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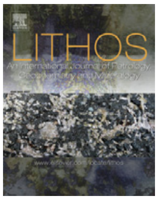

Editorial

Large Igneous Provinces and supercontinents: Toward completing the plate tectonic revolution

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ABSTRACT

Regional groupings of a majority, or all, of Earth's crustal blocks have occurred several times in Earth history, but only the most recent supercontinent Paleozoic Pangea/Gondwana, is well characterized. Prior Precambrian supercontinents are postulated: Rodinia (ca. 1 to 0.7 Ga), Nuna/Columbia (ca. 1.8 to 1.3 Ga) and Kenorland/supercratons (ca. >2.7 to 2.0 Ga), but the configuration of each is poorly known. A new methodology using Large Igneous Provinces (LIPs) offers an opportunity for fast-tracking progress toward robust Precambrian reconstructions. Comparison of the LIP 'barcode' record between crustal blocks allows identification of which blocks were likely to have been nearest neighbors in past supercontinents. Restoration of the primary geometry (radiating or linear) of regional dyke swarms (the plumbing system of LIPs) offers another reconstruction criterion. A consortium of companies is providing funding for dating of essentially all major regional dyke swarms and sill provinces to complete the 'barcoding of all major crustal blocks, and 13 of the papers in this special issue provides examples of this progress. Seven additional papers provide overviews of important LIPs. Together these 20 papers illustrate the potential for rapid progress using the LIP record for Precambrian supercontinent reconstructions toward completing the plate tectonic revolution which began nearly five decades ago.

1. Introduction

1.1. The reconstruction dream

Almost a century after Wegener's groundbreaking idea that the present continents are dispersed fragments of a former supercontinent, Pangea, that existed some 250 million years ago (e.g., Jacoby, 1981; Wegener, 1912), and nearly five decades after the beginning of the "plate tectonic revolution" of the 1960s (e.g., Oreskes, 2001), a detailed picture has emerged of the kinematics and dynamics of our planet, allowing integration and synthesis of much of the younger geological record. However, determination of robust pre-Pangea paleocontinental reconstructions has resisted solution and remains the unfinished business of the plate tectonic revolution.

A substantial body of evidence suggests that pre-Pangea Precambrian supercontinents have indeed existed (e.g., Bleeker, 2003; Rogers and Santosh, 2004; Li et al., 2008; Meert, 2012; Zhang et al., 2012a; Pesonen et al., 2012): Rodinia (ca. 1.0–0.7 Ga), Nuna (also known as Columbia) (ca. 1.8–1.3 Ga), Kenorland (or multiple supercratons) (late Archean to ca. 2.0 Ga). However, from the Precambrian world, there is no preserved record of ocean floor spreading nor a robust fossil record to help guide paleogeographic reconstructions. Progress on such reconstructions thus has relied on matching details in continental geology from one craton to another. Unfortunately, many such details are 1) inherently fuzzy (e.g., ages of granitoid belts and metamorphism), 2) variable or diachronous along strike (e.g., orogenic belts and their structural trends, ages of structural events), or 3) highly susceptible to modification (e.g., the outlines of sedimentary basin and the "piercing points" they provide) (Bleeker and Ernst, 2006; Ernst and Bleeker, 2010). Paleomagnetism can be effective in testing reconstructions but has limitations. Most of all, it requires study of precisely dated units that contain a record of the paleohorizontal. With the shortage of precise U–Pb ages on suitable units, there are too few key Precambrian paleopoles for testing most Precambrian reconstructions (e.g., Buchan, 2012; Evans and Pisarevsky, 2008).

Large Igneous Provinces (LIPs) and especially their associated regional-scale mafic dyke swarms represent a powerful tool for supercontinent reconstruction, and systematic use of the LIP record, offers a strategy for moving forward toward our collective goal of completing the plate tectonic revolution by producing robust reconstructions into the Precambrian at least back to ca. 2.7 Ga.

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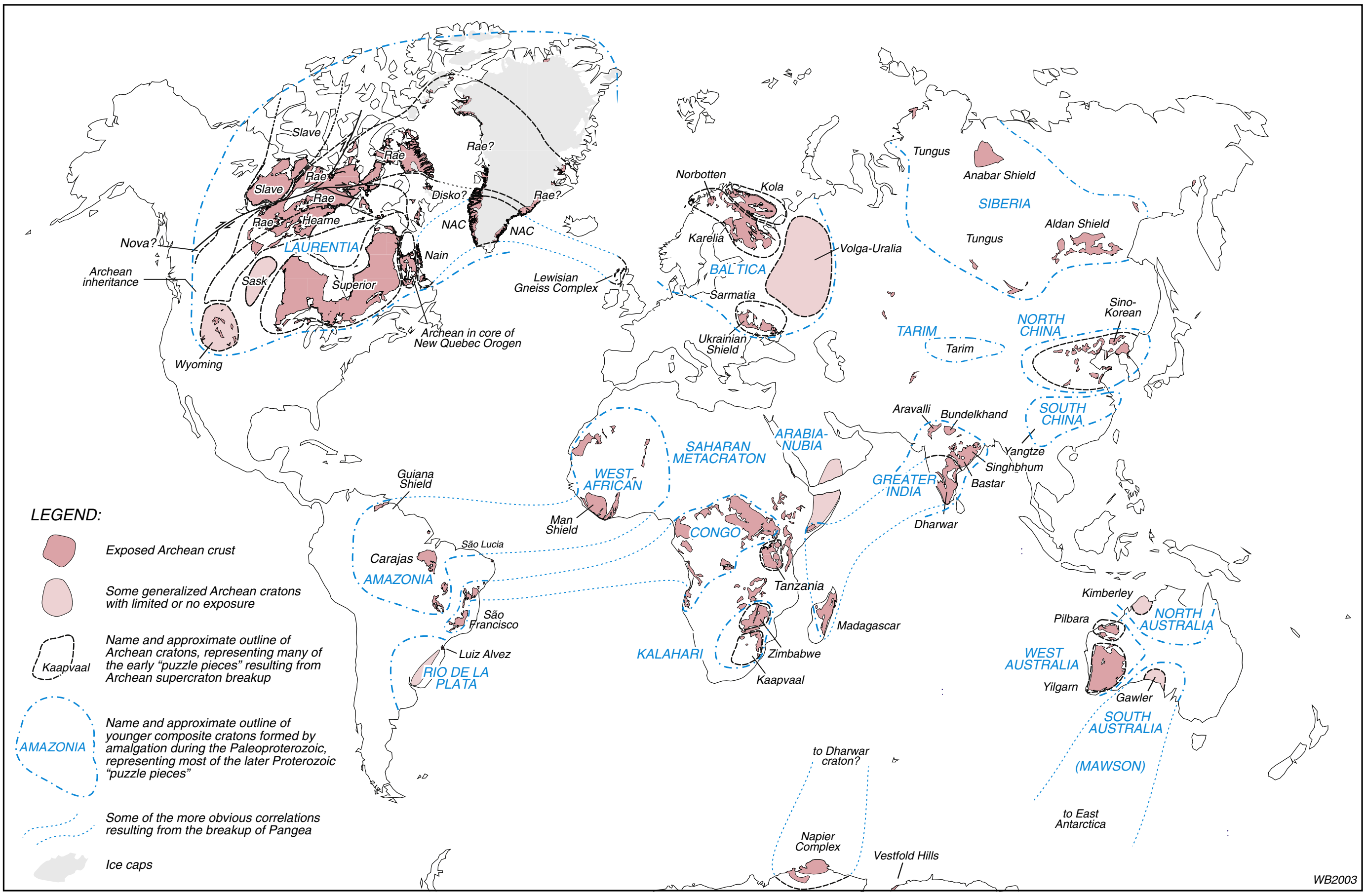

Fig. 1. Generalized distribution of main cratonic blocks relevant to different supercontinents and the focus of discussion in this paper. Modified after Bleeker (2003).

1.2. The LIP method for paleocontinental reconstruction

LIPs are large volume intraplate magmatic events ($>100{,}000\ \text{km}^3$) consisting of volcanic rocks (mainly flood basalts), sill complexes, mafic–ultramafic layered intrusions, and a plumbing system of dyke swarms (e.g., Bryan and Ernst, 2008; Ernst and Buchan, 2001). Many LIPs have associated felsic magmatism (both intrusive and extrusive), carbonatites and in some cases lamprophyres, lamproites and kimberlites. LIPs are typically characterized by a short duration magmatic pulse or pulses (less than 1–5 Myr), and while various origins have been proposed, the dominant model has been deep-seated mantle plumes arising to the base of the lithosphere (Bryan and Ernst, 2008; Coffin and Eldholm, 1994, 2005; Courtillot and Renne, 2003; Ernst and Buchan, 2001, 2003).

The giant dyke swarms of LIPs are of particular interest for use in reconstructions (e.g., Bleeker and Ernst, 2006; Fahrig, 1987; Halls, 1982) because: 1) not only are they an integral part of LIPs, but) they 2) have very large footprints (300–3000 km), 3) were emplaced in short time pulses that can now be dated precisely (see below), 4) are relatively insensitive to uplift (given their vertical orientation), 5) project far into stable cratonic hinterlands, 6) contain rich geometrical and paleo-stress information (with radiating and linear regional trends), 7) provide superior "piercing points", and finally, 8) provide the target rocks of choice for high-quality, precisely dated, paleomagnetic poles ("key poles"). The breakup history of Pangea, Earth's most recent supercontinent, teaches us that LIPs play a pivotal role in continental breakup, typically leaving remnants of flood basalts and their giant feeder dyke swarms on conjugate rifted margins (e.g., Courtillot et al., 1999; Storey, 1995).

The other important reason why LIPs and especially their dolerite dyke swarms and sill provinces are now so valuable for paleocontinental reconstructions is because of numerous advances in U–Pb geochronology, together with the realization that almost all mafic rocks contain trace amounts of baddeleyite (ZrO_2) and/or zircon ($ZrSiO_4$). These U-bearing accessory minerals allow essentially all short bursts of LIP magmatism to be dated precisely and accurately (e.g., Chamberlain et al., 2010; Heaman and LeCheminant, 1993; Krogh et al., 1987; Li et al., 2010; Rioux et al., 2010; Söderlund and Johansson, 2002; Wingate et al., 2002).

Multiple precisely dated events provide, in effect, a magmatic "barcode" (not unlike a supermarket barcode) of ages that "fingerprint" a terrane or crustal block (Bleeker, 2003; Ernst and Bleeker, 2010). These barcodes can be compared between different crustal blocks, to recognize original "nearest neighbors", thus providing important clues in the reconstruction of fragmented supercontinents. In addition, the geometrical information of radiating dyke swarms can define the relative orientation of blocks, while primary paleomagnetic information can further constrain azimuthal orientation, latitude, and relative longitude. Geochemistry can be used to

Fig. 2. Barcode diagram for cratonic blocks grouped in three time intervals relevant to supercontinent reconstructions. Part A is relevant to Pangea. Part B is relevant to the Proterozoic Nuna (Columbia) and Rodinia supercontinents. Part C is relevant to the late Archean supercontinent/supercraton(s). A bar indicates a single pulse. A box can enclose multiple pulses for a single event. Dots on the left side of a bar identify published ages produced by the Project or by associated grants (see Section 4.1). The labeling "Proto-xxx" was used in part C to identify regions likely consisting of more than one cratonic block that cannot yet be separated out. In Part C, Central Hearne and Rae (+NW Hearne) correlate with Hearne and Rae of Fig. 1 (see discussion in Berman et al., 2007).