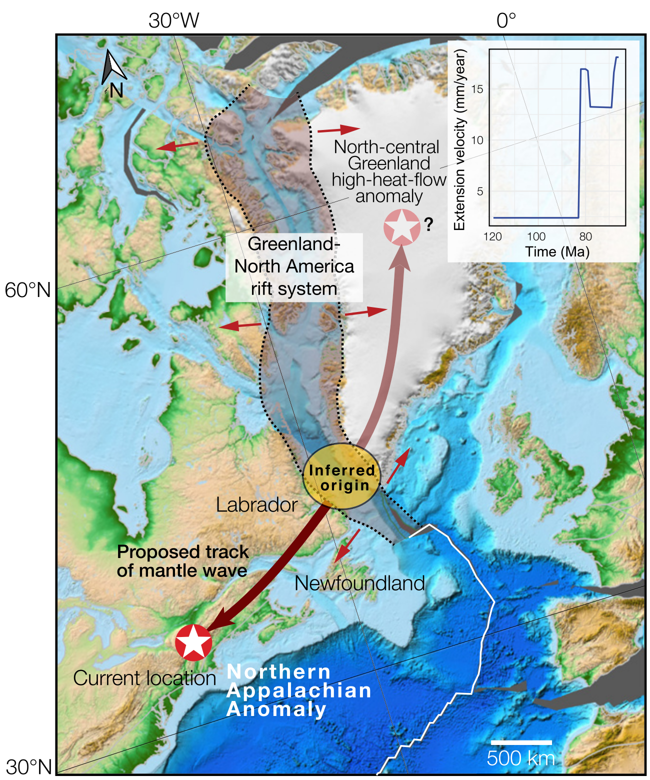

Figure 2. Simplified plate tectonic reconstruction from GPlates (https://www.gplates.org/) showing Labrador Sea rift at point of breakup at ca. 80 Ma (Mercator projection). Also shown is projected track of the chain of convective instabilities. Inset shows extension velocity along Labrador Sea margins, from Brune et al. (2016).

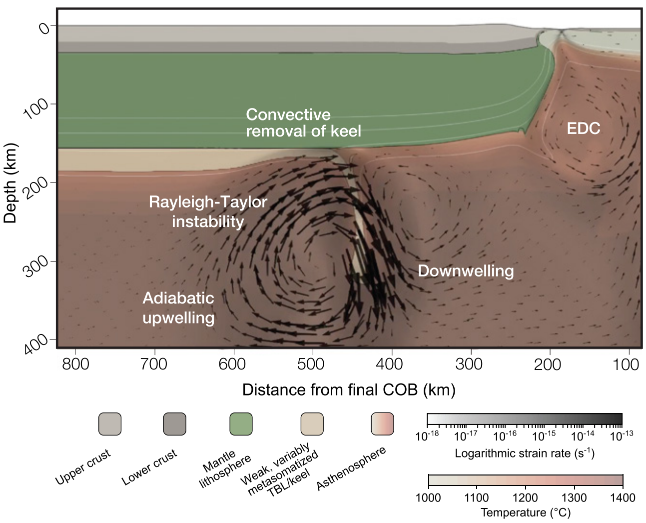

Figure 3. Geodynamic model showing Rayleigh-Taylor instability formation beneath continental lithosphere (model from Gernon et al., 2024). Note convective removal of lowermost lithosphere shown in beige, which is associated with downwelling. This is accompanied by adiabatic upwelling of hotter asthenosphere, warming, and further thinning of continental keel. The temperature is represented by color (see scale). Strain rate is shown in semi-transparent black where darker colors indicate higher strain rates. Black arrows designate linearly scaled velocity vectors with a maximum velocity of 6 cm/yr. EDC—edge-driven convection; COB—continent-ocean boundary; TBL—thermal boundary layer.

with rifting starting at ca. 120 Ma (but potentially as early as the Late Jurassic; Dickie et al., 2011) and breakup occurring at 90–80 Ma, culminating at ca. 82 Ma (Fig. 2). Given the difficulties in associating the upwelling with the Central Atlantic COB—namely, its prolonged tectonic inactivity and the presence of relatively thick lithosphere (Carrero Mustelier and Menke, 2021)—we explore the alternative possibility that the feature represents a convective instability linked to the younger, more distal Labrador Sea margins (Figs. 1–2).

A key characteristic supporting the identification of the NAA as a Rayleigh-Taylor instability is its length scale: the anomaly spans ~350–400 km in diameter (Menke et al., 2016), comparable to the predicted wavelength of such instabilities in geodynamic models, where upwellings are typically ~200 km wide (Fig. 3; Gernon et al., 2024). These features are marked by focused regions of upwelling and downwelling (Fig. 3), with the former capable of locally warming—and thermally eroding—the lithospheric keel. This behavior is consistent with previous interpretations of the NAA as a thermal upwelling and with its earlier diagnosis as an edge-driven convection cell (King and Anderson, 1998; King and Ritsema, 2000)—a dynamically similar phenomenon.

RESULTS AND DISCUSSION

To test a link between the NAA and distal rifting at the Labrador Sea, we measured its geospatial offset from the COB using QGIS software (Fig. 1). The NAA lies ~1830–1880 km from the Labrador Sea margin (Figs. 1 and 4A). Assuming a propagation rate of 20 km/m.y.—consistent with geodynamic models and kimberlite migration (Gernon et al., 2023)—this offset implies initiation at ca. 94–91 Ma (Fig. 4B), between rift onset and breakup, near the timing of rift acceleration (Brune et al., 2016) (Fig. 4B).

The propagation velocity of convective instabilities is controlled in part by activation energy and hence the viscosity of the dripping material used in geodynamic models. Previous work shows that plausible ranges in activation energy yield migration rates of 14–33 km/m.y. (Gernon et al., 2023). The impact of this variability is to broaden the range of possible origination times for the initial instability. Using this range of migration rates and the full span of distances associated with the NAA (Fig. 4A), we conducted a Monte Carlo simulation (10,000 runs) employing beta distributions for both distance and rate. This yields a distribution of estimated origination times (Fig. 4C), with a median of 93.6 Ma and 10th and 90th percentiles of 75 Ma and 116 Ma, respectively. These results do not change our conclusion because most estimates (91%) fall within error of the rifting and breakup window when the initial instability forms (Fig. 4B), and even the lower bounds remain geologically plausible given the tectonic history of the margin.

The modeled migration characteristics of the NAA support its interpretation as a Rayleigh-Taylor instability that has sequentially propagated inboard of the Labrador Sea rift system over time. Numerical and analogue models show that delamination can evolve as drip-like features, which are influenced by lithospheric structure and strain localization (e.g., Elkins-Tanton, 2007). Thus, the stepped, irregular base of the adjacent North American craton likely shaped the geometry of the observed anomaly (Fig. 1). Seismic constraints offer supporting evidence (though not necessarily precluding edge-driven convection). Seismic tomography reveals low-velocity anomalies at 200 km depth (Fig. 1D) that are absent below 550 km (Schmandt and Lin, 2014), perhaps indicating a shallow mantle origin (cf. Fig. 3). In addition, SKS splitting shows the anomaly is associated with localized low magnitude and localized NE-striking upper mantle anisotropy (Long, 2024), indicative of a combination of the vertical and SW-directed mantle flow expected for a SW-migrating convective instability. While the ultimate causal mechanisms differ, our model (Fig. 3) complements the interpretation of the NAA as the upwelling limb of a small-scale convection cell (Menke et al., 2016). A distal origin helps reconcile timing problems noted with the proximal edge-driven convection hypothesis (Carrero Mustelier and Menke, 2021) and the NAA's location hundreds of kilometers inboard of the Central Atlantic COB (Fig. 1B).

An outstanding question is whether the NAA could be linked to the CAA, the second-largest seismic anomaly along the east coast of North America (Figs. 1A and 1C; Fig. S2). Previously, the CAA has been attributed to lithospheric delamination followed by small-scale convection (Mazza et al., 2014; Byrnes et al., 2019). The CAA may represent one or perhaps more Rayleigh-Taylor instabilities (Long et al., 2021). Might this instability also be linked to rifting in the Labrador Sea? Applying the same analysis as before (Fig. 4A) would imply that the CAA originated ca. 135–120 Ma (Fig. 4B; Fig. S3), following the proposed timing of Labrador rift inception in the Late Jurassic (Dickie et al., 2011). Thus, the CAA could represent an early instability associated with the development of a steep lithosphere-asthenosphere boundary gradient during early-stage rifting (cf. Gernon et al., 2023). Indeed, the CAA's inferred low degrees of melting (~1%) (Evans et al., 2019; Mittal et al., 2023) closely match expectations for such instabilities based on hydrous decompressional melting models (Gernon et al., 2023). The CAA region's volcanic history suggests preconditioning to delamination-related melting (Mazza et al., 2014), likely augmented by hydrous phases that weaken the lithospheric keel and locally promote its removal (Evans et al., 2019).

Although the NAA may relate to Cenozoic Appalachian uplift (Fernandes et al., 2019), cold and dry climates and low erosion rates (~10 m/m.y.; Hergarten and Kenkmann, 2019) suggest limited denudation over the past 30 m.y. Nonetheless, lithospheric delamination may have contributed to earlier topographic rejuvenation in the Central Appalachians (Miller et al., 2013). Should we expect to see remnants of earlier instabilities (i.e., weak anomalies) along the proposed path of this chain (Fig. 2)? Relatively sparse seismic coverage north of the NAA—particularly across Newfoundland, Labrador, and the Gulf of St. Lawrence in Canada—limits our ability to detect such anomalies. Even so, if earlier instabilities propagated in a stepwise manner every ~10 m.y., as seen in our geodynamic models (Gernon et al., 2023, 2024), their thermal signals would likely have

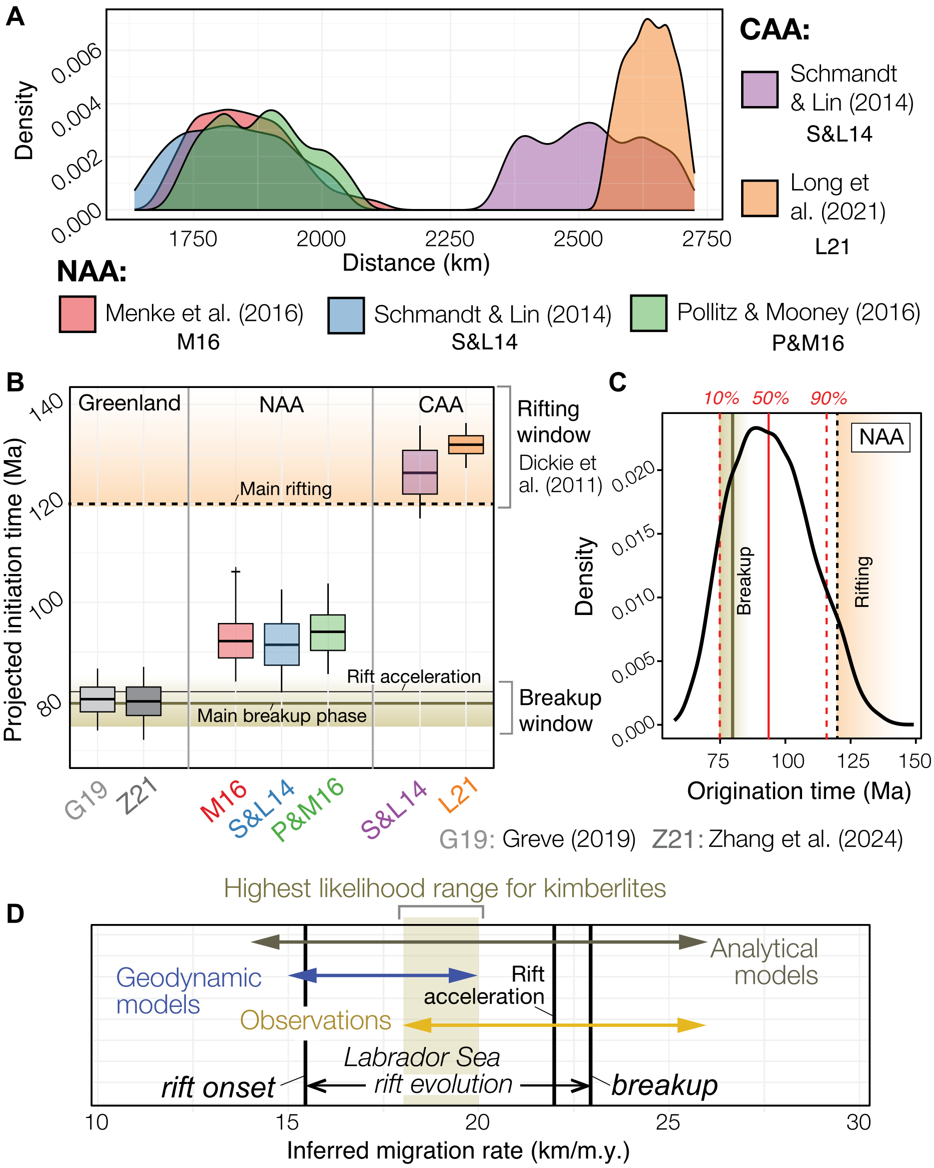

Figure 4. Spatial characteristics of Northern Appalachian Anomaly (NAA) and Central Appalachian Anomaly (CAA) and modeled initiation time of Rayleigh-Taylor instabilities. (A) Distance of NAA and CAA from Labrador Sea continent-ocean boundary (COB) (n = 1000 for each) for four seismic models (labeled). Density represents the relative frequency of data; the area under the curve equals one. (B) Box plot showing projected timing of initiation of NAA-CAA and north-central Greenland anomaly (see Fig. S4 [see text footnote 1]) using measured distances and a migration rate of 20 km/m.y. (C) Density plot of modeled origination times for initial NAA instability, based on 10,000 Monte Carlo simulations using the measured distances from the Labrador Sea COB (panel A) and a beta-distributed migration rate (14–33 km/m.y.; mean = 20 km/m.y.; variance = 10). The same analysis for the CAA is shown in Fig. S3. Vertical red lines show the 10th, 50th, and 90th percentiles. (D) Inferred migration rates of instabilities at probable inception points (i.e., rift onset, rift acceleration, and breakup) alongside constraints from kimberlites (Gernon et al., 2023), including migration rates gleaned from geologic observations and analytical and geodynamic models.

been erased by conductive rethickening of the thermal boundary layer during several tens of millions of years (Yuan et al., 2017).

More speculatively, a pronounced ∼200-km-wide seismic anomaly beneath north-central Greenland (Greve, 2019; Zhang et al., 2024, and references therein) conforms with the projected northward trajectory of the proposed NAA initiation site (Fig. 2), suggesting a possible shared origin. Applying the same geospatial analysis as before, the Greenland anomaly is projected to have formed at ca. 80 Ma, near coincident with breakup (Figs. 4B and 4C; Fig. S4). A model in which an instability arrived more recently may help reconcile the persistence of a thermal anomaly long after other contenders such as the Iceland plume at ca. 60 Ma (e.g., Martos et al., 2018) would likely have dissipated through thermal advection and diffusion. This raises the intriguing possibility of a unified mechanism linking the NAA, CAA, and Greenland anomalies.

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REFERENCES CITED

Afonso, J.C., Salajegheh, F., Szwillus, W., Ebbing, J., and Gaina, C., 2019, A global reference model of the lithosphere and upper mantle from joint inversion and analysis of multiple data sets: Geophysical Journal International, v. 217, p. 1602–1628, https://doi.org/10.1093/gji/ggz094.

Amaru, M.L., 2007, Global travel time tomography with 3-D reference models [unpublished Ph.D. thesis]: Utrecht, Netherlands, Utrecht University, 173 p.

Brune, S., Williams, S.E., Butterworth, N.P., and Müller, R.D., 2016, Abrupt plate accelerations shape rifted continental margins: Nature, v. 536, p. 201–204, https://doi.org/10.1038/nature18319.

Brunsvik, B., Eilon, Z., and Lynner, C., 2024, Plate-scale imaging of eastern US reveals ancient and ongoing continental deformation: Geophysical Research Letters, v. 51, https://doi.org/10.1029/2024GL109041.

Byrnes, J.S., Bezada, M., Long, M.D., and Benoit, M.H., 2019, Thin lithosphere beneath the central Appalachian Mountains: Constraints from seismic attenuation beneath the MAGIC array: Earth and Planetary Science Letters, v. 519, p. 297–307, https://doi.org/10.1016/j.epsl.2019.04.045.

Carrero Mustelier, E., and Menke, W., 2021, Seismic anomalies in the southeastern North American asthenosphere as characterized with body wave travel times from high-quality teleseisms: Tectonophysics, v. 809, https://doi.org/10.1016/j.tecto.2021.228853.

Dave, R., and Li, A., 2016, Destruction of the Wyoming craton: Seismic evidence and geodynamic processes: Geology, v. 44, p. 883–886, https://doi.org/10.1130/G38147.1.

Dickie, K., Keen, C.E., Williams, G.L., and Dehler, S.A., 2011, Tectonostratigraphic evolution of the Labrador margin, Atlantic Canada: Marine and Petroleum Geology, v. 28, p. 1663–1675, https://doi.org/10.1016/j.marpetgeo.2011.05.009.

Elkins-Tanton, L.T., 2007, Continental magmatism, volatile recycling, and a heterogeneous mantle caused by lithospheric gravitational instabilities: Journal of Geophysical Research, v. 112, B03405, https://doi.org/10.1029/2005JB004072.

Espinal, K., Long, M.D., Karabinos, P., and Bourke, J.R., 2024, Lithospheric structure above the Northern Appalachian Anomaly: Initial results from the NEST array: Geophysical Research Letters, v. 51, https://doi.org/10.1029/2024GL109955.

Evans, R.R., Benoit, M.H., Long, M.D., Elsenbeck, J., Ford, H.A., Zhu, J., and Garcia, X., 2019, Thin lithosphere beneath the central Appalachian

Mountains: A combined seismic and magnetotelluric study: Earth and Planetary Science Letters, v. 519, p. 308–316, https://doi.org/10.1016/j.epsl.2019.04.046.
Faul, U.H., and Jackson, I., 2005, The seismological signature of temperature and grain size variations in the upper mantle: Earth and Planetary Science Letters, v. 234, p. 119–134, https://doi.org/10.1016/j.epsl.2005.02.008.
Fernandes, V.M., Roberts, G.G., White, N., and Whittaker, A.C., 2019, Continental-scale landscape evolution: A history of North American topography: Journal of Geophysical Research: Earth Surface, v. 124, p. 2689–2722, https://doi.org/10.1029/2018JF004979.
Gernon, T.M., et al., 2023, Rift-induced disruption of cratonic keels drives kimberlite volcanism: Nature, v. 620, p. 344–350, https://doi.org/10.1038/s41586-023-06193-3; correction available at https://doi.org/10.1038/s41586-023-06960-2.
Gernon, T.M., Hincks, T.K., Brune, S., Braun, J., Jones, S.M., Keir, D., Cunningham, A., and Glerum, A., 2024, Coevolution of craton margins and interiors during continental breakup: Nature, v. 632, p. 327–335, https://doi.org/10.1038/s41586-024-07717-1.
Göğüş, O.H., and Pysklywec, R.N., 2008, Mantle lithosphere delamination driving plateau uplift and synconvergent extension in eastern Anatolia: Geology, v. 36, p. 723–726, https://doi.org/10.1130/G24982A.1.
Greve, R., 2019, Geothermal heat flux distribution for the Greenland ice sheet, derived by combining a global representation and information from deep ice cores: Polar Data Journal, v. 3, p. 22–36, https://doi.org/10.20575/00000006.
Hergarten, S., and Kenkmann, T., 2019, Long-term erosion rates as a function of climate derived from the impact crater inventory: Earth Surface Dynamics, v. 7, p. 459–473, https://doi.org/10.5194/esurf-7-459-2019.
Hosseini, K., Matthews, K.J., Sigloch, K., Shephard, G.E., Domeier, M., and Tsekhmistrenko, M., 2018, SubMachine: Web-based tools for exploring seismic tomography and other models of Earth's deep interior: Geochemistry, Geophysics, Geosystems, v. 19, p. 1464–1483, https://doi.org/10.1029/2018GC007431.
King, S.D., and Anderson, D.L., 1998, Edge-driven convection: Earth and Planetary Science Letters, v. 160, p. 289–296, https://doi.org/10.1016/S0012-821X(98)00089-2.
King, S.D., and Ritsema, J., 2000, African hot spot volcanism: Small-scale convection in the upper mantle beneath cratons: Science, v. 290, p. 1137–1140, https://doi.org/10.1126/science.290.5494.1137.
Long, M.D., 2024, Evolution, modification, and deformation of continental lithosphere: Insights from the eastern margin of North America: Annual Review of Earth and Planetary Sciences, v. 52, p. 549–580, https://doi.org/10.1146/annurev-earth-040522-115229.
Long, M.D., et al., 2021, Evaluating models for lithospheric loss and intraplate volcanism beneath the Central Appalachian Mountains: Journal of Geophysical Research: Solid Earth, v. 126, https://doi.org/10.1029/2021JB022571.
Martos, Y.M., Jordan, T.A., Catalán, M., Jordan, T.M., Bamber, J.L., and Vaughan, D.G., 2018, Geothermal heat flux reveals the Iceland hotspot track underneath Greenland: Geophysical Research Letters, v. 45, p. 8214–8222, https://doi.org/10.1029/2018GL078289.
Mazza, S.E., Gazel, E., Johnson, E.A., Kunk, M.J., McAleer, R., Spotila, J.A., and Coleman, D.S., 2014, Volcanoes of the passive margin: The youngest magmatic event in eastern North America: Geology, v. 42, p. 483–486, https://doi.org/10.1130/G35407.1.
Menke, W., Skryzalin, P., Levin, V., Harper, T., Darbyshire, F., and Dong, T., 2016, The Northern Appalachian Anomaly: A modern asthenospheric upwelling: Geophysical Research Letters, v. 43, p. 10,173–10,179, https://doi.org/10.1002/2016GL070918.
Miller, S.R., Sak, P.B., Kirby, E., and Bierman, P.R., 2013, Neogene rejuvenation of central Appalachian topography: Evidence for differential rock uplift from stream profiles and erosion rates: Earth and Planetary Science Letters, v. 369–370, p. 1–12, https://doi.org/10.1016/j.epsl.2013.04.007.
Mittal, V., Long, M.D., Evans, R.L., Byrnes, J.S., and Bezada, M., 2023, Joint analysis of seismic and electrical observables beneath the Central Appalachians requires partial melt in the upper mantle: Geochemistry, Geophysics, Geosystems, v. 24, https://doi.org/10.1029/2022GC010690.
Müller, R.D., et al., 2019, A global plate model including lithospheric deformation along major rifts and orogens since the Triassic: Tectonics, v. 38, p. 1884–1907, https://doi.org/10.1029/2018TC005462.
Pollitz, F.F., and Mooney, W.D., 2016, Seismic velocity structure of the crust and shallow mantle of the Central and Eastern United States by seismic surface wave imaging: Geophysical Research Letters, v. 43, p. 118–126, https://doi.org/10.1002/2015GL066637.
Porter, R., Liu, Y., and Holt, W.E., 2016, Lithospheric records of orogeny within the continental U.S.: Geophysical Research Letters, v. 43, p. 144–153, https://doi.org/10.1002/2015GL066950.
Schmandt, B., and Lin, F.-C., 2014, *P* and *S* wave tomography of the mantle beneath the United States: Geophysical Research Letters, v. 41, p. 6342–6349, https://doi.org/10.1002/2014GL061231.
Tao, Z., Li, A., and Fischer, K.M., 2021, Hotspot signatures at the North American passive margin: Geology, v. 49, p. 525–530, https://doi.org/10.1130/G47994.1.
Yuan, X., Heit, B., Brune, S., Steinberger, B., Geissler, W.H., Jokat, W., and Weber, M., 2017, Seismic structure of the lithosphere beneath NW Namibia: Impact of the Tristan da Cunha mantle plume: Geochemistry, Geophysics, Geosystems, v. 18, p. 125–141, https://doi.org/10.1002/2016GC006645.
Zhang, T., Colgan, W., Wansing, A., Løkkegaard, A., Leguy, G., Lipscomb, W., and Xiao, C., 2024, Evaluating different geothermal heat flow maps as basal boundary conditions during spin-up of the Greenland ice sheet: The Cryosphere, v. 18, p. 387–402, https://doi.org/10.5194/tc-18-387-2024.

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