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Forum Reply

Mid-Proterozoic geomagnetic field was more consistent with a dipole than a quadrupole

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We thank Sears (2024) for his Comment on our recent paper, which utilized robust paleomagnetic data and geology-based plate reconstructions to constrain the geometry of the geomagnetic field in the mid-Proterozoic (Gong et al., 2023). Based on a novel quantitative analysis, we showed that the mid-Proterozoic geomagnetic field was more likely to be a geocentric-axial dipole (GAD) instead of a normal-tesseral quadrupole (NTQ) as proposed earlier by Sears (2022). In his Comment, Sears agrees that our analytical tests are "rigorous and valid." However, he incorrectly asserts that our treatment of solely Laurentian data is statistically indistinguishable between GAD and NTQ for all studied time windows. As we noted specifically (p. 574), "t-test results showed that during 1485–1425 Ma, a GAD would yield significantly smaller minimum residuals than an NTQ, no matter whether data are included from only Laurentia, or Laurentia and Baltica, or all three cratons." Thus, our early Mesoproterozoic analysis favors GAD without relying on any tectonic reconstructions, for the time interval with the most complete dataset. In our paper, we also discussed why GAD and NTQ would give similar results in the 1790–1740 Ma and 1095–1080 Ma intervals: For the test to be powerful, data need to be spatially widespread. As an extreme case, if all the paleomagnetic data are tightly clustered, such as those from Laurentia's Mid-Continent Rift, it would be fairly easy to find GAD or NTQ models with comparable success. This is why we first focused our analysis on Laurentia and then expanded it to other cratons by carefully choosing reconstructions with independent geologic/stratigraphic support (Gong et al., 2023).

After demonstrating that solely Laurentian data favor GAD over NTQ in the 1485–1425 Ma interval, we found an even stronger quantitative argument for GAD through the same period when considering some geologically based Laurentia+Baltica+Siberia reconstructions in the core of Nuna supercontinent (Gower et al., 1990; Ernst et al., 2016). The principal aspects of Sears' Comment are his putative concerns about our selected reconstructions' admissibility in Neoproterozoic time. Our analysis does not require Nuna reconstructions to extend to such younger intervals; however, Sears' critiques are only peripherally relevant to this particular problem. Additionally, Sears cites literature that was published in 2007 and 2008, prior to important advances in Proterozoic chronostratigraphic correlations across the regions of concern. Both the East Greenland/Svalbard and Timanide margins of Laurenta+Baltica, which are conjoined in our preferred Nuna model, contain complementary records of Meso-Neoproterozoic passive margin development (Cawood et al., 2010; Cawood and Pisarevsky, 2017; Kuznetsov et al., 2021) that are consistent with all paleogeographically viable models of Nuna breakup and Rodinia assembly (reviewed by Evans, 2021). Concerning the longevity of our preferred Laurentia+Siberia connection, the most recent comprehensive review of Siberia's Baikalian-Patom rift margin (Gladkochub et al., 2019) shows that it was likely established ca. 720 Ma, coeval with that of northern Laurentia and that older Meso-Neoproterozoic arcs from the Baikal-Muya and adjacent regions (considered to be problematic by Sears) are highly allochthonous with respect to the Siberian craton—accreting only later during the Ediacaran-Cambrian Baikalian orogeny. Therefore, not only are these Neoproterozoic concerns inapplicable to our Mesoproterozoic test of the geomagnetic field, but additionally there is no mismatch of ages between the relevant rift margins as claimed by Sears.

Last, we want to highlight the need for geodynamic viability of any proposed nonuniformitarian geomagnetic field geometry in deep time. Geodynamo models of possible nonuniformitarian states (e.g., Driscoll, 2016) suggest that an NTQ field should be rapidly changing and cannot maintain stability for hundreds of millions of years as required in the model of Sears (2022). By contrast, a GAD field's longevity and stability are supported by both geodynamo models (Olson, 2013) and geological records (Evans, 2006). Thus, from both a theoretical standpoint as well as our most recent statistical tests—using the single Laurentian craton example as well as geologically robust juxtapositions of Baltica and Siberia—GAD is a more suitable geomagnetic field model than NTQ for mid-Proterozoic time.

REFERENCES CITED

Cawood, P.A., and Pisarevsky, S.A., 2017, Laurentia-Baltica-Amazonia relations during Rodinia assembly: Precambrian Research, v. 292, p. 386–397, https://doi.org/10.1016/j.precamres.2017.01.031.

Cawood, P.A., Strachan, R., Cutts, K., Kinny, P.D., Hand, M., and Pisarevsky, S., 2010, Neoproterozoic orogeny along the margin of Rodinia: Valhalla orogen, North Atlantic: Geology, v. 38, p. 99–102, https://doi.org/10.1130/G30450.1.

Driscoll, P.E., 2016, Simulating 2 Ga of geodynamo history: Geophysical Research Letters, v. 43, p. 5680–5687, https://doi.org/10.1002/2016GL068858.

Ernst, R.E., et al., 2016, Long-lived connection between southern Siberia and northern Laurentia in the Proterozoic: Nature Geoscience, v. 9, p. 464–469, https://doi.org/10.1038/ngeo2700.

Evans, D.A.D., 2006, Proterozoic low orbital obliquity and axial-dipolar geomagnetic field from evaporite palaeolatitudes: Nature, v. 444, p. 51–55, https://doi.org/10.1038/nature05203.

Evans, D.A.D., 2021, Meso-Neoproterozoic Rodinia supercycle, *in* Pesonen, L.J., et al., eds., Ancient Supercontinents and the Paleogeography of Earth: Amsterdam, Netherlands, Elsevier, p. 549–576, https://doi.org/10.1016/B978-0-12-818533-9.00006-0.

Gladkochub, D.P., Donskaya, T.V., Stanevich, A.M., Pisarevsky, S.A., Zhang, S., Motova, Z.L., Mazukabzov, A.M., and Li, H., 2019, U-Pb detrital zircon geochronology and provenance of Neoproterozoic sedimentary rocks in southern Siberia: New insights into breakup of Rodinia and opening of Paleo-Asian Ocean: Gondwana Research, v. 65, p. 1–16, https://doi.org/10.1016/j.gr.2018.07.007.

Gong, Z., Evans, D.A., Zhang, Z., and Yan, C., 2023, Mid-Proterozoic geomagnetic field was more consistent with a dipole than a quadrupole: Geology, v. 51, p. 571–575, https://doi.org/10.1130/G50941.1.

Gower, C.F., Ryan, A.B., and Rivers, T., 1990, Mid-Proterozoic Laurentia-Baltica: An overview of its geological evolution and a summary of the contributions made by this volume, *in* Gower, C.F., et al., eds., Mid-Proterozoic Laurentia-Baltica: Geological Association of Canada Special Paper 38, p. 1–20.

Kuznetsov, N.B., Baluev, A.S., Terekhov, E.N., Kolodyazhnyi, S.Yu., Przhiyalgovskii, E.S., Romanyuk, T.V., Dubenskiy, A.S., Sheshukov, V.S., Lyapunov, S.M., Bayanova, T.B., and Serov, P.A., 2021, Time constraints on the formation of the Kandalaksha and Keretsk grabens of the White Sea paleo-rift system from new isotopic geochronological data: Geodynamics & Tectonophysics, v. 12, p. 570–607, https://doi.org/10.5800/GT-2021-12-3-0540.

Olson, P., 2013, The geodynamo's unique longevity: Physics Today, v. 66, p. 30–35, https://doi.org/10.1063/PT.3.2177.

Sears, J.W., 2022, Challenging the dipolar paradigm for Proterozoic Earth, *in* Foulger, G.R., et al., eds., In the Footsteps of Warren B. Hamilton: New Ideas in Earth Science: Geological Society of America Special Paper 553, p. 201–211, https://doi.org/10.1130/2021.2553(17).

Sears, J.W., 2024, Mid-Proterozoic geomagnetic field was more consistent with a dipole than a quadrupole: Comment: Geology, v. 52, https://doi.org/10.1130/G51799C.1.