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Petrogenesis of Gunbarrel magmatic rocks: Homogeneous continental tholeiites associated with extension and rifting of Neoproterozoic Laurentia

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ABSTRACT

The ca. 780 Ma Gunbarrel Igneous Event of northwest Laurentia consists of spatially discrete suites of sills, dykes and lavas distributed over a vast area extending from Wyoming in the south to the Wopmay Orogen and the Mackenzie Mountains of Northwest Canada. Thick (≤100 m) sills and rare dykes in Wopmay orogen and thinner (≤30 m) sills, dykes and rare lavas in the Mackenzie Mountains are moderately evolved, augite + oligoclase–labradorite + ilmenite–magnetite gabbros and amygdaloidal basalts. Systematic petrochemical differences between units reveals that each is likely derived from subtly distinct parental magmas collectively exhibiting mutually consistent element variations. The dataset is remarkably homogenous, in particular, the incompatible trace elements and the Sm–Nd isotopes. All rocks preserve petrochemical evidence of an enriched MORB-like mantle source, but a small lithospheric component in the primary magmas resulted in elevated LILE, minor negative HFSE anomalies and sub-depleted mantle but supra-bulk earth εNd values. The lithospheric component was slightly older, modestly fractionated, Sr-depleted, garnet-free (pyroxenitic?) lower crust or, similar material that was previously recycled into the lithospheric mantle. Mineral chemical data for plagioclase and clinopyroxene in chill margin samples from a Hottah sheet in Wopmay orogen, indicates rapid and repeated turbulent mixing of geochemically and thermally similar magmas. These were staged from large, lowermost crust(?) magma chambers centred over an asthenospheric thermochemical anomaly thought to lie to the west of present-day North America. These magmas were then rapidly emplaced across western Laurentia.

1. Introduction

Mafic Large Igneous Provinces (LIPs, Coffin and Eldholm, 1994) including continental flood basalts (CFB) and mafic dyke swarms (MDS) are recognized on many of Earths ancient cratons and have been widely correlated on the basis of similar and overlapping precise U–Pb baddeleyite ages (Heaman et al., 1992; Heaman and LeCheminant, 1993; Ernst, 2007; Heaman, 2008; Ernst and Bleeker, 2010) and paleogeographical data (Buchan et al., 1993, 1998; Halls and Davis, 2004; Li et al., 2008; Evans, 2009). Integrated geochronological, paleomagnetic, as well as geochemical data on ancient mafic igneous events can therefore be powerful tools in the reconstruction of previous supercontinents. Reconstruction of Earths ancient cratons, which have utilized mainly paleomagnetic and geochronological data for mafic dyke swarms, has resulted in the construction of global "geochronological barcodes" for diverse cratons (e.g., Bleeker and Ernst, 2006; Ernst et al., 2008) establishing a robust tool for supercontinental reconstructions. However, a lack of robust geochronological data for many global large igneous provinces, in particular for Precambrian examples, obfuscates global correlations (e.g., Wingate et al., 1998). Contributing to the difficulties in correlation, robust lithogeochemical and radiogenic tracer isotopes for LIPS are widely lacking, making the testing of constraints problematic. Even in well studied, younger Pangean LIPS of the Atlantic borderlands, a firm understanding of the temporal, spatial and compositional variations is as yet largely incomplete.

Rodinia, the last Precambrian supercontinent was amalgamated in the Proterozoic and was fragmented between ca. 1300 and 600 Ma (Li et al., 2008; Evans, 2009). During this protracted

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break-up event, mafic dyke swarms, cogenetic sills, ultramafic intrusions and volcanic products were emplaced into continental crust undergoing fragmentation and rifting (Ernst et al., 2008). In northwest North America, Neoproterozoic mafic rocks associated with three distinct magmatic events were emplaced during this interval (Buchan and Ernst, 2004): the areally extensive ca. 1270 Ma Mackenzie dyke swarm along with correlative basalts of the Coppermine River area and the ultramafic Muskox intrusion (Dupuy et al., 1992; LeCheminant and Heaman, 1989; Heaman and LeCheminant, 1993; Schwab et al., 2004; Mackie et al., 2009); the ca. 780 Ma Gunbarrel event (Armstrong et al., 1982; Dudás and Lustwerk, 1997; Harlan et al., 2003) and; the youngest, ca. 720 Ma Franklin event incorporating the Coronation Sills and Natkusiak basalts (Heaman et al., 1992; Dupuy et al., 1995; Pehrsson and Buchan, 1999; Shellnut et al., 2004). Previously proposed and generally contested correlations of late Neoproterozoic LIPs between North America and other continents has been based largely on geological similarities, radiometric ages and paleomagnetic settings (e.g., Park et al., 1995b; Wingate et al., 1998; Zhou et al., 2002). Numerous other correlations have been suggested using stratigraphic or paleomagnetic data and apparent polar wander paths (e.g., Moores, 1991; Sears and Price, 2000; Li et al., 2008; Evans, 2009).

In western North America, the Gunbarrel sills (Fig. 1) have been precisely dated by U–Pb baddeleyite methods (Harlan et al., 2003) and have well-constrained paleogeographic data (Park et al., 1989, 1995a,b). With few exceptions (Sandeman et al., 2007; Ootes et al., 2008; Ernst and Buchan, 2010), however, modern and robust lithogeochemical and radiogenic isotopic data for these 780 Ma gabbroic and basaltic rocks are lacking. Prior to this work, only a limited dataset comprising a few partial geochemical analyses are available for the 780 Ma Gunbarrel igneous event (e.g., Dudás and Lustwerk, 1997; Ernst and Buchan, 2010), making lithogeochemical and isotopic comparison with other Neoproterozoic LIPs difficult (e.g., Park et al., 1995b; Wingate et al., 1998; Zhou et al., 2002). In this contribution, we present a modern and robust lithogeochemical dataset including Nd radiogenic isotopic data for some of the 780 Ma Gunbarrel rocks in northwestern North America. The samples are from two areally separate geological settings of gabbroic sills and dykes in the Neoproterozoic Mackenzie Mountains (ca. 0.85 Ga) and a third group of samples from gabbroic sheets and dykes in the Paleoproterozoic Wopmay orogen (ca. 1.9 Ga) of the Northwest Territories of Canada. We supplement these data with a single Sm–Nd isotopic analysis of the analogous Christmas Lake dyke (Condie et al., 1969) that cuts the Archaean Wyoming craton of the western United States. Collectively, the datasets provide the first rigorous lithogeochemical fingerprints on the Gunbarrel event that can help to better constrain the proposed correlations with contemporaneous LIPs on other continents.

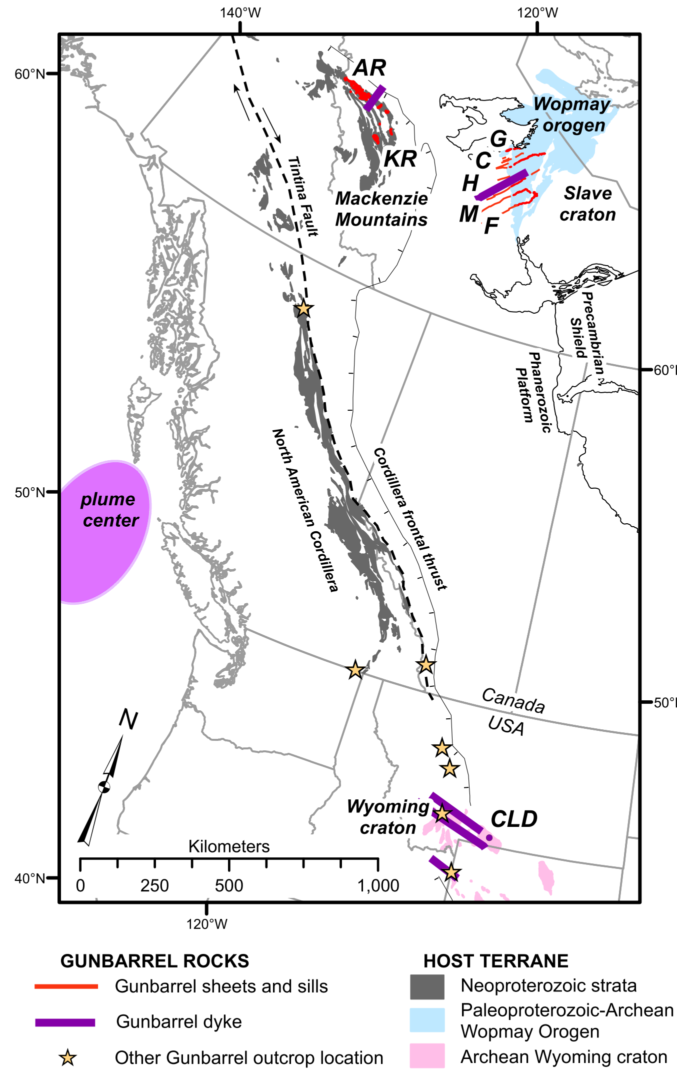

Fig. 1. Simplified geological map of northwestern North America. Thick black line with arrows indicates movement on Tintina fault; barbs on Cordilleran frontal thrust are on the hangingwall side. Sill traces under the Phanerozoic platform are from new aeromagnetic data in these regions (http://www.nrcan.gc.ca/earth-sciences/products-services/geoscience-data-repository/11824). The dyke trends, plume centre, and locations of the Christmas Lake dyke and other Gunbarrel outcrops are from Park et al. (1995b) and Harlan et al. (2003). More detailed maps of the sill outcrops in the northern Mackenzie Mountains and Wopmay orogen are in Park et al. (1995b), Sandeman et al. (2007) and Ootes et al. (2008). AR – Arctic Red River area; KR – Keele River area; F – Faber sheet; H – Hardisty dyke; M – Margaret sheet; C – Calder sheet; G – Gunbarrel sheet; CLD – Christmas Lake dyke.

2. Regional setting, U–Pb geochronology and paleomagnetic background

In Canada, Gunbarrel rocks comprise gabbroic to basaltic sills, dykes and lavas in the northern Cordillera (Mackenzie Mountains) of the Northwest Territories, dykes in the Rocky Mountains of northern British Columbia and sheets (subhorizontal but not bedding concordant) and dykes in the western Precambrian Canadian Shield of the Northwest Territories (Park et al., 1989; Harlan et al., 2003; Ernst and Buchan, 2004; Fig. 1). They also occur as dykes in both the Archaean Wyoming craton of the Rocky Mountains and in the Tobacco Root Mountains of Montana (Fig. 1; Condie et al., 1969; Harlan et al., 2003). Sills, sheets, less common dykes and a thin sequence of amygdaloidal basalt flows in the Mackenzie Mountains and Wopmay orogen are the focus of this study. In the Mackenzie Mountains (Fig. 1), stratiform gabbro sills, locally referred to as Tsezotene sills, intrude the Neoproterozoic Mackenzie Mountains Supergroup (<1083 Ma; Jefferson and Parrish, 1989), a clastic sedimentary sequence deposited in an epicratonic sea through to passive margin environment (Turner and Long, 2008). The sills are restricted to the northern parts of the Cordillera where rocks of the Mackenzie Mountains Supergroup are exposed and were examined in a northwestern Arctic Red River transect (AR: Fig. 1) and in a southeast Keele River area (KR: Fig. 1). With the exception of the correlative Little Dal basalts (LD: Fig. 1), a locally preserved series of tholeiitic basalt flows at the top of the Little Dal Group of the Mackenzie Mountains Supergroup (Narbonne and Aitken, 1995; Dudás and Lustwerk, 1997), the sills and correlative dykes are the only identified Proterozoic magmatic rocks in the region (Ernst and Buchan, 2004). They are most common as 1–50 m thick, bedding concordant sheets in the Tsezotene Formation and as sills