U-Pb Zircon Geochronology Results for the Angle, Donkey Flat, Farnsworth Peak, Fort Douglas, and Quincy Spring Quadrangles, Utah

by

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INTRODUCTION

This open-file report makes available raw analytical data from laboratory procedures completed to determine the age of rock samples collected during geologic investigations funded or partially supported by the Utah Geological Survey (UGS) and the U.S. Geological Survey National Cooperative Geologic Mapping Program (STATEMAP). The references listed in table 1 generally provide additional information such as sample location, geologic setting, and significance or interpretation of the samples in the context of the area where they were collected. The data were prepared by Paul B. O'Sullivan, Principal Manager with GeoSep Services, Moscow, Idaho, under contract to the UGS. These data are highly technical in nature and proper interpretation requires considerable training in the applicable geochronologic techniques.

The data can be accessed electronically as attachments to the PDF file of this report and are available at http://ugspub.nr.utah.gov/publications/open_file_reports/ofr-660/ofr-660.zip.

Table 1. *Sample numbers and locations.*

Sample #	7.5' quadrangle	Latitude (°N) WGS84	Longitude (°W) WGS84	Reference
T3	Farnsworth Peak	40.63223	112.14668	Clark and others (2016)
T46	Quincy Spring	40.58470	112.99034	Clark and others (2016)
RF07282014-1	Donkey Flat	40.581927	109.408058	Jensen and others (2016); Sprinkel and others (in prep.)
ZA_FtD_011	Fort Douglas	40.830703	111.836808	Anderson and McKean (in prep.)
		UTM84-12 E	**UTM84-12 N**	
A072514-1	Angle	417932	4222177	Biek and others (2015)

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Jensen, P.H., Sprinkel, D.A., Kowallis, B.J., and Brown, K.D., 2016, Geologic map of the Donkey Flat quadrangle, Uintah County, Utah: Utah Geological Survey Miscellaneous Publication 16-2DM, 8 p., 2 plates, scale 1:24,000.

Sprinkel, D.A., Rybczynski, D.J., Kowallis, B.J., Dehler, C.M., and Pederson, J.L., in preparation, Geologic map of the Dutch John 30′ x 60′ quadrangle, Daggett and Uintah Counties, Utah, Moffat County, Colorado, and Sweetwater County, Wyoming: Utah Geological Survey Map, GIS data, 3 plates, scale 1:62,500.

Zircon U-Pb Dating Methodology

Published Methods

Detailed descriptions of the methods followed by GSS to produce and process their ZrnUPb data have been presented in numerous peer-reviewed manuscripts. These include Bradley et al. (2009), Hults et al. (2013), and Moore et al. (2015).

Sample Preparation

Zircon grains were isolated and prepared for LA-ICP-MS analysis using standard procedures combined with specific customized procedures described by Donelick et al. (2005). These customized procedures were designed to maximize recovery of: 1) all possible grain sizes present within a sample by minimizing the potential loss of smaller grain sizes through the use of water-table devices, and 2) complete grains with as close to full terminations by minimizing grain breakage and/or fracturing inherent with the standard procedures typically used to separate individual grains from the original rock material. Use of these procedures results in a significantly greater range of recovered grain sizes, as well as a higher percentage of "complete" grains being retained during the mineral separation process (Fig. 1).
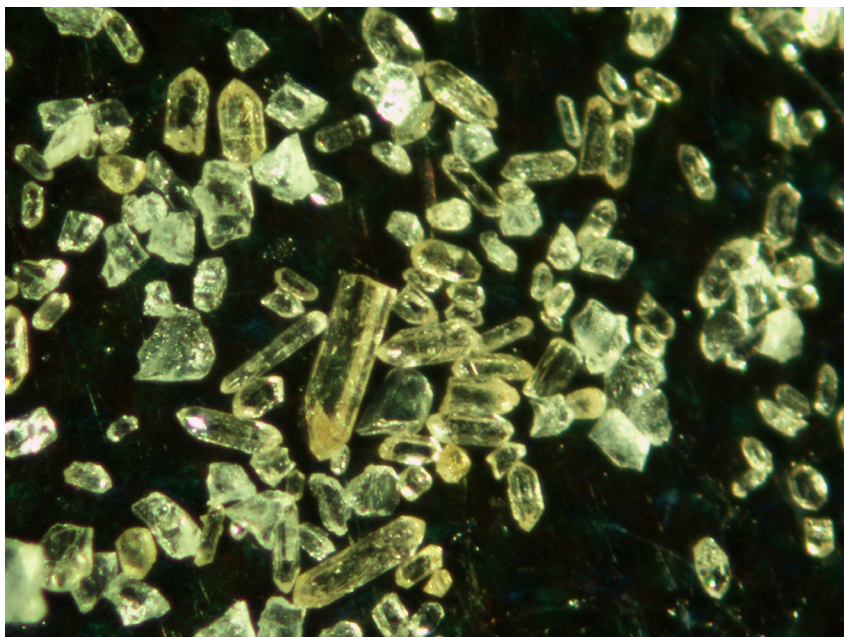
Fig. 1. Example zircon separate from GSS Project 025, showing a wide range in grain-shapes and grain-sizes after sample processing by GSS mineral separation procedures. Importantly, a significant number of tiny grains, as well as complete grains were recovered.

Whole rock samples were first run multiple (minimum = 3) times through a Chipmunk brand jaw crusher with the minimum jaw separation set to 2-3 mm. The crushed material was then sieved through 300 μm nylon mesh, and the <300 μm size fraction washed with tap water and allowed to dry at room temperature. Zircon grains were separated from other mineral species using a combination of lithium metatungstate (density ~2.9 g/cm^3), Frantz magnetic separator,

diiodomethane (density ~3.3 g/cm^3), and hand-panning separation procedures. Epoxy wafers (~1 cm x 1 cm) containing zircon grains for LA-ICP-MS were polished manually using 3.0 µm and 0.3 µm Al$_2$O$_3$ slurries to expose internal zircon grain surfaces. The polished zircon grain surfaces were washed in 5.5 M HNO$_3$ for 20 s at 21ºC in order to clean the grain surfaces prior to introduction into the laser system sample cell.

LA-ICP-MS Session Details

LA-ICP-MS data collection was performed at the Geoanalytical Laboratory, Washington State University, Pullman, Washington, U.S.A following conditions and parameters presented in Table 1. Individual zircon grains were targeted for data collection using a New Wave YP213 213 nm solid state laser ablation system using a 20 µm diameter laser spot size, 5 Hz laser firing rate, and ultra high purity He as the carrier gas. Isotopic analyses of the ablated zircon material were performed using a ThermoScientific Element2 magnetic sector mass spectrometer using high purity Ar as the plasma gas. The following masses (in amu) were monitored for 0.005 s each in pulse detection mode(Pb, Th, and U isotopes): 202, 204, 206, 207, 208, 232, 235, and 238.

Table 1. ICP-MS and laser ablations system operating conditions and data acquisition parameters

ICP-MS: operating conditions	
Instrument	Finnigan Element II Magnetic Sector ICP-MS
Forward power	1.25 kW
Reflected power	<5 W
Plasma gas	Ar
Coolant flow	15 l/min
Carrier flow	1.0 l/min (Ar) 0.8 l/min (He)
Auxiliary flow	1.0 l/min
ICP-MS: data acquisition parameters	
Dwell time	24 milliseconds per peak point
Points per peak	3
Mass window	5%
Scans	200
Data acquisition time	29.5 sec
Data acquisition mode	E scanning
Isotopes measured	^{43}Ca or ^{29}Si and ^{238}U
Laser ablation system: operating conditions	
Laser type	New Wave Neodymium: YAG
Wavelength	213 nm
Laser mode	Q switched
Laser output power	10 J/cm^2
Laser warm up time	6 sec
Shot repetition rate	5 Hz
Sampling scheme	spot (20 µm)

At time = 0.0 s, the mass spectrometer began monitoring signal intensities; at time = 6.0 s, the laser began ablating zircon material; at time = 30.0 s, the laser was turned off and the mass

spectrometer stopped monitoring signal intensities. A total of 200 data scans were collected for each zircon spot analyzed comprising: approximately 55 background scans; approximately 20 transitions scans between background and background+signal, approximately 125 background+signal scans. A scheme was developed to check whether mass 238 experienced a switch from pulse to analog mode during data collection and a correction procedure was employed to ensure the use of good quality intensity data for masses 235 and 238 when such a switch was observed.

UPb Data Analysis

Previous LA-ICP-MS studies of UPb zircon dating used the so-called intercept method, which assumes that isotopic ratio varies linearly with scan number due solely to linearly varying isotopic fractionation (Chang et al., 2006; Gerhels et al., 2008). The data modeling approach favored here was the modeling of background-corrected signal intensities for each isotope at each scan. Background intensity for each isotope was calculated using a fitted line (for decreasing background intensity) or using the arithmetic mean (for non-decreasing background intensity) at the global minimum of selected isotopes (^{206}Pb, ^{232}Th, and ^{238}U) for the spot. Background+signal intensity for each isotope at each scan was calculated using the median of fitted (2nd-order polynomial) intensity values for a moving window (7 scans wide here) that includes the scan. The precision of each background-corrected signal intensity value was calculated from the precision of background intensity value and the precision of the background+signal intensity value.

Zircon UPb age standards used during analysis are summarized in Table 2, including the 1099±0.6 Ma FC zircon (FC-1 of Paces and Miller, 1993) used here as the primary age standard. Isotopic data for FC were used to calculate Pb/U fractionation factors and their absolute errors for each FC data scan at each FC spot; these fractionation factors were smoothed session-wide for each data scan using the median of fitted (1st-order polynomial) fractionation factor values for a moving window that includes the current FC spot and scan.

Table 2. Zircon age standards.

Standard	Standard	U-Pb age (±2σ)	Reference
FC	Duluth complex	1099.0 ± 0.6 Ma	Paces and Miller, 1993
F5	Duluth complex	1099.0 ± 0.6 Ma (assumed equal to FC-1)	Paces and Miller, 1993
IF	Fish Canyon Tuff	28.201 ± 0.012 Ma	Lanphere et al., 2001; Kuiper et al., 2008
MD	Mount Dromedary	99.12 ± 0.14 Ma	Renne et al., 1998
T2	Temora2, Middledale gabbroic diorite	416.78 ± 0.33 Ma	Black et al., 2004
TR	Tardree Rhyolite	61.23 ± 0.11 Ma	Dave Chew, personal communication

Pb/U Fractionation Factor

Under the operating conditions of LA-ICP-MS sessions, fractionation factors are occasionally found to vary strongly with scan number, decreasing with increasing scan number (presumably

due to increasing ablation pit depth and the effect this has on fractionation; e.g., Paton et al., 2010). The zircon crystal lattice is widely known to accumulate α-radiation damage (e.g., Zhang et al., 2009 and references therein). It is assumed that increased α-damage in a zircon leads to a decrease in the hardness of the zircon; this in turn leads to a faster rate of laser penetration into the zircon during ablation leading to dependence of isotopic fractionation on the degree of zircon lattice radiation damage. Ages calculated for all zircon age standards, when those standards were treated as unknowns, were used to construct a fractionation factor correction curve (exponential form) in terms of accumulated radiation damage. The notion of matrix-matched zircon standard and zircon unknown has been proposed largely on the basis of trace element chemistry (e.g., Black et al., 2004). In this study, time and lattice damage, parameters invisible to instruments used to characterize trace element chemistry, were introduced and applied based on measured U and Th chemistries to effectively matrix-match standard and unknown zircons.

Common Pb Correction

Common Pb was subtracted out using the Stacey and Kramer (1975) common Pb model for Earth. Ages and common Pb ratio were determined iteratively using a pre-set, session-wide minimum common Pb age value (default for each session was the age of the oldest age standard which for both Ap and Zrn was 1099 Ma FC-1 and/or FC-5z).

Preferred Age

Uranium decay constants and the $^{238}U/^{235}U$ isotopic ratio reported in Steiger and Yäger (1977) were used in this study. $^{207}Pb/^{235}U_c$ ($^{235}U_c = 137.88^{238}U$), $^{206}Pb/^{238}U$, and $^{207}Pb/^{206}Pb$ ages were calculated for each data scan and checked for concordance; concordance here was defined as overlap of all three ages at the 1σ level (the use of 2σ level was found to skew the results to include scans with significant common Pb). The background-corrected isotopic sums of each isotope were calculated for all concordant scans. The precision of each isotopic ratio was calculated by using the background and signal errors for both isotopes. The fractionation factor for each data scan, corrected for the effect of accumulated α-damage, was weighted according to the ^{238}U or ^{232}Th signal value for that data scan; an overall weighted mean fractionation factor for all concordant data scans was used for final age calculation.

If the number of concordant data scans for a spot was greater than zero, then either the $^{206}Pb/^{238}U$ or $^{207}Pb/^{206}Pb$ age was chosen as the preferred age, whichever exhibited the lower relative error. If zero concordant data scans were observed, then the common Pb-corrected age based on isotopic sums of all acceptable scans was chosen as the preferred age. Common Pb was subtracted out using the Stacey and Kramer (1975) common Pb model for Earth. Ages and common Pb ratio were determined iteratively using a pre-set, session-wide minimum common Pb age value (default for each session was the age of the oldest age standard which for both Ap and Zrn was 1099 Ma FC-1 and/or FC-5z).

Preferred Age Precision

Errors for the isotopic ratios $^{207}Pb/^{235}U_c$ ($^{235}U_c = 137.88^{238}U$), $^{206}Pb/^{238}U$, and $^{207}Pb/^{206}Pb$ at each scan included errors from the background-corrected signal values for each isotope, the

fractionation factor error, and an additional relative error term required to force 95% of the FC ages to be concordant. Errors for the isotopic ratios $^{207}Pb/^{235}U_c$ ($^{235}U_c = 137.88^{238}U$), $^{206}Pb/^{238}U$, and $^{207}Pb/^{206}Pb$ at each scan included errors from the background-corrected signal values for each isotope, the fractionation factor error, and an additional relative error term required to force 95% of the FC ages to be concordant. Asymmetrical negative-direction and positive-direction age errors were calculated by subtracting and adding, respectively, the isotopic ratio errors in the appropriate age equation (Chew and Donelick, 2012).

Moving-Median Smoothing

Moving-median smoothing (MMS) is applied here to a subset (window) of *N* data points *x, y* of width *m* values of *x* to which a polynomial of order *n* is fitted. For each value of *x* at each position of the data window, a value of *y* is calculated for the fitted polynomial. The window is positioned with the right-hand boundary at the left-hand *x* value and then shifted *N-1* times until the left-hand boundary of the window is positioned at the right-hand *x* value. At each *x* position, *m* fitted values of *y* are calculated and the median of these fitted values is taken.

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