Supplementary Information

Ultrafast Magmatic Buildup and Differentiation to Produce Continental Crust During Subduction

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**CA-TIMS Methods**

U-Pb dates were obtained by the chemical abrasion isotope dilution thermal ionization mass spectrometry (CA-TIMS) method from analyses composed of single zircon grains. Zircon grains were separated from rocks using standard techniques and mounted in epoxy and polished until the centers of the grains were exposed. Cathodoluminescence (CL) images were obtained with a scanning electron microscope at the University of Puget Sound. Zircon was removed from the epoxy mounts and subjected to a modified version of the chemical abrasion method\(^1\), reflecting analysis of single grains or fragments of grains. Grains or fragments of grains were selected for dating based on CL images.

Zircon was placed in a muffle furnace at 900°C for 60 hours in quartz beakers. Single grains or fragments were then transferred to 3 ml Teflon PFA beakers and loaded into 300 µl Teflon PFA microcapsules. Fifteen microcapsules were placed in a large-capacity Parr vessel, and the crystals partially dissolved in 120 µl of 29 M HF for 12 hours at 180°C. The contents of each microcapsule were returned to 3 ml Teflon PFA beakers, the HF removed and the residual grains or fragments immersed in 3.5 M HNO₃, ultrasonically cleaned for an hour, and fluxed on a hotplate at 80°C for an hour. The HNO₃ was removed and the grains or fragments were rinsed twice in ultrapure H₂O before being reloaded into the same 300 µl Teflon PFA microcapsules (rinsed and fluxed in 6 M HCl during sonication and washing of the grains) and spiked with the Boise State University mixed \(^{233}\text{U}-^{235}\text{U}-^{205}\text{Pb} \) tracer solution. These chemically abraded grains or fragments were dissolved in Parr vessels in 120 µl of 29 M HF with a trace of 3.5 M HNO₃ at 220°C for 48 hours, dried to fluorides, and then re-dissolved in 6 M HCl at
180°C overnight. U and Pb were separated from the zircon matrix using an HCl-based anion-exchange chromatographic procedure\textsuperscript{2}, eluted together and dried with 2 μl of 0.05 N H\textsubscript{3}PO\textsubscript{4}.

Pb and U were loaded on a single outgassed Re filament in 5 μl of a silica-gel/phosphoric acid mixture\textsuperscript{3}, and U and Pb isotopic measurements made on a GV Isoprobe-T multicollector thermal ionization mass spectrometer equipped with an ion-counting Daly detector. Pb isotopes were measured by peak-jumping all isotopes on the Daly detector for 100 to 160 cycles, and corrected for 0.18 ± 0.03%/a.m.u. (1 sigma error) mass fractionation. Transitory isobaric interferences due to high-molecular weight organics, particularly on \textsuperscript{204}Pb and \textsuperscript{207}Pb, disappeared within approximately 30 cycles, while ionization efficiency averaged 10\textsuperscript{4} cps/pg of each Pb isotope. Linearity (to ≥1.4 x 10\textsuperscript{6} cps) and the associated deadtime correction of the Daly detector were monitored by repeated analyses of NBS982, and have been constant since installation. Uranium was analyzed as UO\textsubscript{2}\textsuperscript{+} ions in static Faraday mode on 10\textsuperscript{11} ohm resistors for 200 to 250 cycles, and corrected for isobaric interference of \textsuperscript{233}U\textsuperscript{18}O\textsuperscript{16}O on \textsuperscript{235}U\textsuperscript{16}O\textsuperscript{16}O with an \textsuperscript{18}O/\textsuperscript{16}O of 0.00206. Ionization efficiency averaged 20 mV/ng of each U isotope. U mass fractionation was corrected using the known \textsuperscript{233}U/\textsuperscript{235}U ratio of the Boise State University tracer solution.

Five to 14 analyses were performed for each of six samples. Weighted mean \textsuperscript{206}Pb/\textsuperscript{238}U dates were calculated from equivalent dates (i.e., probability of fit >0.05) using Isoplot 3.0\textsuperscript{4} and are interpreted as being the igneous crystallization ages for the plutonic rocks or ages of metamorphism. Errors on the weighted mean dates are the internal errors based on analytical uncertainties only, including counting statistics, subtraction of tracer
solution, and blank and initial common Pb subtraction. They are given at the 2σ confidence interval. These errors should be considered when comparing our dates with \( ^{206}\text{Pb}/^{238}\text{U} \) dates from other laboratories that used the same Boise State University tracer solution or a tracer solution that was cross-calibrated using EARTHTIME gravimetric standards. When comparing our dates with those derived from other geochronological methods using the U-Pb decay scheme (e.g., laser ablation ICPMS), a systematic uncertainty in the tracer calibration should be added to the internal error in quadrature. When comparing our dates with those derived from other decay schemes (e.g., \( ^{40}\text{Ar}/^{39}\text{Ar} \), \( ^{187}\text{Re}-^{187}\text{Os} \)), systematic uncertainties in the tracer calibration and \( ^{238}\text{U} \) decay constant should be added to the internal error in quadrature. These errors are given as \( ^{206}\text{Pb}/^{238}\text{U} \) date ± x / y / z Ma, where x is the internal error, y includes the uncertainty in the tracer calibration, and z includes the uncertainties in the tracer calibration and \( ^{238}\text{U} \) decay constant. Errors on the dates from individual grains are also given at the 2σ confidence interval.

U-Pb dates and uncertainties were calculated using \( ^{235}\text{U}/^{205}\text{Pb} \) of 77.93 and \( ^{233}\text{U}/^{235}\text{U} \) of 1.007066 for the Boise State University tracer solution, and U decay constants. \( ^{206}\text{Pb}/^{238}\text{U} \) ratios and dates were corrected for initial \( ^{230}\text{Th} \) disequilibrium using a \( \text{Th}/\text{U}[\text{magma}] = 3.0 \), resulting in an increase in the \( ^{206}\text{Pb}/^{238}\text{U} \) dates of ~0.09 Ma. All common Pb in analyses was attributed to laboratory blank and subtracted based on the measured laboratory Pb isotopic composition and associated uncertainty. U blanks are difficult to precisely measure, but are estimated at 0.07 pg.

Seven aliquots of the EARTHTIME 100 Ma synthetic solution were measured during this experiment using the Boise State University tracer solution and the same mass
spectrometry methods described above. Each aliquot was 4-6 pg of radiogenic Pb, slightly smaller than the average analysis measured during the experiment. The weighted mean $^{206}\text{Pb}/^{238}\text{U}$ and $^{207}\text{Pb}/^{235}\text{U}$ dates are $100.08 \pm 0.03 / 0.10$ and $100.04 \pm 0.13 / 0.16$ Ma, respectively. These dates agree with the known dates determined by analysis of large aliquots measured with the EARTHTIME mixed $^{233}\text{U}-^{235}\text{U}-^{202}\text{Pb}-^{205}\text{Pb}$ tracer solution (D. Condon, unpublished data).

**U-Pb Geochronology Results**

**Sample VF01**

CL-dark and –bright cores with oscillatory and sector zoning are overgrown by thin CL-bright unzoned rims present on most grains. Cores are interpreted as having formed during igneous crystallization and rims during metamorphism. Rims were avoided during selection of grains for dating. Five dates from five grains are equivalent with a weighted mean of $471.68 \pm 0.15 / 0.48 / 0.69$ Ma (MSWD = 0.7, probability of fit = 0.62) that is the interpreted igneous crystallization age.

**Sample FA0920**

CL-dark and –bright cores with oscillatory and sector zoning are overgrown by thin CL-bright unzoned rims present on most grains. Cores are interpreted as having formed during igneous crystallization and rims during metamorphism. Rims were avoided during selection of grains for dating. Seven dates from fragments from four grains are equivalent with a weighted mean of $471.64 \pm 0.15 / 0.48 / 0.69$ Ma (MSWD = 2.1, probability of fit = 0.06) that is the interpreted igneous crystallization age.
Sample FA0914

CL-dark and –bright cores with oscillatory and sector zoning are overgrown by CL-bright unzoned and sector-zoned rims of variable thickness present on most grains. Cores are interpreted as having formed during igneous crystallization and rims during metamorphism. Seven dates from fragments from four grains composed of igneous zircon are equivalent with a weighted mean of $471.25 \pm 0.14 / 0.48 / 0.68$ Ma (MSWD = 1.4, probability of fit = 0.23) that is the interpreted igneous crystallization age. Three fragments from two grains composed of metamorphic zircon are equivalent with a weighted mean of $468.95 \pm 0.63 / 0.77 / 0.92$ Ma (MSWD = 1.5, probability of fit = 0.22) that is the interpreted metamorphic age.

Sample FA0910

CL-dark and –bright cores with oscillatory and sector zoning are overgrown by CL-bright unzoned and sector-zoned rims of variable thickness present on most grains. Cores are interpreted as having formed during igneous crystallization and rims during metamorphism. Seven dates from fragments from five grains composed of igneous zircon are equivalent with a weighted mean of $470.25 \pm 0.14 / 0.47 / 0.68$ Ma (MSWD = 1.3, probability of fit = 0.24) that is the interpreted igneous crystallization age. Four dates from fragments from three grains composed of metamorphic zircon are equivalent with a weighted mean of $469.81 \pm 0.77 / 0.89 / 1.02$ Ma (MSWD = 1.1, probability of fit = 0.37) that is the interpreted metamorphic age. A date of $469.26 \pm 0.44$ Ma is from a fragment that is interpreted as being a mixture of igneous and metamorphic zircon. A date of
465.26 ± 0.31 Ma is from grain that is interpreted as having suffered a moderate amount of Pb loss.

**Sample FA0907**

CL-dark and –bright cores with oscillatory and sector zoning are overgrown by thin CL-bright unzoned rims present on most grains. Cores are interpreted as having formed during igneous crystallization and rims during metamorphism. Rims were avoided during selection of grains for dating. The nine oldest dates from fragments from five grains are equivalent with a weighted mean of 469.14 ± 0.11 / 0.47 / 0.69 Ma (MSWD = 0.9) that is the interpreted igneous crystallization age. Five younger dates as young as 467.02 ± 0.32 Ma are from five grains are that are interpreted as containing metamorphic rims.

**Sample GVF12**

CL-dark and –bright oscillatory-zoned zircon is interpreted as having formed during igneous crystallization. Five grains yielded a weighted mean date of 467.38 ± 0.15 / 0.48 / 0.68 Ma (MSWD = 0.6) that is the interpreted igneous crystallization age. One other grain yielded a date of 475.45 ± 0.32 Ma that is interpreted as reflecting the presence of an inherited component.
Figure S1: Plot of $^{206}\text{Pb}/^{238}\text{U}$ dates from single grains or fragments analyzed by CA-TIMS. Plotted with Isoplot 3.0 (Ludwig, 2003). Error bars are at $2\sigma$. Weighted mean dates are shown and represented by the gray boxes behind the error bars. One date from FA0910 with a large error is not plotted.
Figure S2: CL images of zircon. See Table S1 for analytical details from labeled grains and fragments. Dashed lines show approximately where the grains were fragmented.
References


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(d) Measured ratio corrected for spike and fractionation only. Fractionation correction is 0.18 ± 0.03 (1 sigma) %/amu (atomic mass unit) for single-collector
(b) Model (b) FA0910
(g) Calculations based on the decay constants of Jafla et al. (1997) to 206Pb and 206Pb dates corrected for initial disequilibrium in 230Th/238U using Th/U [magma] = 3.
(f) Errors are 2 sigma, propagated using algorithms of Schmidt and Schnee (2007) and Crowley et al. (2007).