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Alberta Energy Regulator

Geochronology in Support of the Alberta Table of Formations: Uranium-Lead Isotope Dating of Zircon from Upper Albian Ash Beds in Alberta

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Abstract

The purpose of this study is to confirm and possibly refine the age and stratigraphic correlations of Upper Albian strata in Alberta using U-Pb isotope dating of zircons collected from ash beds in subsurface drill core. This study strives to update the late Albian age boundaries for the Alberta Table of Formations, created and maintained by the Alberta Geological Survey. The ages of Upper Albian strata in the Alberta Basin have been determined primarily through a biostratigraphic approach, which leaves a considerable degree of uncertainty with regards to the true depositional age of these sand-rich intervals. Ash beds are useful in dating deposits due to their high potential to preserve depositional-aged grains of zircon. Ash beds from subsurface core that intersect Upper Albian strata were collected from the Paddy Member of the Peace River Formation (northwestern Alberta), the Viking Formation (central Alberta), and the Bow Island Formation (southern Alberta). Fourteen ash beds from 13 wells across the province were sampled for zircon grains to be dated by U-Pb analysis using laser-ablation inductively coupled plasma–mass spectrometry. Nine of the samples had enough zircon grains to produce usable dates for the formations. The reported average ages for the Paddy Member (Peace River Formation) include 101.3 ±1.4 and 100.7 ±1.4 Ma. The reported average ages for the Viking Formation include 98.8 ±1.6, 98.6 ±2.5, 98.5 ±2.8, and 98.2 ±1.7 Ma. The reported average ages for the Bow Island Formation include 104.0 ±1.9 and 99.3 ±1.4 Ma. It was determined that future studies must be conducted to reliably adjust or reconfirm the age boundaries of the Viking, Peace River, and Bow Island formations on the Alberta Table of Formations.

1 Introduction

Sand-rich intervals of Albian strata across the province of Alberta have primarily been dated using a biostratigraphic approach (Stelck, 1958; Caldwell et al., 1978; Stelck and Koke, 1987; Stelck et al., 2000). The Paddy Member of the Peace River Formation (northwestern Alberta), the Viking Formation (central Alberta), and the Bow Island Formation (southern Alberta) are inferred to be approximately age-equivalent strata and belong to the *Haplophragmoides gigas* foraminiferal zone, which spans much of the Upper Albian (Figure 1; Stelck et al., 2000). Although this allows for broad correlations of the sand-rich intervals across the province, it does not provide a precise depositional age, which would eventually allow for a more refined stratigraphic model to be created for the Upper Albian. The Alberta Table of Formations includes the approximate age ranges for stratigraphic units across the province (Alberta Geological Survey, 2019). The minimum depositional age of Upper Albian deposits is approximately 101 Ma.

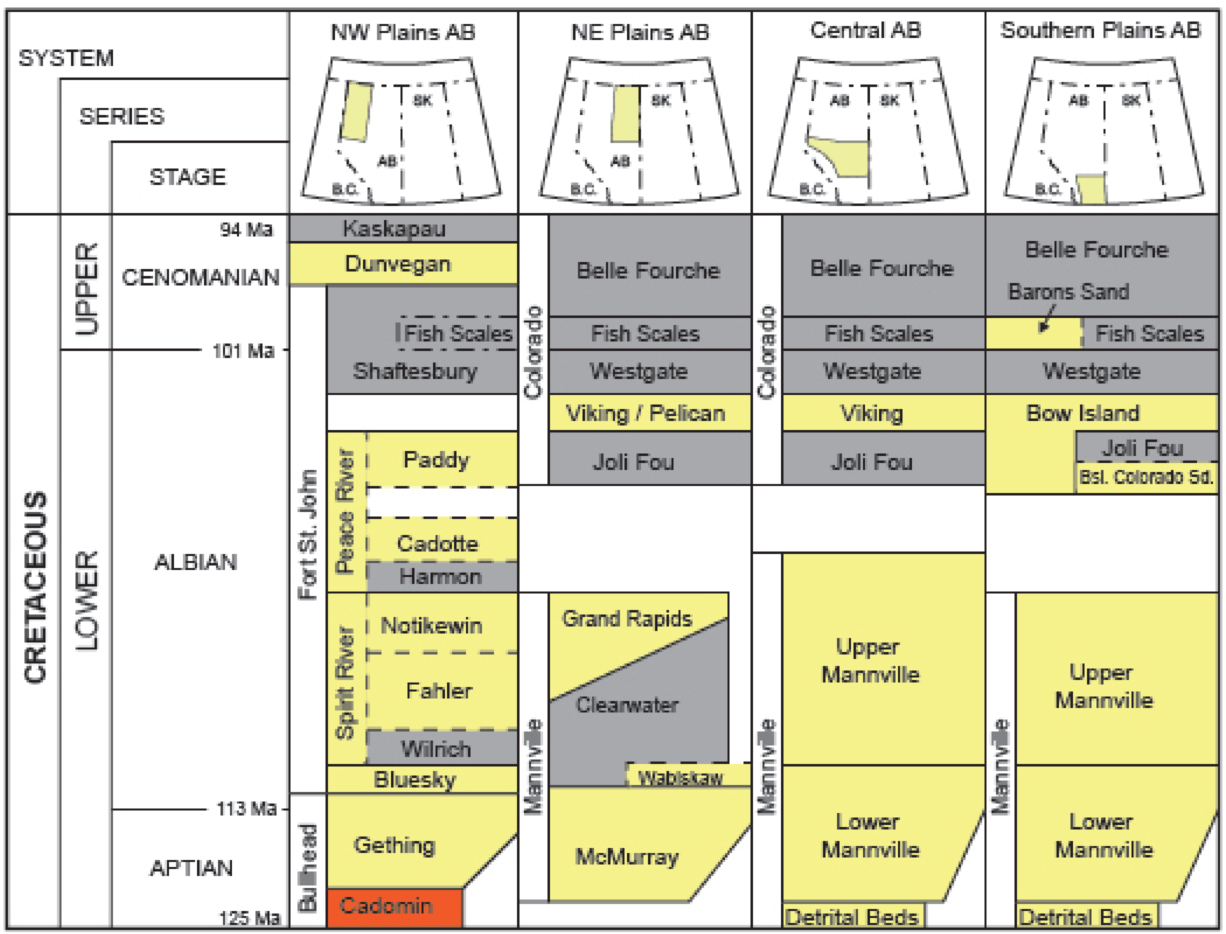

Figure 1. Lithostratigraphic nomenclature for the Albian strata across Alberta (Schultz et al., 2020; modified from Alberta Geological Survey, 2019). Abbreviation: Bsl. Colorado Sd., Basal Colorado Sand.

In this study, ash beds from Albian strata across Alberta were sampled. The zircon grains found in the ash were submitted for U-Pb dating analysis using laser-ablation inductively coupled plasma–mass spectrometry (LA-ICP-MS). In total, 14 bentonite samples were taken from subsurface core, however, only nine samples had enough zircon grains to reliably date the sample. The ages that were calculated for these samples provide an opportunity to reevaluate the age range for the Upper Albian on the Alberta Table of Formations (Alberta Geological Survey, 2019).

1.1 Stratigraphic Nomenclature

1.1.1 Peace River Formation (Paddy Member)

The Peace River Formation was first defined by McConnell (1893) in a study of outcrops along the Peace and Smoky rivers. The formation was initially divided into four informal units by Wickenden (1951): the basal sandstone member, the middle shale member, the Cadotte Member (after McLearn, 1944), and the continental member. The Alberta Study Group (1954) assigned three formal lithostratigraphic members for the Peace River Formation, which are currently used to subdivide the unit: the Harmon (formerly middle shale member), Cadotte, and Paddy (formerly continental member) members.

The Paddy Member was placed in the *Haplophragmoides gigas* foraminiferal zone by Stelck (1958), indicating that it has a potential age equivalence to the Viking and Bow Island formations. The Paddy Member has been assigned to the *Haplophragmoides gigas* foraminiferal subzone and contains the molluscan index fossil *Inoceramus comancheanus* (Figure 2; Stelck, 1958; Stelck and Koke, 1987).

1.1.2 Viking Formation

The 'Viking sand' was first described by Slipper (1918) in a study of the Viking-Kinsella gas field in east-central Alberta. The sand-rich interval was elevated to formation status by Stelck (1958). The Viking Formation overlies the Joli Fou Formation and underlies the Westgate Formation. Formal subdivisions do not exist for the Viking Formation as it tends to form thin intervals in the subsurface. The Viking Formation was initially mapped using an allostratigraphic approach (Boreen and Walker, 1991; Pattison, 1991; Pattison and Walker, 1994; Roca et al., 2008) and has more recently been defined using a sequence stratigraphic approach (Schultz et al., 2020, 2022). Boreen and Walker (1991) subdivided the Viking Formation into five allomembers (A to E), which were separated by regional discontinuities (VE1 to VE4). The sequence stratigraphic approach by Schultz et al. (2022) divides the Viking Formation into at least four sequences of deposition and follows the Depositional Sequence IV nomenclature to map and characterize systems tracts (Catuneanu et al., 2011).

The Viking Formation was initially dated biostratigraphically by identifying foraminifera species that were found in mud-rich beds. The Viking Formation is placed in the *Haplophragmoides gigas* foraminiferal zone (Figure 2; Stelck et al., 2000).

1.1.3 Bow Island Formation

The Bow Island Formation is the southern Alberta equivalent of the Viking Formation and Paddy Member (Figure 2). The term 'Bow Island' was first used to describe the interbedded sandstones and mudstones that occur between the underlying Mannville Group and the overlying 'Fish Scale' sandstone (Glaister, 1959). The unit was elevated to formation status by Glaister (1959) who proposed that the sand-dominated intervals between the Mannville Group and previously unnamed marine shales of the Westgate Formation should constitute the Bow Island Formation. Having received limited attention in the literature prior to the 1990s, the Bow Island Formation has been studied more thoroughly in recent years (e.g., Cox, 1993; Raychaudhuri, 1994; Reinson et al., 1994; Pedersen et al., 2002; Roca et al., 2008). The formation has been divided into three informal members, which include the lower, middle, and upper members.

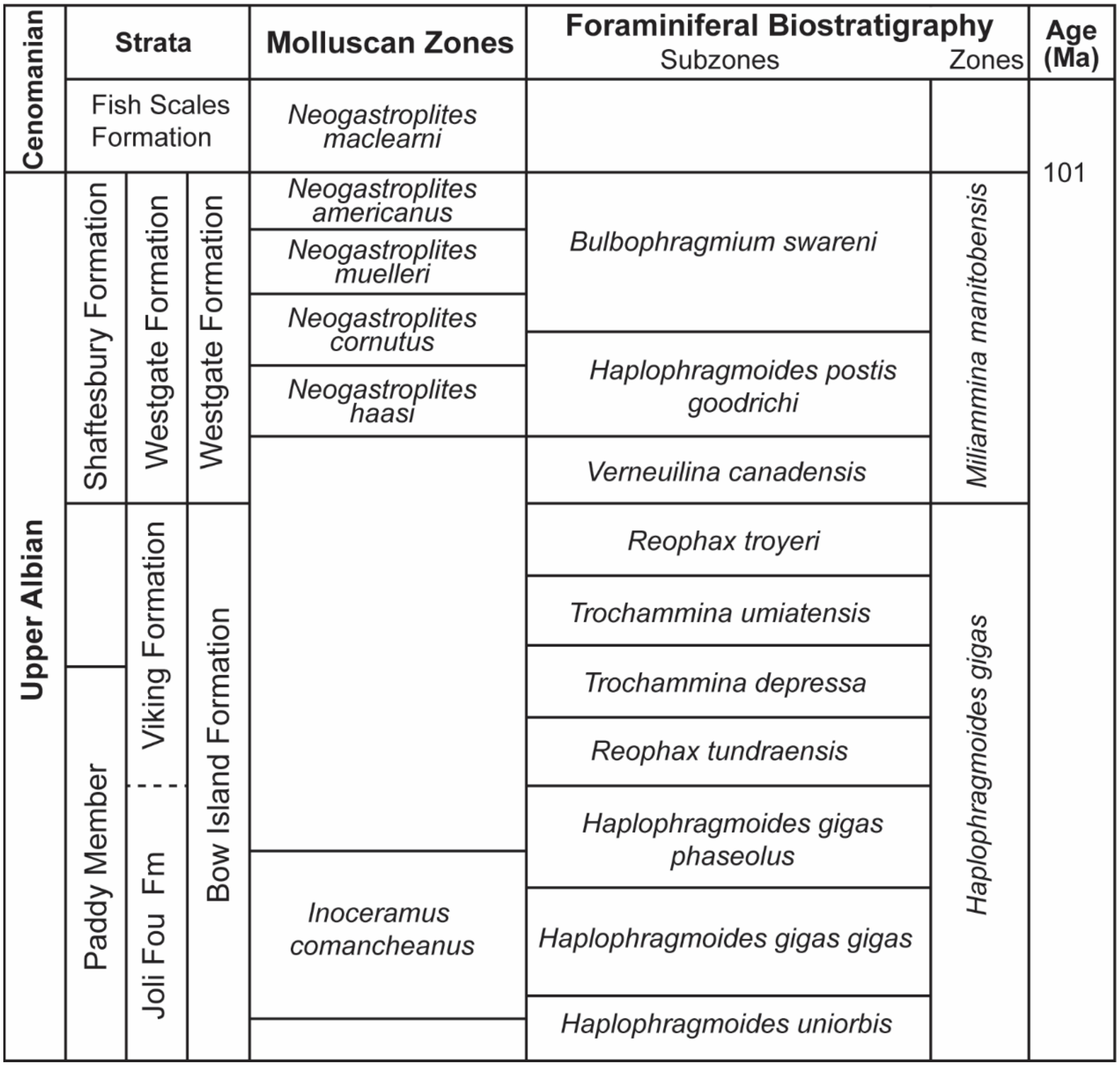

Figure 2. Foraminiferal and molluscan zones in Alberta (modified from Stelck et al., 2000, © Canadian Science Publishing or its licensors).

The lower portion of the Bow Island Formation was initially assigned to the *Haplophragmoides gigas* foraminiferal zone and the upper portion and part of the Westgate Formation were assigned to the *Miliammina manitobensis* foraminiferal zone (Caldwell et al., 1978). Stelck et al. (2000) make a distinction between the foraminiferal zones of the upper Bow Island Formation and Westgate Formation (Figure 2), which makes the upper Bow Island Formation biostratigraphically equivalent to the Viking Formation. The lower portion is biostratigraphically equivalent to the Joli Fou Formation, Viking Formation, and Paddy Member.

1.2 Radiometric Dating

Bentonite is formed by the chemical alteration of volcanic ash when it comes in contact with water (Figure 3). Minerals such as biotite, sanidine, zircon, and apatite are commonly found in bentonite beds and are used in radiometric dating techniques such as those using the potassium-argon (K-Ar) or uranium-lead (U-Pb) decay series.

Figure 3. Example of an ash bed in a Viking Formation core from well 100/03-19-058-03W5/0 at 3118 ft. (950 m). The ash bed/bentonite is outlined in red. The length of each core sleeve is approximately 75 cm and the core diameter is 3 in. (7.6 cm).

1.2.1 Potassium-Argon (K-Ar) Dating

Potassium-argon dating measures the radioactive decay of an isotope of potassium-40 (^{40}K) into argon-40 (^{40}Ar). This technique is widely used as many rocks contain potassium-bearing minerals (e.g., feldspar), but there are limitations associated when analyzing the argon. A common issue that leads to large error margins is postdepositional recrystallization or alteration, which causes a loss or excess of argon. These scenarios cause the age of the dated mineral to read younger or older than the true age, leading to a large margin of uncertainty.

1.2.2 Uranium-Lead (U-Pb) Dating

Uranium-lead dating measures the radioactive decay of uranium-235 (^{235}U) to lead-207 (^{207}Pb). Uranium in this decay series has a long half-life (~710 million years) and is generally incorporated into a variety of minerals, such as zircon and apatite. Lead is generally not incorporated into zircon, therefore any lead present in the grain is likely the result of radioactive decay of uranium to lead, which allows for the timing of geological events to be measured. Zircon extracted from bentonite beds is likely to be depositional-aged, which refines the timing of eruption and subsequent deposition. Zircon analyzed by this method can be microscopic (see Matthews and Guest, 2016), however, it has to be abundant enough to obtain reliable concordant results to determine the depositional age.

1.2.3 Previous K-Ar Dating of the Viking Formation

Radiometric dating of bentonites in Upper Albian strata has been limited despite numerous wells throughout the basin containing thick (5 to 45 cm) ash beds (e.g., Tizzard and Lerbekmo, 1975). Tizzard and Lerbekmo (1975) dated bentonite samples from three Viking Formation wells in east-central Alberta. Biotite and sanidine were analyzed using K-Ar dating, which yielded a large range of possible dates (Table 1). The 100/01-13-023-07W4/0 well yielded an age of 118 Ma from dating sanidine grains and an age of 98 Ma from dating biotite grains, indicating that argon leakage may have occurred in this sample. From the sample data, Tizzard and Lerbekmo (1975) suggested an average age of 100 Ma for the bentonites, however, measured ages for all of the samples ranged from 118 to 94 Ma, indicating potential issues with argon leakage in the samples.

1.3 Study Location

Ash beds were sampled from subsurface cored intervals in wells across Alberta (Figure 4) from the Upper Albian strata of the Peace River (Paddy Member; northwestern Alberta), Viking (central Alberta), and Bow Island formations (southern Alberta). No samples were taken from outcrop localities, however, future studies of Upper Albian ash beds in outcrop areas may help elucidate and refine the stratigraphic relationships and correlations between these areas and subsurface units.

Samples were taken throughout the province in order to provide more information about the age range of the sand-rich intervals (Figure 5, Table 2). To date, no published dating information is available for the Paddy Member or Bow Island Formation. Sampling across the province provides possible age ranges for Upper Albian strata and allows for broad correlations between the sandy intervals.

1.4 Methodology

Approximately 30 to 50 g of bentonite from each well core sample were sent to the University of Calgary (Calgary, Alberta) to be analyzed in the Geo- and Thermochronology Laboratory. Ash bed samples underwent a mineral separation process under a microscope to hand select any usable zircon grains (Table 2). These grains were then mounted for analysis by LA-ICP-MS.

Table 1. Data from previous radiometric dating (K-Ar) of Viking Formation samples by Tizzard and Lerbekmo (1975). The percentage given with the minerals analyzed is a reflection of the purity of the sample analyzed. In some scenarios, it was challenging to extract pure sanidine and biotite, indicating that there may have been other minerals contaminating the sample results. The decay constants used in the study were e = 5.85 x 10^{-11}/year and B = 4.72 x 10^{-10}/year, K^{40}/K = 0.000119 (at ratio).

UWI	Depth	Mineral Analyzed	Age (Ma)
100/11-23-023-14W4/0	2647 ft. (807 m)	Sanidine (95%)	95
100/11-23-023-14W4/0	2647 ft. (807 m)	Biotite (100%)	94
100/01-13-023-07W4/0	2441 ft. (744 m)	Sanidine (90%)	118
100/01-13-023-07W4/0	2441 ft. (744 m)	Biotite (95%)	98
100/01-13-023-07W4/0	2373 ft. (723 m)	Sanidine (85%)	105
100/10-07-026-14W4/0	3037 ft. (926 m)	Sanidine (95%)	103

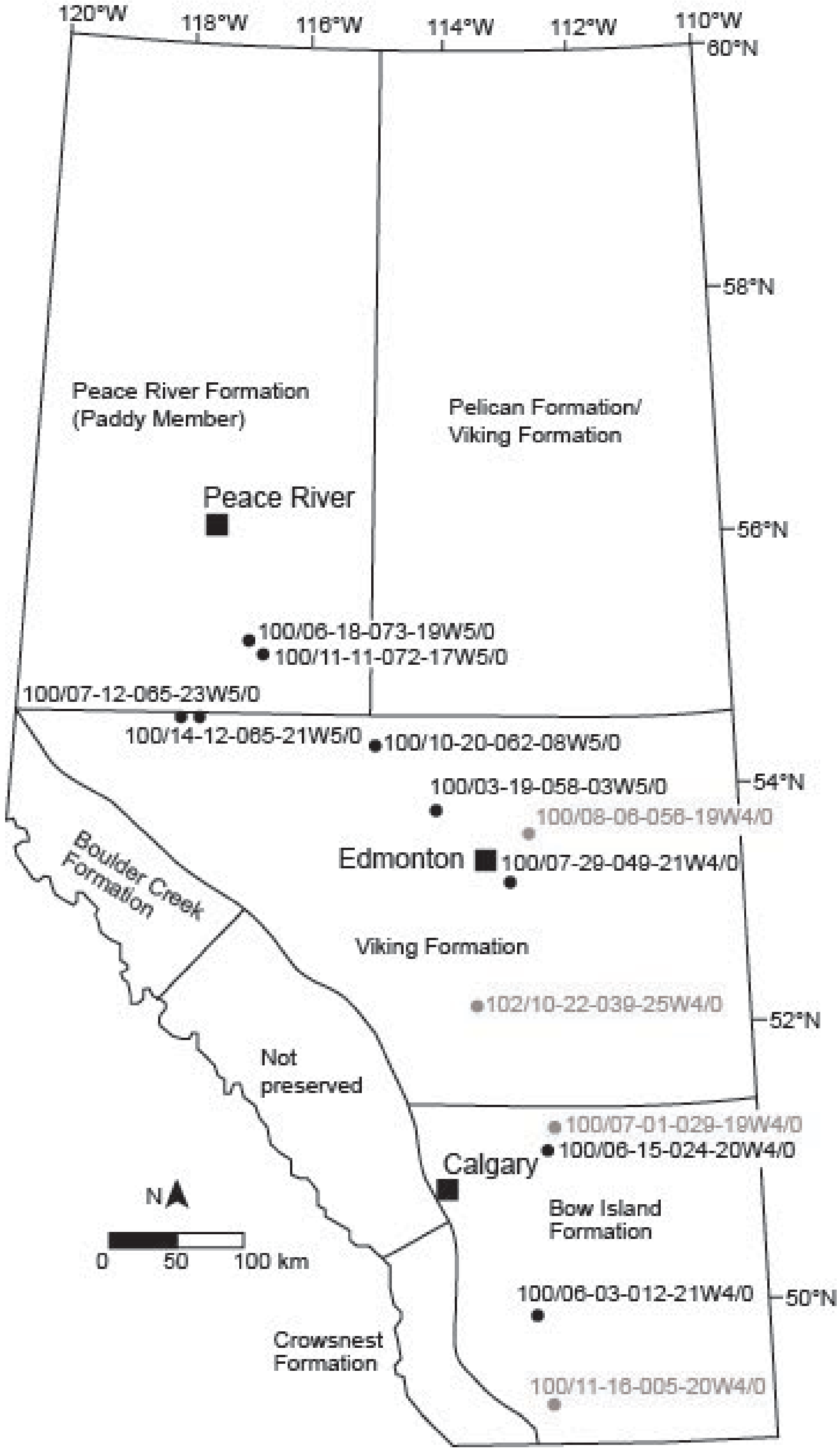

Figure 4. Locations of wells (black dot) sampled for the study. The geographic divisions from the Table of Formations (after Alberta Geological Survey, 2019) are superimposed on the map. Samples labelled in grey indicate samples that did not contain any usable zircon or apatite grains for dating. The Crowsnest Formation in southwestern Alberta is a volcanic unit and is a potential source of the ash that was sampled in the study.

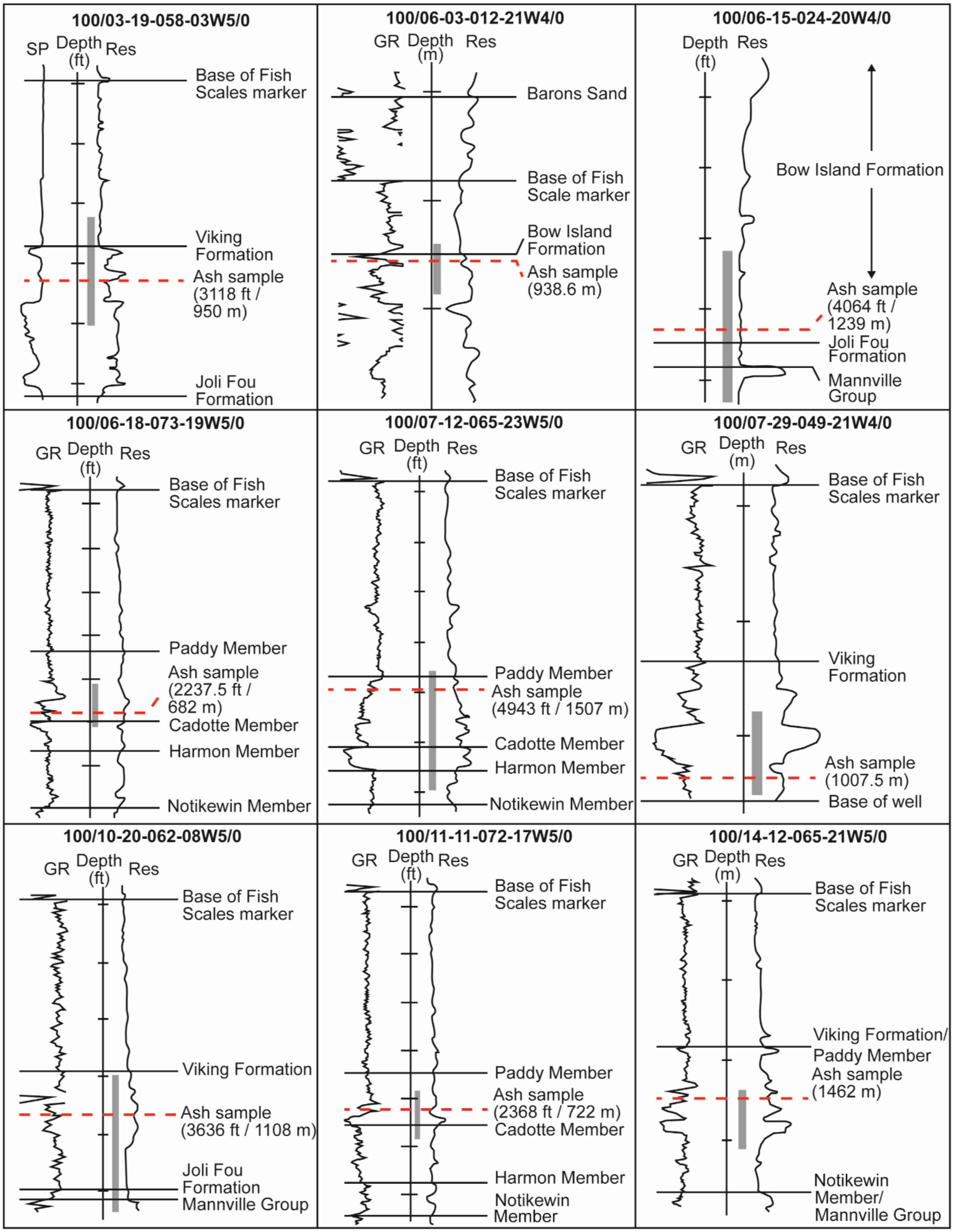

Figure 5. Location of sampled ash is indicated on geophysical well logs. The depth intervals indicated for the wells measured in feet is 25 ft. (7.6 m). The depth intervals indicated for the wells measured in metres is 25 m. Abbreviations: GR, gamma ray; Res, resistivity; SP, spontaneous potential.

Table 2. Location of samples selected for the study. The selected grains were mounted for U-Pb dating analysis. Some samples contained no usable zircon or apatite grains but were included in this table to show the intended sample distribution.

UWI	Latitude	Longitude	Formation	Depth	Zircon (est. abundance)	Apatite (est. abundance)
100/03-19-058-03W5/0	54.023034	-114.439355	Viking	950 m (3118 ft.)	Yes (10)	Yes (30)
100/06-03-012-21W4/0	49.967443	-112.791984	Bow Island	938.6 m	Yes (100)	Yes (10s)
100/06-15-024-20W4/0	51.043415	-112.717273	Bow Island	1239 m (4064 ft.)	Yes (10)	Yes (10)
100/06-18-073-19W5/0	55.320983	-116.916381	Peace River (Paddy Mb.)	682 m (2237.5 ft.)	Yes (100s)	Yes (100)
100/07-01-029-19W4/0	51.449695	-112.543774	Viking	1144.8 m	No	No
100/07-12-065-23W5/0	54.607615	-117.337730	Peace River (Paddy Mb.)	1507 m (4943 ft.)	Yes (5)	No
100/07-29-049-21W4/0	53.256684	-113.035520	Viking	1007.5 m	Yes (100)	N/A
100/08-06-056-19W4/0	53.809394	-112.807843	Viking	646.4 m	No	No
100/10-20-062-08W5/0	54.379380	-115.160574	Viking	1108 m (3636 ft.)	Yes (100)	N/A
102/10-22-039-25W4/0	52.371689	-113.514970	Viking	1476 m (4841 ft.)	No	No
100/11-11-072-17W5/0	55.224930	-116.506174	Peace River (Paddy Mb.)	722 m (2368 ft.)	Yes (100s)	Yes (100s)
100/11-16-005-20W4/0	49.387490	-112.644091	Bow Island	968 m (3175.1 ft.)	No	No
100/11-16-005-20W4/0	49.387490	-112.644091	Bow Island	985 m (3233 ft.)	No	No
100/14-12-065-21W5/0	54.614971	-117.039401	Viking/Peace River (Paddy Mb.)	1462 m	Yes (10)	No

2 Results

Four approaches to interpreting the analytical results were employed to provide insight into potential maximum depositional ages. The youngest single grain age (YSG) is a measure of the age of the youngest detrital zircon (Dickinson and Gehrels, 2009). The weighted mean average is calculated using the youngest 2-sigma grain cluster (YGC2s) methodology, which includes an internal and external error range of at least three grains (Dickinson and Gehrels, 2009). The Tau average dating method provides the maximum depositional age (MDA) of the zircon (Barbeau et al., 2009). The youngest graphical age peak (YPP), by contrast, is a determination of the youngest possible age (Dickinson and Gehrels, 2009).

The results of the four methods are summarized in Table 3 and presented graphically in Figures 6 to 8. The diagrams display the values for the YGS, YGC2s, Tau, and YPP calculations of MDA. Values for YGC2s were only provided when at least three usable zircon grains were available to include in calculations.

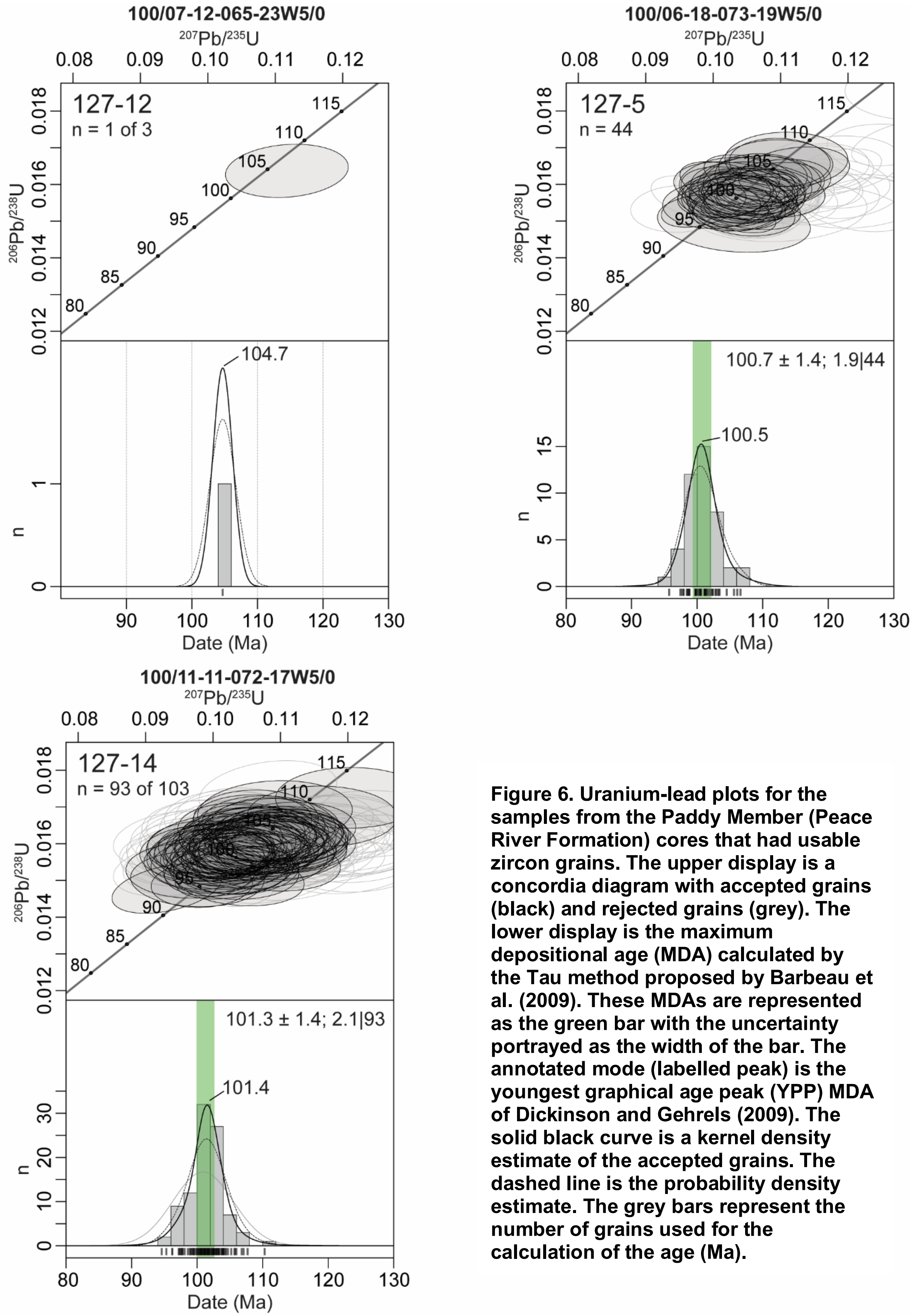

Figure 6. Uranium-lead plots for the samples from the Paddy Member (Peace River Formation) cores that had usable zircon grains. The upper display is a concordia diagram with accepted grains (black) and rejected grains (grey). The lower display is the maximum depositional age (MDA) calculated by the Tau method proposed by Barbeau et al. (2009). These MDAs are represented as the green bar with the uncertainty portrayed as the width of the bar. The annotated mode (labelled peak) is the youngest graphical age peak (YPP) MDA of Dickinson and Gehrels (2009). The solid black curve is a kernel density estimate of the accepted grains. The dashed line is the probability density estimate. The grey bars represent the number of grains used for the calculation of the age (Ma).

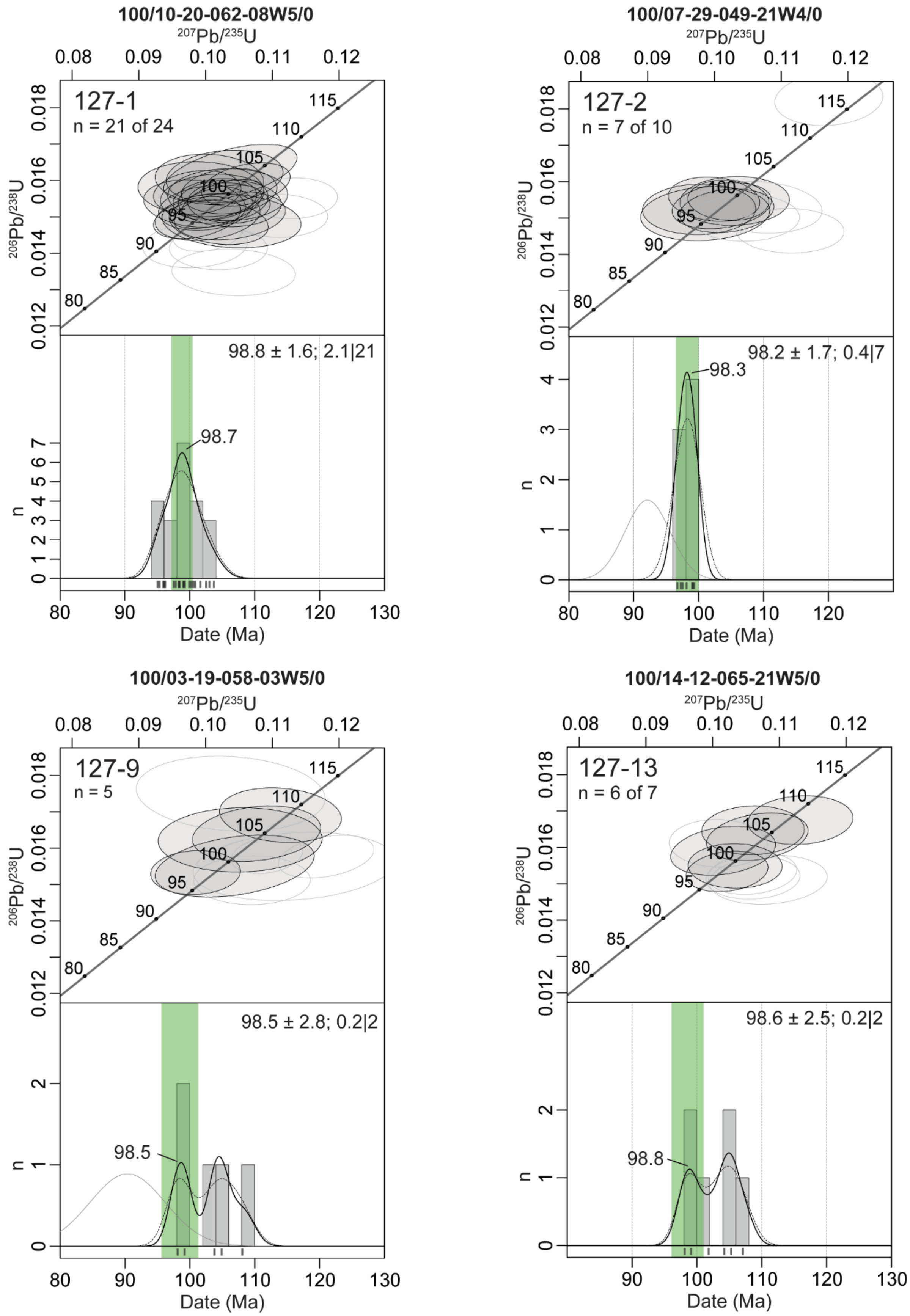
100/10-20-062-08W5/0
127-1
n = 21 of 24
98.8 ± 1.6; 2.1|21
98.7
100/07-29-049-21W4/0
127-2
n = 7 of 10
98.2 ± 1.7; 0.4|7
98.3
100/03-19-058-03W5/0
127-9
n = 5
98.5 ± 2.8; 0.2|2
98.5
100/14-12-065-21W5/0
127-13
n = 6 of 7
98.6 ± 2.5; 0.2|2
98.8
$^{207}Pb/^{235}U$
$^{206}Pb/^{238}U$
n
Date (Ma)

Figure 7. (previous page) Uranium-lead plots for the samples from Viking Formation cores that had usable zircon grains. The upper display is a concordia diagram with accepted grains (black) and rejected grains (grey). The lower display is the maximum depositional age (MDA) calculated by the Tau method proposed by Barbeau et al. (2009). These MDAs are represented as the green bar with the uncertainty portrayed as the width of the bar. The annotated mode (labelled peak) is the youngest graphical age peak (YPP) MDA of Dickinson and Gehrels (2009). The solid black curve is a kernel density estimate of the accepted grains. The dashed line is the probability density estimate. The grey bars represent the number of grains used for the calculation of the age (Ma).

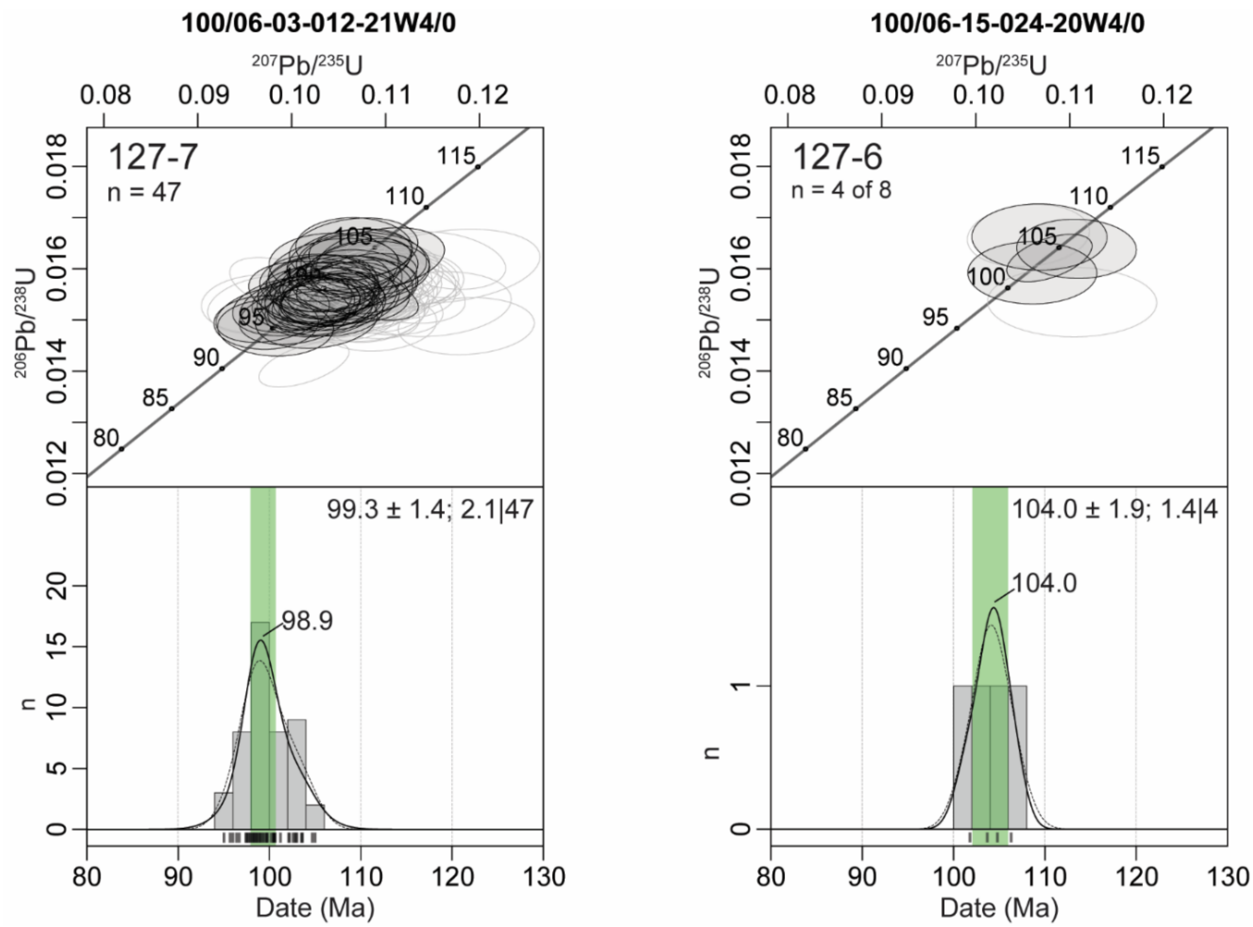

Figure 8. Uranium-lead plots for the samples from Bow Island Formation cores that had usable zircon grains (upper Bow Island Formation on the left and lower Bow Island Formation on the right). The upper display is a concordia diagram with accepted grains (black) and rejected grains (grey). The lower display is the maximum depositional age (MDA) calculated by the Tau method proposed by Barbeau et al. (2009). These MDAs are represented as the green bar with the uncertainty portrayed as the width of the bar. The annotated mode (labelled peak) is the youngest graphical age peak (YPP) MDA of Dickinson and Gehrels (2009). The solid black curve is a kernel density estimate of the accepted grains. The dashed line is the probability density estimate. The grey bars represent the number of sampled grains used for the calculation of the age (Ma).

Table 3. Ages of zircons from Albian strata. Abbreviations: $2s_{total}$ (Ma), 2-sigma error in millions of years; $2s_{total}$ (%), 2-sigma error in percent; Grain Count, number of grains used in the run; MDA, maximum depositional age; MSWD, mean square weighted deviation; n_{zircon}, number of zircon grains collected; Tau, average dating method; YGC2s, youngest 2-sigma grain cluster; YPP, youngest graphical age peak; YSG, youngest single grain.

UWI	Formation/ Member	n_{zircon}	YSG[1]			YGC2s[1]					Tau[2]					YPP[1]
			MDA (Ma)	$2s_{total}$ (Ma)	$2s_{total}$ (%)	MDA (Ma)	$2s_{total}$ (Ma)	$2s_{total}$ (%)	MSWD	Grain Count	MDA (Ma)	$2s_{total}$ (Ma)	$2s_{total}$ (%)	MSWD	Grain Count	MDA (Ma)
100/06-18-073-19W5/0	Paddy	44	95.7	4.3	4.5	100.2	1.3	1.3	1.0	38	100.7	1.4	1.4	1.9	44	100.5
100/07-12-065-23W5/0	Paddy	3	104.7	4.0	3.8											104.7
100/11-11-072-17W5/0	Paddy	103	94.6	3.7	3.9	99.8	1.3	1.3	1.0	55	101.3	1.4	1.3	2.1	93	101.4
100/10-20-062-08W5/0	Viking	24	95.0	3.4	3.6	98.1	1.4	1.5	1.2	17	98.8	1.6	1.6	2.1	21	98.7
100/07-29-049-21W4/0	Viking	10	96.7	4.0	4.2	98.2	1.7	1.8	0.3	7	98.2	1.7	1.8	0.4	21	98.3
100/03-19-058-03W5/0	Viking	5	98.1	3.4	3.4	101.0	5.6	5.6	3.2	4	98.5	2.8	2.9	0.2	2	98.5
100/14-12-065-21W5/0	Viking	7	98.1	3.1	3.2	100.5	4.5	4.5	2.9	4	98.6	2.5	2.5	0.2	2	98.8
100/06-15-024-20W4/0	Bow Island	8	101.8	3.4	3.3	104.0	1.9	1.9	1.4	4	104.0	1.9	1.9	1.4	4	104.0
100/06-03-012-21W4/0	Bow Island	47	95.0	3.1	3.3	98.6	1.3	1.3	1.0	35	99.3	1.4	1.4	2.1	47	98.9

[1]Dickinson and Gehrels (2009)
[2]Barbeau et al. (2009)

2.1 Peace River Formation (Paddy Member) Ages

The Paddy Member of the Peace River Formation was sampled from core from four wells in west-central Alberta. Two of these wells occur on the lateral transitional boundary between the Paddy Member and the Viking Formation. The ages from the 100/14-12-065-21W5/0 well sample fall closer to ages from the Viking Formation samples thus well 100/14-12-065-21W5/0 is included in Section 2.2, “Viking Formation Ages.” The ages and error margins are summarized in Table 3 and presented graphically in Figure 6. The YSG MDA calculated values include 104.7 ±4.0, 95.7 ±4.3, and 94.6 ±3.7 Ma. The YGC2s weighted mean average MDA calculated values include 100.2 ±1.3 and 99.8 ±1.3 Ma. The weighted mean average MDAs were calculated by the Tau method and include 101.3 ±1.4 and 100.7 ±1.4 Ma. The YPP MDA calculated values include 104.7, 101.4, and 100.5 Ma.

2.2 Viking Formation Ages

The Viking Formation was sampled from core from three wells in central Alberta. Also included in this section are the results for a sample from well 100/14-12-065-21W5/0 that falls on the lateral transitional boundary between the Paddy Member and the Viking Formation. The ages and error margins are summarized in Table 3 and presented graphically in Figure 7. The YSG MDA calculated values include 98.1 ±3.4, 98.1 ±3.1, 96.7 ±4.0, and 95.0 ±3.4 Ma. The YGC2s weighted mean average MDA calculated values include 101.0 ±5.6, 100.5 ±4.5, 98.2 ±1.7, and 98.1 ±1.4. The weighted mean average MDAs were calculated by the Tau method and include 98.8 ±1.6, 98.6 ±2.5, 98.5 ±2.8, and 98.2 ±1.7 Ma. The YPP MDAs were calculated at 98.8, 98.7, 98.5, and 98.3 Ma.

2.3 Bow Island Formation Ages

The Bow Island Formation was sampled at two stratigraphic intervals—the lower and upper Bow Island Formation—in the core from two wells. Core from an additional well (100/11-16-005-20W4/0) was sampled in the middle and upper Bow Island Formation, however, no usable zircon grains were available for analysis. The results are summarized in Table 3 and presented graphically in Figure 8.

The YSG MDA for the lower Bow Island Formation was 101.8 ±3.4 Ma. The weighted mean average MDA using the YGC2s calculation and the Tau method both yielded similar results of 104.0 ±1.9 Ma. The YPP MDA for the lower Bow Island Formation is 104.0 Ma.

The upper Bow Island Formation had a YSG MDA calculated at 95.0 ±3.1 Ma. The weighted mean average MDA using the YGC2s calculation is 98.6 ±1.3 Ma. The Tau method weighted mean average MDA is 99.3 ±1.4 Ma. The YPP MDA for the upper Bow Island Formation is calculated to be 98.9 Ma.

3 Summary

Samples were collected from 14 discrete ash bed intervals in the Peace River, Viking, and Bow Island formations. Of these samples, only nine yielded usable zircon grains for U-Pb dating analysis. Maximum depositional ages for each sample were calculated using four methods: (i) youngest single grain; (ii) youngest 2-sigma grain cluster; (iii) average depositional age (Tau method); and (iv) youngest graphical age peak. Error margins for each calculation technique are provided in millions of years and as a percentage.

The purpose of this study was to assign a more refined depositional age to Upper Albian units and to potentially adjust their age boundaries on the Alberta Table of Formations. Although the ages of the Viking Formation are younger than the current upper limit of 101 Ma, the error margins associated with the U-Pb dates would still place the deposits close to the 101 Ma boundary. Therefore the units’ age boundaries on the Table of Formations will not be changed at this time but re-evaluated when pertinent additional data become available from other studies. Nevertheless, this study provides important new geochronological data for Upper Albian deposits across Alberta and generally confirms the biostratigraphic ages previously determined for these deposits.

4 References

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