U-PB DETRITAL ZIRCON PROVENANCE OF THE PROTEROZOIC NOPEMING AND PUCKWUNGE FORMATIONS NORTHEASTERN MINNESOTA

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INTRODUCTION

The Puckwunge and Nopeming Formations are quartzose sandstones that are believed to be correlated. Determination of paleoflow is very limited due to the paucity of the exposures in Minnesota. There is question as to whether or not the formations are correlative due to the opposing directions of the paleocurrent, but further investigation has led to the belief that the two formations are indeed correlative (Ojakangas and Morey, 1982).

The Puckwunge, Nopeming and Bessemer Formations are quartz sandstones exposed in Minnesota and Michigan along the margin of the Keweenawan rift igneous-tectonic province (1.1-1.06 Ga), and unconformably overly the oldest and lowest basalt flows. The basalts contain pillows and the sands are distinguished as inter-pillow fill suggesting they were unlithified when the basalts were extruded into water. Thus, they can be correlated regionally. These three sands rest unconformably on a variety of basement rocks and, given the age constraints of the overlying Keweenawan basalts and underlying basement rocks, these sandstones are excellent candidates for a provenance study using detrital zircons. The Nopeming sandstone was collected west of Duluth, MN and the Puckwunge sandstone near Grand Portage in northeastern Minnesota (Ojakangas and Morey, 1982).

RESULTS

The Puckwunge sandstone is compositionally mature consisting of 89% quartz, and displays moderate textural maturity. Many of the quartz grains contained overgrowths and were undulatory monocrystalline grains in close contact. Zircon, hair-like rutile needles, minor amounts of apatite and titanite are also present in the sample.

Four radiometric age populations arise from the 87 concordant grains when the results are analyzed in 25 Ma bins and range from 1.8-2.0 Ga, 2.6-2.8 Ga, 3.0 Ga, and 3.2-2.4 Ga (Fig. 1). Subpopulations can be organized and are consistent with orogenic, thermal or some sort of tectonic event. Paleoflow data as gathered by Mattis (1972, unpublished) has only local significance and indicates the paleocurrent to the southeast with readings to the northwest and southwest.

The Nopeming is compositionally and texturally mature consisting of 81% quartz and well rounded grains with abraded overgrowths. There is a lot more space between the quartz grains with respect to the Puckwunge Formation. Zircon, hair-like rutile needles and minor amounts of pyroxene are also present in the sample. 127 zircon grains analyzed and 113 grains proved to be concordant.

The detrital zircons produced five populations ranging from 1.1 Ga, 1.7-2.0 Ga, 2.2-2.3 Ga, 2.4-2.8 Ga, and 3.0 Ga (Fig. 2). Groupings

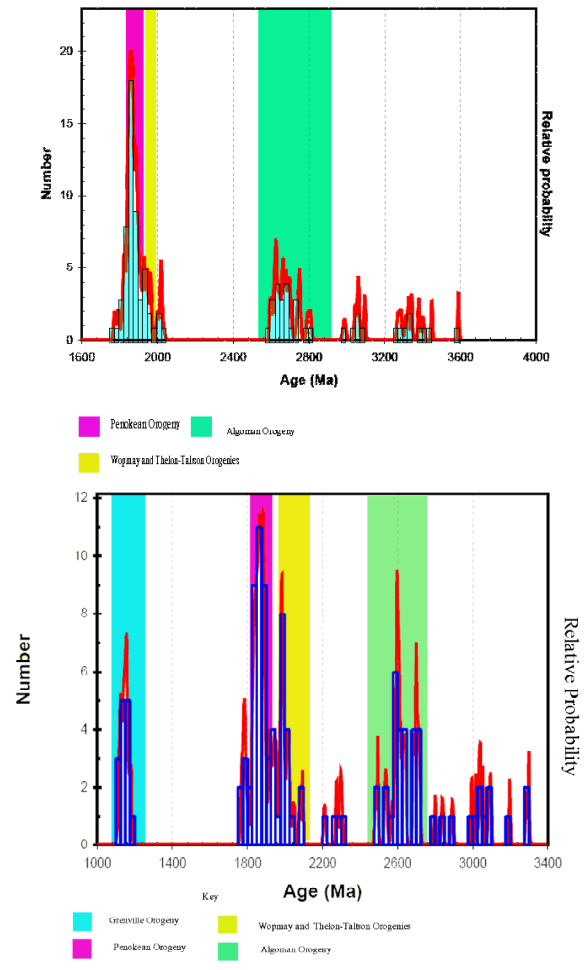

Figure 1. Frequency histograms with 25 Ma bins with related orogenic events; (a) The Puckwunge Formation, and (b) The Nopeming Formation.

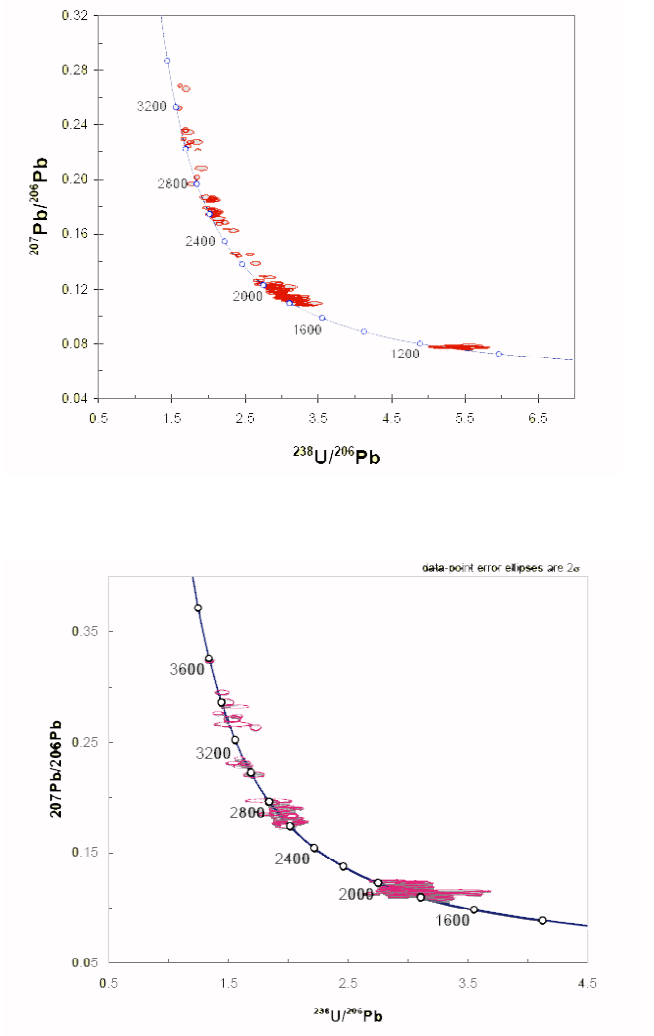

Figure 2. Concordia plots displaying data with a 2□ error envelope; (a) Data for the Nopeming Formation, and (b) data for the Puckwunge Formation.

of subpopulations within the five larger populations are consistent with tectonic or thermal events. Paleoflow indicators yield a strong paleocurrent to the northwest with a few reading to the northeast and the southwest, but this data has only local significance due to the lack of good exposures.

DISCUSSION

The provenance of many detrital zircons in the samples can be discerned by comparison with known ages of basement rock in the western portion of the Canadian Shield, local gneissic terrains, granitic intrusions, and plutonic, volcanic and basement rock of the Superior Craton. Intensive geochronologic studies of basement rock in central to west-central Canada, various parts of Michigan and Wisconsin, and the Minnesota have been utilized to aid in this comparison. The detrital ages are the ages of the source rock from which the sandstone originated, but due to the well roundedness of the grains, most have probably been recycled through several sedimentary units before reaching the final site of deposition in the base of the Keweenawan rift.

Puckwunge Formation

Most of the detrital ages can be associated with previous U-Pb geochronology work done on local granites, gneisses, magmatism, metamorphic events and rocks associated with tectonic events. The first subpopulaton extended from 1870-1814 Ma matching the recently dated igneous and metamorphic rocks associated with the Penokean Orogeny (Holm et al, 2005). Zircons display internal morphologies that are indicative of igneous and metamorphic origins such as zoning, showing metamorphic recrystallization, metamorphic banding and oscillatory rims showing incorporation of original zircons into younger magmas. Syn and post-tectonic granites and rhyolite volcanism occurring 1869, 1812, and 1770-1760 Ma also could be potential sources for zircon detritus.

The second grouping of zircons within the first population (1.8-2/0 Ga) spans 1.97-1.84 Ga. Magmatic and metamorphic rocks of the western Canadian Shield associated with the Wopmay Orogeny comply with the ages of found in the Puckwunge Formation such as the felsic Hepburn Intrusives (1.9-1.84 Ga) and rocks of the Hottah Terrain in the Western Canadian Shield (St-Onge and King, 1987). Internal zircon morphology and a southerly-southeasterly paleoflow direction support this interpretation. The rocks of the Theton-Taltson Orogeny of western Canada (2.0-1.9 Ga) are potential sources that is supported by paleocurrent data (S-SE) and internal zircon morphology. Attributing the Wopmay and Theton-Taltson orogenic events as major contributors to the Puckwunge Fm. is a little more difficult due to the distal nature of the source regions.

The first grouping of the second population (2.6-2.8 Ga) spans from 2594 ± 4 Ma to 2703 ±7 Ma. Ages of the granite-greenstone and older granitic rocks (gneissic) of the Superior Province are of suitable age. The region experienced a relatively short lived period of intense magmatism occurring from 2770-2660 Ma (Corfu and Davis, 1992). Plutons in the Superior craton have precise age matches with some of the detrital zircons in the sample (Zaleski et al, 1999). Another region is the magmatic and high-grade metamorphic rocks associated with the Algoman Orogeny (2.7-2.5 Ga). Felsic tuff, diorite, and felsic pyroclastic rock from the southeastern part of the Favourable Lake greenstone belt I the Sachigo Province yield U-Pb ages that match the ages of rocks in the second subpopulation. All of the formations fit the constraints of the southerly-southeasterly paleocurrent direction (Corfu, and Ayres, 1991). The third population (3.0 Ga) of ages match the known U-Pb ages of gneisses and intrusives of the Archean Marshfield Terrain (Van Wyck, and Norman, 2004). In the Superior Province in Ontario, there were periods of sporadic magmatism from 3200-2800 Ma (Corfu and Davis, 1992). Three of the U-Pb ages yielded relatively similar ages that can be ascribed to a known metamorphic event occurring from 3350-3300 Ma in the Minnesota River Valley (Bickford et al, 2006).

Nopeming Formation

The detrital U-Pb zircon ages obtained from the Nopeming Formation are consistent with tectonic events and their associated magmatic and high-grade metamorphic rocks that are largely of a relatively proximal area. The first major population (1.1 Ga) contains a group of dates that are consistent with rocks from the Grenville Province.

A group of ages in the second population (1.7-2.0 Ga) have most likely been derived from the Penokean Orogenic Belt and post-tectonic granite emplacement and rhyolite volcanism. Detrital ages that are post-Penokean within the population match the ages of magmatic and high-grade gneisses associated with the Wopmay Orogeny (1.97-1.84 Ga) and the

Thelon-Taltson Orogeny (St-Onge and King, 1987). The source regions are consistent with paleocurrent direction (S-SE) of the Nopeming sands.

The first grouping in the fourth population (2.4-2.8 Ga) yield ages that match the ages of rocks associated with the Algoman Orogeny (2.7-2.5 Ga). A few grains could have been derived from the Montevideo or Morton Gneisses growth of rims on older zircons, 2619 Ma (Bickford et al, 2006), granites and monzodiorties of the Superior Province (Zaleski et al, 1999), and rocks of the Slave and western Churchill Provinces of Western Canada (St-Onge and King, 1987). All of these regions are consistent with the regional paleoflow (S-SE).

The last population (3.0 Ga) contains zircons that are most likely derived from either the Superior gneissic terrains (3.6-3.0 Ga) or from the Marshfield Terrain (3.2-2.7 Ga; Johnson and Winter, 1999). This interpretation is consistent with paleoflow data (S-SE) and the internal morphologies of the grains. 3080 Ma there was growth of zircon rims in the Montevideo Gneiss that is consistent with some of the U-Pb ages obtained (Bickford et al, 2006).

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