Precambrian Research 175 (2009) 1–15

Contents lists available at ScienceDirect

Precambrian Research

journal homepage: www.elsevier.com/locate/precamres

Evidence for enrichment of subcontinental lithospheric mantle from Paleoproterozoic intracratonic magmas: Geochemistry and U–Pb geochronology of Martin Group igneous rocks, western Rae Craton, Canada

R.M. Morelli[a,*], R.P. Hartlaub[b], K.E. Ashton[a], K.M. Ansdell[c]

[a] Energy and Resources, Government of Saskatchewan, Regina, Saskatchewan, Canada S4P 3V7
[b] Department of Mining and Mineral Exploration, British Columbia Institute of Technology, Burnaby, British Columbia, Canada V5G 3H2
[c] Department of Geological Sciences, University of Saskatchewan, Saskatoon, Saskatchewan, Canada S7N 5E2

ARTICLE INFO

Article history:
Received 28 May 2008
Received in revised form 14 April 2009
Accepted 17 April 2009

Keywords:
Martin group
Intracontinental basin
Geochemistry
Geochronology
Subcontinental lithospheric mantle
Mantle enrichment

ABSTRACT

The Paleoproterozoic Martin Group, located in the Rae Craton of northwestern Saskatchewan, is a sequence of intercalated siliciclastic deposits and mafic igneous rocks that were deposited in a fault-controlled intracratonic basin. Based on field relationships, mafic volcanic rocks and sills of the Martin Group have historically been viewed as genetically related to a suite of regionally extensive mafic dikes. In this study, the geochemical characteristics of the three mafic suites (volcanic rocks, sills, and dikes) were used to interpret their respective magmatic histories, to assess the possibility of a genetic relationship between the suites, and to deduce the nature of the magma source. Geochemically, these rocks range from subalkaline (tholeiitic) basalts to alkali basalts or trachyandesites and contain trace element compositions consistent with emplacement in an intracontinental setting. All three suites are highly enriched in light rare earth elements but have anomalously low concentrations of high field strength elements (e.g. Nb, Ta, Hf, Zr) relative to other trace elements. The trace element compositions suggest derivation of all three suites from a common subcontinental lithospheric mantle source that had experienced a complex enrichment history, including modification of depleted mantle by ancient subduction-related components and by small degree asthenospheric melts. A common, enriched source for these magmas is confirmed by their identical initial Nd isotopic compositions (ε_{Nd} at the time of emplacement of −3.7 to −5.3), likely indicative of input of isotopically evolved crust to the source region during the subduction-related enrichment. The overall similarity of chemical compositions for the three suites indicates that regional emplacement of the mafic dikes and (localized?) magmatism within the Martin Group was essentially part of the same mafic magmatic event in the area, though slight intersuite compositional variations might reflect differences in magma evolution histories. A U–Pb baddeleyite date from one dike broadly dates this magmatic event at ca. 1818 Ma, though it must have occurred as a series of magmatic pulses that alternated with periods of sedimentary deposition within the Martin basin. The dike magmas infiltrated pre-existing fractures, whereas the intrabasinal suites might have utilized major faults associated with basin genesis (e.g. the Black Bay fault) as magma conduits.

1. Introduction

The Rae Craton and adjacent Hearne Craton to the east (Fig. 1) form the Archean nucleus of the Churchill Province, one of multiple Archean provinces that provide the framework of the Laurentian supercontinent (Hoffman, 1988, 1989). The 'Rae-Hearne' Cratons are flanked to the west by the ca. 2.0–1.93 Ga Thelon-Taltson Magmatic Zone (Hoffman, 1988; Chacko et al., 2000) and to the southeast by ca. 1.95–1.8 Ga rocks comprising the Trans-Hudson Orogen (Hoffman, 1988; Lewry and Collerson, 1990). These two orogenic events resulted in pronounced Paleoproterozoic tectonic reworking of intervening Archean rocks throughout the Churchill Province (Hoffman, 1988, 1989; Ashton et al., in press).

Numerous Paleoproterozoic siliciclastic basins overlie the Archean rocks in the Churchill Province and represent evidence of this crustal reworking (Fraser et al., 1970; Ashton et al., in press). Some such basinal successions include contemporaneous mafic igneous rocks, reflecting localized extensional magmatism. An important example, covering a large expanse of the east-central Rae Craton (Fig. 1), is the Baker Lake Basin and igneous rocks of the Christopher Island Formation (e.g. LeCheminant et al., 1987; Peterson et al., 2002). Additionally, the Nonacho Group sedimentary

* Corresponding author. Tel.: +1 306 787 2568.
E-mail address: Ryan.Morelli@gov.sk.ca (R.M. Morelli).

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doi:10.1016/j.precamres.2009.04.005

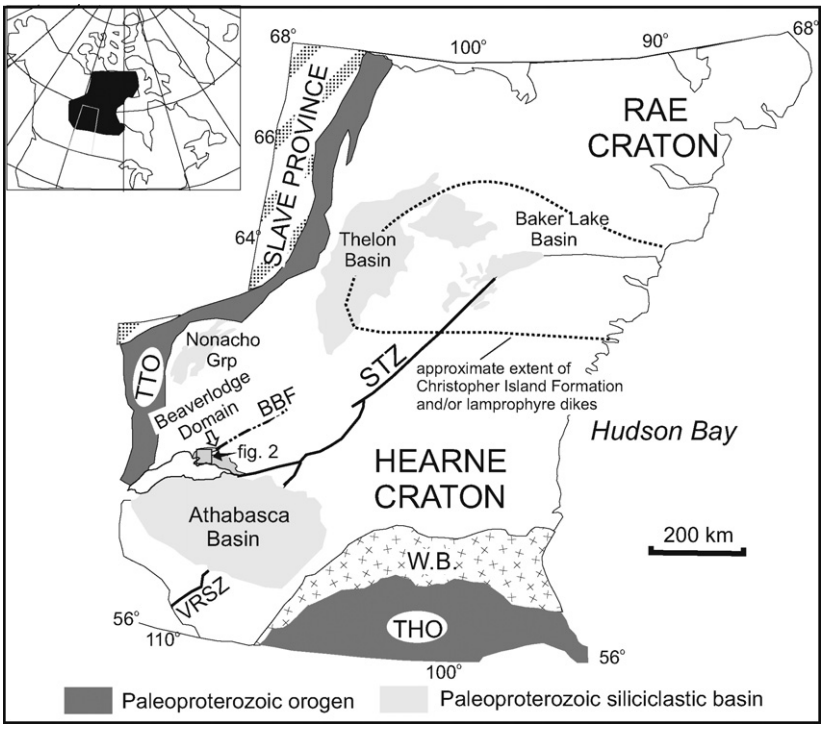

Fig. 1. Generalized geologic map of the Churchill Province and bounding orogens showing location of Proterozoic intracratonic basins in the Rae and Hearne Cratons (after Hoffman, 1988; TTO = Thelon-Taltson Orogen; THO = Trans-Hudson Orogen; WB = Wathaman Batholith; BBF = Black Bay Fault; STZ = Snowbird Tectonic Zone; VRSZ = Virgin River Shear Zone).

rocks of the western Rae Craton are spatially proximal to the Sparrow mafic dike swarm (McGlynn et al., 1974), though the exact genetic relationship, if any, is currently unknown. Though slightly younger, the Thelon and Athabasca Basins represent Proterozoic sedimentation centers, the former of which is also associated with mafic (shoshonitic) magmas (Peterson, 1995).

The Paleoproterozoic Martin Group, situated in northwestern Saskatchewan and the focus of this study, represents a Paleoproterozoic extensional basin that predates sedimentary rocks of the Athabasca Group, which are known to have been deposited after 1740 Ma (Rainbird et al., 2007). The Martin Group (MG), located in the Beaverlodge Domain in the Uranium City area (Fig. 1), records a ca. 5000 m-thick, siliciclastic-dominated red bed sequence with subordinate intercalations of mafic volcanic flows and sills. It has been suggested that a locally extensive suite of east- to southeast-trending mafic dikes acted as feeders to the MG mafic flows and sills (Tremblay, 1972), due to striking lithological similarities and field relationships that suggest close temporal relationships. Previous studies of the MG provided lithological and structural descriptions (Tremblay, 1972), stratigraphic characteristics (Mazimhaka and Hendry, 1984), and suggested several modes of basin formation (Fraser et al., 1970; Ramaekers, 1981; Ashton et al., 2001). The objective of the present study is to elucidate the age and the geochemical and Sm–Nd isotopic characteristics of these three mafic igneous suites (i.e. volcanic rocks, sills, and dikes) in order to constrain their tectonic setting of emplacement and to assess possible intersuite genetic relationships and magma source characteristics. This information augments our understanding of the tectonic evolution of the Churchill Province in northern Canada and helps to characterize the nature of the underlying crust and lithospheric mantle.

2. Regional geology

The MG is discontinuously exposed over an area of ~3000 km^2 (Mazimhaka and Hendry, 1984), with most exposures comprising small, fault-controlled successions. The main remnant of the depositional basin, covering ~250–300 km^2, is located immediately east of Uranium City and is the only portion of the MG known to host coeval igneous rocks (Fig. 2). The basin was fault-controlled and deposited over a highly irregular unconformity surface that varies in character from a sharp contact to local regolith (Tremblay, 1972; Mazimhaka and Hendry, 1984). The Archean to Paleoproterozoic basement to the MG encompasses an array of metamorphosed rock types and is referred to herein as 'undifferentiated basement' (Fig. 2). Comprehensive descriptions of basement units are provided by Tremblay (1972), Hartlaub (1999), and Ashton et al. (2000, 2001), and a brief summary of the principal basement lithologies are provided below.

The oldest rocks in the region comprise the 'Basement Complex' (Persons, 1983; Hartlaub et al., 2004) which represents a number of granitoid inliers including the Lodge Bay (3060 ± 40 Ma; Hartlaub et al., 2004), Elliot Bay (3014 ± 10 Ma; Persons, 1983) and Cornwall Bay (2999 ± 7 Ma; Hartlaub et al., 2004) granites. Three suites of Neoarchean to Paleoproterozoic intrusive rocks have also been identified as basement to the MG. The oldest of these is a ca. 2.6 Ga suite of granitic to tonalitic plutons (Hartlaub et al., 2004). A second intrusive episode at ca. 2.3 Ga is represented by the granitic to gabbroic 'North Shore Plutons' (O'Hanley et al., 1994; Hartlaub, 2004), which might have originated during terrane accretion related to subduction on the western margin of the Rae Craton (Hartlaub et al., 2007). The Basement Complex is unconformably overlain by an extensive amphibolite facies supracrustal sequence, consisting of basal quartzites, carbonates, ultramafic to intermediate igneous rocks, iron formations, and clastic sedimentary rocks, collectively referred to as the Murmac Bay Group (Macdonald, 1983). The Murmac Bay Group is of uncertain age and origin, but has been hypothesized as a rift succession (Wilson, 1998; Hartlaub et al., 2004) that was deposited after 2330 Ma (Ashton and Hunter, 2003). The final period of igneous activity prior to deposition of the MG is represented by a ca. 1930 Ma suite of crustally derived, pink to