Queen Maud block: A newly recognized Paleoproterozoic (2.4–2.5 Ga) terrane in northwest Laurentia

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ABSTRACT

The Queen Maud block of Arctic Canada is central to understanding the Proterozoic tectonic history of northwestern Laurentia, but its crustal history is largely unknown. Results of an in situ U-Pb zircon, monazite, and whole-rock Sm-Nd study through the central and eastern Queen Maud block indicate: (1) widespread 2.46–2.50 Ga magmatism derived from Neoarchean source rocks, (2) an extensive NE-trending 2.44–2.39 Ga sedimentary belt characterized by 2.45–2.50 Ga detritus, and (3) regional ca. 2.39 Ga granulite metamorphism. There is no evidence of metamorphic or magmatic activity at 1.9–2.0 Ga, concurrent with orogenesis in the adjacent Taltson-Thelon belt. We propose that the eastern Queen Maud block was the site of an incipient continental rift ca. 2.5 Ga. Exhumation of 2.46–2.50 Ga granitoids produced in the early stages of rifting provided detritus to a short-lived basin that underwent granulite metamorphism ca. 2.39 Ga.

Keywords: Queen Maud block, Paleoproterozoic, U-Pb zircon, Sm-Nd, Laurentia.

INTRODUCTION

The Queen Maud block of Arctic Canada occupies the keystone tectonic position between the Archean Slave and Churchill Provinces (Fig. 1), but due to its remote location has received negligible research attention. As a result, Laurentia-scale geotectonic models incorporating the Queen Maud block are generally based on research conducted in surrounding tectonic domains, or through use of remotely sensed geophysical data.

Two tectonic models currently exist for the origin of the Queen Maud block. The first maintains that the Slave and Churchill Provinces were separated by an ocean basin that closed by subduction beneath the Churchill Province, followed by a Himalayan-style collision at 1.9–2.0 Ga (Hoffman, 1987). In this model, the Taltson-Thelon magmatic zone is analogous to the modern-day Himalayas and the Queen Maud block to a deeply eroded Tibetan Plateau (Fig. 1).

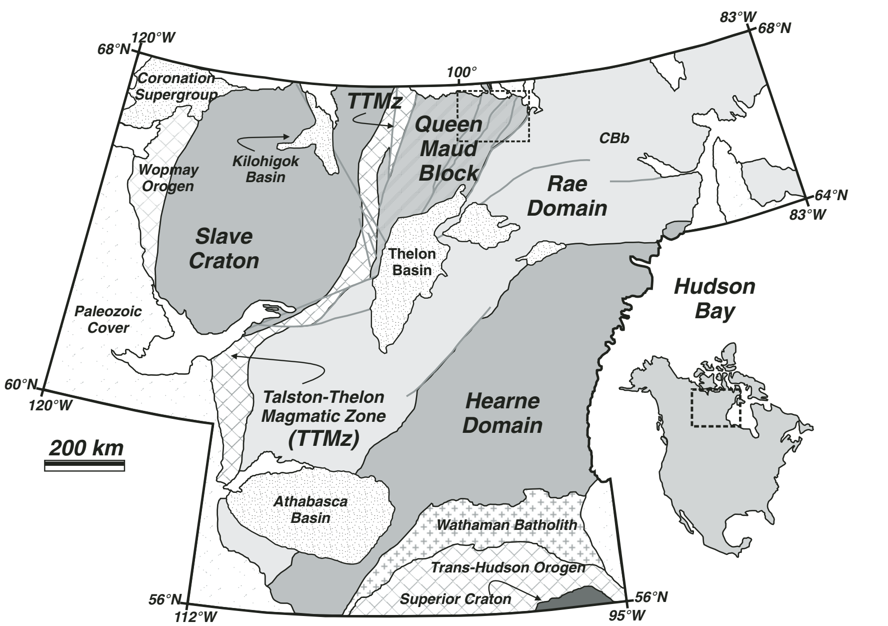

Figure 1. Tectonic elements of northwestern Laurentia including major cratonic blocks, surrounding Paleoproterozoic orogens, and Proterozoic sedimentary basins (modified after Hanmer et al., 2004). Area of Queen Maud block investigated for this study is outlined and detailed in Figure 2. CBb is Committee Bay belt.

An alternative model (Chacko et al., 2000) proposes that the Slave and Churchill Provinces were not separated ca. 2.0 Ga, but were together in the earliest Paleoproterozoic or Archean. Thus the Taltson-Thelon magmatic zone is similar to present-day plate interior mountain belts of Central Asia (e.g., Tian Shan). If the Queen Maud block represents a Tibetan-style orogenic plateau, there should have been extensive metamorphic and tectonic reworking of mid-crustal levels ca. 1.9–2.0 Ga. In contrast, the second model predicts that the Queen Maud block should have been little affected at 1.9–2.0 Ga and should largely preserve earlier periods of magmatism, metamorphism, and deformation.

To test these models, we conducted the first extensive geochronological and isotopic study of the Queen Maud block and adjacent Churchill Province. Our results mandate a reinterpretation of the Queen Maud block and its role in the assembly of northwestern Laurentia.

REGIONAL GEOLOGY

The Churchill Province comprises variably reworked Archean continental crust bound to the west by the 2.0–1.9 Ga Taltson-Thelon magmatic zone (e.g., Hoffman, 1989) and to the southeast by the 1.9–1.8 Ga Trans-Hudson orogen (Fig. 1). The province is divided along the Snowbird tectonic zone into the Rae and Hearne domains (Hoffman, 1989; Hanmer et al., 2004). Rocks of the north-central Rae domain consist of 2.73–2.68 Ga greenstone belts, underlain by slightly older basement that is largely obscured by Neoarchean granitoids; Sm-Nd model ages indicate 3.0–2.8 Ga crustal precursors at depth (Skulski et al., 2003). A widespread Neoarchean granitoid bloom occurred at 2.62–2.58 Ga (Skulski et al., 2003), after which granitoid magmatism generally ceased in the northern Rae domain until 1.85–1.81 Ga plutonism associated with Trans-Hudson orogenesis (Peterson et al., 2002). The majority of the Churchill Province has also been subjected to greenschist to upper amphibolite facies metamorphism associated with Trans-Hudson orogenesis. Older metamorphic events from 2.3 to 2.4 Ga are recorded in the Committee Bay belt of the north-central Rae domain (Berman et al., 2005) and in the southwestern Rae domain, accompanied by plutonic activity (Bostock and van Breemen 1994; McNicoll et al., 2000; Hartlaub et al., 2007).

GEOLOGY OF THE QUEEN MAUD BLOCK

The Queen Maud block is on the northwest margin of the Rae domain (Fig. 1). Reconnaissance mapping determined that the block comprises largely high-grade, quartzofeldspathic gneisses, granitoids, and metavolcanic and metasedimentary rocks (Heywood, 1961; Fraser 1964). Further subdivision is based on aeromagnetic data (Geological Survey of Canada, 2006) that outline three N- to NE-trending domains (Fig. 2), including an eastern magnetic high, a uniform central magnetic low (blue in Fig. 2), and an internally complex western magnetic high. Field work conducted during this study demonstrates that magnetic high domains are dominated by deformed tonalites to granodiorites, most of which contain orthopyroxene. The central magnetic low is dominated at the surface by migmatized pelitic and semipelitic metasedimentary rocks characterized by garnet-bearing melt leucosomes. This NE-trending belt of supracrustal rocks is here termed the Sherman Group. Mafic dikes were identified in the eastern high and mafic xenoliths in the two westerly domains. The occurrence of the garnet–cordierite–potassium feldspar assemblage in pelitic rocks indicates regional, low- to moderate-pressure granulite facies metamorphism. Samples of the main lithologies were collected from the three aeromagnetic domains and the adjacent Rae domain (Fig. 2).

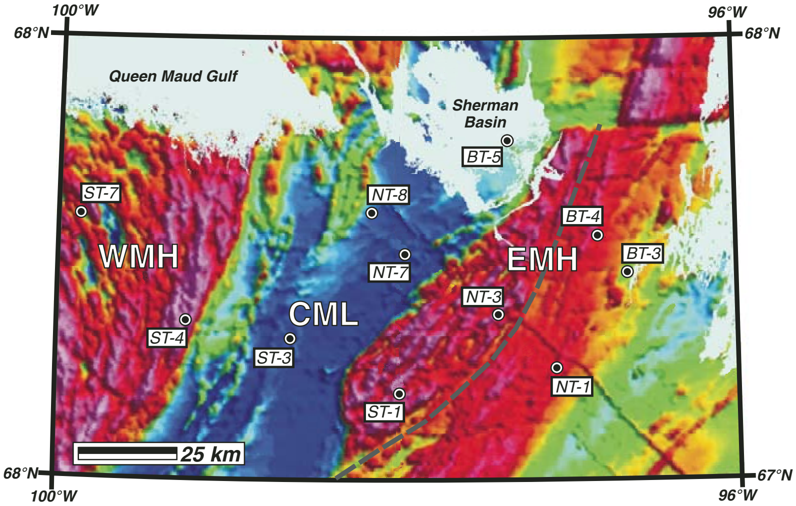

Figure 2. Aeromagnetic map of northeastern and north-central Queen Maud block showing sample locations described in text. Magnetic domains: WMH—western magnetic high; CML—central magnetic low; EMH—eastern magnetic high. Magnetic highs comprise deformed granitoids; magnetic low is mainly metasedimentary rocks. Dashed line is our proposed boundary between Queen Maud block and Rae domain.

IN SITU U-Pb ZIRCON, MONAZITE, AND WHOLE-ROCK Sm-Nd ANALYSES

Zircon and monazite were analyzed for their U-Pb isotopic composition (see GSA Data Repository Table DR2[1]) in standard petrographic thin sections by laser ablation–multicollector inductively coupled plasma–mass spectrometry using a novel in situ technique (Simonetti et al., 2006). Age calculations were made using Isoplot Version 3.0 (Ludwig, 2003), and are summarized in Table DR1.

The U-Pb zircon ages obtained for eight granitoid samples, in which many of the zircons exhibit oscillatory zoning, are interpreted to represent igneous crystallization ages. Ages between 2.60 and 2.70 Ga obtained for samples ST-1a (2636 ± 11 Ma), NT-1 (2595 ± 10 Ma), BT-3 (2689 ± 11 Ma), and BT-4 (2702 ± 16 Ma) are similar to previously reported Neoarchean granitoid ages from the northern Rae domain. In contrast, samples ST-4b (2476 ± 10 Ma), ST-7 (2457 ± 24 Ma), NT-3a (2490 ± 29 Ma), and NT-7 (2497 ± 19 Ma), yield ages between 2.46 and 2.50 Ga, distinct from known ages of the north-central Rae domain (Skulski et al., 2002). Whole-rock Sm-Nd isotopic data were also obtained for these samples and yield depleted mantle model ages of 2.8–3.1 Ga (calculated using the depleted mantle model of Goldstein et al.[1984]; Tables DR1 and DR3).

Three metasedimentary samples were investigated using in situ U-Pb monazite geochronology to delimit timing of regional metamorphism (Fig. DR1). Sample ST-3a reveals a two-part history. Two grains have cores that exhibit patchy compositional variations mantled by homogeneous rims (Fig. 3). Analyses from patchy cores yield a composite weighted mean $^{207}Pb/^{206}Pb$ age of 2481 ± 7 Ma, coeval with 2.46–2.50 Ga zircon ages of the granitoids. Analyses from grain rims (n = 3) and homogeneous grains (n = 10) yield a weighted mean $^{207}Pb/^{206}Pb$ age of 2385 ± 5 Ma. Core-rim relationships are not observed in samples ST-4a or NT-8, but the age pattern is repeated, with some monazite yielding ages coeval with zircon crystallization, and others defining a ca. 2.39 Ga monazite growth event. Given the occurrence of these monazite grains in melt leucosomes, we interpret the ca. 2.39 Ga age to reflect timing of granulite facies metamorphism.

DETRITAL ZIRCON U-Pb ANALYSES

The U-Pb ages for ~90 detrital zircon grains from samples ST-3 and BT-5d were determined to establish age and provenance of the Sherman Group. Probability density plots with stacked histograms for analyses that are <5% discordant are shown in Figure 4 (Table DR2).

Detrital zircons isolated from a migmatized pelite at station ST-3 are predominantly slender and elongate. Analyses of these grains define a narrow range from 2432 to 2608 Ma and primary node at 2496 Ma (Fig. 4). The youngest zircon grain exhibiting oscillatory growth zoning yielded an age of 2452 Ma, interpreted to be the maximum depositional age of the protolith. Zircons isolated from BT-5d are similar to sample ST-3a, with slender, elongate grains dominating. The detrital zircon U-Pb ages define a narrow range from 2345 to 2513 Ma and primary node at 2480 Ma (Fig. 4). The youngest grain exhibiting clear oscillatory growth zoning yielded an age of 2438 Ma, interpreted to be the maximum possible depositional age of the protolith. Given the ca. 2.39 Ga high-grade metamorphism identified by U-Pb monazite dating, zircon grains yielding ages younger than 2390 Ma must have undergone Pb loss or new growth during younger events.

DISCUSSION

The results of this study provide three newly recognized features of the Queen Maud block with important implications for the Paleoproterozoic evolution of northwestern Laurentia. First, 2.46–2.50 Ga felsic to intermediate plutonic rocks underlie at least 5000 km^2 of the block. Felsic igneous rocks with this range of emplacement ages are rare in North America, but include a 2.48 Ga tonalitic gneiss from Boothia Peninsula (Frisch and Hunt, 1993), 2.45–2.50 Ga rocks of the Sask craton (Ashton et al., 1999; Rayner et al., 2005), and the 2.48 Ga Murray granite of the Superior craton (Krogh et al., 1996). Rocks of this age are unknown in the adjacent Rae domain, and their abundance in the Queen Maud block makes it a distinctive feature of this block. Second, the Sherman Group supracrustal rocks define a short-lived (2.44–2.39 Ga) basin dominated by 2.45–2.50 Ga detritus. Third, the Queen Maud block underwent granulite metamorphism ca. 2.39 Ga.

[1]GSA Data Repository item 2007182, Table DR1 (summary of rock types, in situ and grain mount U-Pb laser ablation MC-ICP-MS geochronology, age calculation methods, and whole rock Sm-Nd isotope data), Tables DR2 and DR3 (detailed U-Pb and Sm-Nd isotopic data), and Figure DR1 (photomicrographs displaying the textural relationships of monazite analyzed in situ), is available online at www.geosociety.org/pubs/ft2007.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

Our data indicate that granitoids with 2.46–2.50 Ga crystallization ages, hereafter referred to as Queen Maud granitoids, are located west of a major geophysical lineament (Fig. 2). We propose that this lineament represents the boundary between the Queen Maud block and the Rae domain, the latter being characterized primarily by 2.6–2.7 Ga granitoids. Our proposal does not preclude the presence of Archean rocks in the Queen Maud block, as evidenced by the 2636 ± 11 Ma age obtained for sample ST-1a. Although different in age, Queen Maud and Rae granitoids have similar ranges in ε_{Nd} values and depleted mantle model ages. This suggests that both granitoid suites were derived from similar Neoarchean source rocks.

Intrusion of Queen Maud granitoids was closely followed by deposition of the Sherman supracrustal rocks. Detrital zircons from these rocks have primary age nodes that overlap with Queen Maud granitoids. Combined with the prevalence of slender, elongate, unrounded zircon grains, these facts strongly suggest a proximal source dominated by 2.45-2.50 Ga rocks. Given the high proportion of 2.45–2.50 Ga detrital zircon, we also interpret the 2481 Ma composite age from core analyses of monazite in sample ST-3a to represent ages of detrital monazite. These source rocks may have also provided 2.45–2.50 Ga detritus to other Paleoproterozoic sedimentary basins of the western Churchill Province (e.g., Palmer et al., 2004; Davis et al., 2005).

Formation of the Sherman basin shortly after Queen Maud magmatism is reminiscent of processes in arc and/or backarc or continental rift settings. Arc magmas typically have a wide range in Nd isotope compositions, reflecting contributions from both crust and mantle sources (e.g., DePaolo, 1981). In contrast, Queen Maud granitoids have uniform Nd isotope compositions and appear to be derived almost exclusively from a Neoarchean crustal source. We suggest that Queen Maud granitoids are products of an extensional environment in which upwelling asthenosphere triggered melting of overlying Archean crust (e.g., Foucher et al., 1982). In this scenario, Sherman Group supracrustal rocks were deposited in a rift basin that formed soon after granitoid intrusion. Extensional faulting exhumed newly intruded Queen Maud granitoids, juxtaposing them with basinal sediment and making them available as the dominant detritus source. A potential problem with the rift model is the scarcity of mafic rocks. However, mafic rocks are present within metasedimentary rocks or as dikes or enclaves associated with Queen Maud granitoids. The ages of these mafic rocks remain undetermined, but we predict that these should be coeval with Queen Maud granitoid magmatism and Sherman basin sedimentation.

The hot-plate model of McLaren et al. (2005) is a corroborating model to explain extension and magma production soon followed by compression. This model is well suited for the Paleoproterozoic because it highlights enhanced radioactive heat production, resulting in a hotter

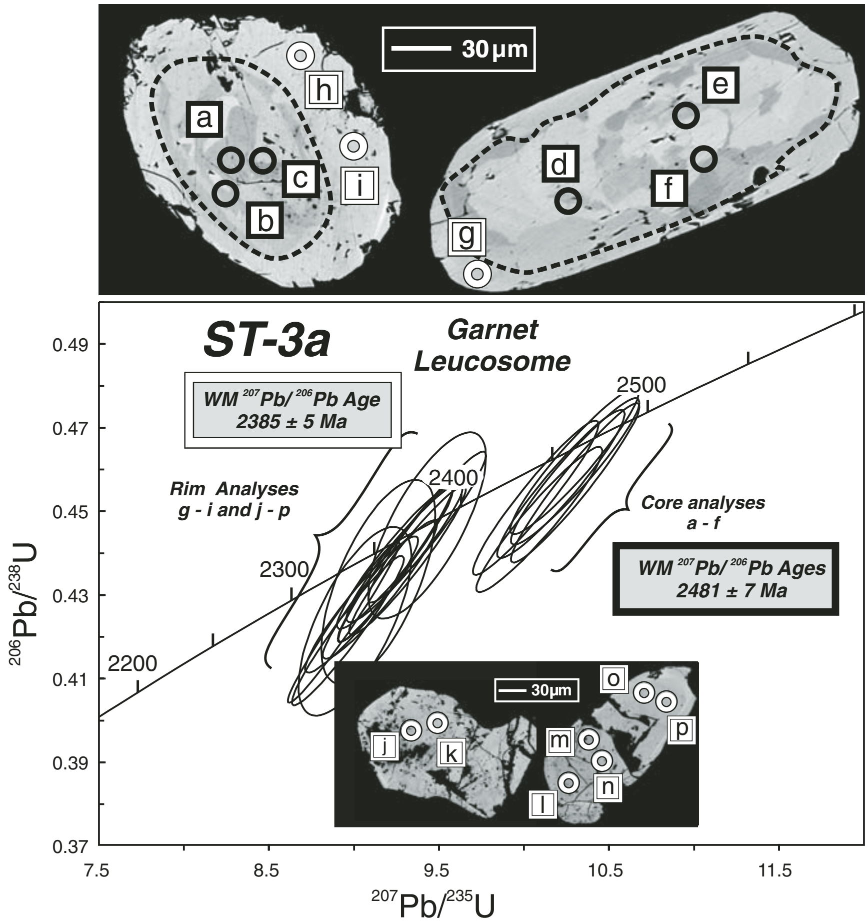

Figure 3. Concordia diagram showing in situ monazite analyses of sample ST-3a. Also shown are backscattered electron images of analyzed grains and locations of laser ablation pits. Older age is composite of core analyses, all identical within analytical error. The younger age population includes three analyses performed on a homogeneous grain not displayed in figure.

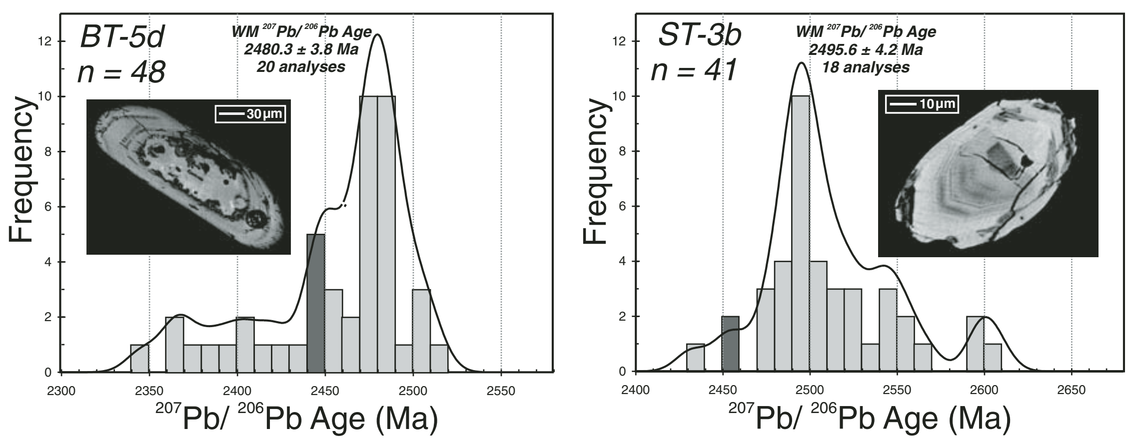

Figure 4. Weighted mean (WM) ^{207}Pb/^{206}Pb ages of detrital zircon in samples ST-3b and BT-5d shown as histograms and cumulative probability plots. Plots do not include analyses >5% discordant or younger age outliers at 1924 and 2162 Ma in BT-5d or older outlier at 3405 Ma in ST-3b. Backscattered electron images are of the youngest grains with clear oscillatory zoning. Darker shaded histogram bins denote age of these grains, which we take to be the maximum possible depositional age of sediment in the Sherman supracrustal belt.

and substantially weaker lithosphere. This lithosphere may require less thermal input for magma production, and may also be more susceptible to deformation by far-field extensional and compressional stresses.

High-grade metamorphism of Sherman Group supracrustals ca. 2.39 Ga could be related to the proposed Arrowsmith orogeny (Berman et al., 2005). Evidence for this orogeny includes ca. 2.35 Ga metamorphism in the Committee Bay belt ~200 km to the east of the Queen Maud block (Berman et al., 2005) and 2.3–2.4 Ga metamorphism and plutonism in the southwestern Rae domain and Taltson-Thelon magmatic zone basement (Bostock and van Breemen, 1994; McNicoll et al., 2000; Hartlaub et al., 2007). The Arrowsmith orogeny in these distal regions has been attributed to far-field effects of eastward-dipping subduction and orogenesis along the western margin of the Rae domain (Hoffman, 1989; Berman et al., 2005; Hartlaub et al., 2007).

Our results do not readily fit the model of Hoffman (1987), i.e., that the Queen Maud block is an eroded Tibetan-style plateau related to the 1.9–2.0 Ga Taltson-Thelon orogen. Unlike large segments of modern-day Tibetan mid-crust (Unsworth et al., 2005), our data for the Queen Maud block show no evidence of mid-crustal reworking concurrent with Taltson-Thelon orogenesis. This suggests that the orogenic plateau model is not applicable or that the areas or crustal level investigated here did not undergo 1.9–2.0 Ga reworking. We propose that a plateau model may be applicable, but would be related to an earlier orogenic cycle, like the Arrowsmith orogeny. Details of this orogeny remain to be established, but one possibility is collision between the Slave and Churchill Provinces ca. 2.39 Ga. Alternatively, the two provinces may have been part of a preexisting Neoarchean supercontinent (e.g., Aspler and Chiarenzelli, 1998), making the Arrowsmith orogeny entirely intraplate in nature.

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