AER/AGS Open File Report 2017-01

Alberta Energy Regulator

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AER/AGS Open File Report 2017-01

U-Pb Detrital Zircon Geochronology of the Jurassic Through Lower Cretaceous Strata of the Rocky Mountains, Southwestern Alberta

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September 2017

ISBN 978-1-4601-0169-8

If you use information from this publication in other publications or presentations, please acknowledge the AER/AGS. We recommend the following reference format:

Pană, D.I., Poulton, T.P. and DuFrane, A. (2017): U-Pb detrital zircon geochronology of the Jurassic through Lower Cretaceous strata of the Rocky Mountains, southwestern Alberta; Alberta Energy Regulator, AER/AGS Open File Report 2017-01, 6 p.

Publications in this series have undergone only limited review and are released essentially as submitted by the author.

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Published September 2017 by:
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Acknowledgements

The authors are indebted to S. Johnston, M. Mihalynuk, and K. Sigloch for important discussions in the field. A. Poulton, S. Johnston, and G. McEwen assisted with sample collection. T. Hadlari, B. Davis, F. Krause, and R. Hildebrand were very generous with helpful advice and criticism at different stages of the report preparation.

Abstract

U-Pb detrital zircon geochronology of samples from Lower Jurassic to Lower Cretaceous stratigraphic units of the southern Canadian Rocky Mountains fold-and-thrust belt documents the presence of detrital zircons with ages close to the time of sediment accumulation. This indicates that the drainage systems that discharged into the local expression of the Western Interior Seaway were accessing western contemporaneous igneous sources in the Cordillera starting at least from the Early Jurassic, long before the Kimmeridgian initiation of the foredeep trough. Older grains in the Jurassic strata reflect the pre-history of the basin distributive province and show an episodic pattern that includes well-defined lower Paleozoic and Grenvillian maxima, and Paleo- to early Neoproterozoic populations, which may reflect recycling of detrital zircons from older clastic formations uplifted in the eastern part of the orogen, or less likely, eastern sources. The data also provide maximum depositional ages for several stratigraphic units of previously uncertain age.

1 Introduction

Sedimentological and paleocurrent data (e.g., Hamblin and Walker, 1978; Poulton et al., 1994), relative crustal subsidence rates (Chamberlain et al., 1989), provenance studies (Ross et al., 2005; Raines et al., 2013), and the earliest dated thrust faults in the Rocky Mountains (Pană and van der Pluijm, 2015) are widely accepted to document the initiation of the Alberta foreland basin during the Late Jurassic. The first appearance of westerly-derived detritus from a rising arc or orogen is often accepted as providing the timing of initiation of the Western Interior foreland basin (Miall, 2009). This report presents baseline detrital zircon geochronological data sets from Lower Jurassic through Lower Cretaceous strata of the western portion of the Western Canada Sedimentary Basin (WCSB), now incorporated in the southeastern Canadian Rocky Mountains fold-and-thrust belt (RM-FTB) (Figure 1, Table 1). We report for the first time syndepositional detrital zircon ages throughout the Jurassic, which may indicate that drainage systems into the Western Interior Seaway were reaching Cordilleran igneous sources since at least the Early Jurassic.

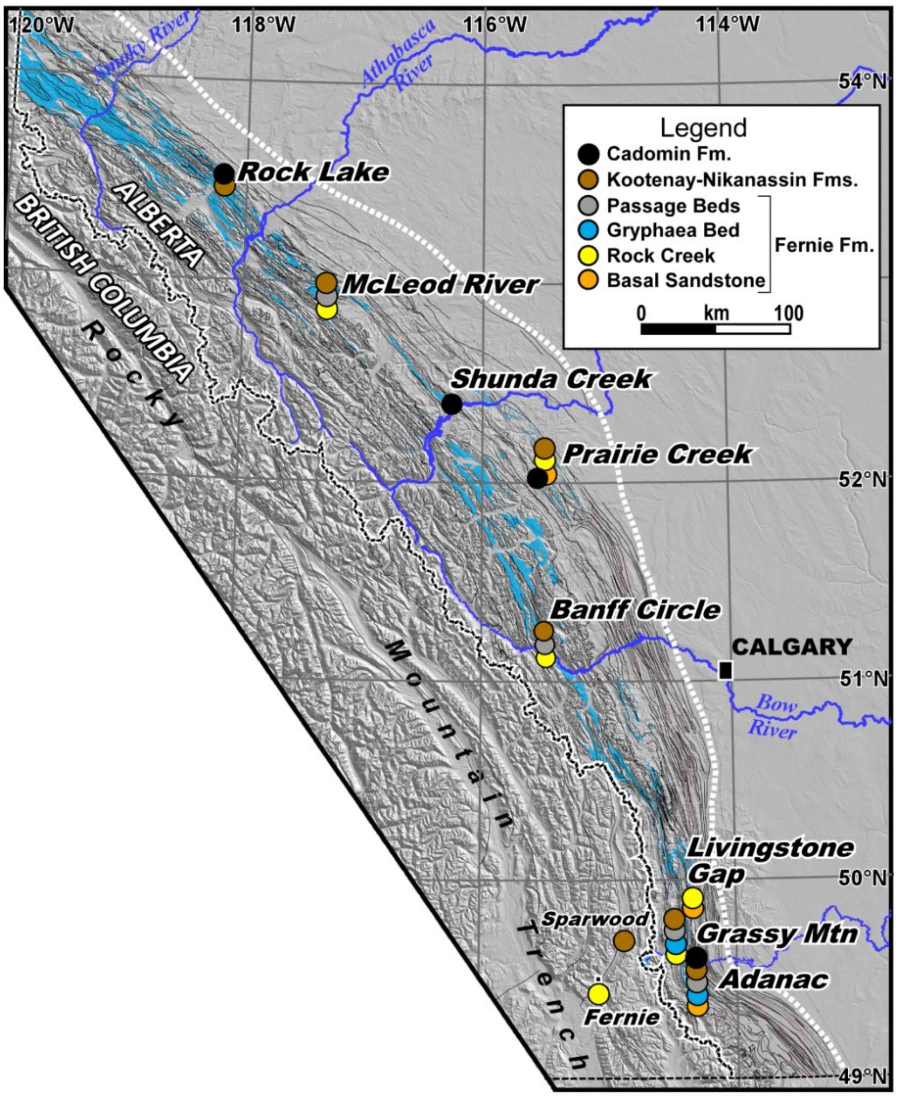

Figure 1. Sketch map showing the sample locations and distribution of undifferentiated Triassic and Jurassic strata (in blue) in the Cordilleran foreland belt of southern Canada (simplified from Pană and Elgr, 2013).

Table 1. Summary of U-Pb geochronological data from detrital zircon samples collected from Jurassic–Lower Cretaceous units, Alberta foreland belt.

	Member	Stratigraphic Age	Sample	General Area	Latitude	Longitude	Youngest Peak *(Ma)*	MSWD	Youngest Age *(Ma)*	Nr. of Grains	
										Used	Rejected
1	Cadomin Fm.	Barremian(?) - Aptian	DP13-158*	ADANAC quarry	49.48683	114.41241	117.6±1.8 (24)	3.9	112±2	98	22
2			DP14-9	Prairie Creek trunk road	52.13826	115.46545	129.9±6.9 (5)	6.4	124±4	98	12
3			DP10-530	Shunda Creek	52.49828	115.99973	158±15 (5)	8.1	108±5	63	26
4			DP11-118A	Rock Lake	53.50895	118.12740	123.4±8.9 (7)	20	112±4	106	20
5	Morrissey Fm. (base)	Tithonian	DP15-133*	Sparwood bridge, Hwy 3	49.72968	114.85802	181.8±4.5 (15)	4.3	166±7	76	34
6			DP13-159	ADANAC quarry road	49.48874	114.41220	164.4±4.1 (9)	4.1	158±4	83	37
7			DP13-154	Grassy Mtn, mine road	49.67025	114.42661	154.8±2.6 (7)	0.97	150±7	105	15
8			DP15-339	Banff Traffic Circle	51.20374	115.51968	152.8±5.1 (7)	4.0	142±7	94	16
9	Nikanassin Fm. (base)	Tithonian	DP14-8	Prairie Creek trunk road	52.13838	115.46533	179±17 (5)	20	162±5	106	14
10			DP14-61	Prospect Creek (McLeod R.)	52.96603	117.32739	161±12 (3)	2.8	156±6	92	20
11			DP11-118B	Rock Lake	53.50895	118.12740	172.3±9.3 (8)	7.1	154±7	36	27
12	Passage Beds	Kimmeridgian - Tithonian	DP13-160	ADANAC quarry road	49.48957	114.41193	154.7±3 (9)	2.3	122±4	97	23
13			DP13-156	Grassy Mtn, mine road	49.67091	114.42587	150.5±2.1 (5)	1.1	109±3	108	12
14			DP15-338	Banff Traffic Circle	51.20598	115.52198	150.9±3.1 (7)	1.4	147±5	101	9
15			DP15-337	Banff Traffic Circle	51.20708	115.52561	166.9±2.8 (5)	0.6	164±6	82	28
16			DP14-60	McLeod River road	52.96867	117.32283	397.2±6.3 (7)	1.5	215±12	74	36
17	Gryphaea Bed	Bathonian	DP13-157*	ADANAC quarry road	49.49289	114.41237	168.62+1.25/-1.49 (37)	*4.7*	*161±8*	65	35
18			DP15-135	------- "-------- *resampled*	49.49289	114.41244	*168.69+1.27/-1.13 (54)*	*1.4*	*162±6*	*72*	*38*
19			DP13-155*	Grassy Mtn, mine road	49.67375	114.41909	169.08+0.99-1.94 (77)	2.5	121±5	95	27
20	Rock Creek Mbr.	Aalenian - Bajocian	DP13-150	Fernie, B.C. Hwy 3	49.42523	115.05009	174.4±4.5 (10)	5.5	162±5	96	24
21			DP15-130	Fernie, B.C. Hwy 3	49.43106	115.05402	171±2	*1.3*	165±6	*73*	*37*
22			DP13-153*	Grassy Mtn, old railroad	49.67108	114.41920	174.5±4.4 (2)	0.3	174±5	95	25
23			DP15-318A	Oldman R., Livingstone Gap	49.87328	114.34584	186±14 (4)	8.9	112±4	86	24
24			DP14-5	Prairie Creek trunk road	52.13921	115.46494	173±16 (6)	23	154±7	101	9
25			DP14-56	McLeod River (RC1)	52.97312	117.32484	408.5±6.1 (4)	1.1	402±15	101	9
26	Poker Chip Shale	Toarcian	DP15-84	Prairie Creek quarry	52.17672	115.45665	186.5±5.3 (10)	2.5	176±7	98	12
27	Basal sandstone	Sinemurian to Toarcian(?)	DP13-161	ADANAC quarry road	49.49497	114.40414	192±19 (7)	0.109	184±36	96	13
28			DP13-164	Oldman R., Livingstone Gap	49.87338	114.34501	201.4±5.0 (2)	0.52	112±4	108	12
29			DP15-85	Prairie Creek quarry	52.17417	115.45464	211±14 (6)	6.3	197±9	94	16

Note: all samples are sandstone except the Gryphaea Bed, which is slightly sandy and cross-bedded fossiliferous limestone; succession of samples in each stratigraphic unit is from south to north. In red, discarded anomalous single grain ages; sample numbers with a star symbol are samples have been reanalysed to confirm the youngest ages.

2 Theory and Method

Our sampling strategy was designed to cover the entire length of the southern Canadian foreland belt between ca. 49°30'N and 53°30'N and the entire Lower Jurassic to Lower Cretaceous stratigraphic succession (Figure 1), which encompasses inferred early stages of the southern Canadian Cordilleran foreland basin. Our sample suite includes 18 samples from all representative coarser clastic units of the Fernie Formation, 7 samples from the first massive (commonly >1 m thick) sandstone bed assigned to the basal Morrissey and Nikanassin formations, and 4 samples from the Cadomin Formation (Table 1). In situ U-Pb zircon data was collected using laser ablation multi collector inductively coupled mass spectrometry (LA-MC-ICP-MS) at the Canadian Centre for Isotopic Microanalysis (CCIM) of the University of Alberta. Approximately 120 individual zircon grains were analysed from each sample, for a total of 3213 single zircon ages, of which approximately 80% (2499 ages) were used for interpretation, whereas the >10% discordant analyses were rejected. For plotting purposes, data were filtered using a 10% discordance filter with the following criteria: for ages less than 500 Ma, concordance was assessed by comparing the $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages, for ages less than 500 Ma, concordance was assessed by comparing the $^{207}Pb/^{235}U$ and $^{206}Pb/^{238}U$ ages. All plots were generated using the Isoplot software of Ludwig (2003). U-Pb geochronology raw data are included in the dataset (AER/AGS Digital Data 2017-0017; Pană, 2017) associated with this report.

3 Examples

Crystallization ages for detrital zircons suggest that the sources did not vary dramatically throughout the Early Jurassic to Early Cretaceous. With the exception of the Gryphaea Bed silty limestone, the proportion of the youngest zircons with ages approximating the depositional age of the sediment is limited; instead a swath of older ages form the majority of recovered zircon grains. This distribution pattern is common in foreland strata sourced both from units caught in the orogen and from the cratonic foreland (Cawood et al., 2012). Most detrital zircons yielded ages older than ca. 1 Ga with a Paleoproterozoic trough in the 2.5–2.3 Ga range. The absence of zircon grains in the 2.5–2.3 Ga range (Arrowsmith age) and the minor proportion of 2.0–1.9 Ga zircons (Taltson age) suggest that the western Canadian Shield did not represent a significant original source. Instead, characteristic to Precambrian portions in all zircon spectra are "Grenville-aged" grains (1000-1200 Ma) with minor Canadian Arctic signatures (ca. 750–500 Ma), both typical of the miogeoclinal units. Also common to all samples are zircons in the Early Paleozoic (ca. 500–400 Ma) age range, with Carboniferous-Permian (350–250 Ma) and early Neoproterozoic (950–750 Ma) troughs.

The youngest peaks in the Lower Jurassic Basal sandstone are Late Triassic, Hettangian, and late Sinemurian. The Triassic zircon may be explained by erosion of the underlying Triassic strata, which must have had a geographic connection to an adjacent magmatic arc associated with ocean closure (now preserved in the Intermontane belt).

The maximum depositional age of the Rock Creek Member is constrained to latest Aalenian (ca. 175 Ma), consistent with the biostratigraphically controlled probable age of its oldest strata. All three Gryphaea Bed limestone samples yielded mostly euhedral zircon grains and apparently normally distributed data points, either from a single age population that indicates local derivation from a single igneous protolith emplaced immediately prior to the carbonate bed deposition, or more likely from quasi-contemporaneous volcanic activity. Based on the agreement within analytical uncertainty, we have used the zircon ages from the three samples to calculate a weighted mean age of 169.0±1 Ma (a coherent group of 167 grains) which is the best estimate of the igneous source, and implicitly the maximum age of the Gryphaea Bed.

Youngest peaks in the Passage Beds samples constrain the upper part of the Passage Beds, including the tree stump-bearing bed at Banff Traffic Circle, to Tithonian (< ca. 150 Ma). A distinctive set of white-weathering turbidite-like sandstone beds at the 'Banff Traffic Circle' outcrop, constrained by our data to be younger than ca. 167 Ma, are difficult to interpret stratigraphically, but, according to most authors, lie within the lower Passage Beds and are thought to be westerly sourced (e.g., Hamblin and Walker, 1979, their figure 4, 64–74 m), but have been interpreted (Cant and Stockmal, 1999) as structurally rotated Pigeon Creek Member, which would be consistent with our zircon age data.

The basal sandstones of the Morrissey and Nikanassin formations, not necessarily correlative along strike, have zircons with youngest peaks showing large age variability and older than the underlying Tithonian upper Passage Beds.

The Cadomin Formation contains two dominant populations, a late Paleoproterozoic population (1950–1700 Ma), which encompasses the ca. 1850 Ma reported by Leier and Gehrels (2011) and the 1700–1900 Ma range of zircon and monazite ages reported by Ross et al. (2005) from the partly correlative Dalhousie Formation, and a Jurassic to Early Cretaceous population. Our youngest age peaks of ca. 120 Ma correspond to the ca. 120 Ma zircon population previously reported from all seven Cadomin samples collected along the foothills of the entire RM-FTB in southern Canada by Leier and Gehrels (2011) and coincide with the Early Cretaceous flare-up in the Coast belt magmatic arc. The presence of ca. 120 Ma zircons (peaks on relative probability diagrams and even slightly younger individual grains) in almost all Cadomin samples, corroborated with the paleontological and stratigraphic data from the overlying late Aptian–early Albian Gething, lower Gladstone and equivalent formations, limits the deposition of the Cadomin Formation to a short, middle Aptian time interval.

4 Conclusions

Our dataset documents the presence of approximately syndepositional detrital zircons in coarser clastic units throughout the Jurassic Fernie Formation. Because no tectonothermal events contemporaneous with the deposition of the Jurassic Fernie Formation are known to the east, these data provide the first evidence for Cordilleran arc-derived detritus in the basin starting at least as early as the Early Jurassic. A small proportion of the zircon grains in each sample is slightly eroded, but euhedral in habit, suggesting first-cycle and limited transport and likely producing the youngest major age peaks in each of the analyzed strata which conform with the depositional age of the host sediment. The ages of these grains are taken to indicate transport systems connecting the Fernie depositional basin to a plate margin where the youngest zircon detritus, with ages approximating the times of deposition in the basin, was most likely derived from the magmatic arc associated with ocean closure and/or collision (Cawood et al., 2012). However, the variety of transcurrent and compressional components that have been recognized in the Cordillera (e.g., Evenchick et al., 2007) preclude recognition of particular source areas or transport vectors.

Sediment provenance is constrained by our detrital zircon data to two distinct source regions, one in the fold-and-thrust belt of the adjacent Canadian Cordillera and the other to the south, including the Cordillera and continental deposits of the United States. We suggest that the marine western edge of the WCSB received detrital zircon grains from a magmatic accretionary arc source since at least the Early Jurassic. The absence of carbonates and phosphates in the Middle Jurassic in the basin and an increase in fine clastic sediment with paleocurrent evidence for northerly transport in the latest Jurassic and earliest Cretaceous indicate gradual transition to a narrow, NNW-SSE oriented foredeep trough with a main fluvial system oriented north-northwest, parallel to the Cordilleran orogenic belt, and consistent with a Jurassic accretionary history.

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