Archean geodynamics: Ephemeral supercontinents or long-lived supercratons

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ABSTRACT

Many Archean cratons exhibit Paleoproterozoic rifted margins, implying they were pieces of some ancestral landmass(es). The idea that such an ancient continental assembly represents an Archean supercontinent has been proposed but remains to be justified. Starkly contrasting geological records between different clasts of cratons have inspired an alternative hypothesis where cratons were clustered in multiple, separate “supercratons.” A new ca. 2.62 Ga paleomagnetic pole from the Yilgarn craton of Australia is compatible with either two successive but ephemeral supercontinents or two long-lived supercratons across the Archean-Proterozoic transition. Neither interpretation supports the existence of a single, long-lived supercontinent, suggesting that Archean geodynamics were fundamentally different from subsequent times (Proterozoic to present), which were influenced largely by supercontinent cycles.

INTRODUCTION

The Archean-Proterozoic transition was one of the most dynamic periods in Earth history, involving globally diachronous cratonization (Bleeker, 2003; Laurent et al., 2014; Cawood et al., 2018), low-latitude glaciation (Evans et al., 1997), and the Great Oxyge...
component, which was removed by low-level demagnetization (heating to \( \sim 200 \, ^\circ C \) or alternating field [AF] demagnetization to \( \sim 7 \, mT \)), appeared sporadically in cores from several sites. After the removal of this magnetically unstable component, a mid-temperature component (MTC) was identified in several sites between 100–300 \( ^\circ C \) and 540 \( ^\circ C \), but it was only prominent enough to be defined at site 16WDS15 (declination \([\text{Dec}] = -225.2^\circ\), inclination \([\text{Inc}] = -53.1^\circ\), cone of 95\% confidence \( \alpha_{95} = 12.0^\circ \)). After removal of these soft components, a characteristic stable component decaying toward the origin of the projection plane was identified with a lower bound of...
unblocking temperatures of 530–565 °C and an upper bound of 570–580 °C in the majority of samples (Fig. 2A).

The characteristic remanent magnetization (ChRM) directions are directed either moderately WNW-and-up or ESE-and-down (Fig. 2B). Excluding two sites with spurious data and one outlier site (16WD353) possibly related to a magnetic reversal or excursion (Table S1), the remaining 12 dikes showed well-clustered and dual-polarity ChRMs (Fig. 2B) that passed a reversal test (McFadden, 1990) with a “C” classification (γ = 5.4°, σ = 14.2°). It should be noted that the inclusion of site 16WD353 did not change the positive result of the reversal test. The ChRM mean direction is Dec = 294.0°, Inc = −58.1°, and α95 = 5.0°, with a corresponding paleomagnetic pole of 36.7°N, −0.5°E and A95 = 7.4°. At site 16WD14, the host granite was sampled for a baked contact test. Although the ChRM direction of the baked host rock is similar to that of the dike, the unbaked granites carried unstable magnetizations, rendering the baked contact test suggestive but inconclusive. Most outcrops in this area did not allow for the measurement of dike dips. However, for those dikes where we could measure dips, vertical/subvertical dike planes were consistently observed. Therefore, no tilt correction was applied to the paleomagnetic data.

The high level and narrow range of unblocking temperatures (Fig. 2A), together with rock magnetic analyses (Figs. S2 and S3), indicate that the ChRM is carried by single-domain/single-vortex magnetite, which is a common carrier of thermal remanence in mafic dikes and is resistant to viscous and/or thermal remagnetization. Both younger dikes swarms, the ca. 2.41 Ga Widgiemooltha dikes (Smirnov et al., 2013) and the ca. 1.89 Ga Boonadgin dikes (Liu et al., 2019), have been shown to preserve primary magnetization (Kilian et al., 2016). Recent geochronologic and stratigraphic studies defining the magmatic barcode and paleogeography when similar APW paths are superimposed. One or the other, but not both, of the supercontinent criteria appear to be satisfied by the data. If all cratons are placed in a contiguous configuration at either 2.6 Ga or 2.4 Ga, then poles of the other age are vastly discrepant (Fig. 3A). This, therefore, is the supercontinent solution only possible if there were two different, short-lived configurations that were reorganized between these two times, i.e., requiring an ~180° rotation of Superia relative to Sclavia (Fig. 3A). This solution of ephemeral supercontinents is only weakly supported by the poles of individual ages, but it is difficult to reject without more data.

Using poles for more than one age window, the relative longitude and azimuthal orientations of the Superior and Sclavia supercontinents can be tested (Mitchell et al., 2014). Strikingly, the poles from Superior and Sclavia for these two time periods form APW paths of broadly similar arc distance (Fig. 3B). At face value, the
similarity in paths could signify coherent tectonic motion of a single supercontinental plate. However, overlapping the paleomagnetic poles results in a geographic separation of Superia and Sclavia of ~4000 km (Fig. 3B), which is suggestive of separate supercratons at this time, similar to the separation of the Slave and Superior cratons between 2.2 and 2.0 Ga (Mitchell et al., 2014). A single supercontinent solution would only be possible if essentially all remaining Archean cratons not considered here, due to a lack of constraints, happened to exactly fill the gap between Superia and Sclavia, leading to a dramatically elongated supercontinent not observed at any other time on Earth. Although conceivable, such a possibility seems ad hoc. Whereas the ephemeral supercontinents solution requires dramatic plate reorganization, the separate supercratons solution does not need to invoke any relative motion between Superia and Sclavia within paleomagnetic uncertainty, where the nearly identical APW paths of the separated supercratons could represent either true polar wander (Mitchell, 2014) or the mean motion of the continents with respect to external oceanic plates (Steinberger and Torsvik, 2008). Finally, the disparity between glacial deposits, which are preserved on all cratons of Superia (Fig. 3B) but on none of those of Sclavia, could provide independent support for the hypothesis of at least two distinct and spatially separated supercratonic landmasses across the Archean-Proterozoic transition. Paleoproterozoic glacial deposits are paradoxically found at low latitudes and have been interpreted as evidence of either snowball Earth (Evans et al., 1997) or high-obliquity (Williams et al., 1998) models. Face-value interpretation of Figure 3B would appear to imply that the high-obliquity scenario should be considered for Paleoproterozoic times. However, further study is needed to test this scenario.
ACKNOWLEDGMENTS
This work was supported by an Australian Research Council Laureate Fellowship grant to Z.X. Li (FL150100133), grants from the National Natural Science Foundation of China (41809833 and 48881010) and the Chinese Academy of Sciences (IGGCAS201905) to R.N. Mitchell, and the Ministry of Science and Higher Education of the Russian Federation grant (075–15–2019–1883) to S.A. Pisarevsky. This is an International Geoscience Programme (IGCP) 648 “Supercontinent Cycles & Global Geodynamics” contribution. Comments from Wouter Bleeker and two anonymous reviewers greatly improved the manuscript.

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