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SUPPLEMENT 1: METHODS

Whole Rock Compositions

Samples for whole rock analysis were prepared by removing weathered fractions of the sample and then pulverizing representative splits with a C-steel ring and puck mill. Each of these powders were weighed and then dried at 1,000°C in a high temperature oven. After drying, samples were reweighed to obtain loss on ignition values. Lithium borate flux was added to each sample at a ratio of 1:5. This mixture was melted in a platinum crucible and poured into a platinum mold to make glass discs. These discs were analyzed for major element concentrations on the PW2400 X-ray fluorescence spectrometer (XRF) at the University of Alabama. The United States Geological Survey andesite reference material AGV-1 was analyzed as an internal standard after every 10 unknowns. XRF methodology, precision, and accuracy at the University of Alabama is described in Stowell et al. (2010). Major element rock concentrations are reported in Table 2.

Mineral Textures and Compositions

Mineral assemblages and textures were identified by optical petrography on a polarizing microscope. Additional textural data and qualitative mineral compositions were obtained from

X-ray intensity maps of thin sections. Quantitative mineral compositions and mineral zoning were obtained from individual point analyses and lines of point analyses, respectively. X-ray maps and quantitative point analyses were obtained on the JEOL 8600 electron probe microanalyzer (EPMA) at the University of Alabama following methods described in Stowell et al. (2010). The X-ray maps were obtained using a Bruker energy dispersive spectrometer and Esprit software. Quantitative point analyses were obtained using wavelength dispersive spectrometers, CitZAF correction techniques (Armstrong, 1984), and Probe for EPMA software (www.probe-software.com). Major element data for garnet and other phases were first qualitatively assessed with K_α X-ray maps and then quantified as appropriate with point analyses and line scans. Inclusion and nonstoichiometric analyses were filtered out of the quantitative data. Additional information about EPMA methods and analytical precision at the University of Alabama can be found in Stowell et al. (2010).

Garnet and zircon in granulite were analyzed for REE and other selected trace elements in order to evaluate the Sm and Nd concentrations and zoning in garnet obtained by isotope dilution on the VG Sector 54 Thermal Ionization Mass Spectrometer (TIMS), the igneous versus metamorphic origin of both minerals, and the equilibration of these minerals with other phases during growth. Garnet trace element compositions were obtained by laser ablation inductively coupled plasma mass spectrometer (LA-ICP-MS) at the U.S. Geological Survey Central Mineral and Environmental Resources Science Center Lakewood, CO. A 193 nm Excimer LA system coupled to a quadrupole ICP-MS was used to ablate samples. Instrument operating conditions are described in Stowell et al. (2010). Nine hundred laser ablation analyses were collected in a grid of ca. 150 μm spots from rim to rim (1.1 cm) across garnet grain number 4 in sample 12NZ04b. Analyses included all major elements and numerous trace elements, including Ti, Y, Zr, La, Ce,

Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu. Each analysis was evaluated for the presence of inclusions using characteristic elemental concentrations (i.e. P for apatite) and only the clean garnet portion of each analysis was processed and included in the data.

Select trace element concentrations in zircon were obtained on the sensitive high resolution ion microprobe with reverse geometry (SHRIMP-RG) in the Stanford-USGS Micro Analysis Center (SUMAC). Each spot that was analyzed for U-Pb isotope geochronology was also analyzed for La, Ce, Nd, Sm, Eu, Gd, Dy, Er, and Yb. Analyses were obtained using an O_2^- ion beam with a 3–6 nA primary beam current. U-Pb geochronology and trace element analyses (Y, REE) were conducted simultaneously using an average spot size of ~22–28 μm on the SHRIMP-RG (see Schwartz et al. 2016 for details). A Sri Lankan zircon megacryst CZ3 (Ireland and Williams, 2003) was used as the primary reference material. Reference materials were analyzed after every ten unknowns. Methods closely follow those discussed by Mazdab and Wooden (2006) and are detailed in Schwartz et al. (2014).

Zircon U-Pb Geochronology and Trace Element Compositions

Zircon was separated from crushed rock samples using a Wifley water table, heavy liquids, Frantz isodynamic magnetic separator at California State University Northridge, and hand picked to obtain ca. 50 zircon grains from each sample. Grains were mounted in epoxy, polished, then imaged using cathode-luminescence (CL) on a scanning electron microprobe (SEM) at the Stanford-USGS SHRIMP-RG laboratory. Zircon were characterized by their internal structures through SEM CL imagery (Fig 9) prior to analysis. In general, analytical spots were chosen from CL image brightness in order to target zones with the highest U concentrations. After isotopic

analysis, high resolution images were obtained for select grains using the Gatan MiniCL detector attached to the University of Alabama JEOL 8600 electron probe micro-analyzer.

Uranium-lead isotope ratios were obtained by SHRIMP-RG ion microprobe following methods outlined by Schwartz et al. (2017), Compston et al. (1984), and Williams (1998). Zircon standards were analyzed after every 3-4 unknown analyses. Zircon reference CZ3, was used for U concentration and zircon R33 was used as the U-Pb age standard. Raw data were reduced using SQUID (Ludwig, 2001) and ages were calculated with Isoplot 3.00 (Ludwig, 2003). Corrections for common Pb were made following methods of Tera and Wasserburg (1972) using measured $^{207}Pb/^{206}Pb$ and $^{238}U/^{206}Pb$ ratios and an age-appropriate Pb isotopic composition of Stacey and Kramers (1975). Age results that were greater than % discordant were discounted. The $^{206}Pb/^{238}U$ ages are reported in Table 3.

Garnet Geochronology

Sm-Nd ages utilize ^{147}Sm decay to ^{143}Nd and require construction of isochrons because no minerals exclusively incorporate the parent element during growth. Precise ages require isotope ratios for minerals and/or rock aliquots with significantly different Sm/Nd ratios. Unlike most common minerals garnet strongly fractionates Sm over Nd during growth due to ca. 2.0% difference in ionic radii (Shannon, 1976). Therefore, garnet combined with whole rock and or other minerals produces a large range of Sm/Nd and is generally favored for dating metamorphic rocks. However, mineral inclusions in garnet and diffusion of Sm and Nd at temperatures over 700°C may result in meaningless or reset ages, respectively. Although Sm and Nd may diffuse in garnet, similarity in the charge and ionic radii of these parent and daughter elements result in very similar diffusion rates (e.g., Carlson 2012; Bloch and Ganguly, 2015) and relatively simple

interpretation of the results. This study employs mechanical separation and chemical leaching techniques to minimize inclusion contaminants. Large garnet grains combined with trace element maps were employed to aid identification of diffusional resetting. Nonetheless, the possible effects of REE-bearing inclusions and diffusion of REE in garnet are considered further in the Discussion section.

Methods for garnet geochronology are modified from Stowell and others (2014). Samples were chosen in order to obtain >0.5 cm garnet crystals with a minimal number of inclusions and relatively homogeneous matrix mineralogy. This strategy provides the best opportunity to obtain garnet: free of REE rich inclusions that might effect the ages, least effected by late-stage re-equilibration by diffusion and recrystallization, and in equilibrium with the matrix minerals. Sample preparation included drilling out garnet with a drill press to separate garnet splits from whole grains. Whole or core/rim garnet pieces were crushed using a carbide steel mortar and pestle. Garnet fragments were first manually picked under a binocular microscope to remove mineral inclusions. Additional inclusions were removed by leaching with HF and $HClO_4$ acid (e.g., Gatewood et al., 2015). The leached garnet was dissolved in HF and HCl enclosed in Savillex© screw-top Perfluoroalkoxy vials. Rare earth element fractions were separated and concentrated from samples using disposable polyprep BioRad ion chromatography columns. Samarium and Nd splits were collected from the REE concentrates using methylactic acid (MLA) and custom-designed 23 cm silica glass columns. Samarium isotopes were measured as metal and Nd isotopes measured as oxide using a VG Sector 54 Thermal Ionization Mass Spectrometer (TIMS) at the University of North Carolina-Chapel Hill or the University of Alabama RadIs facility (http://radis.as.ua.edu). Neodymium isotope ratios were normalized to $^{146}Nd/^{144}Nd = 0.7219$ then used with Sm isotope values to compute final isotope ratios and

elemental concentrations by isotope dilution. The JNdi Nd standard was run as an oxide periodically during the data collection with $^{143}Nd/^{144}Nd = 0.512117 \pm 13$ ppm. Final Nd and Sm isotope ratios were plotted with ISOPLOT (Ludwig, 2003) to calculate isochron ages (Table 3).

Pressure-Temperature-Time Paths

Pressure and temperature estimates for metamorphism and pressure-temperature-time (PTt) paths for the Breaksea Sound area are from isochemical phase diagram sections (pseudosections) that were constructed in the 10-component system MnO– Na_2O– CaO– K_2O– FeO– MgO– Al_2O_3– SiO_2– H_2O– TiO_2 (MnNCKFMASHT) chemical system. All of the sections were constructed with THERIAK-DOMINO (deCapitani and Brown, 1987; de Capitani and Petrakakis, 2010), the Holland and Powell (1998) thermodynamic data set version 5.5 (November 2003), and whole rock compositions following the methods in Stowell et al. (2010, 2014). Solution models for solid phases are those used in Stowell et al. (2014). Mineral activity models, and program DOMINO were compiled by Doug Tinkham (Laurentian University). Water content for isochemical P-T phase diagram sections were chosen from T versus XH_2O diagram sections as the minimum H mole fraction required to produce the observed metamorphic peak mineral assemblage. Garnet granulite sample 12NZ04b was modeled from the whole rock composition because mineral zoning (including garnet) is insignificant. Eclogite sample 12NZ01a contains zoned garnet and the whole rock composition was adjusted to subtract out the garnet cores in order to calculate P-T phase diagram sections that model garnet rim equilibrium.