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Short communication

Dinosaur eggshells from the Santonian Milk River Formation of Alberta, Canada

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ABSTRACT

The North American fossil record of dinosaur eggshells for the Cretaceous is primarily restricted to formations of the middle (Albian–Cenomanian) and uppermost (Campanian–Maastrichtian) stages, with a large gap in the record for intermediate stages. Here we describe a dinosaur eggshell assemblage from a formation that represents an intermediate and poorly fossiliferous stage of the Upper Cretaceous, the Santonian Milk River Formation of southern Alberta, Canada. The Milk River eggshell assemblage contains five eggshell taxa: *Continuoolithus*, *Porituberoolithus*, *Prismatoolithus*, *Spheroolithus,* and *Triprismatoolithus*. These ootaxa are most similar to those reported from younger Campanian–Maastrichtian formations of the northern Western Interior than they are to ootaxa reported from older middle Cretaceous formations (i.e., predominantly *Macroelongatoolithus*). Characteristics of the Milk River ootaxa indicate that they are ascribable to at least one ornithopod and four small theropod species. The taxonomic affinity of the eggshell assemblage is consistent with the dinosaur fauna known based on isolated teeth and fragmentary skeletal remains from the formation, although most ornithischians and large theropods are not represented by eggshell. Relative to the Milk River Formation eggshell, similar oospecies occurring in younger Cretaceous deposits tend to be somewhat thicker, which may reflect an increase in body size of various dinosaur lineages during the Late Cretaceous.

1. Introduction

Dinosaur eggshells are useful indicators of taxonomic diversity and faunal composition, particularly in formations or paleogeographic regions where skeletal remains are sparse (Tanaka et al., 2016; Zelenitsky et al., 2017). Cretaceous dinosaur egg remains from North America are reported primarily from formations of the middle (Albian–Cenomanian) and uppermost (Campanian–Maastrichtian) stages. Uppermost Cretaceous formations (e.g., Aguja, Dinosaur Park, Fruitland, Hell Creek, North Horn, Oldman, Two Medicine, and Willow Creek formations) have yielded several dinosaur ootaxa, which have been ascribed primarily to ornithopods (e.g., *Spheroolithus*) and small theropods (e.g., *Continuoolithus*, *Prismatoolithus*) (Zelenitsky and Hills, 1996, 1997; Zelenitsky et al., 1996, 2017; Bray, 1999; Zelenitsky and Sloboda, 2005; Welsh and Sankey, 2008; Jackson and Varricchio, 2010, 2016; Tanaka et al., 2011). Only one ootaxon, *Macroelongatoolithus*, has been described from middle Cretaceous formations (e.g., Dakota, Wayan, and uppermost Cedar Mountain formations), and has been assigned to giant oviraptorosaurs (Zelenitsky et al., 2000; Huh et al., 2014; Simon, 2014; Krumenacker et al., 2017; Pu et al., in press). The differences in eggshell taxonomic composition between middle and uppermost Cretaceous formations reflect some of the changes indicated by skeletal remains that occurred in dinosaur faunas during the Late Cretaceous in North America (Weishampel et al., 2004). There is, however, a dearth of dinosaur fossils from intervening Upper Cretaceous stages, specifically from the Turonian through the Santonian. Here we provide the description of a dinosaur eggshell assemblage from the Santonian Milk River Formation of southern Alberta, Canada,

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which has bearing on our understanding of the Late Cretaceous dinosaur faunas of North America.

2. Geological setting and locality

The Milk River Formation is widespread in the subsurface of southern Alberta, although exposures are limited to coulees and river valleys east of the town of Milk River. This formation is the first of several regressive-transgressive clastic wedges deposited during the Late Cretaceous in the Western Canada Basin in response to Cordilleran orogenic pulses. It overlies the calcareous marine shales of the Colorado/Alberta Group and is overlain by the marine Pakowki Formation, making it stratigraphically equivalent to the Telegraph Creek and Eagle formations of Montana (Payenberg et al., 2002). The Milk River Formation is subdivided into three members. In ascending stratigraphic order, they are: 1) the Telegraph Creek member, dominated by offshore shales; 2) the Virgelle member, composed of storm-dominated shoreface sandstones at the base and tidal channel or estuarine sandstones at the top; and 3) the Deadhorse Coulee member, consisting of mudstones, sandstones, and coal beds of alluvial origin (for a review, see Meyer et al., 1998; Braman, 2001; and Payenberg et al., 2002). The age of the formation has been constrained to the late Santonian (~84.5–83.5 Ma) on the basis of bio-, palyno-, and magnetostratigraphy as well as radiometrically-dated volcanic deposits (Payenberg et al., 2002).

The Deadhorse Coulee Member is considered to be latest Santonian in age (Braman, 2001; Payenberg et al., 2002) and is the only member of the Milk River Formation known to preserve fossil remains of terrestrial organisms. Macrofloral remains suggest that the Santonian was characterized by a warm and humid climate (Bell, 1963; Wolfe and Upchurch, 1987; Upchurch and Wolfe, 1993), while microfloral assemblages indicate a landscape of open forests with shallow ponds (Braman, 2001; Kalgutkar and Braman, 2008). The Deadhorse Coulee Member has produced a diverse fauna composed of amphibians, bony fishes, chondrichthyans, crocodylomorphs, dinosaurs, mammals, squamates, and turtles, although most are represented by microvertebrate remains and isolated or partial skeletal remains (for a recent review, see Larson, 2010; Ryan et al., 2012; Evans et al., 2013; Larson et al., 2014). This faunal assemblage documents a transitional phase in Late Cretaceous ecosystems that preserves the last occurrences of archaic taxa and the earliest representatives of faunas typical of the latest Cretaceous (e.g., Fox, 1968; Larson, 2010).

Although bones and teeth are known from the Deadhorse Coulee Member, fossil eggshells have yet to be reported. Here we describe fossil eggshell fragments (n ≈ 400) recovered from a single locality over several field seasons between 2009 and 2015 in outcrops of the member exposed along Verdigris Coulee (Fig. 1). The fossil locality is inferred to be situated in the upper half of the member, based on correlation with regional stratigraphic sections (see Larson, 2010). The eggshells were found on a small hill where the exposures consist of channel sandstones interbedded with pedogenically modified mudstones, and appear to have weathered out of a cross-stratified channel sandstone near the top of the butte (Fig. 2).

3. Materials and methods

Eggshell fragments were classified into various morphotypes based on macro- and microstructures using a stereomicroscope, and their thicknesses (with and without ornamentation) were measured with digital calipers and a micrometer. The microstructure and ultrastructure of each eggshell morphotype were studied using stereoscopic (Leica M80), petrographic (Leica DM 2500P), and scanning electron (FEI Quanta FEG 250 SEM) microscopes. Radial thin sections for each eggshell morphotype were produced for examination with a petrographic microscope, particularly for polarized light microscopy (PLM). For scanning electron microscopy (SEM), eggshell fragments were ultrasonically cleaned, dried with compressed gas, and were affixed to aluminum stubs with double-sided carbon tape. The fragments were then examined on the inner and outer surfaces, as well as on freshly-fractured radial surfaces.

The description of the eggshell focuses on morphological features that differ from similar ootaxa found in other formations. The eggshells are classified using a parataxonomic scheme previously established for fossil eggs (Zhao, 1975; Hirsch, 1994).

The eggshells are accessioned in the collections of the Royal Tyrrell Museum of Palaeontology (TMP), Drumheller, Alberta, Canada, and in the Zelenitsky Egg Catalogue (ZEC) at the University of Calgary, Calgary, Alberta, Canada. Although all eggshells are from the same locality and horizon, they have been assigned different

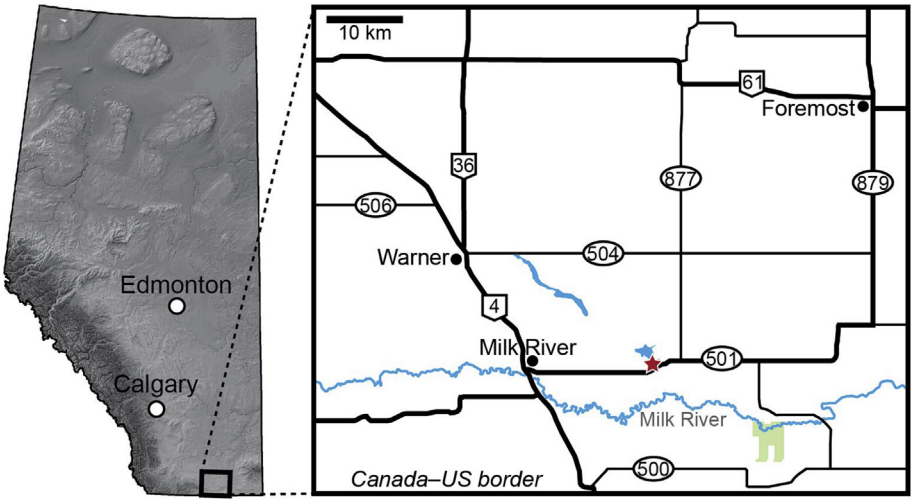

Fig. 1. Map showing the location of the Milk River Formation eggshell locality in Verdigris Coulee, southern Alberta, Canada.