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Zircon U-Pb, Hf and O isotope constraints on growth versus reworking of continental crust in the subsurface Grenville orogen, Ohio, USA

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ABSTRACT

Combined U-Pb, O and Hf isotope data in zircon allows discrimination between juvenile and reworked crust, and is therefore a useful tool for understanding formation and evolution of the continental crust. The crustal evolution of basement rocks in central North America (Laurentia) is poorly constrained, as it is almost entirely overlain by Palaeozoic cover. In order to improve our understanding of the evolution of this region we present U-Pb, O and Hf isotope data from zircon in drill-core samples from the subsurface basement of Ohio. The Hf isotope data suggests juvenile crust formation at ~1650 Ma followed by continued reworking of a single reservoir. This 1650 Ma reservoir was tapped at ~1450 Ma during the formation of the Granite-Rhyolite Province and subsequently reworked again during the Grenvillian orogeny. The ~1650 Ma crust formation model age for the suite of samples along with the presence of ~1650 Ma magmatic rocks suggests an eastward extension of the Mazatzal Province (or Mazatzal-like crust) and makes it a possible protolith to the subsurface basement of Ohio and surrounding Mesoproterozoic (i.e. Grenville-age) rocks. The eastward extension of this ~1650 Ma crustal reservoir into Ohio requires a revision of the crustal boundary defined by Nd isotopic data to be located further east, now overlapping with the Grenville front magnetic lineament in Ohio. In fact, the easternmost sample in this study is derived from a more depleted reservoir. This limits the extent of >1.5 Ga basement in subsurface Ohio and constrains the location of the crustal boundary. Further, syn-orogenic magmatism at ~1050 Ma suggests a potential extrapolation of the Interior Magmatic Belt into Ohio. Oxygen isotopic data in zircon suggests that during Grenvillian metamorphism, zircon recrystallisation occurred in the presence of heavy $\delta^{18}O$ fluids resulting in zircon with elevated $\delta^{18}O$ values.

1. Introduction

The Precambrian covers nearly 90% of Earth's history, yet only 6% of the Earth's surface outcrops are Precambrian basement rocks (Goodwin, 1996). This makes geological interpretation and modelling of the Precambrian evolution difficult and hampers our understanding of the large-scale crustal evolution of continents. For example, the Grenville Province in North America is one of the most studied Precambrian orogens on Earth. It is, however, poorly known in its entirety since it only crops out in limited areas south of Canada; the Adirondack Mountains (Daly & McLelland, 1991), the Llano Uplift (Mosher, 1998), the Franklin and Van Horn Mountains (Bickford et al., 2000) and the Sierra del Cuervo (Fig. 1, Rivers et al., 2012). Inliers of Grenvillian lithotectonic units also occur in the southern and central Appalachian orogen (Sinha et al., 1996; Hatcher et al., 2004). Current knowledge about the orogen is largely based on data from the Canadian Shield and our understanding of the vast unexposed subsurface Grenville Province is based on geophysical surveys and few basement penetrating deep drill cores (e.g. Rivers et al., 2012). Recent work on the evolution of rocks affected by Grenvillian orogenesis in the mid-continent have focused on zircon U-Pb and Sm-Nd analyses on the few available exposed outcrops (i.e. Daly & McLelland, 1991; McLelland et al., 1993; Van Schmus et al., 1996; Rohs & Van Schmus, 2007; Fisher et al., 2010; Fig. 1).

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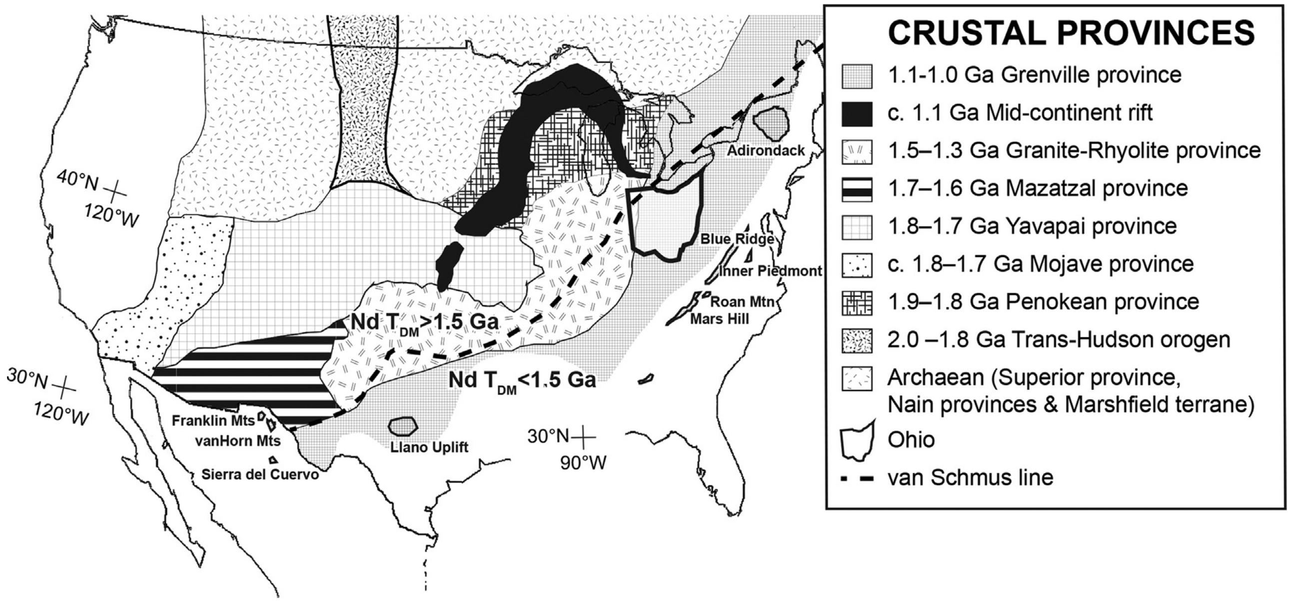

Fig. 1. Crustal Provinces of the Mid-Continent showing the crustal distribution today, re-drawn after Goodge and Vervoort (2006). The dashed black "Van Schmus line" divides the continent between rocks with Sm-Nd t_{DM} ages >1.5 Ga and t_{DM} ages <1.5 Ga (Van Schmus et al., 1996).

The term Grenville is commonly used for both the Grenville Orogenic Province in North America and for a time-period connected to a global event of coeval orogenesis during which Rodinia was assembled (Cawood et al., 2007). Here, we follow the nomenclature of Rivers (2008), and the term Grenville only refers to the Orogenic Province. The Grenville Province in North America is mainly exposed in eastern Canada from the Labradorian coast, southwest to the Great Lakes where it is covered by Phanerozoic rocks in the east central U.S. (Fig. 1).

To assess the extent and crustal characteristics of Grenvillian rocks in the subsurface of the central US, we present new *in situ* zircon U-Pb, Lu-Hf and O isotope data for six deep drill core samples that were selected due to their proximity to the proposed western extent of the Grenvillian orogen (i.e. the Grenville front magnetic lineament), in Ohio, USA. In order to understand the evolution of the Grenville in North America it is necessary to establish the pre-Grenvillian crustal components of Laurentia. We explore the involvement of juvenile versus reworked Paleoproterozoic continental crust, and present a tentative model for the isotopic geochemical evolution of basement crust in Ohio, and its implications for the general evolution of the Grenville orogen.

2. Geological setting

The Grenville Province consists of a number of orogenic thrust stacks along the present-day eastern margin of North America and formed during the Mesoproterozoic in a continent–continent collisional orogenic system superimposed on an accretionary orogenic system (Tollo et al., 2004; Rivers et al., 2012). Worldwide, Grenvillian-age Orogenic Provinces are found on a number of continents including Amazonia, Baltica, Australia and Antarctica and are all related to the assembly of Rodinia (e.g., Li et al., 2008). Recent work has suggested that the southern and central portion of Grenville in eastern Laurentia was accreted when the proto-North-American plate collided with another continent at the Laurentian margin (e.g., Loewy et al., 2003; Fisher et al., 2010). Key elements of pre-Grenvillian basement are summarised below (Fig. 1).

2.1. Penokean Province (1.9 to 1.8 Ga)

During middle Palaeoproterozoic, igneous and metasedimentary rocks formed the Penokean Province through oceanic arcs (Pembine-Wausau terrane), microcontinent accretion (Marshfield terrane), and subsequent deformation of both the associated Archaean basement and Palaeoproterozoic supracrustal rocks of the adjacent Superior craton. The Penokean Province extends from central Minnesota eastward to Ontario, Canada where it pinches out at the Grenville Front in Ontario (Davidson, 1995; Holm, 1999). Whole-rock Nd model ages of the Penokean belt are quite uniform at about 2.1 Ga (Barovich et al., 1989; Holm et al., 2005) and Hf model ages of A-type granites intruding the Penokean Province range from 2.2 to 2.1 Ga (Goodge & Vervoort, 2006).

2.2. Ga Yavapai Province (1.8 to 1.7)

Juvenile crust assembly in volcanic arcs between 1.8 and 1.7 Ga were subsequently accreted along the southeastern margin of Laurentia forming the Yavapai Province, which currently extends from Arizona to the mid-continent (Karlstrom & Humphreys, 1998; Van Schmus et al., 2007; Whitmeyer & Karlstrom, 2007). Whole-rock Nd model ages for the Yavapai Province range between 2.0 and 1.8 Ga (DePaolo, 1981). Numerous granitoids intruded the Penokean and Yavapai Provinces between 1.72 and 1.68 Ga.

2.3. Mazatzal Province (1.7 to 1.6 Ga)

The 1.7–1.6 Ga Mazatzal Province contains juvenile crust that formed in continental arcs and back-arcs (Shaw & Karlstrom, 1999) and whole-rock Nd isotopic data yield depleted mantle model ages of 1.8–1.7 Ga (Bennett & DePaolo, 1987; Wooden & DeWitt, 1991; Aleinikoff et al., 1993). The Mazatzal Province is adjacent to the Yavapai Province and extends from the southwestern U.S.A. through the mid-continent to the related Labradorian orogen in Canada (Whitmeyer & Karlstrom, 2007).

2.4. Granite-Rhyolite Province (1.5 to 1.3 Ga)

During early to middle Mezoproterozoic era (ca. 1.55–1.35 Ga), the Granite-Rhyolite Province was formed through anatectic melting and addition of juvenile melts to the southern margin of Laurentia (Van Schmus et al., 1996). Van Schmus et al. (1996) outlined a crustal boundary across the mid-continent extending from Mexico to Ontario. It separates Nd-t_{DM} >1.5 Ga crust from Nd-t_{DM}