Report of Investigation

Boise State University Isotope Geology Laboratory

Prepared for: Paul Fix, Project Geologist, AngloGoldAshanti
Samples: AR-0036, AR-0037, AR-0038, AR-0040, AR-0041, FR-0010, KR-0004, RR-0080

An abundant population of relatively large, (approximately 100-300 micron in long dimension), elongate, prismatic zircon crystals was separated from a hand sample of each sample by conventional density and magnetic methods. The entire zircon separate was placed in a muffle furnace at 900°C for 60 hours in quartz beakers to anneal minor radiation damage; annealing enhances cathodoluminescence (CL) emission (Nasdala et al., 2002), promotes more reproducible interelement fractionation during laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) (Allen and Campbell, 2012), and prepares the crystals for subsequent chemical abrasion (Mattinson, 2005). No mounting or imaging was required as the majority of the zircon were metamict to the degree that CL response would be poor and laser data would produce discordant and imprecise data.

U-Pb geochronology methods for isotope dilution thermal ionization mass spectrometry follow those previously published by Davydov et al. (2010) and Schmitz and Davydov (2012). Zircon crystals were subjected to two different version of a modified chemical abrasion method outlined in Mattinson (2005). The first set of samples (AR-0036, AR-0037, AR-0038, AR-0040, AR-0041), 30-40 zircon crystals were chemically abraded in bulk in a single step with concentrated HF at 160°C for 12 hours. From this bulk leach, small fragments were selected for final dissolution. The second set of samples (FR-0010, KR-0004, RR-0080), single crystal fragments plucked from grain mounts were individually abraded in a single step with concentrated HF at 180°C for 12 hours. U-Pb dates and uncertainties for each analysis were calculated using the algorithms of Schmitz and Schoene (2007) and the U decay constants of Jaffey et al. (1971). Uncertainties are based upon non-systematic analytical errors, including counting statistics, instrumental fractionation, tracer subtraction, and blank subtraction. These error estimates should be considered when comparing our $^{206}Pb/^{238}U$ dates with those from other laboratories that used tracer solutions calibrated against the EARTHTIME gravimetric standards. When comparing our dates with those derived from other decay schemes (e.g., $^{40}Ar/^{39}Ar$, ^{187}Re-^{187}Os), the

uncertainties in tracer calibration (0.03%; Condon et al., 2015; McLean et al., 2015) and U decay constants (0.108%; Jaffey et al., 1971) should be added to the internal error in quadrature. Quoted errors for calculated weighted means are thus of the form ±X[Z], where X is solely analytical uncertainty and Z is the combined analytical and U decay constant uncertainties.

AR-0036: Thirty zircon crystals were selected for bulk CA-TIMS based morphology and the absence of inclusions. Bulk chemical abrasion in concentrated HF at 160° for 12 hours resulted in major dissolution of the zircon crystals, leaving only small fragments of crystals. Eight fragments were selected for final dissolution. Four of the eights analyses are concordant and equivalent, with a weighted mean $^{207}Pb/^{206}Pb$ date of 2680.05 ± 0.50[2.38] Ma (MSWD = 0.71), which is interpreted as dating the crystallization age for this granodiorite.

AR-0037: Thirty zircon crystals were selected for bulk CA-TIMS based morphology and the absence of inclusions. Bulk chemical abrasion in concentrated HF at 160° for 12 hours resulted in major dissolution of the zircon crystals, leaving only small fragments of crystals. Seven fragments were selected for final dissolution. Four of the seven analyses are concordant and equivalent, with a weighted mean $^{207}Pb/^{206}Pb$ date of 2674.01 ± 0.55[2.39] Ma (MSWD = 0.53), which is interpreted as dating the crystallization age for this leucogabbro.

AR-0038: Thirty zircon crystals were selected for bulk CA-TIMS based morphology and the absence of inclusions. Bulk chemical abrasion in concentrated HF at 160° for 12 hours resulted in major dissolution of the zircon crystals, leaving only small fragments of crystals. Eight fragments were selected for final dissolution. Five of the eight analyses are concordant and equivalent, with a weighted mean $^{207}Pb/^{206}Pb$ date of 2681.55 ± 0.46[2.37] Ma (MSWD = 0.51), which is interpreted as dating the crystallization age for this granodiorite.

AR-0040: Thirty zircon crystals were selected for bulk CA-TIMS based morphology and the absence of inclusions. Bulk chemical abrasion in concentrated HF at 160° for 12 hours resulted in major dissolution of the zircon crystals, leaving only small fragments of crystals. Seven fragments were selected for final dissolution. Six of the seven analyses are concordant and equivalent, with a weighted mean $^{207}Pb/^{206}Pb$ date of 2675.09 ± 0.42[2.36] Ma (MSWD = 0.40), which is interpreted as dating the crystallization age for this monzonite.

AR-0041: Thirty zircon crystals were selected for bulk CA-TIMS based morphology and the absence of inclusions. Bulk chemical abrasion in concentrated HF at 160° for 12 hours resulted in major dissolution of the zircon crystals, leaving only small fragments of crystals. Seven

fragments were selected for final dissolution. Four of the seven analyses are concordant and equivalent, with a weighted mean $^{207}Pb/^{206}Pb$ date of 2675.27 ± 0.57[2.39] Ma (MSWD = 0.44), which is interpreted as dating the crystallization age for this monzogranite.

FR-0010: Eight zircon crystals were selected for CA-TIMS based morphology and the absence of inclusions. Chemical abrasion in concentrated HF at 190° for 12 hours resulted in only moderate dissolution of the zircon crystals. Five of the eight analyses are concordant and equivalent, with a weighted mean $^{207}Pb/^{206}Pb$ date of 2693.34 ± 0.55[2.39] Ma (MSWD = 1.67), which is interpreted as dating the maximum depositional age for this metasandstone.

KR-0004: Eight zircon crystals were selected for CA-TIMS based morphology and the absence of inclusions. Chemical abrasion in concentrated HF at 190° for 12 hours resulted in only moderate dissolution of the zircon crystals. Six of the eight analyses are concordant and equivalent, with a weighted mean $^{207}Pb/^{206}Pb$ date of 2690.07 ± 0.43[2.36] Ma (MSWD = 1.03), which may be interpreted as dating the eruption and deposition of pyroclastic components of this volcanoclastic sample, or more conservatively a maximum depositional age of clastic sedimentation.

RR-0080: Seven zircon crystals were selected for CA-TIMS based morphology and the absence of inclusions. Chemical abrasion in concentrated HF at 190° for 12 hours resulted in only moderate dissolution of the zircon crystals. All seven analyses are concordant and equivalent, with a weighted mean $^{207}Pb/^{206}Pb$ date of 2717.66 ± 0.46[2.37] Ma (MSWD = 0.63), which may be interpreted as dating the eruption and deposition of pyroclastic components of this volcanoclastic sample, or more conservatively a maximum depositional age of clastic sedimentation.

Table

Sample Name	Rock Type	Rock Sample/Mineral Separate	Zircon?	Age (Ma)
AR-0007	Quartz Diorite	Rock sample	No zircon	
RR-0044	Intermediate volcanic	Rock sample	No zircon	
KR-0015	Igneous Breccia	Rock sample	No zircon	
RR-0034	Metabasalt	Rock sample	No zircon	
18DL-MH019	Felsic dike	Rock sample	No zircon	
RR-0001	Quartz Monzonite	Mineral separate	No zircon	
FR-0004	Metagreywacke	Mineral separate	No zircon	
AR-0037	Leucogabbro	Mineral separate	Yes, metamict	2674.01 ± 0.55 Ma
AR-0040	Monzonite	Rock sample	Yes, metamict	2675.09 ± 0.42 Ma
AR-0041	Monzogranite	Mineral separate	Yes, metamict	2675.27 ± 0.58 Ma
AR-0036	Granodiorite	Rock sample	Yes, metamict	2680.05 ± 0.50 Ma
AR-0038	Granodiorite	Rock sample	Yes, metamict	2681.55 ± 0.46 Ma
KR-0004	Volcaniclastic	Rock sample	Yes, mixed population	2690.07 ± 0.41 Ma
FR-0010	Metasandstone	Mineral separate	Yes, mixed population	2693.05 ± 0.64 Ma
RR-0080	Volcaniclastic	Rock sample	Yes, mixed population	2717.66 ± 0.47 Ma

References

Allen, C.M., Campbell, I.H., 2012. Identification and elimination of a matrix-induced systematic error in LA–ICP–MS $^{206}Pb/^{238}U$ dating of zircon: *Chemical Geology* 332-333, 157–165. doi:10.1016/j.chemgeo.2012.09.038

Condon, D.J., Schoene, B., McLean, N.M., Bowring, S.A., Parrish, R.R., 2015. Metrology and traceability of U-Pb isotope dilution geochronology (EARTHTIME Tracer Calibration Part I): *Geochimica et Cosmochimica Acta* 164, 464–480. doi:10.1016/j.gca.2015.05.026

Davydov, V. I., Crowley, J. L., Schmitz, M. D., and Poletaev, V. I., 2010, High-precision U-Pb zircon age calibration of the global Carboniferous time scale and Milankovitch-band cyclicity in the Donets Basin, eastern Ukraine: *Geochemistry, Geophysics, Geosystems*, 10.1029/2009GC002736.

Jaffey, A.H., Flynn, K.F., Glendenin, L.E., Bentley, W.C., and Essling, A.M., 1971, Precision measurements of half-lives and specific activities of ^{235}U and ^{238}U: *Physical Review C*, 4:1889-1906.

Mattinson, J.M., 2005, Zircon U-Pb chemical abrasion ("CA-TIMS") method: combined annealing and multi-step partial dissolution analysis for improved precision and accuracy of zircon ages: *Chemical Geology* 220:47-66.

McLean, N.M., Condon, D.J., Schoene, B., Bowring, S.A., 2015. Evaluating uncertainties in the calibration of isotopic reference materials and multi-element isotopic tracers (EARTHTIME Tracer Calibration Part II): *Geochimica et Cosmochimica Acta* 164, 481–501. doi:10.1016/j.gca.2015.02.040.

Nasdala, L., Lengauer, C.L., Hanchar, J.M., Kronz, A., Wirth, R., Blanc, P., Kennedy, A.K., Seydoux-Guillaume, A.M., 2002. Annealing radiation damage and the recovery of cathodoluminescence: *Chemical Geology* 191, 121–140.

Schmitz, M.D., Davydov, V.I., 2012, Quantitative radiometric and biostratigraphic calibration of the globalPennsylvanian – Early Permian time scale: *Geological Society of America Bulletin*, 124:549-577.

Schmitz, M.D., Schoene, B., 2007, Derivation of isotope ratios, errors and error correlations for U-Pb geochronology using ^{205}Pb-^{235}U-(^{233}U)-spiked isotope dilution thermal ionization mass spectrometric data: *Geochemistry, Geophysics, Geosystems* doi:10.1029/2006GC00149.

Stacey, J.S., Kramers, J.D., 1975. Approximation of terrestrial lead isotope evolution by a two-stage model. Earth Planet Sci. Lett. 26, 207-221.