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Reconstructing deep crustal dynamics in a large, hot orogen: Application of integrated zircon petrochronology and petrological modeling to the Canadian Grenville Province

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The timing and conditions of high pressure (HP) metamorphism, crustal anatexis, and shear zone formation are of primary importance in understanding lithosphere-scale dynamics of collisional orogens. Within the western Grenville Province, Ontario, Canada, a number of structural and metamorphic relationships are preserved that represent specific orogenic stages or processes. Lower allochthonous domains contain variably retrogressed mafic complexes that typically retain vestages of earlier HP metamorphic assemblages (e.g. garnet porphyroblasts, kyanite, and rutile) within a matrix dominated by incomplete decompression reactions (e.g. pseudomorphous diopside + sodic plagioclase intergrowths after omphacite and concentric coronas of aluminous minerals surrounding kyanite). Zircon from these samples yield U-Pb ages between 1085-1097 Ma, and exhibit REE characteristics consistent with crystallization in an eclogite-facies (garnet-rich, plagioclase-poor) mineral assemblage. REE partitioning between zircon and garnet suggests zircon growth coincided with the latter stages of garnet growth. Titanium concentrations in zircon constrain crystallization temperatures between ∼678-736 °C, whereas Zr concentration in rutile yield crystallization temperatures of ∼705-740 °C (for rutile inclusions in garnet) and 742-764 °C (for rutile in the matrix). Intersection of zircon and rutile crystallization temperature with the calculated stability field for the HP assemblage (Grt+Cpx+Ky+Rt+Zrn±Hbl) yields minimum pressures of ∼15 kbar. Thus, HP metamorphism apparently occurred at ca. 1090 Ma across the orogen, at minimum depths of ∼53 km and T ∼700±50 °C, yielding a geothermal gradient of < 15 °C/km. Widespread high-T, medium-P metamorphism and migmatization in the surrounding gneisses apparently began around 1090-1080 Ma, suggesting a rapidly evolving thermal field synchronous with the exhumation of HP rocks to mid-crustal depths. Zircon U-Pb ages and REE patterns from a large granulite-amphibolite nappe structurally overlying the eclogite-bearing domains indicate that the hot nappe was emplaced over the orogenic core along kilometer-scale, pegmatite-rich, amphibolite-facies shear zones by ca. 1100 Ma. Thus, petrochronological data constrain a sequence of nappe emplacement, HP metamorphism, and migmatization evolving over ∼15-20 Myrs, apparently marking a transition in the deep crustal dynamics from a predominantly thickening phase to a thermally weakened lateral flow phase. Ongoing diffusion modeling of chemical gradients in garnet crystals, reaction coronas, and symplectites should yield tighter constraints on the duration of HT residence and cooling/exhumation rates.