Wahbi, A.M., Blum, M.D., and Doerger, C.N., 2022, Early Cretaceous continental-scale sediment routing, the McMurray Formation, Western Canada sedimentary basin, Alberta, Canada: GSA Bulletin, https://doi.org/10.1130/B36412.1.

# Supplemental Material

**Supplemental Data 1.** Analytical methods followed at the Arizona LaserChron Center.

**Supplemental Data 2.** U-Pb detrital zircon (DZ) ages from randomly picked samples.

**Supplemental Data 3.** U-Pb DZ ages from biasly picked samples.

**Analytical methods followed at the Arizona LaserChron Center**

In general, we followed the instructions, methods and guidelines provided by the Arizona LaserChron Center. Their webpage below provides a thorough description of these steps:

https://sites.google.com/laserchron.org/arizonalaserchroncenter/home

Sandstone samples collected for U-Pb analysis of detrital zircon (DZ) grains included outcrop and subsurface core samples. Fist-size outcrop samples were collected in-person, selected on the basis of grain size (medium- to fine-grained), and composition (quartz arenite) since DZ grains are associated with such grain size and composition. Subsurface core sample were collected by delegated personnel in charge of core handling and sampling after the appropriate depth was provided. Sampling of these samples was administered by the authors and/or associates. Core sample collection followed the same criteria as outcrop samples. Samples were stored in sealed sample bags to avoid contamination, and were shipped to the ALC facilities.

Standard practice of mineral separation included:

- Crushing and grinding sandstone samples into sediment using multiple tools
- Separating low-density minerals using a Wilfley Table
- Removing high-density minerals by utilizing their physical properties (using hand magnet and Frantz magnetic separator to separate ferromagnetic and paramagnetic minerals) and chemical properties (separation according to density using heavy liquids – diiodomethane)

Separated DZ grains are then mounted by spreading grains on an adhesive surface, assembled on a mount using epoxy and then polished and labeled appropriately. Standard fragments were also included in each mount (see more details below). DZ grains are mapped and identified using a

magnifying/imaging microscope and backscattered electron microscopy. Samples upgraded for maximum depositional age analysis were additionally imaged using cathodoluminescence.

For provenance analysis, DZ grains were subject to a random pick to identify targets for U-Pb analyses, with individual grains examined to identify spots with no overgrowths, rims or obvious radiation damage. Alternatively, however, U-Pb analysis-reruns for maximum depositional age were biased-picked to identify characteristics that suggested young ages, and/or minimal transport and recycling over time (e.g., light colors, euhedral shapes; Silver and Deutsch, 1963; Gehrels et al., 2011; Pettit et al., 2019).

U-Pb geochronology of DZ grains is conducted by laser ablation multi-collector inductively coupled plasma mass spectrometry (LA-MC-ICPMS) at the Arizona LaserChron Center (Gehrels et al., 2006; Gehrels et al., 2008). U-Pb dating utilizes the U-Pb decay system and the $^{238}U/^{235}U$ constant relationship (Steiger and Jäger, 1977). Determined ages are considered concordant if the lie on a Concordia line (Wetherill, 1956), and are otherwise rejected. LA-ICPMS analysis were conducted utilizing a Nu Plasma HR ICPMS coupled to a New Wave 193 nm ArF laster ablation system equipped with a New Wave SupperCell. The ICPMS has 12 fixed Faraday detectors equipped with $3x10^{11}$ Ω resisters, in addition to four discrete dynode multipliers (ion counters). Laser beam used was between 15-25 microns in diameter and excavate an analysis pit of ~15 microns in depth.

The analyses are conducted by laser ablation of DZ grains. The ablated material is carried in helium into the plasma source of the ICPMS, which is equipped with a flight tube of sufficient width that U, Th, and Pb isotopes are measured simultaneously. All measurements are made in static mode for $^{238}U$, $^{232}Th$, $^{208}Pb$-$^{206}Pb$, and discrete dynode ion counters for $^{204}Pb$ and $^{202}Hg$. Ion yields are ~0.8 mv per ppm. Each analysis consists of a 15-second integration on

peaks with the laser off (for backgrounds measurements), 15 one-second integrations with the laser firing, and a 30 second delay to purge the previous sample and prepare for the next analysis. The laser is set at 7 Hz pulse frequency and a drill rate of ~0.7 microns per second. For each sample, the sequence is started by analyzing five standards, one standard between every four to five unknowns and three standards at the end.

Each session is started by calibrating the ICPMS using a standard solution, which is replaced by a mixture of He carrier gas (0.38 L/min) and Ar make-up gas (0.90 L/min). Laser sensitivity is set at ~80,000 cpc/ppm for U for 30 micron beam. Blum and Pecha (2014) old mounts are retrieved for re-analysis in the upgraded samples.

Standards used are SL and FC and R33. The primary standard is the Sri Lanka zircon (SL), used by ALC since 2005. The crystal was calibrated originally by ID-TIMS in-house, and subsequently by CA-TIMS by Jim Mattinson (results reported in Gehrels et al., 2008), which contains ~518 ppm U and 68 ppm Th, $^{206}Pb/^{204}Pb$=18,000, and a concordant age of 563.5±2.3 Ma (2σ). FC are large zircon crystals from the Duluth Gabbro complex, assumed to be the same age as the FC1/AS3 samples (1099 ± 2 Ma) analyzed by Paces and Miller Jr (1993) and Schmitz et al. (2003). R33 are small crystals yield an ID-TIMS age of 419.3 ± 0.4 Ma (Black et al., 2004).

Data was reduced using the "agecalc" excel program by first importing raw data from the Nu ICPMS software. The first correction is for $^{204}Hg$ measurement in background phase by subtracting measured $^{202}Hg$ during laser ablation phase according to the $^{202}He/^{204}He$ estimated natural value of 4.35. Common Pb is Hg-corrected based on the measured $^{204}Pb$ and assuming the Stacey-Kramers composition of common Pb (Stacey and Kramers, 1975). Uncertainties of 1.5 for $^{206}Pb/^{204}Pb$ and 0.3 for $^{207}Pb/^{204}Pb$ are applied to these compositional values based on the variation in Pb isotopic composition in modern crystal rocks.

Inter-element fractionation of Pb/U is generally ~5%, whereas apparent fractionation of Pb isotopes is generally <0.2%, where standards with known age are run every fifth measurement to correct for this fractionation. The uncertainty resulting from the calibration correction is generally 1-2% (2-sigma) for both $^{206}Pb/^{207}Pb$ and $^{206}Pb/^{238}U$ ages. $^{206}Pb/^{207}Pb$ and $^{206}Pb/^{204}Pb$ fractionation correction is calculated as the average and standard deviation of the accepted one-second integrations. A 2σ filter is used to remove outliers, and final ratios are carried to conduct further reductions. $^{206}Pb/^{238}U$ and $^{208}Pb/^{232}Th$ fractionation correction is carried by the regression of the latter 10 values in the session to determine the most likely value at integration #6. The uncertainty is reported as the standard deviation of this initial value, and final ratios are carried to conducted further reductions. Uncertainties shown are at the 1-sigma level, and include only measurement errors. Analyses that are >20% discordant (by comparison of $^{206}Pb/^{238}U$ and $^{206}Pb/^{207}Pb$ ages) or >5% reverse discordant are not considered further.

The resulting interpreted ages are plotted on Pb*/U concordia diagrams and relative age-probability diagrams using the routines in Isoplot (Ludwig, 2008). The age-probability diagrams show each age and its uncertainty (for measurement error only) as a normal distribution, and sum all ages from a sample into a single curve. Composite age probability plots are made in agecalc, which normalizes each curve according to the number of constituent analyses, such that each curve contains the same area, and then stacks the probability curves.

Internal error component for each $^{206}Pb^*/^{238}U$ and $^{208}Pb^*/^{232}Th$ measurement include the uncertainty returned from fractionation correction and that resulted from the measurement of $^{206}Pb/^{204}Pb$. For $^{206}Pb^*/^{207}Pb^*$ measurements, internal error correction includes the uncertainty from fractionation correction and that from $^{206}Pb/^{204}Pb$.

External error corrections included internal error correction of standards. They also include: 1) correction for common Pb following corrected values set by Zartman and Doe (1981) and Mattinson (1987), 2) correction for carried uncertainty in age of primary calibration standard, and 3) uncertainty carried from decay constant of $^{238}U$, $^{235}U$ and $^{232}Th$ following the reported constants of Steiger and Jäger (1977).

Ages are determined using a weighted mean calculation, which weights each analysis according to the square of its uncertainty. The final age is accordingly controlled by analysis with smaller errors. The weighted mean is an express of the uncertainty that arises from the scatter resulted from internal errors, but uncertainty derived from external errors are also incorporated in our weighted mean calculations by adding the square value for each error and calculating the square root of all: total error.

Below is a summary and additional notes to accompany data files:

1. Analyses with >10% uncertainty (1-sigma) in $^{206}Pb/^{238}U$ age are rejected.
2. Analyses with >10% uncertainty (1-sigma) in $^{206}Pb/^{207}Pb$ age are rejected, unless $^{206}Pb/^{238}U$ age is <500 Ma.
3. Best age is determined from $^{206}Pb/^{238}U$ age for analyses with $^{206}Pb/^{238}U$ age <1000 Ma and from $^{206}Pb/^{207}Pb$ age for analyses with $^{206}Pb/^{238}U$ age > 1000 Ma.
4. Concordance is based on $^{206}Pb/^{238}U$ age / $^{206}Pb/^{207}Pb$ age. Value is not reported for $^{206}Pb/^{238}U$ ages <500 Ma because of large uncertainty in $^{206}Pb/^{207}Pb$ age.
5. Analyses with $^{206}Pb/^{238}U$ age >500 Ma and with >20% discordance (<80% concordance) are rejected.
6. Analyses with $^{206}Pb/^{238}U$ age >500 Ma and with >5% reverse discordance (<105% concordance) are not included.
7. All uncertainties are reported at the 1-sigma level, and include only measurement errors.
8. Systematic errors are as follows (at 2-sigma level): [sample 1: 2.5% ($^{206}Pb/^{238}U$) and 1.4% ($^{206}Pb/^{207}Pb$)].
9. Analyses conducted by LA-MC-ICPMS, as described by Gehrels et al. (2008).
10. U concentration and U/Th are calibrated relative to Sri Lanka zircon standard and are accurate to ~20%.
11. Common Pb correction is from measured $^{204}Pb$ with common Pb composition interpreted from Stacey and Kramers (1975).
12. Common Pb composition assigned uncertainties of 1.5 for $^{206}Pb/^{204}Pb$, 0.3 for $^{207}Pb/^{204}Pb$, and 2.0 for $^{208}Pb/^{204}Pb$.

13. U/Pb and $^{206}Pb/^{207}Pb$ fractionation is calibrated relative to fragments of a large Sri Lanka zircon of 563.5±3.2 Ma (2-sigma).
14. U decay constants and composition as follows: $^{238}U = 9.8485 \times 10^{-10}$, $^{235}U = 1.55125 \times 10^{-10}$, $^{238}U/^{235}U = 137.88$.
15. Weighted mean and concordia plots determined with Isoplot (Ludwig, 2008).

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