DETRITAL ZIRCON MAXIMUM DEPOSITIONAL DATES FOR THE JURASSIC CHINITNA AND NAKNEK FORMATIONS, LOWER COOK INLET, ALASKA: A PRELIMINARY VIEW

Trystan M. Herriott, Marwan A. Wartes, Paul B. O'Sullivan, and Robert J. Gillis

Preliminary Interpretive Report 2019-5

Oblique aerial view east-southeastward across the head of Oil Bay. Strata exposed along the shoreline and uplands near Oil Bay comprise Jurassic forearc basin units of lower Cook Inlet. Detrital zircon samples collected from sandstone beds that crop out above the tidal flats at photograph-center are the subject of this report. The east shore of Oil Bay (visible below skyline-center) is ~4 km long, for sense of scale. See figure 1 for further context. Photograph by T.M. Herriott.

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DETRITAL ZIRCON MAXIMUM DEPOSITIONAL DATES FOR THE JURASSIC CHINITNA AND NAKNEK FORMATIONS, LOWER COOK INLET, ALASKA: A PRELIMINARY VIEW

Trystan M. Herriott,[1] Marwan A. Wartes,[1] Paul B. O'Sullivan,[2] and Robert J. Gillis[1]

INTRODUCTION

The Alaska Division of Geological & Geophysical Surveys leads a basin analysis program in Cook Inlet of south-central Alaska. This program aims to improve understanding of the region's petroleum geology and includes work in the Iniskin Bay–Tuxedni Bay area of lower Cook Inlet (Gillis, 2013, 2014; Wartes, 2015; Herriott, 2016; fig. 1). A major focus of these studies is the Jurassic forearc stratigraphy, which hosts the basin's oil source rocks (LePain and others, 2013). Robust biostratigraphic constraints provide temporal context for this economically significant Jurassic succession (for example, Detterman and Westermann, 1992), although no modern radioisotopic dates are available to render absolute age control.

Chronostratigraphy is an integral part of basin analysis, and geochronologic dates are commonly obtained to refine existing frameworks that have historically relied on paleontologic collections. Primary volcanic strata that could directly establish depositional ages are generally not recognized in the Jurassic forearc stratigraphy that crops out along the Iniskin–Tuxedni trend. Fortunately, sediment supplied to the basin during the Jurassic was sourced from the contemporaneously active Talkeetna arc (Trop and Ridgway, 2007; LePain and others, 2013). In light of this, we collected detrital zircon samples from Jurassic forearc strata in the study area to determine maximum depositional ages (Gehrels, 2014). This report presents uranium–lead (U–Pb) detrital zircon dates for the Chinitna and Naknek Formations, permitting insights into the depositional ages of these units and revealing discrepancies between this new geochronology and the long-established biostratigraphy and/or the current geologic time scale.

GEOLOGIC CONTEXT

Cook Inlet is a long-lived forearc basin that hosts a thick Jurassic–Cenozoic stratigraphic record (Fisher and Magoon, 1978; LePain and others, 2013). The Middle Jurassic Tuxedni Group lies at or near the base of this stratigraphy and is overlain by the Middle Jurassic Chinitna Formation and Upper Jurassic Naknek Formation (LePain and others, 2013; fig. 1). The Chinitna and Naknek comprise marine forearc strata that crop out extensively in the Iniskin–Tuxedni area (Detterman and Hartsock, 1966; fig. 1). The Chinitna is typically ~700 m thick and includes Tonnie Siltstone Member and Paveloff Siltstone Member (Detterman and Hartsock, 1966; Herriott and others, 2018). The Naknek is commonly ~1500 m thick, comprising the Chisik Conglomerate Member, lower sandstone member (informal), Snug Harbor Siltstone Member, and Pomeroy Arkose Member (Detterman and Hartsock, 1966; Herriott and others, 2017).

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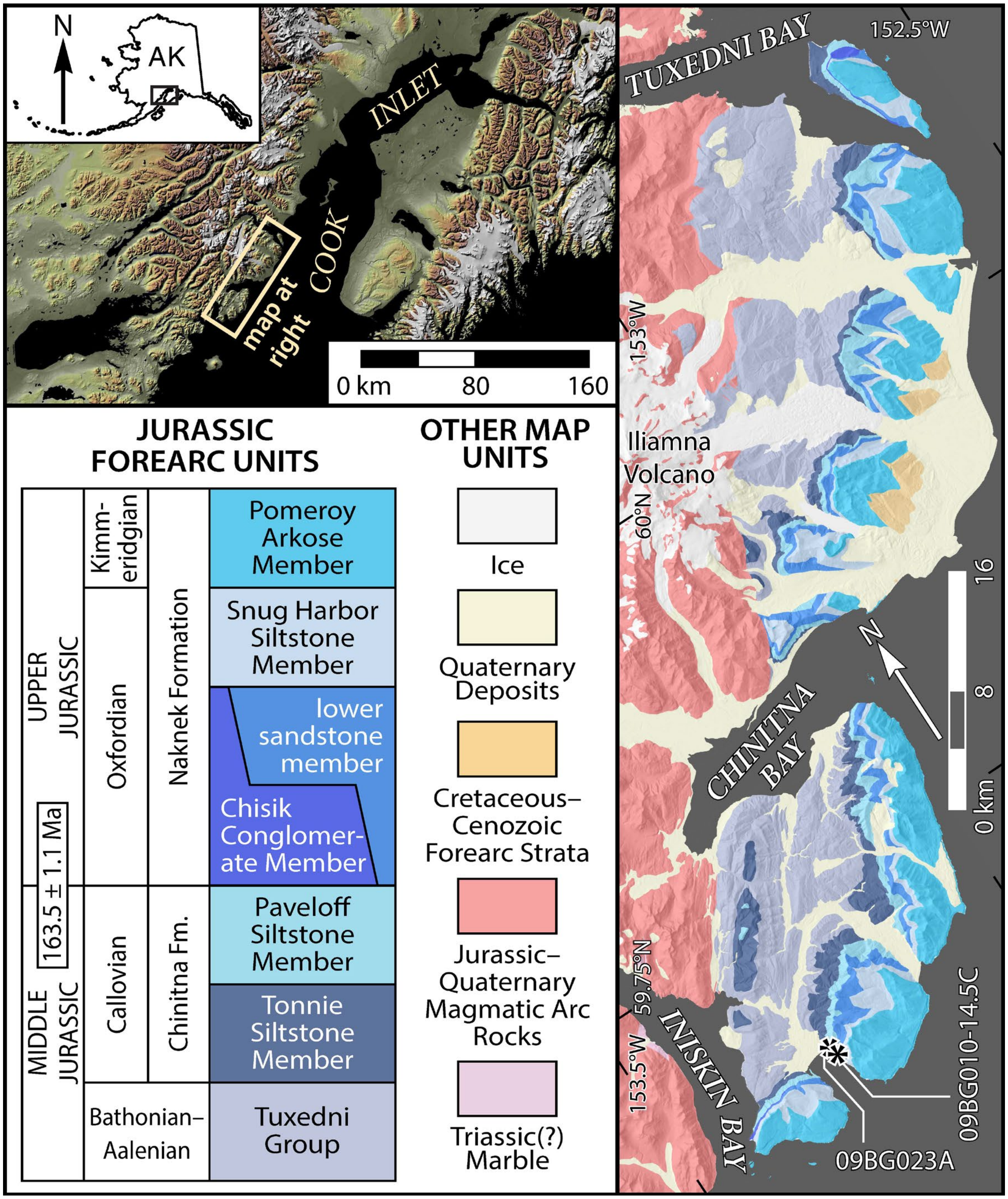

Figure 1. Location map of lower Cook Inlet, including geology of the Iniskin Bay–Tuxedni Bay study area. Geology of the Chinitna and Naknek Formations is by the authors. Simplified geology of the Tuxedni Group and parts of the magmatic arc is by the authors and colleagues; simplified geology of the Iliamna Volcano summit area and region southwest of Iniskin Bay is adapted from Wilson and others (2012). Stage assignments for Jurassic forearc units are from Detterman and Westermann (1992). Date at Middle–Upper Jurassic boundary is from Gradstein and others (2012).

The ammonite-based biostratigraphy indicates that Paveloff Siltstone Member is Callovian (Imlay, 1975) and that lower sandstone member is Oxfordian (Imlay, 1981), bracketing the Middle–Late Jurassic transition (fig. 1; see Detterman and Westermann, 1992). Detrital zircon samples collected from shallow-marine strata near the base of Paveloff and from the lowermost part of lower sandstone are the subject of this report.

METHODS

We conducted laser ablation-inductively coupled plasma mass spectrometry (LA-ICPMS) U–Pb detrital zircon geochronology of two sandstone samples from Oil Bay (fig. 1). Samples were prepared and analyzed by GeoSep Services, following the LA-ICPMS analytical methods described by Bradley and O'Sullivan (2017; see analytical methods II). Sample descriptions are presented in appendix 1.

U–Pb dates from the Paveloff and lower sandstone samples are used to establish what we refer to as maximum depositional *dates*. This distinction emphasizes that laboratory reports present *dates*, and *ages* are derived from dates that interpreters ascribe geologic significance (Schoene, 2014). Three maximum depositional dates were determined for each sample (after Dickinson and Gehrels, 2009): youngest single grain (YSG); youngest mode of the kernel density estimation (YMKDE); and weighted mean of the youngest cluster of grains (n≥3) that overlap at 2σ uncertainty (YC2σ).

Kernel density estimations were plotted in IsoplotR (Vermeesch, 2018), setting kernel bandwidth to calculated (default) values and permitting independent (per sample) and adaptive modulation. The youngest mode (in other words, peak) for each sample was carefully picked graphically and rounded to the nearest 0.5 Ma. YC2σ selection and cutoff criteria for each sample were set by the minimum date plus 2σ value (Sharman and others, 2018). Weighted mean dates and mean square weighted deviation and probability of fit values were calculated with Isoplot (Ludwig, 2012). Reported uncertainties for weighted mean dates are 2σ internal values of Ludwig (2012) and thus only reflect uncertainty propagated from individual dates. However, systematic sources of uncertainty may limit these weighted mean results to being no more precise than ~±2% (2σ) (Chang and others, 2006; see also Horstwood and others, 2016).

RESULTS AND MAXIMUM DEPOSITIONAL DATES

Nearly all detrital zircon dates in this study are Jurassic (n=219/220), with only one latest Triassic date (fig. 2). See appendix 1 for isotopic ratios, dates, and additional LA-ICPMS data. Maximum depositional dates for Paveloff and lower sandstone are illustrated in figure 2 and summarized in table 1. YSG constraints are significantly younger than the YC2σ determinations that are in turn younger than the YMKDE results. The context and significance of these maximum depositional dates are presented below.

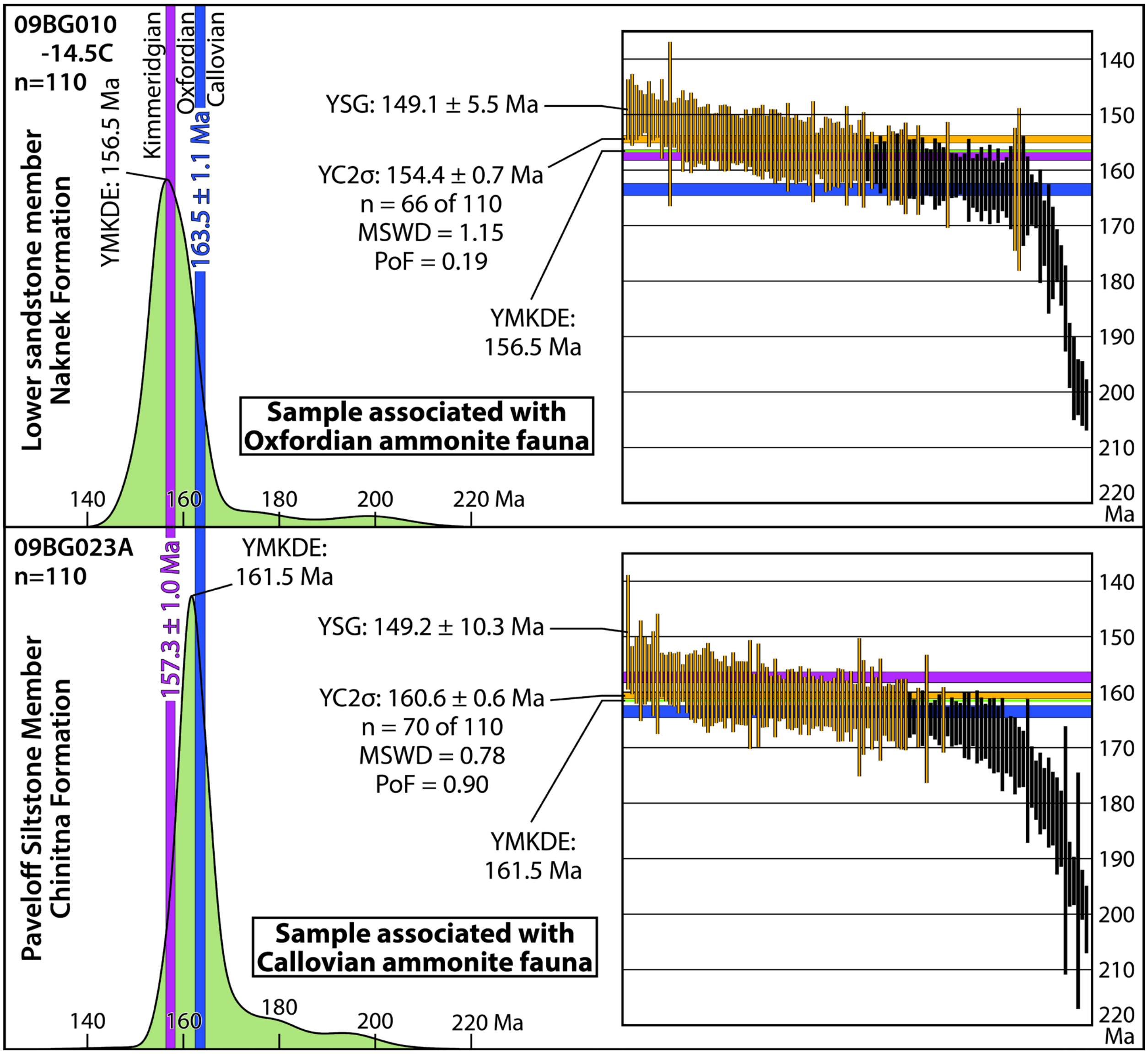

Figure 2. Normalized kernel density estimation plots (left) and ranked date plots (right; vertical bars are individual dates reflecting 2σ confidence intervals) for U–Pb detrital zircon dates from Paveloff Siltstone Member and lower sandstone member. Note the three maximum depositional date determinations for each sample and their relations to stage boundaries (from Gradstein and others, 2012; see blue and purple bars); the youngest kernel density estimation mode date (YMKDE) for each sample is also depicted on the ranked date plots for comparison (see green bars). Individual grain dates highlighted in light orange are included in the youngest 2σ cluster weighted mean dates (YC2σ; reported uncertainty is 2σ internal [see text and Ludwig, 2012]). Bars for stage boundaries and YC2σ dates are scaled to thicknesses that reflect reported uncertainties. Ammonite fauna associations noted in bold type are after Detterman and Westermann (1992). Kernel density estimations were plotted in IsoplotR, an R-based application (Vermeesch, 2018); ranked date plots were plotted in KDX, a Java-based application (Spencer and others, 2017). Additional abbreviations: MSWD—mean square weighted deviation; n—sample size; PoF—probability of fit; YSG—youngest single grain.

Table 1. Summary of maximum depositional dates for Paveloff Siltstone Member (Chinitna Formation) and lower sandstone member (Naknek Formation). Relative stratigraphic position is meters above base of Paveloff at Oil Bay, where the unit is ~333 m thick (Herriott and Wartes, 2014). Dates reported in Ma (mega-annum before present). Abbreviations: MSWD—mean square weighted deviation; n—sample size; PoF—probability of fit; YC2σ—youngest 2σ cluster (weighted mean; reported uncertainty is 2σ internal); YMKDE—youngest kernel density estimation mode; YSG—youngest single grain.

Stratigraphic Unit	Relative Stratigraphic Position (meters)	n	YSG		YMKDE	YC2σ (n≥3 grains)				
			Date	±2σ	Date	Date	±2σ	n	MSWD	PoF
lower sandstone	345	110	149.1	5.5	156.5	154.4	0.7	66	1.15	0.19
Paveloff	25	110	149.2	10.3	161.5	160.6	0.6	70	0.78	0.90

DISCUSSION

A major goal of this work is to establish independent age constraints for the sampled stratigraphy. The existing chronostratigraphic framework for the Jurassic forearc basin of lower Cook Inlet is based on biostratigraphic associations within the context of the geologic time scale. The new maximum depositional dates of this study are invariably younger than the existing chronostratigraphy suggests. These discrepancies range from several million years to potentially greater than ~10 million years (fig. 2; refer also to Herriott and others, 2017). Additionally, selecting a preferred maximum depositional date from detrital zircon results is a nontrivial but critical undertaking (see Coutts and others, 2019) and has implications for how old Paveloff and lower sandstone are interpreted to be.

The YSG method is a straightforward approach that appears to directly acknowledge that a sedimentary rock cannot be older than the youngest detrital zircon that it contains (Houston and Murphy, 1965). Unfortunately, analytical, systematic, and geologic sources of uncertainty undermine the utility and accuracy of YSG determinations (see Schaltegger and others, 2015). A marked benefit for both the YMKDE and YC2σ methods is that they rely on larger sample sizes. A limitation of the YMKDE approach is that the sample size may become too large if the peak includes older detrital constituent dates that are statistically inconsistent with a single young population (see criteria of Spencer and others, 2016). Furthermore, density estimation mode dates are not accompanied by an uncertainty value, and uncertainty is probably the most significant consideration in evaluating detrital zircon maximum depositional dates. Dickinson and Gehrels (2009) describe the YC2σ method as their "most statistically robust" measure of detrital zircon maximum depositional age. The YC2σ approach simply recognizes that any variability of true age within the sub-sample of zircon is not resolved at 2σ uncertainty. Mean square weighted deviations for each YC2σ population sample of this study are consistent with single populations (Spencer and others, 2016, 2017) but remain notably young with respect to existing constraints (fig. 2).

The challenge of selecting preferred detrital zircon maximum depositional dates is not unique to this study. Rather, our challenge is underscored by a too-young “problem” that can be either amplified or diminished by selecting one maximum depositional date determination or another. Furthermore, the discrepancies described here may reflect uncertainty in biostratigraphic correlations and/or the geologic time scale itself (see Schmitz, 2018). However, we also cannot preclude that systematic uncertainty (for example, matrix effects; see Allen and Campbell, 2012) or geologic uncertainty (for example, Pb-loss) may subtly but critically impact the LA-ICPMS data (see Schoene, 2014). It is also noteworthy that the data presented here are not alone in rendering maximum depositional constraints for Jurassic forearc units in southern Alaska that are ostensibly too young. In fact, detrital zircon dates from the Naknek Formation of the Alaska Peninsula (Finzel and Ridgway, 2017) and Talkeetna Mountains (Reid and others, 2018; Stevens Goddard and others, 2018) similarly yielded results that are in many cases younger than biostratigraphic relations tied to the geologic time scale readily permit.

The value of detrital zircon U–Pb dates from convergent margin strata is clearly demonstrated by several recent studies (for example, Daniels and others, 2018; Englert and others, 2018; Coutts and others, 2019). There is also excellent potential for detrital zircon data to constrain stratigraphic correlations between well studied outcrops and subsurface geology in resource-bearing basins (see Wainman and others, 2018). In detail, however, the questions raised in this report and by other Jurassic detrital zircon datasets in southern Alaska are effectively intractable without independent and, ideally, high-precision geochronology (for example, U–Pb chemical abrasion-thermal ionization mass spectrometry). Ultimately, the detrital zircon dates presented here were the impetus for the companion study by Herriott and others (2019), which explicitly aimed to resolve the problematic relations noted herein and are undoubtedly not exclusive to Jurassic forearc strata of southern Alaska. The work by Herriott and others (2019) independently establishes high-precision maximum depositional ages for all members of the Chinitna and Naknek Formations, highlights the complexities of obtaining and interpreting LA-ICPMS geochronologic data, and provides practical recommendations for applying detrital zircon geochronology as a chronostratigraphic tool in Meso–Cenozoic sedimentary basins.

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APPENDIX 1

Detrital Zircon Sample Descriptions

09BG010-14.5C: Lower sandstone member (informal), Naknek Formation—Very coarse-grained sandstone from ~11.5 meters above base of member. Sample collected from a very thick bed near the top of a ~12-m-thick, coarsening- and thickening-upward package of shallow-marine strata that is consistent with deltaic sedimentation. Sample locality lies along the east shore of Oil Bay; note that location coordinates (N59.66258° W153.27545° [NAD83]) are tied to the base of a measured section that lies 14.5 m stratigraphically below the sampled bed. See Wartes and others (2013, 2015), Herriott and Wartes (2014), and Herriott and others (2017) for additional detailed descriptions of lower sandstone member.

09BG023A: Paveloff Siltstone Member, Chinitna Formation—Fine-grained, thin-bedded sandstone from ~25 m above base of member. Sample collected from a dark-gray-brown and gray-green weathering sandy siltstone and very fine-grained sandstone succession that likely records shelfal sedimentation. Sample locality (N59.66939° W153.28048° [NAD83]) lies along the east shore of Oil Bay. See Herriott and Wartes (2014), Wartes and Herriott (2015) and Herriott and others (2016, 2018) for additional detailed descriptions of Paveloff Siltstone Member.

Detrital Zircon U–Pb Geochronology Data Tables

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