Garnet Pyroxenite and Granulite Xenoliths from Northeastern Alberta: Evidence of ~1.5 Ga Lower Crust and Mantle in Western Laurentia

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Summary

Xenoliths from the Kendu ultramafic body in the Birch Mountains kimberlite field of northeastern Alberta present an unprecedented opportunity to document the lower crust and mantle beneath the Taltson magmatic zone, and in this region of western Laurentia. We show that what is at depth, is not the same as what is at surface, and elucidate questions such as when and where these xenoliths formed, and their relationship to the evolution of western Laurentia. Representative garnet pyroxenite, mafic granulite and granulite xenoliths have temperature regimes of between 730º and 1130º C with pressure estimates of 27-32 kbar, 19 kbar and 14 kbar, respectively. These P-T conditions are significantly different from known uppermost crustal studies of the Taltson magmatic zone, which has ages of 1.99-1.93 Ga with P-T estimates of between ca. 5-7 kbar and 850°-1045°C (e.g., Berman and Bostock, 1997; Grover et al., 1997). An important result of this work is the discovery of Mesoproterozoic ~1.5 Ga lower crust/mantle (>45 km) rocks that are significantly younger than the regions uppermost crustal rocks and tectonic assembly. The age discrepancy has significant implications for the evolution of western Laurentia and reveals an intriguing chronological link with widespread Mesoproterozoic intracratonic anorogenic magmatism that was prominent throughout the continental United States at ca. 1450-1475 Ma.

Introduction

The crystalline basement of northern Alberta represents the westernmost part of the North American craton, or Laurentia. Direct study of basement and of exhumed upper mantle and lower crustal rocks in this region is not feasible because these rocks are covered by a westerly thickening wedge of carbonate, evaporite and clastic sedimentary sequences of the Western Canadian Sedimentary Basin. The 1990's discovery of kimberlitic rocks (i.e., kimberlite and non-archetypal kimberlite ultrabasic rocks) in northern Alberta provides a significant new means to access crustal to mantle environments as the deep-forming ultramafic magma ubiquitously sampled and transported fragments (or xenoliths) of these materials to the Earth's surface.

A suite of xenoliths from the Kendu ultramafic body, which is located in the Birch Mountains kimberlite field of northeastern Alberta (Fig 1), was collected for mineralogical, geochemical and multi-isotope studies. The subsequent data represent a first-time view of the lower crust to mantle in this part of Laurentia and below the southern continuation of the 2,500 km long 2.0-1.9 Ga Taltson-Thelon orogenic belt, which in Alberta is known as the Taltson magmatic zone.

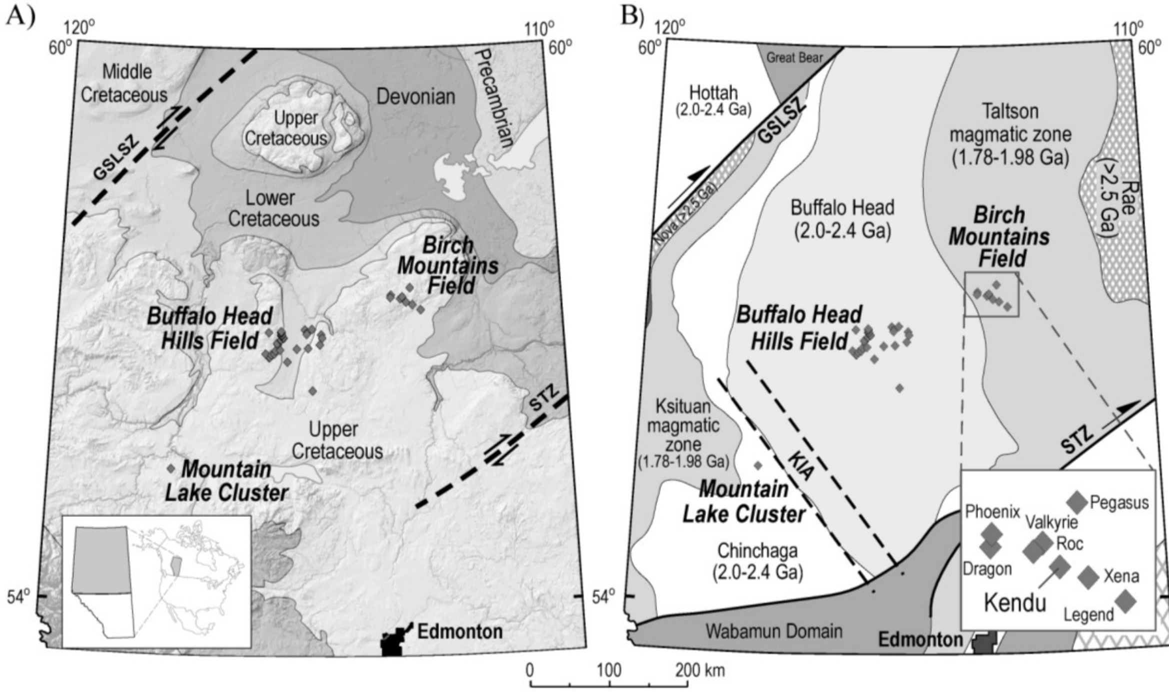

Fig. 1 Geological setting of northern Alberta with the location of ultrabasic to kimberlite occurrences in the Mountain Lake, Buffalo Head Hills and Birch Mountains fields. A) Bedrock geology from Hamilton et al. (1999), and B) inferred basement tectonic domains from Ross et al. (1994); inset map in B) shows the location of the Kendu kimberlite in the Birch Mountains field.

Xenolith Classification and Characteristics

Twenty-three xenoliths from the Kendu body were subdivided into three groups: garnet pyroxenite, mafic granulite, and granulite. The mainly bimineralic, coarse-grained garnet pyroxenite has rounded to subhedral garnet set in an anhedral to interstitial matrix of clinopyroxene with minor (5-8%) orthopyroxene. Relative to this dataset, high Mg# garnet (68-70), diopside (90-92) and whole rock (68-70), and mantle-type $\delta^{18}O$ diopside (4.7‰) and garnet (5.6‰), characterize the garnet pyroxenite. Petrographically, the mafic granulite has 120º triple junctions and coesite (quartz)-like radial expansion fractures in garnet. The mafic granulite comprises grossular-rich garnet, sodic plagioclase and has a whole rock chondrite-normalized REE pattern with a distinctly positive Eu/Eu* (1.8 to 4.7) commonly suggestive of a plagioclase-rich protolith. The scattered whole rock chondrite-normalized LREE profile and garnet REE with positive Eu/Eu*, coupled with $\delta^{18}O$ (5.9‰), high whole rock epsilon Nd (e.g., +40 and +49.2) and garnet $^{143}Nd/^{144}Nd$ ratios that mimic whole rock (e.g., 0.51516), attest to the uniqueness of the mafic granulite. The granulite has moderately high $\delta^{18}O$ (6.8‰ and 7.5‰) and negative epsilon Nd (-6.6 to -15.1), the latter of which is similar to those epsilon Nd values reported by Suman et al. (2000) for the surficial expression of the Taltson magmatic zone (-3.1 to -17.9; average -6.4; n=48).

Geochronology

A four-point Sm-Nd isochron age of 1477±10 Ma (MSWD of 0.84) has been obtained for the granulite using whole rock (x2), clinopyroxene and garnet fractions. In addition, there is general agreement between this Sm-Nd age and a three-point Lu-Hf age of 1602±150 Ma (whole rock, clinopyroxene and garnet fractions) to support the Mesoproterozoic granulite age in two isotopic systems. Trace-element data and chondrite-normalized REE-patterns recorded by the granulite garnet, suggest that this xenolith suite is the most strongly re-equilibrated in this study. Hence, the 1477±10 Ma Sm-Nd isochron is the most precise age determination for these data.

Errorchrons combining the granulite Lu-Hf and Sm-Nd data with those from garnet pyroxenite and mafic granulite xenoliths yielded ages that are within error to the ~1477 Ma granulite isochron age. This lends additional support to a Mesoproterozoic event, and further implies that mantle in this region may have also formed, or was influenced, during the Mesoproterozoic.

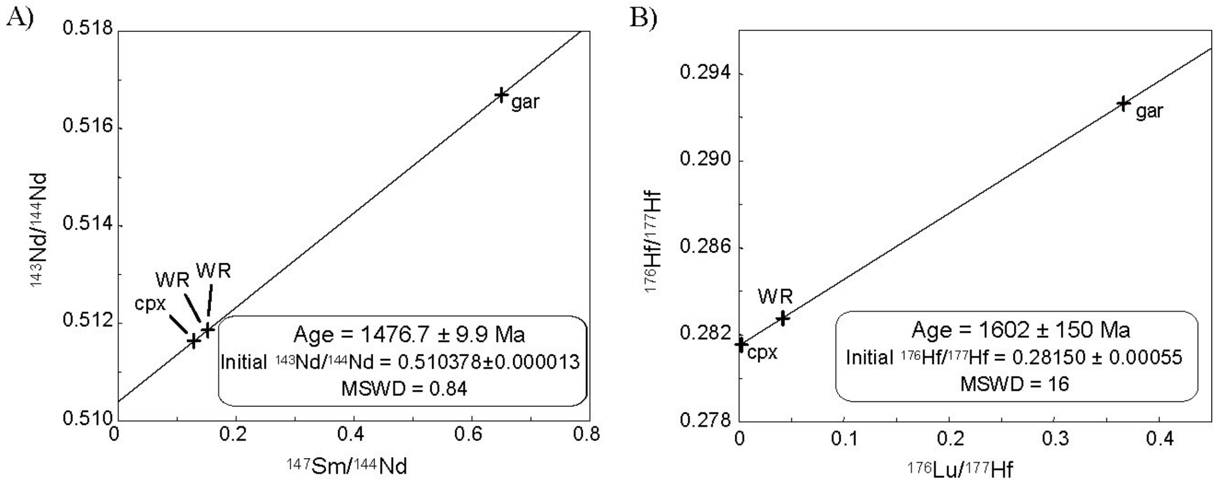

Fig. 2. Sm-Nd and Lu-Hf isotopic compositions of granulite xenolith X-10 from the Kendu body. Abbreviations: garnet (gar), clinopyroxene (cpx) and whole rock (WR).

Inferred Pressure-Temperature

The garnet pyroxenite xenoliths in this study have ultrahigh temperatures of about 1130º C and near ultrahigh to ultrahigh pressures of 27-32 kbar consistent with a depth of approximately 89-106 km (assuming a pressure-depth conversion factor of 3.3 km/kbar). The mafic granulite and granulite xenoliths reported in this study have similar to slightly lower T regimes (730º-825º C) to those reported for the Taltson magmatic zone, but with significantly higher pressure estimates of 19 kbar and 14 kbar (versus 5-7 kbar for the Taltson magmatic zone), consistent with depths of approximately 63 km and 46 km, respectively.

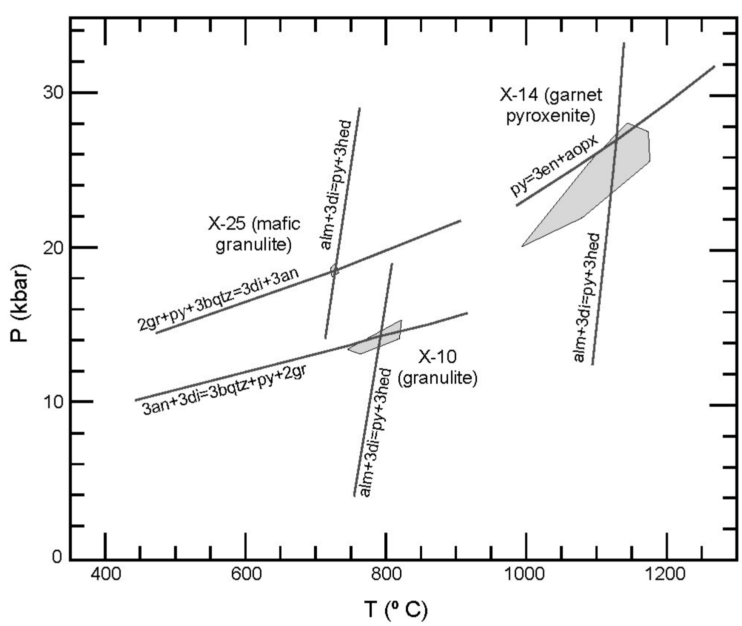

Fig. 3. Estimated pressure-temperature conditions using TWQ thermobarometry (Berman 2007) for garnet pyroxenite (xenolith sample X-14), mafic granulite (X-25) and granulite (X-10). The polygons represent the range of P-T values calculated from the extreme range of compositions analyzed in respective xenoliths. The average P-T for each xenolith is shown by the intersection of the independent equilibria used in each calculation. Abbreviations: anorthite (an), almandine (alm), aluminum-orthopyroxene (aopx), diopside (di), enstatite (en), grossular garnet (gr), hedenbergite (hed), b-quartz (bqtz), and pyrope garnet (py).

Discussion

There are no known analogous 1.5 Ga tectonothermal events in northern Alberta, or in the neighbouring regions. At continental scale, the amalgamation of Laurentia was followed by widespread Mesoproterozoic intracratonic anorogenic (A-type) magmatism that was prominent at ca. 1450-1475 Ma (e.g., Goodge and Vervoort, 2006). A-type ~1.5 Ga granites were emplaced into 200-300 Ma older heterogeneous Proterozoic crust from California to Wyoming to Wisconsin and represent one of the largest genetically connected magmatic provinces on Earth. Internal Sm-Nd and Lu-Hf granulite isochron ages of 1477±10 Ma and 1602±150 Ma with initial $^{176}Hf/^{177}Hf$ ratios of 0.281567-0.292628 obtained in this study leave a speculative link between intracratonic A-type magmatism and the lower crust/mantle beneath the Taltson magmatic zone.

Major tectonism related to continental growth in this part of western Laurentia ceased sometime between 1.9-1.7 Ga. Thus, a significant result of this work is the discovery of upper mantle to lower crustal rocks that are ~220 Ma younger than the youngest tectonometamorphic event in the region, and ~520 Ma younger than the uppermost Taltson magmatic zone crust. It is possible that the western margin of Laurentia be modeled by terranes that underthrust one another on a large scale in which case, at >45 km depth beneath the Taltson magmatic zone is an under-thrusted terrane of another age/affinity that is not represented at the surface. A problem with this model is that there is a significant time lapse between known orogenesis and the ~1.5 Ga granulite unveiled by this study.

Alternatively, if the Taltson magmatic zone is intracontinental (e.g., Chacko et al., 2000), then it is possible that some of the rock types documented in this study are the result of restite crust-mantle reaction at the expense of a thickening crust and underplating; a process that could explain the products of different temporal events, including the younger ~1.5 Ga event dated in the lower crust/mantle by this study.

Acknowledgements

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