Excavation and Identification of the Geologically Oldest Sauropod Dinosaur Skeleton in North America: Implications for the Origin and Evolution of Sauropods

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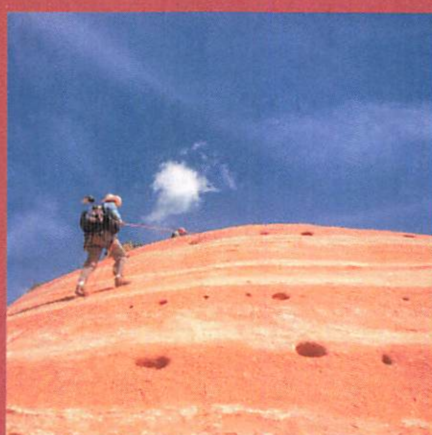

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INTRODUCTION

The first dinosaur discovered in Utah, the sauropod *Dystrophaeus viaemalae*, was found in 1859 by J. S. Newberry in East Canyon, San Juan County, Utah. The specimen is from the lower Tidwell Member of the Upper Jurassic Morrison Formation (~160 mya) and is the only sauropod known from this member; it is therefore older than the diverse fauna of sauropods from higher levels of the Morrison Formation and from the Cretaceous formations of North America. The specimen is therefore critical to understanding the origins and evolution of sauropod dinosaurs in North America. A few elements of this animal were excavated by Newberry in 1859; the site was relocated in 1989 by Moab naturalist Fran Barnes and some surface bone fragments were collected at that time. We revisited the site in 1998, and then, thanks to a Discovery Pool Grant from the Canyonlands Natural History Association, returned during the field seasons of 2014 and 2015 and collected approximately 29 large and small field jackets containing bones in the host matrix sandstone, an amount occupying approximately two cargo pallets.

BACKGROUND

In 1859, Captain J. N. Macomb led a U.S. Army engineering survey from Santa Fe, New Mexico, to the confluence of the Colorado and Green rivers. Along the way, the group camped in what is now East Canyon, south of Moab, in August. During their stay, expedition geologist J. S. Newberry discovered several bones of a sauropod in the rocks above the Entrada Sandstone cliffs on the north side of the canyon near the camp. He admitted in his report that they were ill equipped to excavate these bones, although they removed several (Newberry, 1876; Brinkman, 2005, 2010). He also mentioned that there were bones still in the ground that they were unable to remove upon their departure. Paleontologist E. D. Cope (1877) named the animal *Dystrophaeus viaemalae* soon after the Newberry report, and von Huene (1904) later further described the material, comparing it to the Middle Jurassic sauropod *Cetiosaurus* from the United Kingdom. The site was relocated in 1988 (Barnes, 1990, 1997), and additional surface material was collected again shortly after that, in September 1989. Gillette (1996a) re-illustrated the type material now at the Smithsonian Institution, which consists mostly of forelimb material (slender ulna, partial radius, and metacarpals), a cast of which is on display at the Museum of Moab. The excavation site is being considered for placement on the National Register of Historic Places.

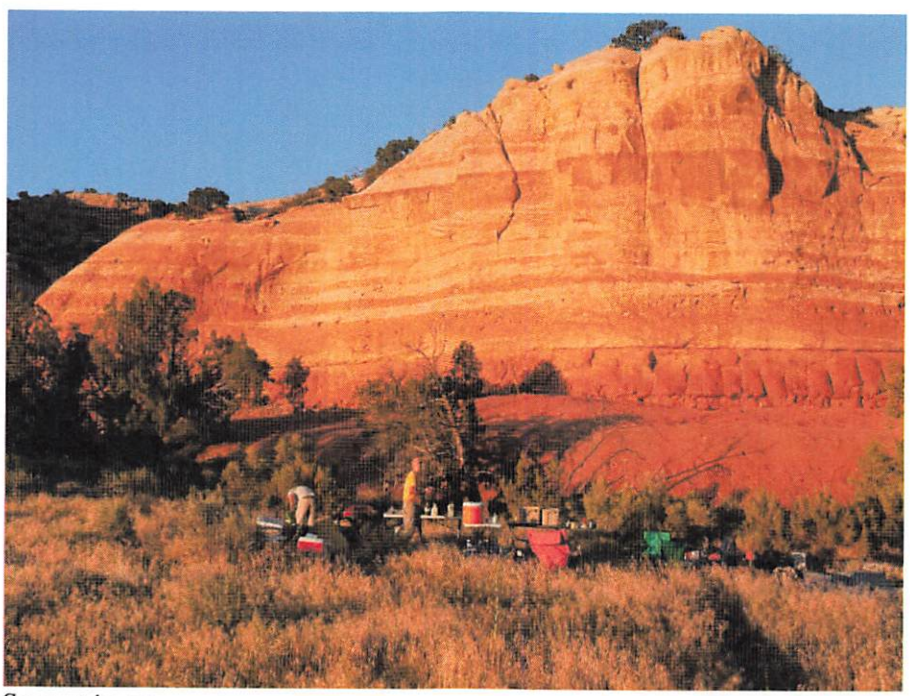
View of Dystrophaeus *site in 1998. Pit visible on left half of photo.*

Bones and tracks of prosauropods have been found in many areas of Upper Triassic to Lower Jurassic rock exposures in the western United States, so the existence of sauropodomorphs on this continent from earliest dinosaur times is well established. However, true sauropods do not have a good record in North America until the Late Jurassic, during deposition of the Salt Wash and Brushy Basin members of the Morrison Formation. The sauropod fauna of the Morrison Formation includes taxa such as *Apatosaurus*, *Diplodocus*, *Camarasaurus*, *Brachiosaurus*, *Barosaurus*, and *Haplocanthosaurus*, the first three of which are relatively common, with the latter three rare (Dodson et al., 1980; Foster, 2003). All of these taxa are known from the Salt Wash Member or higher. *Dystrophaeus* is the only identifiable sauropod specimen known from below the Salt Wash in the Tidwell Member. Unidentifiable sauropod material reported by Armstrong and McReynolds (1987) as being approximately 12 m above the Entrada Sandstone in Colorado National Monument would be from the middle of the Tidwell Member, whereas the *Dystrophaeus* material came from 2.5–3.0 m above the base of the Tidwell (in a local Tidwell section 10 m thick; Gillette, 1996b). As such, it is the geologically oldest sauropod skeleton in North America.

At the time of Gillette's (1996b) report no evidence of sauropods had been found stratigraphically below the *Dystrophaeus* East Canyon quarry. There were thus several hypotheses concerning the origin of sauropods in North America. What was apparent was that despite the presence of prosauropods in North America during the Triassic (evidenced by tracks), true sauropods appear to have originated elsewhere and dispersed to North America sometime before or at the very beginning of the Late Jurassic. *Dystrophaeus* then seems to have been possibly ancestral to some of the Morrison Formation sauropods of the later Late Jurassic. The question was whether the arrival of sauropods in North America occurred before or after the beginning of the Late Jurassic (and the base of the Morrison Formation, marked by the J-5 unconformity). It is now clear, based on an unequivocal sauropod trackway from the upper Entrada Sandstone in Grand Staircase-Escalante National Monument, Utah, that sauropods arrived before the end of the Middle Jurassic (i.e., before the time of deposition of the Tidwell and before the J-5 unconformity) and were thus present on this continent before *Dystrophaeus*'s time (Foster et al., 2000). But trackways cannot tell us more than that sauropods were present; if we want to know how these sauropods related to later North American sauropods, and to the original populations from other parts of the world from which these first North American sauropods emigrated, we need to study fossilized skeletal material. But limb elements reveal a limited amount of taxonomically useful data. We need more diagnostic material, such as vertebrae or skull elements, in order to unravel the mystery of the origins and later evolution of these keystone species of the Jurassic.

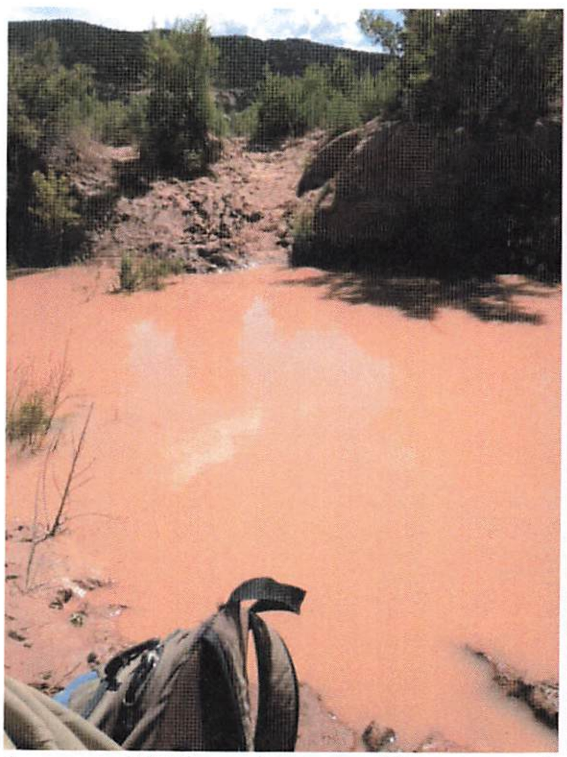
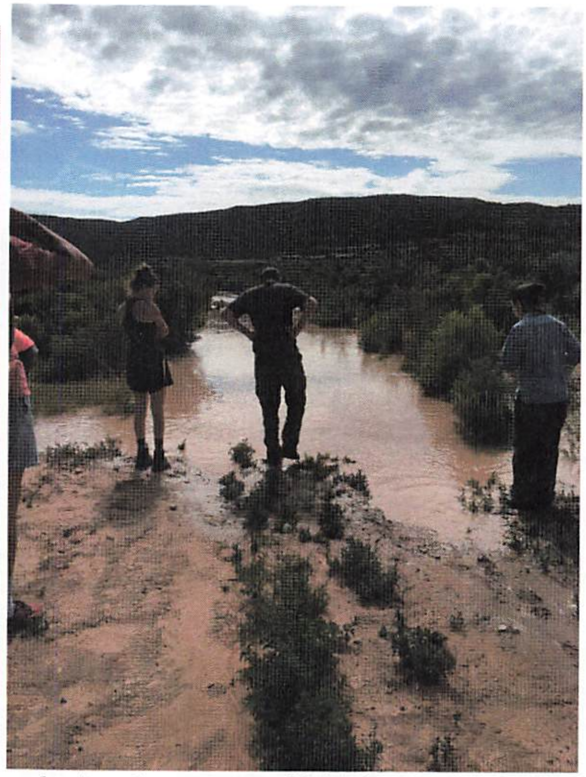
FIELD WORK

We returned to the *Dystrophaeus* site and excavated more material so that we could better identify how it fits into the evolutionary picture of these animals in North America. Our work consisted of a 10-day stretch in August of 2014, a three day interval in October 2014, and a 6-day period in July of 2015, each time with a crew of between 3 and 7.



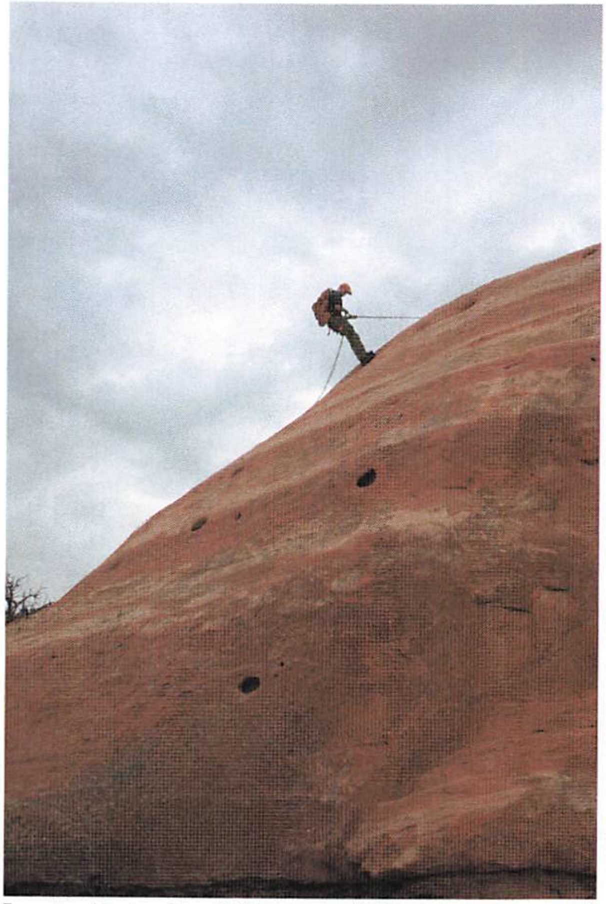
Sunset in camp.

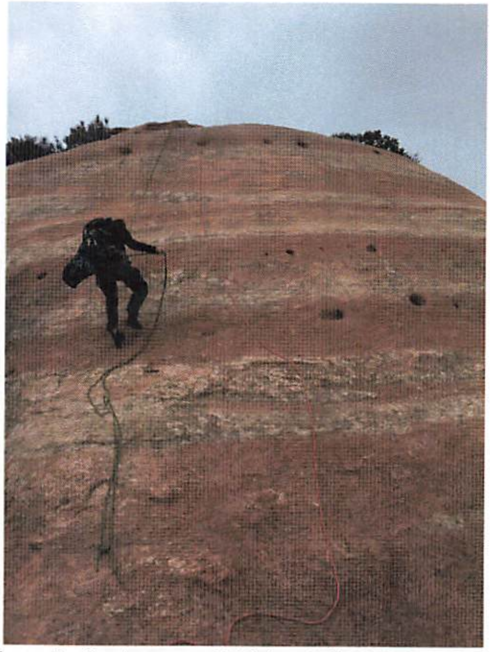
The site is above a cliff in a remote canyon of southeastern Utah and access to it for work on such a large animal was very challenging. The crew camped at the base of the Entrada Sandstone cliffs and ascended climbing ropes each morning, followed by a short hike and then a second set of ropes just below a short but steep hike up the final slope to the quarry. Water and plaster and other supplies had to be brought up this route as they were used up as well. When field jackets were dry they had to be moved down the

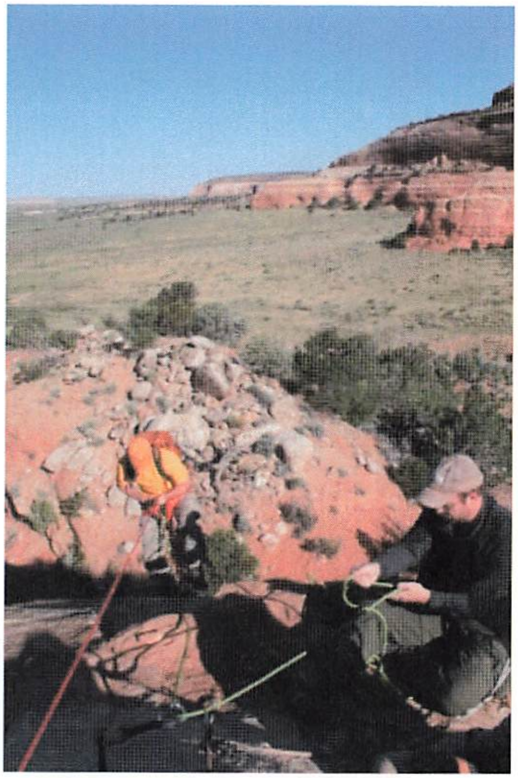
Access in 2015 was hampered by wet weather during the summer. Vehicles could not get in to base of cliffs, so access was by wading and hiking. Left, East Canyon arroyo was nearly waist deep and was crossed twice daily; right, road in was impassable.

slope by hand. Some field jackets were light enough (less than 80 lbs) to be carried down in a frame pack. Larger jackets had to be worked down by nearly the full crew. First, we used river straps to secure each jacket of between 80 and 300 lbs to a search and rescue backboard. Two lengths of climbing webbing were tied to the back of the board as "brakes" and a person in front had another rope to control the left-right path of the board. We then slide the backboard and jacket down the slope and over the rocks and down the first pitch next to the climbing ropes. A crew of about 5 then carried the backboard like a stretcher across a relatively flat section and then we prepared to lower it down the lower pitch of ropes. This was done by using a second set of river straps to secure the backboard and jacket to a four-caster furniture dolly. The whole assembly was then tied with a static line climbing rope that was run through a grigri. One crew member then belayed the assembly down the cliff while anchored at the top, and the two brakemen on the webbing lines controlled the direction of the descent. A crew at the bottom secured the jacket and unstrapped everything when it got to the bottom. After this, the crew would re-ascend and go back to work in the quarry. At the end of the day, everyone rappelled back down to camp.





Lower Entrada cliffs ascended with ropes each day. Left, August 2014; right, July 2015.

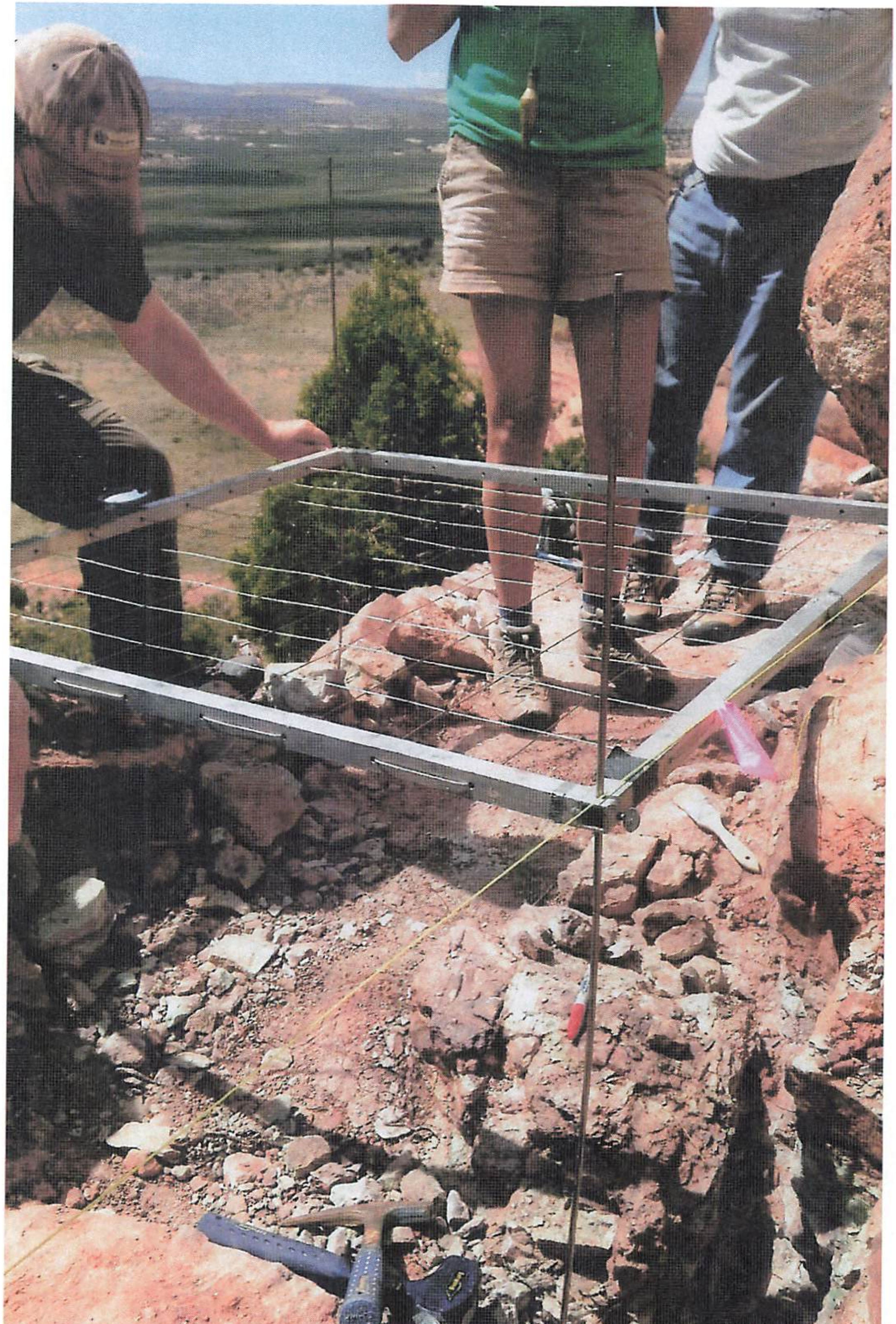

Top of lower pitch of climbing route, August 2014. The quarry is about 250 feet above the canyon floor and most of the height had to be climbed with ropes.


Clearing overburden rock off the top of the bone layer. July 2015.

Because of the labor intensive nature of getting the jackets down, and of getting supplies and equipment continually up to the site, we estimate that we spent about 60% of our time each day engaged in logistical operations, and less time actually excavating the site than we had anticipated.

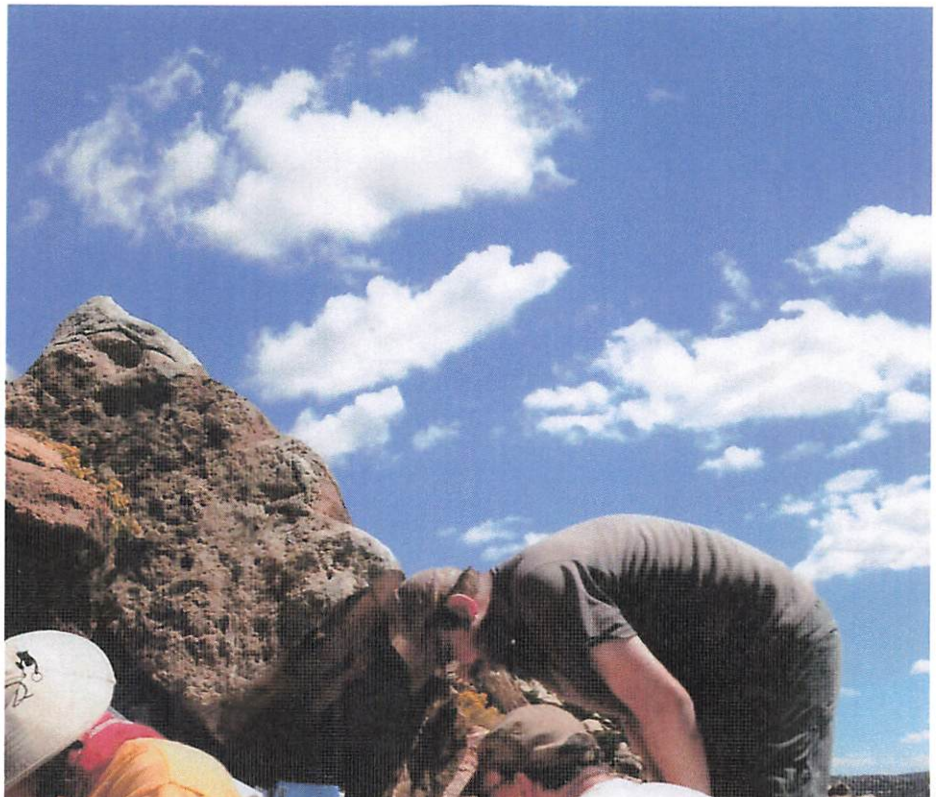
What we did find at the site was that there was a much greater concentration of bone in the host matrix sandstone layer than we had expected. We started out planning to locate bones, dig around them, trench them, pedestal and jacket them and get them out. In practice, the sandstone was so full of bone that we couldn't dig around anything, and we ended up just using natural cracks and pry bars to break the sandstone up into manageable chunks and jacket these individually and carry them out for preparation in the lab. In essence, we began a process of transporting the entire bone layer back to the lab and delayed seeing what any of the bones were until we get them prepared. We ended up with two pallets worth of bones including 9 major field jackets and 20 minor ones, plus one box of Ziploc bags of bones.

Excavating the west side of the quarry, with bones covered with plaster and burlap. July 2015.

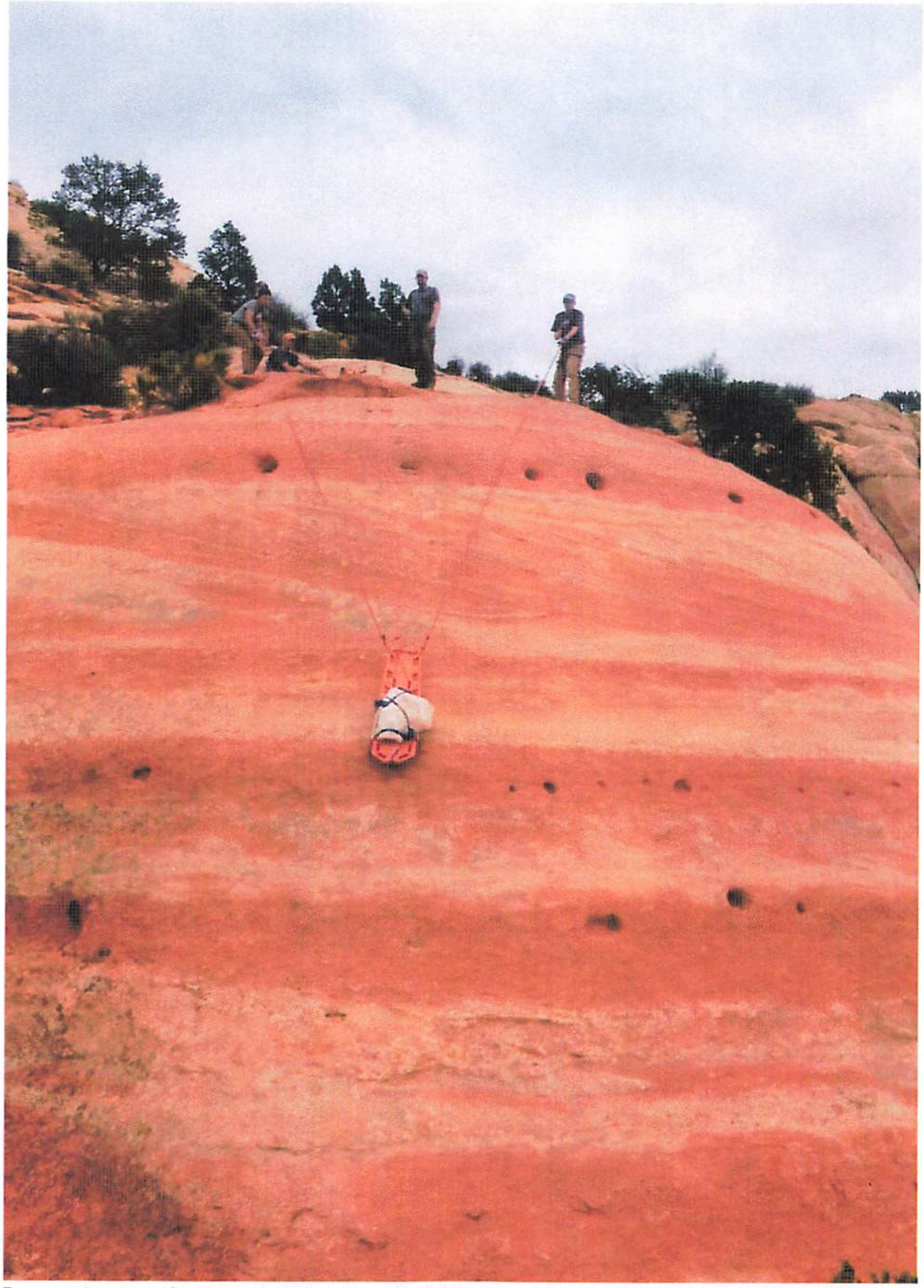


Mapping bones in the quarry, August 2014.

Two blocks of bone in sandstone, wrapped in plaster and burlap, in the quarry. October 2014.



Rolling a plaster and burlap field jacket, August 2014.



Lowering a plaster and burlap field jacket down the Entrada Sandstone cliff using a backboard, furniture dolly, river straps, and climbing rope, harnesses, and webbing. August 2014.

Pallets of field jackets from the East Canyon Dystrophaeus Quarry ready for preparation at the Natural History Museum of Utah. January 2015.

A list of what we collected follows:

Field Number	Identification	Element	Grid Location
ECDQ-01	Grid stake from 1989	--	--
ECDQ-02	*Dystrophaeus*	metatarsal frag?	B1
ECDA-03	*Dystrophaeus*	indet. bones	C1, C -1, D1, D -1
ECDQ-04	*Dystrophaeus*	mid-caudal centrum	E -1
ECDQ-05	*Dystrophaeus*	indet. bones	B1, C1, B -1, C -1
ECDQ-06	*Dystrophaeus*	indet. bones	C1, D1
ECDQ-06.1	*Dystrophaeus*	small block assoc. w/ ECDQ-06	
ECDQ-07	Wood(?)	impression in ss	B1
ECDQ-08	*Dystrophaeus*	mid-distal caudals	E1, F1, E -1, F -1
ECDQ-09	*Dystrophaeus*	indet. bones	E -1
ECDQ-10	*Dystrophaeus*	metatarsal and indet.	C1, B1
ECDQ-11	Indeterminate	small hollow limb bone	B1
ECDQ-12	*Dystrophaeus*	rib fragments	B1
ECDQ-13	*Dystrophaeus*	indet. bones	B1
ECDQ-14	*Dystrophaeus*	indet. bones	B1, C -1
ECDQ15-01	Crocodylomorpha?	Skull frag.?	Upper breccias

ECDQ15-02A	*Dystrophaeus*	indet. bones	--
ECDQ15-02B	*Dystrophaeus*	indet. bones	--
ECDQ15-03	*Dystrophaeus*?	Ilium	east area
ECDQ15-04	*Dystrophaeus*	Small rib	--
ECDQ15-05	*Dystrophaeus*	indet. bones	--

RESULTS

Excavation

The quarry is in a thin sandstone about 2.5–3 m up into the Tidwell Member of the Morrison Formation (Tidwell named by Peterson, 1988; Bernier and Chan, 2006, had the quarry at 3.6 m up, but we measured it to be lower in the Tidwell); the Tidwell is about 8 m thick at the site. The quarry sandstone is in the lenticular sandstone facies of Bernier and Chan (2006), which represents channel and associated overbank deposits within floodplain and lucustrine sediments. Below the Tidwell in the area is the Summerville Formation, and above the Tidwell is the Salt Wash Member of the Morrison Formation (Doelling, 2004). The top bed of the Summerville just a few meters under the quarry is a massive to planar-bedded sandstone unique to the area and known as the Bed at Black Steer Knoll (O'Sullivan, 1981). By the definition of Lucas et al. (1995), the Tidwell Member would be part of the Summerville Formation and not the Morrison, but we disagree with this assignment.

We found an abundance of bones at the site, as well as at least one impression of wood and a bivalve mollusc in the quarry sandstone. The number of bones was far more than we could excavate in the 18 days we spent at the site during the three trips we made. Within the jackets and bags that we collected there were probably several hundred bones and bone fragments. We would estimate that there remain several hundred bones at the site still.

The two main reasons we were not able to get all the material out are that there simply was more material at the site than we imagined, even based on our preliminary visits to the site, and that getting the equipment and supplies up and the material we collected out was even more time consuming than we anticipated.

Lab Work

We've prepared or have currently in preparation five blocks from the *Dystrophaeus* Quarry that were collected in 2014. Three of these are small float blocks found already eroded out, and one other block (ECDQ-05) is a small in situ block that was on the weathered broken edge of the quarry. The largest block we've started prep on is ECDQ-08 ("Keegan's caudals"), which has produced some nice material. Although fragmentary, there are pieces in "ECDQ14 Float Slope East" and ECDQ-05 that should be both informative and identifiable. Preparation has been slow because the matrix is hard, and there is very poor separation between the bone and matrix. Thus, we can only assign *Dystrophaeus* blocks to the more advanced preparators at NHMU. Nonetheless, we are slowly getting a feel for how to prepare the material, so preparation should start to go a bit quicker now. Examples of some of the prepared material appear in photos below.

Rib collected from the site in 2014.

Contents of field jacket ECDQ-05 after preparation.

Two caudal vertebrae from field jacket ECDQ-08 after preparation.

Museum Work

We also went through the collections of the Natural History Museum of Utah to take a closer look at the material collected by Dave Gillette and Fran Barnes in 1989. There were approximately 290 elements numbered, although many of these included multiple pieces; a large majority of these numbers comprised unidentifiable bone fragments. A few of the identifiable elements included: 1) a fragment of a possible foot bone; 2) two rib fragments; 3) a possible distal caudal vertebra centrum; 4) the distal end of a foot bone; and 5) a tooth in sandstone.

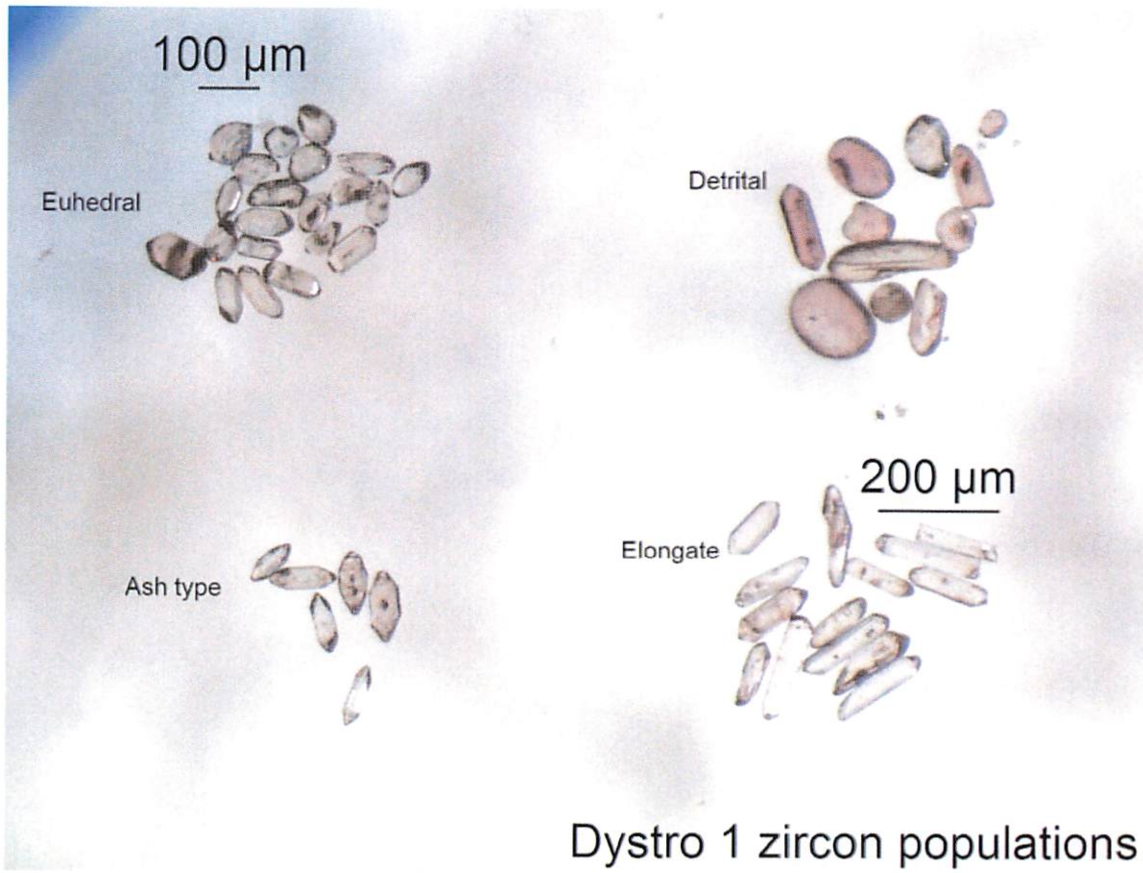
We also were able to photograph and CT scan the original Newberry material at the Smithsonian's National Museum of Natural History. This allowed us to begin comparing the bone and matrix from Newberry's material to what we collected in 2014 and 2015.

Bone fragments from the 1989 work at the quarry, in the Natural History Museum of Utah, January 2015.

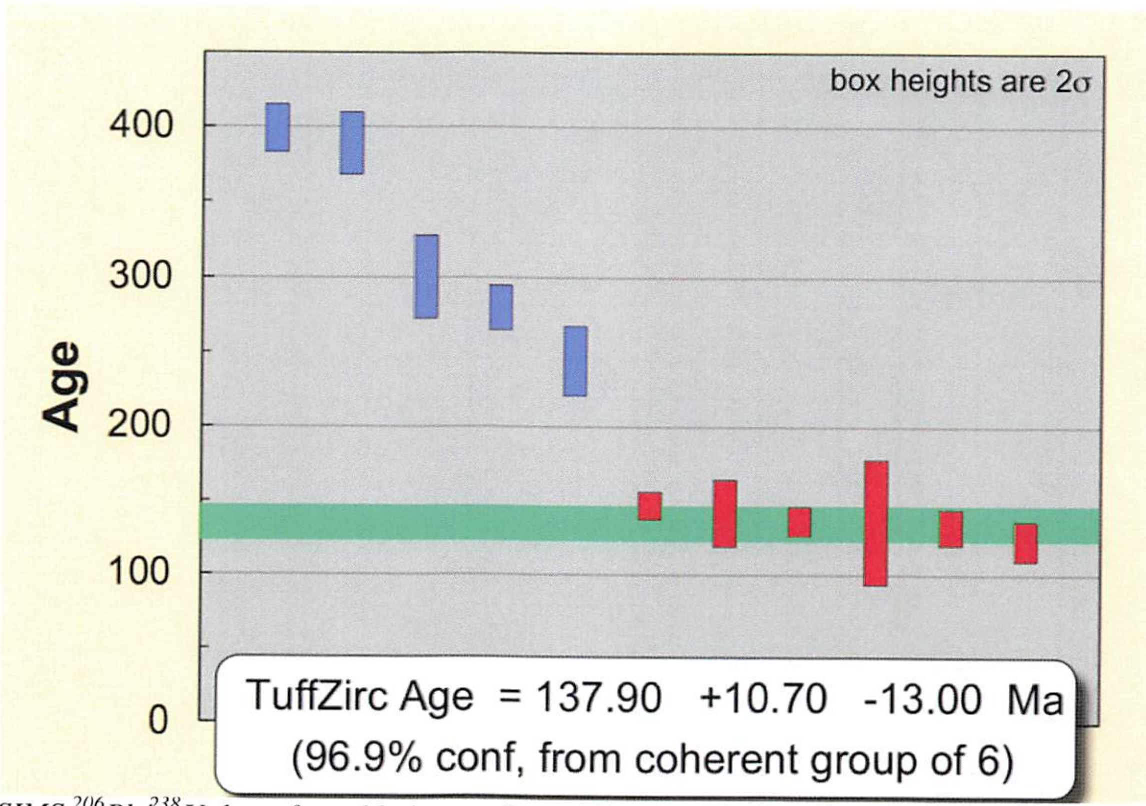
CT scan model of the ulna of Dystrophaeus *collected by John S. Newberry. USNM 2364.*

Radiometric Date

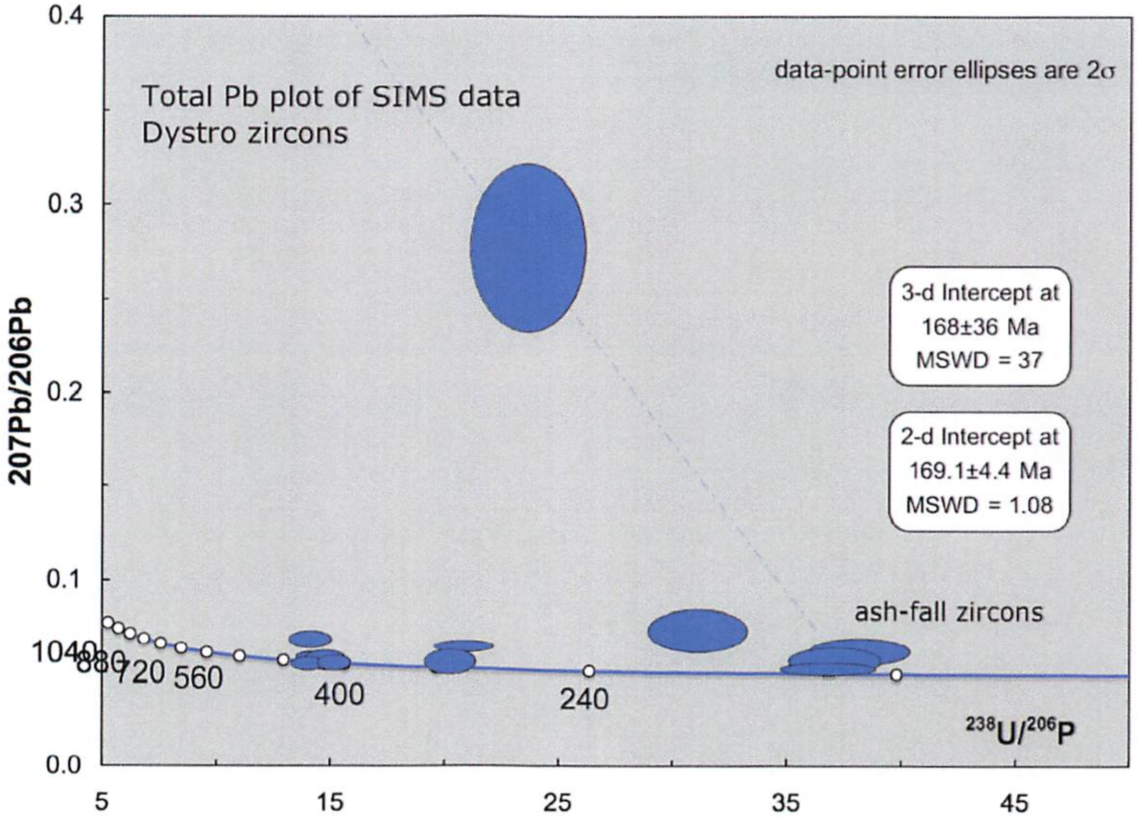
Mudstone samples were collected from immediately above the quarry sandstone. Zircons were concentrated from the sample by using an ultrasonic deflocculation system to float off clays, followed by standard density and magnetic separations to purify zircon from the recovered crystals. A variety of zircon morphologies were recovered with three populations of euhedral grains that could represent ash-fall zircons plus rounded grains that are clearly detrital. A subpopulation of euhedral grains with elongate tips and sharp facets are particularly likely to be ashfall grains (figure below). Thirty-three grains representing all 3 euhedral subpopulations of zircons were mounted in epoxy and analyzed by ion beam spot analysis (secondary ion mass spectrometry, SIMS) at UCLA. The results from 13 of these are shown in figures below. The SIMS results are somewhat imprecise due to high amounts of common Pb and the inherent imprecision from SIMS. The calculated dates can vary from 167 Ma to 137±11 Ma depending on the method used to mathematically remove the common Pb component. Although these results didn't produce a reliable date, they did indicate the likely presence of an ashfall component in the zircon population.



Subpopulations of zircons recovered from Dystrophaeus *zircon sample. Euhedral grains with elongate tips, shown in the lower left, have morphological characteristics that are typical of ash-fall grains. Euhedral and elongate grains may also include ash-fall zircons. The rounded grains in the upper right are clearly detrital grains incorporated during deposition.*



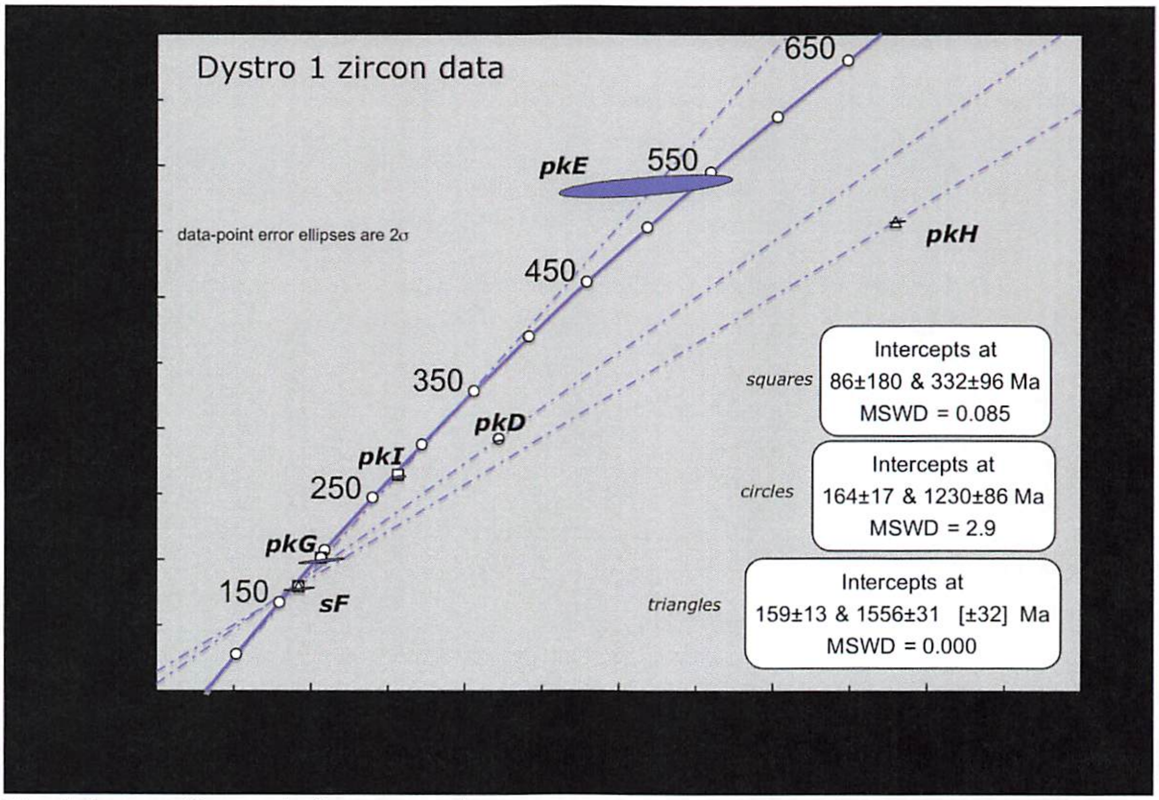
SIMS $^{206}Pb/^{238}U$ dates from 11 zircons, Dystrophaeus *sample. The data have been corrected for common Pb using the ^{204}Pb method. The youngest dates come from grains with ash-fall morphological characteristics.*



Total Pb, 3-dimensional, Tera-Wasserburg plot of SIMS data from Dystro 1 zircon sample. The third dimension is $^{204}Pb/^{206}Pb$, the common Pb component, which plots into the paper. Data define two clusters, an ashfall component, ca. 169 Ma and detrital components, ca. 200 to 400 Ma. Total Pb plots are more inclusive as they solve for the common Pb component rather than imposing a correction before plotting.

Consequently, a selection of zircons with ash-fall characteristics was processed by chemical abrasion for thermal ionization mass spectrometry (CA-TIMS). This method commonly removes all the common Pb and all the effects of Pb loss, producing both accurate and highly precise dates. Data from CA-TIMS was finalized in late July 2015 from analytical work at the University of Wyoming.

Zircons are small and relatively low in radiogenic Pb, so several multi-grain picks (6 grains each; pk) were dissolved as well as a single large grain (sF) to make sure to have enough Pb to measure (7 to 20 picograms). The data plot in a non-linear, triangular shaped pattern interpreted to indicate inheritance in each of the dissolutions as either whole, older grains and/or older zircon cores. The ages of inheritance vary from at least 250 to 1600 Ma. The lower intercepts of various combinations of points converge at approximately 160 Ma, near the expected age for this sample. The best estimate of the depositional age is based on the $^{206}Pb/^{238}U$ date from single grain F, 166±1.3 Ma, but this is likely to be an upper limit as even this analysis appears to include an older core in that the data are discordant ($^{207}Pb/^{235}U$ date of 171±15 Ma). These CA-TIMS results are comparable to the SIMS spot data that were previously reported. The SIMS data are less precise, but indicated inheritance at least as old as 500 Ma, and a volcanic age estimate between 167 to 137 Ma. Additional single grain and select multi-grain analyses will be attempted to narrow down the age of volcanism more precisely.



Final data on Dystro 1 zircon sample.

At this point the age estimates are close to what we would have expected for the Tidwell Member of the Morrison Formation, about 155–165 Ma, but we haven't been able to get a date precise enough to compare with other samples from the Tidwell.

CONCLUSIONS

These are a few things that we can conclude from our work at this point. Most of these are based on questions in our original proposal.

- Although we cannot yet tell what type of sauropod *Dystrophaeus* is, based on the newly excavated caudal vertebrae, it is not likely a diplodocine, nor even, based on the tooth, likely a diplodocid. Beyond that it is still difficult to say much just yet.

- In order to determine the relative (and possibly numeric) age of the individual we would need a complete anterior rib and a femur. Because these were not found, we can't yet say how old this individual is.

- Although the radiometric age results proved not to be as precise as we would have hoped, there were enough zircons to determine that the skeleton is geologically most likely about 155–160 million years old. This is right around the Kimmeridgian-Oxfordian stage boundary in the Late Jurassic and is several million years older than most other known Morrison Formation sauropods.

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Project Budget Summary

Budget Category	CNHA Grant $ Spent	Museum of Moab In-Kind	NHMU/UU In-Kind	BLM In-Kind
Travel	$438.10		$500.00	$100.00
Per Diem	$1500.00			
Field Assistant Salary	$1872.00			
Supplies	$1840.48		$1000.00	
U/Pb Date	$2312.65			
Histological Samples	$0.00			
PI Time		$3640.00		
Co-Investigator Time			$3640.00	$500.00
Totals	$7963.23	$3640.00	$5140.00	$600.00

Project Budget Detail

Budget Category	Date	Amount	Sub-Category	Spent on	Total
Travel	9/14/12 10/16/14 6/2/15 7/24/15	$274.45 $43.20 $67.65 $52.80	Mileage	Mileage	$438.10
Per Diem	8/20/14	$1500.00	Field Crew	Food	$1500.00
Salary	9/4/14 9/4/14 10/16/14	$832.00 $832.00 $208.00	Field Assistants	Salary	$1872.00
Supplies	8/20/14 8/21/14 8/22/14 8/22/14 8/25/14 11/17/14 11/18/14 11/18/14 11/18/14 6/15/15 7/1/15 7/8/15 7/8/15 7/24/15 8/19/15	$440.98 $62.65 $53.62 $29.09 $45.80 $51.47 $41.97 $20.97 $3.49 $9.00 $62.22 $70.96 $29.95 $846.35 $71.96	Field Supplies	Climbing gear Climbing gear Shade tent Burlap/plaster Tools/B/P Acryloid Water jugs Plaster Propane Acryloid bottles PB adhesive Acetone/jug Burlap NMHU field ex Lab supplies	$1840.48
U/Pb Date	7/15/15 10/22/15	$2300.00 $12.65	Zircon sample	Processing	$2312.65
Totals					$7963.23

Final Grant Disbursement

CNHA grant payments: 2014, $4347.50
2/18/15, $2173.75
Total = $6521.25

Amount spent on project: $7963.23

Final amount requested on grant: **$1441.98**