

A Spinops sternbergorum (Ornithsichia: Ceratopsia) parietal from the Dinosaur Park Formation (upper Campanian) of Muddy Lake, Saskatchewan

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Abstract

The upper Campanian deposits of the Dinosaur Park Formation at Muddy Lake, Saskatchewan, are known to contain the bones of one or more horned dinosaur species, but definitive diagnostic material has remained elusive. Here, we describe a newly recognized partial parietal from these deposits, bearing a single spike-like epiossification that projects posterolaterally from the frill margin. The element is most plausibly attributable to the centrosaurine *Spinops sternbergorum*, a species otherwise known only from Dinosaur Provincial Park, Alberta. Juvenile ceratopsids appear to be relatively abundant at the Muddy Lake locality, which was proximal to the Western Interior Seaway. We suggest that such lowland coastal settings might have been important breeding grounds for horned dinosaurs.

Key words: Horned dinosaurs; Ceratopsia; Muddy Lake; Saskatchewan; Dinosaur Park Formation; Campanian

Introduction

The Dinosaur Park Formation (DPF) at Dinosaur Provincial Park, Alberta, contains one of the best studied dinosaur assemblages in the world (Currie and Koppelhus 2005), as it documents the diversity and evolution of a single chronofauna (*sensu* Olson 1952) during the late Campanian (Ryan and Evans 2005; Mallon *et al.* 2012; Mallon 2019). The DPF is exposed elsewhere in southeastern Alberta and southwestern Saskatchewan (Eberth and Hamblin 1993; Gilbert *et al.* 2020), but those outcrops are neither as well exposed nor as fossiliferous as the DPF. Consequently, their fossil assemblages are not yet as well understood.

The northernmost exposure of the DPF occurs at Muddy Lake, ~12 km south of Unity, Saskatchewan (Figure 1). Exposures there are limited in geographic and stratigraphic extent, but they are fossil bearing and host a mixed microsite (Royal Saskatchewan Museum, Regina, Saskatchewan, Canada [RSKM] locality 73C06-0001) containing the remains of typi-

cal Late Cretaceous vertebrate taxa, including fishes, amphibians, mammals, champsosaurs, turtles, crocodilians, tyrannosaurids, ornithomimids, paravians, hadrosaurids, and ceratopsids (Eberth *et al.* 1990; Brinkman *et al.* 1998).

Isolated ceratopsid elements are also common. Two ceratopsid nasal horncores were described by Eberth *et al.* (1990). One of them (RSKM P2105.1) closely resembles the condition in *Centrosaurus apertus* and other members of the tribe Centrosaurini; however, Eberth *et al.* (1990) were unable to find a match for the other (RSKM P1990.6) among then-known ceratopsids, and they tentatively suggested that it might represent a new taxon. Unfortunately, because nasal horncores vary so widely in morphology even within a single taxon or population (e.g., Sampson *et al.* 1997; Frederickson and Tumarkin-Deratzian 2014), they are of limited diagnostic value at the species level. In isolation, the nasal horncores at Muddy Lake are probably not diagnoseable beyond Centrosaurini indeterminate.

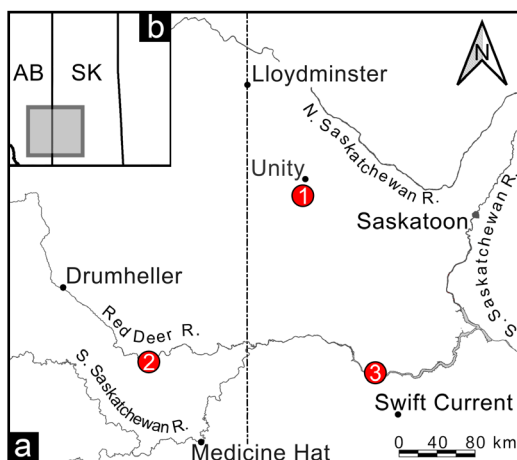


FIGURE 1. a. Map showing location of Muddy Lake exposures (1), Dinosaur Provincial Park (2), and Lake Diefenbaker bonebed (3) along b. the Alberta (AB)/Saskatchewan (SK) border.

In this contribution, we briefly review the ceratopsid material collected from the Muddy Lake badlands and describe a newly recognized parietal element, which is of greater diagnostic utility within Ceratopsia (Dodson *et al.* 2004). We also discuss the implications of the Muddy Lake fossils for matters of ceratopsid palaeobiology.

Geological Setting

The DPF is the youngest and most fossiliferous of three terrestrial formations (along with the Foremost and Oldman formations, in ascending order; Figure 2) that comprise the regressive-transgressive clastic wedge of the middle-upper Campanian Belly River Group (Eberth and Hamblin 1993; Eberth 2005). This clastic wedge is bounded below by the marine Pakowki Formation and the Lea Park Formation in Alberta and Saskatchewan, respectively, and is bounded above by the marine Bearpaw Formation in both provinces. The Belly River Group consists primarily of mudstones, sandstones, and occasional coaly layers that represent alluvial-coastal plain and nearshore deposits along the margin of the Western Interior Seaway. In the area of Dinosaur Provincial Park, Alberta, the group is ~270 m thick, with the uppermost ~90 m exposed in outcrop (Eberth 2005). Uranium-lead dating of the bentonite exposures here has recently yielded ages between 76.718 ± 0.020 and 74.289 ± 0.014 million years ago for the DPF (Ramezani *et al.* 2022).

The Belly River Group wedge thins eastward to a thickness of no more than 75 m (including sub-surface) in the area of Muddy Lake, Saskatchewan (Eberth *et al.* 1990), ~235 km northeast of Dinosaur

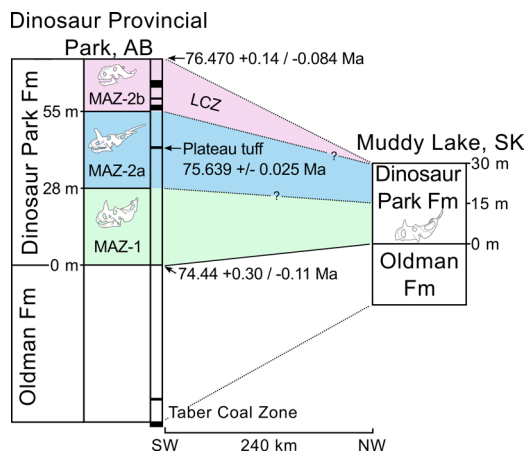


FIGURE 2. Correlation of the Dinosaur Park and Oldman formations in Dinosaur Provincial Park, Alberta (AB), with the equivalent formations at Muddy Lake, Saskatchewan (SK). Radiometric dates from Eberth *et al.* (2023), Dinosaur Provincial Park megaherbivore assemblage zones from Mallon *et al.* (2012). Note: Fm, Formation; LCZ, Lethbridge Coal Zone; Ma, mega-annum; MAZ, Megaherbivore Assemblage Zone.

Provincial Park. Here, the outcrop measures just 55 m thick, exposing part of the Oldman Formation (25 m) and the entirety of the DPF (30 m). Despite palynostratigraphic analysis (Eberth *et al.* 1990), more precise correlation with the deposits at Dinosaur Provincial Park has not yet been possible. Local fossil vertebrate remains are restricted to the lower 15 m of the DPF.

Review of Muddy Lake Ceratopsid Material

Beyond the mixed bonebed assemblage mentioned above, the exposures of the DPF at Muddy Lake have also yielded isolated bones, distributed over ~21 sites, collected primarily by T.T.T. during the late 1980s. Isolated ceratopsid bones—many quite small (juvenile size class of Ryan *et al.* 2001)—are most common, representing various parts of the skeleton (Figure 3). Two nasal horncores were ably described by Eberth *et al.* (1990), but we will comment further on the aberrant horncore (RSKM P1990.6). This horncore (Figure 3e) is notable for its relative shortness, subcircular cross-section, and forward inclination. We note, however, that it has buckled in two places—near the base and at mid-length—which somewhat exaggerates its slant. Nevertheless, the forward inclination of the horncore can only partly be explained by post-depositional factors, and we agree with Eberth *et al.* (1990) that the specimen is without equal in the ceratopsid fossil record. Despite its relatively small size (apicobasal length = 13 cm), the lack of an internasal

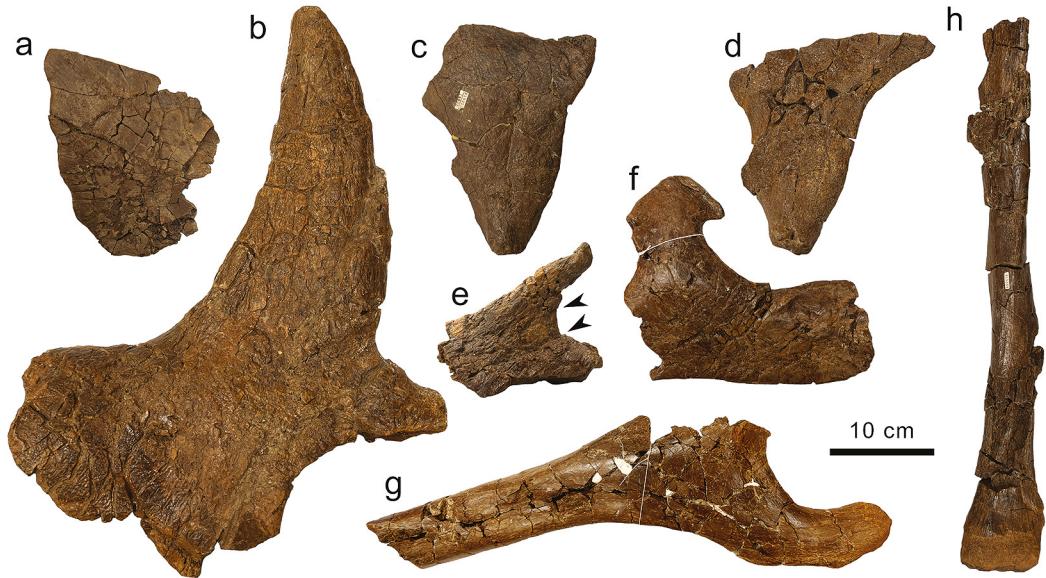


FIGURE 3. Ceratopsid material from the Dinosaur Park Formation at Muddy Lake, Saskatchewan, Canada. a. Right squamosal (RSKM 1951.65), lateral view. b. Nasal horncore (RSKM P2105.1), right lateral view. c. Right jugal (RSKM P1990.1), lateral view. d. Right jugal (RSKM P2159.25), lateral view. e. Nasal horncore (RSKM P1990.6), right lateral view; arrows indicate areas of buckling. f. Partial right dentary (RSKM P1951.68), right lateral view. g. Proximal right ischium (RSKM P2305.3), lateral view. h. Probable left fibula (RSKM 2305.4), anterior view. Photos: Jordan Mallon.

suture suggests that it may be somatically mature, although we cannot discount the alternative possibility that the unusual horncore is pathological or developmentally anomalous.

Other ceratopsid material from Muddy Lake is shown in Figure 3. Most of the elements are not diagnostic beyond the family level; however, aside from the nasal horncores described by Eberth *et al.* (1990), the single right squamosal (RSKM 1951.65; Figure 3a) can also be confidently attributed to the subfamily Centrosaurinae, based on its stout proportions and the presence of a “step” along the medial parietal contact (Dodson *et al.* 2004). The element is small (anteroposterior length ~20 cm, as preserved) and bears six episquamosal loci. It also exhibits a long-grained surface texture indicative of its immature status (Sampson *et al.* 1997; Brown *et al.* 2009). Two isolated jugals (RSKM P1990.1 and P2159.25) are likewise quite small and lack fused epijugals (Figure 3c,d), characteristic of juvenile ceratopsids (Sampson *et al.* 1997; Horner and Goodwin 2008).

Description of RSKM P2178.1

Originally identified in the field as a rib, this, in fact, proves to be a partial left transverse parietal bar bearing a large epioassification (Figure 4a,b; 3D model available for restricted download at <https://www.morphosource.org/concern/media/000>

701290?locale=en). As preserved, the transverse bar measures ~27 cm across. The contact with the median parietal bar is missing. The transverse bar is broken anteriorly, so it is not possible to determine whether a parietal fenestra was originally present, which is otherwise common in ceratopsids (Dodson *et al.* 2004). The surficial bone is smooth and without vascular sulci.

An enlarged (midline apicobasal length = 19 cm) epiparietal spike caps the margin of the transverse bar laterally. The basal suture is visible dorsally but not ventrally. The spike is narrow dorsoventrally, lies entirely within the plane of the frill, and projects posterolaterally, gently curving laterally along its length. The epioassification is scored lengthwise on the dorsal surface by two deep sulci. Similar sulci are otherwise seen on the marginal epioassifications and nasal horncores of some centrosaurines (e.g., Sampson *et al.* 1997; Mallon *et al.* 2022) and, very rarely, chasmosaurines (e.g., Royal Tyrrell Museum of Palaeontology, Drumheller, Alberta, Canada [TMP] specimen 2015.018.0012). There are otherwise no other obvious signs of epioassifications or their attachments along the preserved transverse parietal bar.

We interpret RSKM P2178.1 as plausibly attributable to *Spinops sternbergorum*.

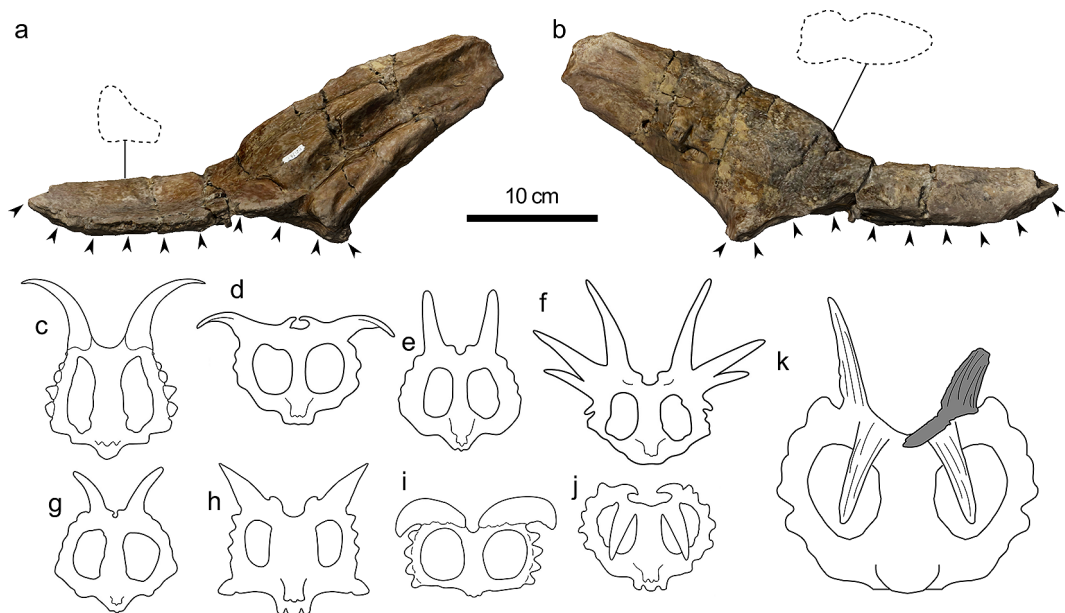


FIGURE 4. Parietal fragment of RSKM P2178.1 showing attached epioossification and centrosaurine frills for comparison. a. Anterior view (dashed outline shows cross-section of incomplete transverse parietal bar). b. Posterior view (dashed outline shows cross-section at base of epiparietal spike). Arrows in a and b point to broken bone margins. c. *Diabloceratops eatoni*. d. *Pachyrhinosaurus lakustai*. e. *Einiosaurus procurvicornis*. f. *Styracosaurus albertensis*. g. *Achelousaurus horneri*. h. *Xenoceratops foremostensis*. i. *Albertaceratops nesmoi*. j. *Centrosaurus apertus*. k. Outline of *Spinops sternbergorum* (NHMUK R16307) showing the proposed placement of RSKM P2178.1. Frill outlines in c–j modified from Ryan *et al.* (2012), in k modified from Farke *et al.* (2011); not to the same scale. Photos: Jordan Mallon.

Discussion

The centrosaurine *S. sternbergorum* is previously known only from Dinosaur Provincial Park (Farke *et al.* 2011). A spike-like epiparietal morphology is not yet known in any chasmosaurine from the DPF, and the avascular nature of the frill is more consistent with a centrosaurine identity. In some regards, the spike superficially resembles the posterolaterally projecting P3 epiparietal (see Sampson *et al.* 1997 for epiparietal numbering scheme) of some pachyrhinosaurins (e.g., *Einiosaurus procurvicornis*, *Achelousaurus horneri*; Figure 4e,g), which are represented in the DPF by just a single example lacking a parietal (Ryan *et al.* 2010). However, pachyrhinosaurin P3 epiparietals do not exhibit the deep sulci seen in RSKM P2178.1. The spike is most consistent with the P2 or P3 epiparietal (depending on the chosen homology scheme; see Farke *et al.* 2011) of *S. sternbergorum*, which similarly projects from the posterior margin of the frill and is deeply sulcate. In the only other known parietals of this species (Natural History Museum [NHMUK], London, United Kingdom specimens R16307 and R16308), the spike is straight and projects strongly posteriorly. However, epiparietal curvature and orientation are known to vary widely

within single centrosaurine populations (e.g., *Centrosaurus apertus*, Brown 2013; *Styracosaurus albertensis*, Brown *et al.* 2020; *Pachyrhinosaurus lakustai*, Currie *et al.* 2008), and the differences between the RSKM and NHMUK specimens are wholly within the expected realm of variation. In *S. sternbergorum*, the posteriorly projecting (P2 or P3) epiparietal spike is laterally adjacent to an anteriorly curled P1 epiparietal (Farke *et al.* 2011). This has likely broken away in RSKM P2178.1, but the dorsally raised bone surface here (Figure 4a) may indicate the base of this P1 epiparietal. Our taxonomic identification of the parietal element is consistent with the other Muddy Lake centrosaurine material noted above.

The original *S. sternbergorum* material described by Farke *et al.* (2011) was collected from a bonebed by Charles H. Sternberg in 1916. Unfortunately, the original locality within the Steveville badlands of Dinosaur Provincial Park is unknown, and it is therefore not possible to situate the material stratigraphically. Local exposures limit the locality to either the uppermost Oldman Formation or the lower DPF. Our identification of the Muddy Lake centrosaurine as *S. sternbergorum* suggests the latter might be the more likely host stratum. This interpretation is consistent

with the fact that the only centrosaurine presently known from the Oldman Formation in Dinosaur Provincial Park (and its equivalent in the Comrey Sandstone near Onefour, Alberta) is *Coronosaurus brinkmani*, known from hundreds of elements distributed between two bonebeds (Ryan and Russell 2005).

From the preferential preservation of ceratopsid microfossils (e.g., teeth) at Muddy Lake and other localities proximal to the ancient Western Interior Seaway, Brinkman *et al.* (1998) hypothesized that ceratopsids may have preferred living in the coastal lowlands. Further, based on the abundance of ceratopsid bonebeds ~235 km to the southwest at Dinosaur Provincial Park, distal to the ancient seaway, they reasoned that ceratopsids may have regularly migrated westward to more inland settings, where they lived communally for at least part of the year. However, Brinkman *et al.* (1998) were unable to situate the nesting grounds of these animals for lack of evidence.

It is remarkable that so many of the isolated bones from Muddy Lake belong to small, likely juvenile, ceratopsids. Similar remains are also known from Dinosaur Provincial Park (e.g., Dodson and Currie 1988; Currie *et al.* 2016), although apparently in lower relative abundance. If the inland-coastal migration hypothesis of Brinkman *et al.* (1998) is correct, it is conceivable that the eastern, lowland deposits at Muddy Lake represent ceratopsid nesting grounds. However, we note that embryonic and hatchling bones are yet unknown at Muddy Lake, as are eggshells, so this speculation may be premature (the apparently uncalcified eggshells of ceratopsians makes it less likely that supporting evidence is forthcoming; Norrell *et al.* 2020). The ichnologic record is uninformative regarding ceratopsid movements, being largely devoid of ceratopsid tracks. We note that the *C. apertus* bonebed at Lake Diefenbaker (Figure 1), recently described by Demers-Potvin and Larsson (2024), suggests that ceratopsids lived communally in coastal lowlands proximal to the ancient seaway, as well.

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