Geochronology of the DNM 16 Quarry

Electronic Supplementary Material 1 for:

“First complete sauropod dinosaur skull from the Cretaceous of the Americas and the evolution of sauropod dentition”

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In the absence of diagnostic fossils and recognizable ash horizons, the age of DNM 16 was assessed by U-Pb detrital zircons dates obtained via Laser Ablation Multicollector Inductively Coupled Plasma Mass Spectrometry (LA-MC-ICPMS). Utilization of detrital zircons assumes that fluvial systems incorporate crystals from an array of ash fall events and that the youngest peak age in a given sample approximates the time of deposition (Greenhalgh and Britt 2007). Detrital zircon samples were collected from two horizons at DNM 16; the quarry sandstone and a smectitic mudstone beneath that sandstone. Dates obtained from the mudstone zircons indicate that the *Abydosaurus* bonebed and basal Mussentuchit Member of the Cedar Mountain Formation are no older than 104.46 ± 0.95 Ma.

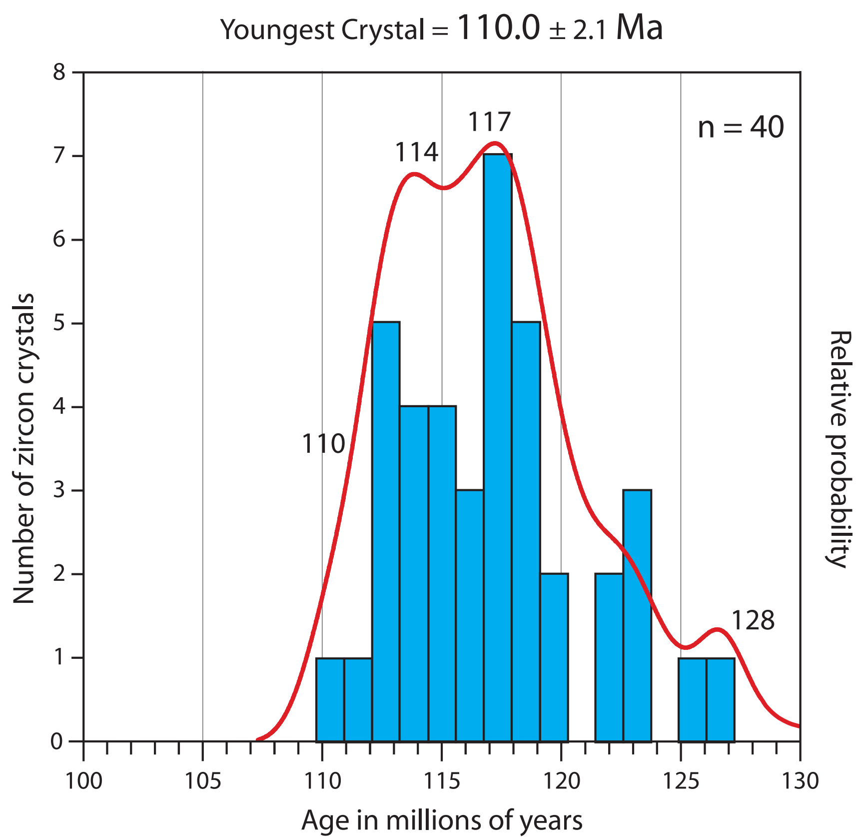
Methods

Two samples, DNMZ-16 and PV1, were processed by standard zircon extraction techniques at Brigham Young University. Samples were prepared by crushing in a roller mill, heavy mineral concentration on a Wilfley table, followed by tetrabromoethane flotation separation, and magnetic separation. Zircon crystals were selected from the concentrate under 10–30x magnification using a binocular microscope. Because our goal is to determine the age of deposition (maximum depositional age), we deviated from standard detrital zircon methods and selected only the most pristine (unabraded) crystals. Crystals were mounted in a 1 inch puck and polished to expose their interior. U-Pb geochronology of the zircon crystals was conducted by Laser Ablation Multicollector Inductively Coupled Plasma Mass Spectrometry (LA-MC-ICPMS) at the

Arizona LaserChron Center, University of Arizona, Tucson. A single spot was analyzed on each crystal with a laser beam diameter of 35 microns. The analytical methods follow those provided in Gehrels et al. (2006, 2008) and provides reproducibility of 1–2% and age accuracy of 1% or better at the 2 sigma level (Gehrels et al. 2008).

Results & Discussion

Detrital zircons were recovered from two samples in order to determine the age of the quarry horizon. Analytical results from these samples are provided in ESM 2.



ESM1 Figure 1. Relative age probability plot of single crystal detrital zircon U/Pb dating of sample DNMZ-16, which comes from the bone-bearing sandstone. The youngest crystal dates to 110.0 ± 2.1 Ma. See ESM 2 for data.

Sample DNMZ-16 is from the quarry matrix itself, a sandstone described earlier. Sample PV-1 is from a highly smectitic mudstone that is incised by a lateral equivalent of the bone-bearing sandstone, about 40 meters southeast of the quarry. Because the sole purpose of these analyses is to determine approximate time of deposition, only Cretaceous-aged crystals are considered here, but there were only two pre-Cretaceous crystals in each of the samples (see ESM 2). Forty crystals exhibiting little to no abrasion were analyzed from DNMZ-16. The probability density plot routine of Isoplot 3.71 (Ludwig, 2003) yields two overlapping probability peaks at circa 114 and 117 Ma (ESM1 Fig. 1). An older peak at about 126 Ma is also present and corresponds to the circa 125 Ma ages recovered from the basal Cedar Mountain Formation (Greenhalgh and Britt 2007). The youngest crystal dates to about 111 Ma while the youngest probability peak conservatively provides a depositional age no older 114 Ma. Ages yielded by PV-1, however, demonstrate that dates recovered from DNMZ-16 were sourced from older strata and substantially predate the time of deposition. PV-1, from the mudstone below the quarry sandstone, contains abundant euhedral crystals with little or no evidence of abrasion and multiple age peaks (see Text Fig. 2b). Sixty three of these crystals were analyzed yielding a number of peaks, indicating the mudstone includes zircons reworked from multiple, Early Cretaceous volcanic ash falls. To determine the time of deposition, age data were analyzed via the AgePick routine of Gehrels et al. (2008), which yields a conservative (older) age of about 108.3 ±2.3 Ma. The youngest probability density plot peak at 104.62 Ma, was obtained by Isoplot 3.71 (Ludwig 2003), based on three crystals, whose weighted average ages is 104.46 ± 0.95 Ma with probability fit of 0.99 and a confidence of 0.93% based on 2 sigma internal errors. We take this date to be the maximum depositional age of the basal Mussentuchit Member and the DNM-16 bonebed – the actual time of deposition could be younger. The crystals, of course, date the time of zircon crystallization in the magmatic source, which is here assumed to be close to the time of eruption and deposition. The recovered ages show detrital zircon U-Pb age strengths (the ability to determine the maximum depositional ages of units lacking recognizable volcanic ash horizons) and weaknesses (1. the ages must be understood to the maximum ages of the horizons -- the date of deposition could be younger; 2. reworked crystals usually outnumber younger crystals or younger crystals may not be present in the sample size – as in DNMZ-16; 3. multiple superimposed horizons must be dated so that reworking can be recognized). At the DNM-16 quarry, the recovered geochronological data show conclusively that the bonebed is no older than 104.46 ± 0.95 Ma (Albian). These data, combined with dates of about 98 Ma (Cifelli et al., 1997; Garrison et al., 2007) from the upper horizons of the Mussentuchit Member of the Cedar Mountain Formation farther to the south indicate that *Abydosaurus* certainly dates to the latter part of the middle Albian.

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