



## SOFT-BODIED FOSSIL OF A LIZARD FROM THE PARACHUTE CREEK MEMBER, GREEN RIVER FORMATION (EOCENE), UTAH

Kenneth Carpenter



10 cm



# GEOLOGY OF THE INTERMOUNTAIN WEST

*an open-access journal of the Utah Geological Association*

ISSN 2380-7601

Volume 5

2018

## Editors

Douglas A. Sprinkel  
Utah Geological Survey  
801.391.1977  
GIW@utahgeology.org

Bart J. Kowallis  
Brigham Young University  
801.422.2467  
bkowallis@gmail.com

Thomas C. Chidsey, Jr.  
Utah Geological Survey  
801.537.3364  
tomchidsey@utah.gov

Steven Schamel  
GeoX Consulting, Inc.  
801.583-1146  
geox-slc@comcast.net

## Production

Cover Design and Desktop Publishing  
Douglas A. Sprinkel

Cover

*Lizard preserved as a carbon film from the Parachute Creek Member of the Green River Formation (Eocene), Uinta Basin, Utah.*



*This is an open-access article in which the Utah Geological Association permits unrestricted use, distribution, and reproduction of text and figures that are not noted as copyrighted, provided the original author and source are credited.*

## UGA Board

October 2018 – September 2019

President	Peter Nielsen	peternielsen@utah.gov	801.537.3359
President-Elect	Leslie Heppler	lheppler@utah.gov	801.538.5257
Program Chair	Gregory Schlenker	gcsgeoscience@gmail.com	801.745.0262
Treasurer	Dave Garbrecht	garbrechtd@yahoo.com	801.916.1911
Secretary	George Condrat	gcondrat@loughlinwater.com	435.649.4005
Past President	Paul Inkenbrandt	paulinkenbrandt@utah.gov	801.537.3361

## UGA Committees

Environmental Affairs	Craig Eaton	eaton@ihi-env.com	801.633.9396
Geologic Road Sign	Terry Massoth	twmassoth@hotmail.com	801.541.6258
Historian	Paul Anderson	paul@pbageo.com	801.364.6613
Outreach	Greg Nielson	gnielson@weber.edu	801.626.6394
Membership	Rick Ford	rford@weber.edu	801.626.6942
Public Education	Paul Jewell	pwjewell@mines.utah.edu	801.581.6636
	Matt Affolter	gfl247@yahoo.com	
Publications	Paul Inkenbrandt	paulinkenbrandt@utah.gov	801.537.3361
Publicity	Paul Inkenbrandt	paulinkenbrandt@utah.gov	801.537.3361
Social/Recreation	Roger Bon	rogerbon@xmission.com	801.942.0533

## AAPG House of Delegates

2017–2020 Term	Tom Chidsey	tomchidsey@utah.gov	801.537.3364
----------------	-------------	---------------------	--------------

## State Mapping Advisory Committee

UGA Representative	Jason Blake	blake-j@comcast.net	435.658.3423
--------------------	-------------	---------------------	--------------

## Earthquake Safety Committee

Chair	Grant Willis	gwillis@utah.gov	801.537.3355
-------	--------------	------------------	--------------

## UGA Website

**www.utahgeology.org**

Webmasters	Paul Inkenbrandt	paulinkenbrandt@utah.gov	801.537.3361
------------	------------------	--------------------------	--------------

## UGA Newsletter

Newsletter Editor	Bill Lund	uga.newsletter@gmail.com	435.590.1338
-------------------	-----------	--------------------------	--------------

*Become a member of the UGA to help support the work of the Association and receive notices for monthly meetings, annual field conferences, and new publications. Annual membership is \$20 and annual student membership is only \$5. Visit the UGA website at [www.utahgeology.org](http://www.utahgeology.org) for information and membership application.*

*The UGA board is elected annually by a voting process through UGA members. However, the UGA is a volunteer-driven organization, and we welcome your voluntary service. If you would like to participate please contact the current president or committee member corresponding with the area in which you would like to volunteer.*



## Soft-Bodied Fossil of a Lizard From the Parachute Creek Member, Green River Formation (Eocene), Utah

**Kenneth Carpenter**

*Prehistoric Museum, Utah State University Eastern, 155 Main St., Price, UT 84501; and Museum of Natural History, University of Colorado, Boulder, CO 80302; Ken.Carpenter@usu.edu*

### ABSTRACT

A rare specimen of soft tissue preservation of a lizard from the Parachute Creek Member of the Eocene Green River Formation, Uinta Basin, Utah, is described. The preservation is unusual in that it is a mineralized body lacking the skeleton. This, and other small boneless vertebrate specimens also from the Parachute Creek, indicate occasional demineralizing conditions in Lake Uinta, but not apparently in the other two lakes of the Green River Formation—Fossil Lake and Lake Gosuite.

### INTRODUCTION

Fossil lizards are a rare in the Eocene Green River Formation. Grande (2013) reported three taxa, including two specimens of the varanid *Saniwa ensidens* (described by Rieppel and Grande, 2007), three specimens of the shinisaur (crocodile lizard) *Bahndwivici ammoskius* (described by Conrad, 2006), and a single specimen of the iguanian *Afairiguana avius* (described in Conrad and others, 2007). To this list are several specimens of lizards represented by two-dimensional, mineralized bodies lacking the skeletons, which had dissolved away. Although some of these specimens have been known for decades (e.g., Grande, 1984), only recently has one been described (Conrad and others, 2014). The specimen consists of the anterior half in dorsal view on part and counterpart slab and is remarkable for the dark mineral film preservation of the eyeballs and brain, in addition to the mineralized scales. Edwards and others (2011, 2012) presented Fourier Transform InfraRed and Synchrotron Rapid Scanning X-Ray Fluorescence elemental maps of two other specimens (but no mor-

phological description). These show that the mineralized scales preserved relicts of the amide and sulfur compounds that they inferred were derived from the original keratinous skin. These specimens had previously been illustrated in Grande (1984).

Recently, a nearly complete soft-bodied lizard specimen was found in the collections at the Colorado School of Mines, Golden, Colorado. The specimen was collected during a school fieldtrip by W.R. Keller “approximately 21 miles south-southwest of Vernal, Utah” (figure 1), which would place the site near what is now the Ouray National Wildlife Refuge. The specimen was figured as a salamander by Johnson (1954) probably because of the rounded head. Minute scales, however, clearly establish its lacertilian nature. The locality information is suspect because strata 21 miles south-southwest of Vernal is predominately Holocene alluvium and eolian deposits (Sprinkel, 2007), the lower part of the Brennan Basin Member of the Duchesne River Formation, and Member C of the Uinta Formation both Eocene in age. The matrix of the specimen,

*Citation for this article.*

*Carpenter, K., 2018, Soft-bodied fossil of a lizard from the Parachute Creek Member, Green River Formation (Eocene), Utah: Geology of the Intermountain West, v. 5, p. 263–269.*

© 2018 Utah Geological Association. All rights reserved.

For permission to use, copy, or distribute see the preceding page or the UGA website, [www.utahgeology.org](http://www.utahgeology.org), for information. Email inquiries to [GIW@utahgeology.org](mailto:GIW@utahgeology.org).

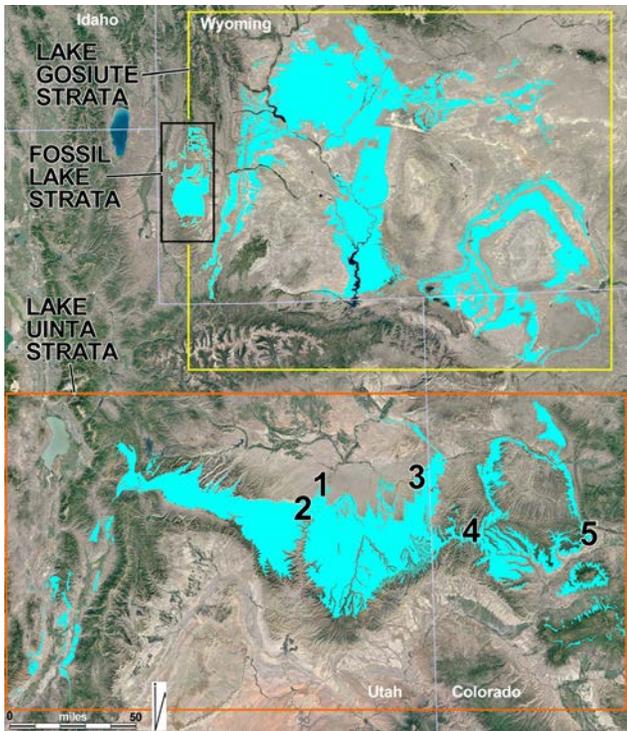


Figure 1. Map showing the distribution of the Green River Formation that identify Lake Uinta, Lake Gosuite, and Fossil Lake. All of the boneless vertebrate skeletons are from the Parachute Creek Member of the Lake Uinta strata. (1) Southwest of Vernal CSMGM 14156 (this report); (2) Nine Mile Canyon (Stokes, 1978, assumed to be shed skin, but in context of this report may be a demineralized lizard); (3) Bonanza (Grande, 1984; Edwards and others, 2011; also boneless fish CEUM 81827); (4) Douglass Pass (Langston and Rose, 1978; Grande, 1984; Edwards and others, 2012); (5) Anvil Points (Conrad and others, 2014). Green River Formation map based on KML files from Mineral Resources Online Spatial Data (undated) and imagery from Google Earth.

however, is more like the greenish-gray shales of unweathered Parachute Creek Member of the Green River Formation. The nearest exposures of that member is along Willow and Hill Creeks, more than 39 miles south-southwest of Vernal and south of Fort Duchesne, Uintah County. These two creeks border the east and west side of Big Pack Mountain. Alternatively, there are other exposures of the Parachute Creek Member along the Green River about 40 miles southwest Vernal. It is unfortunate that no additional information is available to narrow the location.

Measurements were determined using ImageJ 1.50e

on an image captured using a high-resolution flatbed scanner (1200 dpi) to minimize parallax. All measurements were rounded to nearest millimeter owing to a certain level of uncertainty about the edges of certain morphological points.

## ABBREVIATIONS

CEUM—College of Eastern Utah Prehistoric Museum (now Prehistoric Museum, Utah State University); CSMGM—Colorado School of Mines Geological Museum.

## SYSTEMATIC PALEONTOLOGY

SQUAMATA Oppel, 1811

?IGUANIA Cope, 1864

Gen et sp. indet.

## Specimen

CSMGM 14156 skin impression and mineralized film of nearly the entire body (figure 2).

## Locality

South-southwest of Vernal, Utah, presumably near Big Pack Mountain or along the Green River, Uintah County, Utah. Probably from the Parachute Creek Member, Green River Formation.

## Description

The specimen is the mineralized body of a lizard preserved in ventral view (figure 2). Both forelimbs are appressed against the body making it look armless. The hind legs are parallel with the left leg folded across the abdomen. The short, rounded head is an artifact due to a thin layer of matrix covering the tip of the snout; no trace of a gular dewlap is seen. Matrix also covers the distal end of the tail. The covering matrix will probably not come off easily or cleanly as attested by previous attempts in the 1970s to remove matrix over the lower limbs with a needle. Most likely an attempt to mechanically expose the snout will result in considerable damage. The specimen has a midline length of 242 mm as exposed; it has an estimated snout-vent length of 141 mm assuming the snout is 3 mm longer and that the vent was approximately in the vicinity of the left knee ( $\pm$



Figure 2. Ventral view of CSMGM 14156. Boxes A to C are shown in figure 3. Small yellow box is small pyritic mass probably of gastric residue. White box shows possible degassing rupture; note displaced skin along bottom edge. Scale in cm.

5 mm). The maximum width of the head is 22 mm, and the midline length of the visible portion is 25 mm measured perpendicular to the maximum width. The neck is approximately 14 mm wide and midline length of 13 mm. The maximum width of the body is 32 mm. The right arm is 23 mm assuming the dark spot at the proximal end is the location of the humeral head. The elbow cannot be identified with certainty, so the separate arm segments are not measured; the manus is either hidden by matrix or in the missing counter slab. The left thigh is approximately 20 mm, the left lower leg 21 mm, and the incomplete left foot 23+ mm. The maximum width of the complete right thigh is 12 mm. All of the width measurements are undoubtedly increased due to compaction of the three-dimensional (3D) body; lengths generally do not change as much.

Traces of bone are seen as irregular, very dark struc-

tures in the tail but lack detail (figures 2 and 3C). The vertebrae in a short segment in the middle of the tail are displaced. A small blob of pyritic mass in the lower abdominal region probably formed due to localized reducing environment from decomposition of gastric residue (yellow box in figure 2).

Scales are seen all over the body, and the most prominent are those on the neck, chest, and thigh (figure 3). They are tiny, granular, nonoverlapping, and those on the neck and thigh are arranged in rows. Those on the neck become progressively larger towards the midline (figure 3A). The scales along the anterior edge of the thigh appear to be a little larger and closely packed, whereas those on the posterior side are smaller and granular. The scales on the tail are square to rectangular, lacking any evidence of having osteoderms, and arranged in longitudinal rows (figure 3C). These scales

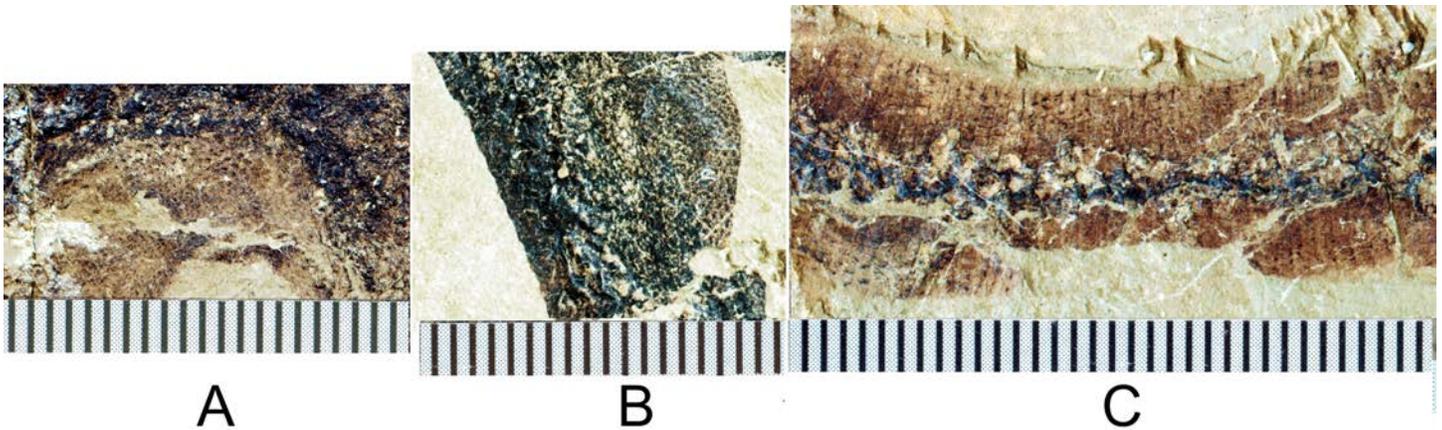


Figure 3. Closeups of squamation: (A) neck region; (B) right inner thigh; (C) mid-tail. Scales in mm.

often have a small, darker spot along the posterior edge. None of the lateral scales of the tail show evidence of having had osteoderms as in *Bahndwivici*, which would predictably be seen as giving the margin of the tail an irregular, slightly jagged appearance. The squamation of CSMGM 14156 is similar to that of BHI-102B figured by Edwards and others (2011, figure 1a), suggesting the two specimens probably belong to the same taxon.

## DISCUSSION

The measurements given above in conjunction with figure 2 strongly suggest that CSMGM 14156 is a medium-sized lizard, having a relatively short, wide head on a distinct neck, wide body, short-limbs, and with tiny granular scales on the belly and transverse rows of small, square or rectangular scales on the underside of the tail. From these characters, CSMGM 14156 is questionably referred to as either a gecko or iguanid. The referral relies heavily on what CSMGM 14156 is not. For example, the apparent absence of osteoderms eliminates anguids, scincids, helodermids, etc., the presence of a distinct neck is another factor eliminating scincids, and the well-developed, although short limbs, eliminates the anelliids, etc. The small size of the granular scales covering the body supports the interpretation that the local environment in the vicinity of the Green River lakes was warm and humid (e.g., Wegener and others, 2014).

Numerous matrix-filled fissures cut across the body and tail dividing it into segments. These fractures are

clean and suggest that the skin was subjected to tension force pulling it apart as if brittle. This can best be seen where the skin is broken into smaller pieces that are slightly displaced (figure 3C). There is also some evidence for shearing forces causing a slight offset of the skin, such as the front half of the body relative to the back half (figure 2). The fissures are post-depositional because there must have been sediment holding everything in place as the fissures formed, possibly as a result of sediment compaction.

The postmortem subaquatic decay of a lizard carcass (collared iguana *Oplurus cuvieri*) over a two-month period was described by Richter and Wuttke (2012). As in other studies of decomposition, decay began within the abdomen, which would have led to typical postmortem bloat and float phase (e.g., Minshall and others, 1991; Rodriguez, 1997). This phase terminates with degassing from rupture of the skin. It is possible that the gap in the skin in the abdominal region of CSMGM 14156 represents the site of the rupture, especially given that the skin along the lower margin does appear to be displaced outwards from the body (white box in figure 2). These features are suggestive of rupture but are not definitive. As in other decomposition studies, Richter and Wuttke (2012) noted that the skin was resilient and long lasting (cf. Minshall and others, 1991; Rodriguez, 1997). In fact, next to bone, skin is one of the most resilient tissues in the dead vertebrate body in the absence of scavengers (Gill-King, 1997).

The fossilization of the skin probably involved microbial authigenic mineralization (Briggs and McMalon,

2016). Such fossilization can replicate extremely fine detail. Edwards and others (2011) presented a taphonomic model to explain the elemental and mineralogical signature of a fossilized lizard skin from the Green River Formation. This model neglects the ubiquitous microbes associated with dead organic material and does not explain the demineralization of the skeleton. I therefore consider their model as incomplete. As mentioned previously, bone is typically the most resilient tissue in the vertebrate skeleton and can survive little changed for thousands of years in wet environments (von Endt and Ortner, 1984; Turner-Walker and Peacock, 2008). Consequently, the fossilization of the skin in CSMGM 14156 at the expense of bone must result from unusual environmental conditions. Low pH is known to demineralize bone hydroxyapatite (Christensen and Myers, 2011). Such an environment can be created within the carcass during autolysis (Gill-King, 1997). Subsequent anaerobic bacterial decomposition also leads to a drop in pH, which can initiate bone demineralization (Child, 1995). But demineralization of bone is not always a simple matter of low environmental pH (Turner-Walker and Peacock, 2008). Bone mineral is also susceptible to dissolution in an environment undersaturated with respect to calcium and phosphate (Turner-Walker and Peacock, 2008). A gentle bottom current would prevent the saturation of calcium and phosphate ions in the local microenvironment around and in the lizard carcass. Added to this is the increase porosity of bone by bacterial collagenase, which can increase the surface to volume ratio and facilitate dissolution (Hedges and Millard, 1995). Experimental work has shown that the collagenase-producing bacterial already reside in the gut of most vertebrates at the time of death, thus bacterial bioerosion can begin soon after death (Child, 1995; White and Booth, 2014).

To narrow the probable cause for the demineralization of CSMGM 14156, it is necessary to consider the specimen in the context of the other boneless specimens. These additional specimens include the lizards cited in Grande (1984), Edwards and others (2011, 2012), and Conrad and others (2014), the hatchling crocodile described by Langston and Rose (1978), and a small clupeoid (CEUM 81827). Plotting these specimens on a distribution map of the Green River Forma-

tion revealed that they are restricted to the Lake Uinta basin (figure 1), and more specifically to the Parachute Creek Member. The question then arises, what is different about the Parachute Creek strata as compared to the other members deposited in Lake Uinta, Lake Gosuite, and Fossil Lake that might reflect a difference in bottom-water chemistry?

The paleolimnology of the Green River Formation is most thoroughly treated in Smith and Carroll (2015), and the Parachute Creek Member in particular by Boak and Poole (2015), Jagniecki and Lowenstein (2015), Rosenberg and others (2015), and Tānavsuu-Milkeviciene and Sarg (2015). Differences in water chemistry between Lake Uinta on the one hand, and Lake Gosuite + Fossil Lake (Buchheim and others, 2015) on the other, are seen in their saline enrichment phases whereby the chemicals already in the water are concentrated. Nahcolite ( $\text{NaHCO}_3$ ) was deposited in Lake Uinta, and trona ( $\text{NaHCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 2\text{H}_2\text{O}$ ) deposited in Lake Gosuite and Fossil Lake. During their high stand phases, the lakes were characterized by stratified dysoxic to anoxic bottom waters (Tānavsuu-Milkeviciene and Sarg, 2012). What made Lake Uinta different during deposition of the Parachute Creek Member is that it was apparently deeper than the other two lakes (Jagniecki and Lowenstein, 2015), which may have resulted in a thicker zone of dysoxic or anoxic bottom water. The decomposition of organic matter in this zone, in the upper sediments and within the lizard carcass by sulfate-reducing bacteria, would create hydrogen sulfide, which in water can create a weak acid. Over time, even a weak acid can be corrosive to bone if it is not removed by weak bottom currents. A weak acid would most likely persist if the carcass was sealed by a thin layer of anoxic mud.

## CONCLUSION

The discovery of a boneless fossilized lizard from Lake Uinta strata is not merely a curiosity but provides insight into the condition of the lake bottom at the time of burial. There are several different ways in which bone can be naturally demineralized. The small size of the bones made them more susceptible to dissolution (von Endt and Ortner, 1984) regardless of which demineralization pathway the skeleton of CSMGM 14156 fol-

lowed. At least six other boneless specimens of fish, alligator, and lizards are known, all from the Parachute Creek Member. These specimens, all small, suggest a commonality in their demineralization. And that leads to the hypothesis that the anoxic conditions at the bottom of Lake Uinta were at times slightly acidic.

## ACKNOWLEDGMENTS

I thank Beth Simons, Colorado School of Mines Geological Museum, who invited me to describe CSMGM 14156. Thanks also to Doug Sprinkel for discussions about the Green River Formation in the vicinity of Cowboy Canyon, and for review comments and corrections. Also to Lance Grande, Field Museum of Natural History (Chicago), for review comments and corrections.

## REFERENCES

- Boak, J., and Poole, S., 2015, Mineralogy of the Green River Formation in the Piceance Creek Basin, Colorado, *in* Smith, M.E., and Carroll, A.R., editors, Stratigraphy and paleolimnology of the Green River Formation, western USA: Dordrecht, Springer, p. 183–209.
- Buchheim, H.P., Biaggi, R.E., and Cushman, R.A., 2015, Stratigraphy and interbasinal correlations between Fossil and the Green River Basin, Wyoming, *in* Smith, M.E., and Carroll, A.R., editors, Stratigraphy and paleolimnology of the Green River Formation, western USA: Dordrecht, Springer, p. 127–151.
- Briggs, D.E., and McMahan, S., 2016, The role of experiments in investigating the taphonomy of exceptional preservation: *Palaeontology*, v. 59, no. 1, p. 1–11.
- Child, A.M., 1995, Microbial taphonomy of archaeological bone: *Studies in Conservation*, v. 40, no. 1, p. 19–30.
- Christensen, A.M., and Myers, S.W., 2011, Macroscopic observations of the effects of varying fresh water pH on bone: *Journal of Forensic Sciences*, v. 56, no. 2, p. 475–479.
- Conrad, J.L., 2006, An Eocene shinisaurid (Reptilia, Squamata) from Wyoming, USA: *Journal of Vertebrate Paleontology*, v. 26, no. 1, p. 113–126.
- Conrad, J.L., Head, J.J., and Carrano, M.T., 2014, Unusual soft-tissue preservation of a crocodile lizard (Squamata, Shinisauria) from the Green River Formation (Eocene) and shinisaur relationships: *The Anatomical Record*, v. 297, no. 3, p. 545–559.
- Conrad, J.L., Rieppel, O., and Grande, L., 2007, A Green River (Eocene) polychrotid (Squamata: Reptilia) and a re-examination of iguanian systematics: *Journal of Paleontology*, v. 81, p. 1365–1373.
- Edwards, N.P., Barden, H.E., Van Dongen, B.E., Manning, P.L., Larson, P.L., Bergmann, U., Sellers, W.I., and Wogelius, R.A., 2011, Infrared mapping resolves soft tissue preservation in 50 million year-old reptile skin: *Proceedings of the Royal Society of London B, Biological Sciences*, v. 278, no. 1722, p. 3209–3218.
- Edwards, N.P., Wogelius, R.A., Bergmann, U., Larson, P., Sellers, W.I., and Manning, P.L., 2012, Mapping prehistoric ghosts in the synchrotron: *Applied Physics A*, v. 111, no. 1, p. 147–155.
- Gill-King, H., 1997, Chemical and ultrastructural aspects of decomposition, *in* Haglund, W.D., and Sorg, M.H., editors, Forensic taphonomy—the postmortem fate of human remains: Boca Raton, Florida, CRC Press, p. 93–108.
- Grande, L., 1984, Paleontology of the Green River Formation, with a review of the fish fauna (2nd edition): Wyoming State Geological Survey Bulletin 63, 333 p.
- Grande, L., 2013, The lost world of Fossil Lake—snapshots from deep time: Chicago, University of Chicago Press, 425 p.
- Hedges, R.E., and Millard, A.R., 1995, Bones and groundwater—towards the modelling of diagenetic processes: *Journal of Archaeological Science*, v. 22, no. 2, p. 155–164.
- Jagniecki, E.A., and Lowenstein, T.K., 2015, Evaporites of the Green River Formation, Bridger and Piceance Creek Basins—deposition, diagenesis, paleobrine chemistry, and Eocene atmospheric CO<sub>2</sub>, *in* Smith, M.E., and Carroll, A.R., editors, Stratigraphy and paleolimnology of the Green River Formation, western USA: Dordrecht, Springer, p. 277–312.
- Johnson, J.H., 1954, The geological museum at “Mines:” *The Mines Magazine*, v. 44, no. 12, p. 31–32.
- Langston, W., and Rose, H., 1978, A yearling crocodilian from the middle Eocene Green River Formation of Colorado: *Journal of Paleontology*, v. 52, p. 122–125.
- Minshall, G.W., Hitchcock, E., and Barnes, J.R., 1991, Decomposition of rainbow trout (*Oncorhynchus mykiss*)

- carcasses in a forest stream ecosystem inhabited only by nonanadromous fish populations: *Canadian Journal of Fisheries and Aquatic Sciences*, v. 48, no. 2, p. 191–195.
- Mineral Resources Online Spatial Data, undated, Colorado: <https://mrdata.usgs.gov/geology/state/state.php?state=CO>; Utah: <https://mrdata.usgs.gov/geology/state/state.php?state=UT>; Wyoming: <https://mrdata.usgs.gov/geology/state/state.php?state=WY>, accessed March 23, 2018.
- Richter, A., and Wuttke, M., 2012, Analyzing the taphonomy of Mesozoic lizard aggregates from Uña (Eastern Spain) by X-ray controlled decay experiments: *Palaeobiodiversity and Palaeoenvironments*, v. 92, no. 1, p. 5–28.
- Rieppel, O., and Grande, L., 2007, The anatomy and relationships of the fossil varanid lizard *Saniwa ensidens* Leidy, 1870, based on a newly discovered complete skeleton: *Journal of Paleontology*, v. 81, p. 643–665.
- Rodriguez, W.C., 1997, Decomposition of buried and submerged bodies, *in* Haglund, W.D., and Sorg, M.H., editors, *Forensic taphonomy—the postmortem fate of human remains*: Boca Raton, Florida, CRC Press, p. 459–468.
- Rosenberg, M.J., Birgenheier, L.P., and Vanden Berg, M.D., 2015, Facies, stratigraphic architecture, and lake evolution of the oil shale bearing Green River Formation, eastern Uinta Basin, Utah, *in* Smith, M.E., and Carroll, A.R., editors, *Stratigraphy and paleolimnology of the Green River Formation, western USA*: Dordrecht, Springer, p. 211–249.
- Smith, M.E., and Carroll, A.R., editors, 2015, *Stratigraphy and paleolimnology of the Green River Formation, western USA*: Dordrecht, Springer, 355 p.
- Sprinkel, D.A., 2007, Interim geologic map of the Vernal 30' x 60' quadrangle, Uintah and Duchesne Counties, Utah, and Moffat and Rio Blanco Counties, Colorado: Utah Geological Survey Open File Report 506DM, 3 plates, scale 1:100,000.
- Stokes, W.L., 1978, Impressions of lizard scales from the Green River Formation (Eocene), Uinta Basin, Utah: *Journal of Paleontology*, v. 25, no. 4, p. 407–410.
- Tänavsuu-Milkeviciene, K., and Sarg, J.F., 2012, Evolution of an organic-rich lake basin—stratigraphy, climate and tectonics—Piceance Creek Basin, Eocene Green River Formation: *Sedimentology*, v. 59, no. 6, p. 1735–1768.
- Tänavsuu-Milkeviciene, K., and Sarg, J.F., 2015, Sedimentology of the world class organic-rich lacustrine system, Piceance Basin, Colorado, *in* Smith, M.E., and Carroll, A.R., editors, *Stratigraphy and paleolimnology of the Green River Formation, western USA*: Dordrecht, Springer, p. 153–181.
- Turner-Walker, G., and Peacock, E.E., 2008, Preliminary results of bone diagenesis in Scandinavian bogs: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 266, no. 3–4, p. 151–159.
- Von Endt, D.W., and Ortner, D.J., 1984, Experimental effects of bone size and temperature on bone diagenesis: *Journal of Archaeological Science*, v. 11, no. 3, p. 247–253.
- Wegener, J.E., Gartner, G.E., and Losos, J.B., 2014, Lizard scales in an adaptive radiation—variation in scale number follows climatic and structural habitat diversity in *Anolis* lizards: *Biological Journal of the Linnean Society*, v. 113, no. 2, p. 570–579.
- White, L., and Booth, T.J., 2014, The origin of bacteria responsible for bioerosion to the internal bone microstructure—results from experimentally-deposited pig carcasses: *Forensic Science International*, v. 239, p. 92–102.