

In "Mesozoic Vertebrate Life" pp.206-218 (2001)  
Darren H. Tanke and Kenneth Carpenter (eds.)  
Indiana University Press, Bloomington and Indianapolis

# 15. Evidence of Hatchling- and Nestling-Size Hadrosaurs (Reptilia: Ornithischia) from Dinosaur Provincial Park (Dinosaur Park Formation: Campanian), Alberta

DARREN H. TANKE AND  
M. K. BRETT-SURMAN

## Abstract

The occurrences of dinosaur eggshell and neonate-size hadrosaur skeletal material from the Late Cretaceous (Campanian) of Dinosaur Provincial Park, Alberta, is reviewed and some skeletal specimens in TMP collections are described. Eggshell fragments occur rarely and only in two microfossil sites dominated by invertebrate shells. This factor may be related to the calcium in the invertebrate shells acting as a buffer to the acidic water conditions of the time. Many of the hadrosaur skeletal elements show little or no stream abrasion, suggesting they originated from areas near the Park, if not from the Park itself. This new material supports recent suggestions that hadrosaurs did not nest only in upland areas, but nested in lowland environments as well.

## Introduction

More than two decades of fieldwork conducted by staff of the Royal Tyrrell Museum of Palaeontology in Dinosaur Provincial Park, Alberta, Canada (fig. 15.1), has resulted in the recovery of many thousands of vertebrate fossils, including those of hatchling or extremely young individuals. On the basis of teeth or skeletal material (especially the latter), neonate-size *Champsosaurus*, crocodylians, turtles, and dinosaurs, including ornithomimids, small theropods (*Saurornitholestes* and *Troodon*), tyrannosaurs, possible ankylosaurs, centrosaurine ceratopsians, and especially hadrosaurs, are now documented. Occurrences of non-nested, neonate hadrosaurs are rarely reported in the

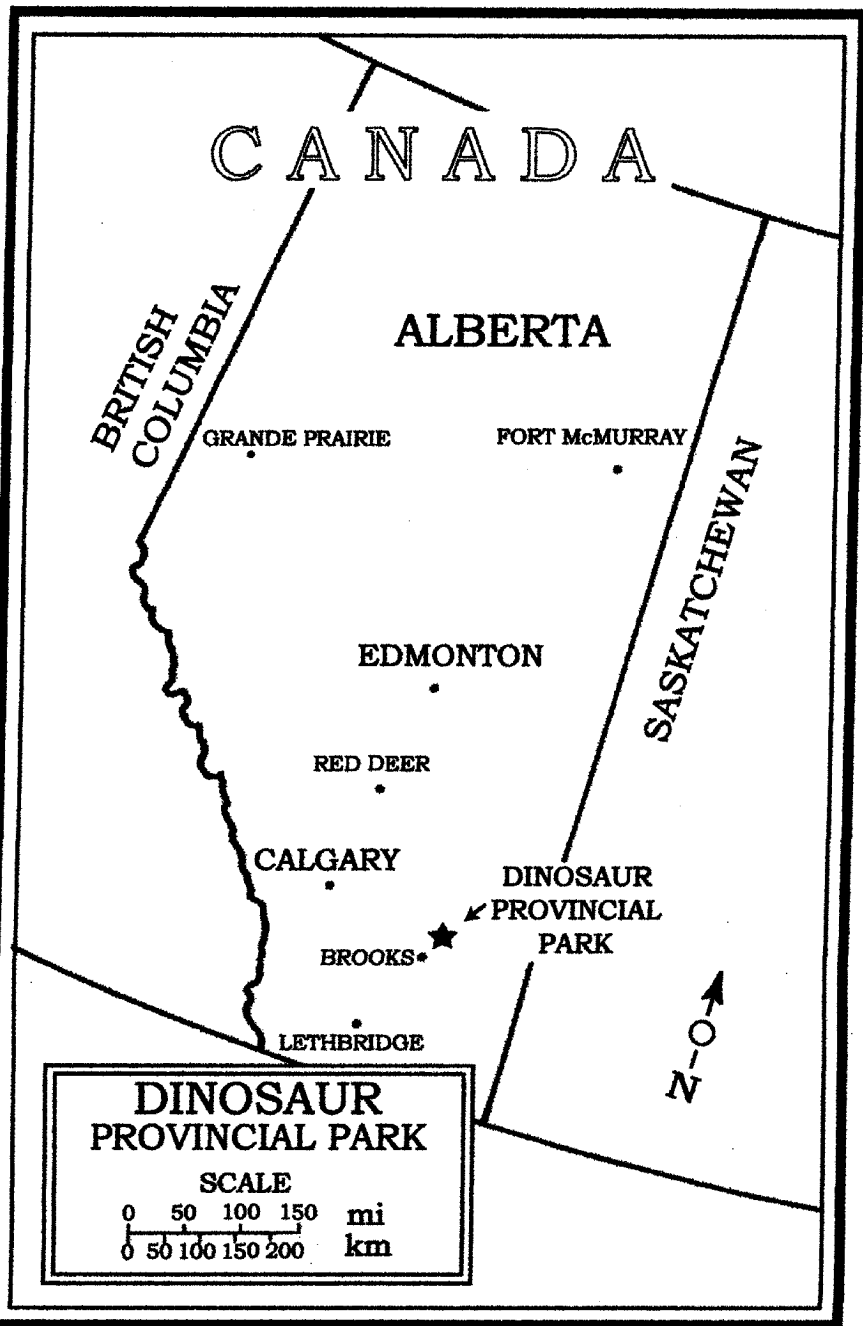


Figure 15.1. Map of Alberta, Canada, showing the location of Dinosaur Provincial Park.

literature (see Carpenter and Alf 1994; Carpenter 1999 for reviews). Numerous disarticulated skeletal remains of neonate-size hadrosaurs from DPP are now known. Some specimens were derived from extremely small and possibly embryonic individuals.

Hatchling- or nestling-size (< 1.5 m total length) hadrosaur skeletal remains have always been poorly represented in the Upper Cretaceous lowland deposits of western North America and elsewhere. This rarity, and the presence of eggs, nests, or nesting horizons preserved in upland facies, originally led previous workers (Sternberg 1955; Horner 1982, 1984) to consider hadrosaur breeding and nesting habits to have occurred in more upland regions. More recent research has indicated hadrosaurs nested in lowlands as well (Carpenter 1982, 1992; Fiorillo 1987). However, neonate-size hadrosaur specimens have only occasionally been previously reported from the lowland facies in Dinosaur Provincial Park (DPP). Sternberg (1955) described several isolated jaws (NMC 619 and NMC 8525), and what is still the best single known specimen from a hatchling-size individual, a partial skull of an unidentified hadrosaurine (NMC 8917). Russell (1967) mentioned isolated remains of hadrosaurs and saurischian dinosaurs from the Late Cretaceous of Alberta that came from individuals "no larger than a full-grown turkey." Dodson (1983, 98) commented briefly on the occurrences of juvenile hadrosaur material recovered from vertebrate microfossil localities. Brinkman (1986) noted occurrences of dinosaur eggshell in the Park. These short and infrequent notations give the impression that fossil material referable to hatchling- and nestling-size hadrosaurs in DPP is extremely rare. This, however, is not true. The apparent rarity of remains is due to fossil collecting biases against smaller specimens or simply not recognizing them in the field.

Recently, the view that hadrosaurs nested predominantly in upland environments has come to be challenged. Fiorillo (1987, 1989), described juvenile hadrosaur material from a lowland deposit in central Montana. Carpenter (1992, 1999) described and figured very small hadrosaur footprints from the Blackhawk Formation of Utah. Most recently, Clouse (1995) reported on extensive hadrosaur nesting grounds and embryonic remains from possible lowland facies near Havre, Montana. Fieldwork at microvertebrate sites and bone beds by the Royal Tyrrell Museum at DPP has resulted in the discovery of several thousand taxonomically diverse specimens. Among these samples occur material from hatchling- to nestling-size hadrosaurs. While such specimens at first appear to be relatively uncommon, an experienced collector can usually find several such specimens per day (Tanke, field observation). The 1992 field season marked the first year a concerted effort was made to find and collect neonate-size hadrosaur bones and this effort was successful, with 43 specimens collected. These finds mostly consist of edentulous dentary fragments, limb bones of varying completeness, pedal elements, and centra, although other elements are represented. Some of the material shows little or no transport abrasion, supporting the hypothesis of nesting by hadrosaurs within or near the Park boundaries, and also confirming Carpenter's (1982) and Fiorillo's (1987, 1989) hypotheses for a lowland nesting behavior in these dinosaurs.

*Institutional Abbreviations:* DPP, Dinosaur Provincial Park, Alberta; NMC, National Museum of Canada (now Canadian Museum of Nature), Ottawa; TMP, Royal Tyrrell Museum of Palaeontology, Drumheller, Alberta.

## Description

### *Eggshell*

Dinosaur eggshell in the Dinosaur Park Formation is known from only two small localities within DPP. Both localities are vertebrate microfossil sites or bone beds (BB), containing countless fragmented remains of pisidiid clams, rare unionid clams (Brinkman 1986; Brinkman et al. 1987), and rare gastropods (Eberth 1990). The presence of many invertebrate shells within these sites [BB 31 (Quarry 156) and BB 98] apparently released calcium carbonate into the acidic water, which acted as a buffering agent to raise the local water pH to levels conducive to nondissolution of eggshell (Carpenter 1982, 1987, 1999).

The eggshell pieces are fragmentary, with no specimens exceeding 1 cm in greatest dimension; they have a pebbled surface texture. They are similar to dinosaur eggshell from Montana described by Jepsen (1931) and Sahni (1972) from the Judith River Formation, and from the Two Medicine Formation (Horner 1999). Referring the DPP eggshell to hadrosaurs is somewhat problematic because a single egg can have different types of surface texture on different parts of the egg. However, the DPP eggshell is similar to that of *Maiasaura*, a hadrosaurid best known from Montana, and eggshell from the Devil's Coulee hadrosaur nesting locality (Currie 1988) in southern Alberta. While it is beyond the scope of this chapter to report on the eggshell histologically, in gross appearance some of the eggshell is hadrosaurian (Zelenitsky, pers. comm. 1999).

### *Bones*

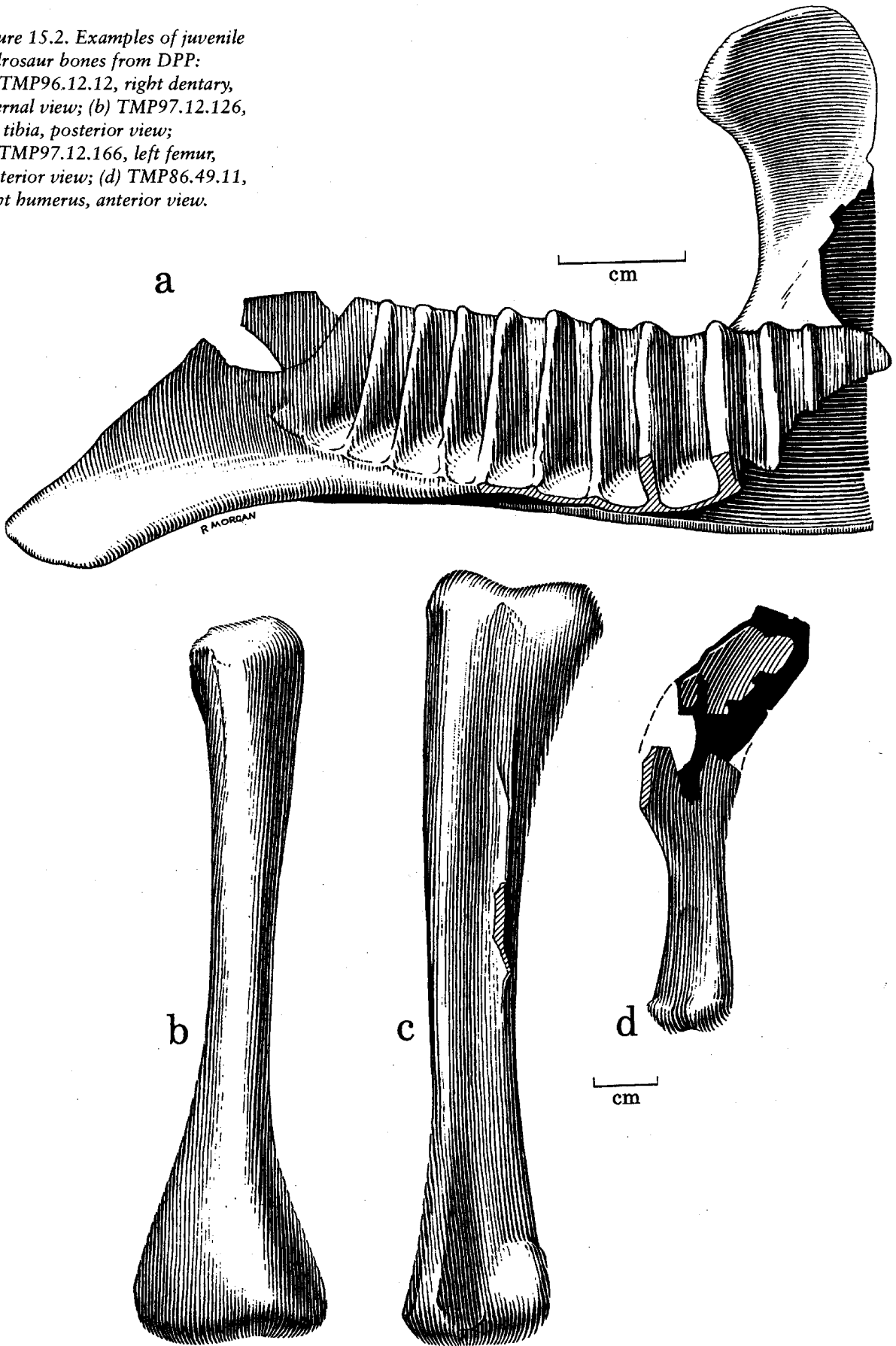
A complete listing of DPP embryonic and neonate hadrosaur bone material housed at TMP is listed in appendix 15.1. Measurements of some of the more complete material are given in appendix 15.2.

Dentaries are well represented in the collection. Many of the dentary fragments bear fresh erosional damage resulting in loss of the coronoid process. It is likely that these specimens were originally buried entire, such as those described by Sternberg (1955). A combination of factors, such as the small size of the specimens and the high erosion rates in DPP, make it difficult to find complete dentaries and other neonate bones. Few specimens preserve the entire series of grooves for tooth emplacements. As noted by Sternberg (1955) and Dodson (1983), most dentaries preserve only about 10 tooth files. TMP neonate hadrosaur material from DPP exhibit 12 tooth files in the maxilla, and 11 tooth files in the dentary (fig. 15.2a; TMP96.12.12).

Limb bones have the same morphology and general proportions as those found in adult animals, and often show predepositional erosion or concave articular ends. This condition is no doubt due to the cartilaginous cap on the ends of these bones (Horner and Weishampel 1988).

Figure 15.2. Examples of juvenile hadrosaur bones from DPP:

- (a) TMP96.12.12, right dentary, internal view;
- (b) TMP97.12.126, left tibia, posterior view;
- (c) TMP97.12.166, left femur, posterior view;
- (d) TMP86.49.11, right humerus, anterior view.



One left humerus (fig. 15.2d; TMP86.49.11) is typical of hadrosaurines, with a deltopectoral crest extending below the midpoint of the shaft. The external texture of the deltopectoral crest (4 mm thick) shows the early formation of the compacta (<0.5 mm thick). The entire length of the humerus is 70 mm.

A left femur (fig. 15.2c; TMP97.12.166) has the apex of the fourth trochanter at the midpoint of the shaft. The base of the trochanter, however, extends cranially almost one-quarter the length of the shaft, a feature not seen in many adults of Campanian age. The shape of the fourth trochanter is primitively an asymmetric triangle that is derived from the pendant hook in the iguanodont condition (Brett-Surman 1989). Over geologic time, the trochanter became an isosceles triangle, a condition seen in many crown group genera of hadrosaurids (Brett-Surman 1989). The change in trochanter shape, from juveniles with a trochanteric base extending cranially, to a trochanter with a restricted base only at the midpoint of the femoral shaft, is a heterochronic feature. The neck between the head and the greater trochanter shows the beginning of development. The anterior trochanter is offset from the greater trochanter. The channel between the distal articular condyles is already formed, even though the condylar surfaces are still not fully ossified. Closure of the channel is seen only in adults, and thus is a growth feature, not taxonomic.

An isolated left tibia (fig. 15.2b; TMP97.12.126) is more developed distally than proximally. The proximal condyles are slightly developed, with the median condyle larger than the lateral condyle and the cnemial crest. The distal end of the tibia has the articular facet for the astragalus formed, mostly on the caudal surface. The craniolateral surface of the outer condyle already has the vertical striations on the compacta where the distal end of the fibula articulates. Fusion of the astragalus and calcaneum to the tibia and fibula is rarely seen, and then only in very old adults.

The pelvis has features in common with those of an adult, indicating that it forms very early in ontogeny. The prepubic portion of one pubis (TMP91.36.367) has a neck (50 mm) that is longer than the blade (34 mm), as is typical of hadrosaurines. The postpubis is as long as the prepubis, a condition of neonates (Brett-Surman 1989). Most of the bone texture is woven, with the compacta on the external surface just beginning to form.

Vertebrae are represented by centra only. Like the limb bones, these show proportions comparable to adult-size animals. Embryonic *Hypacrosaurus* material from Devil's Coulee shows that the neural arches were well developed, with all processes present, but are not fused to the centra. It is likely that tiny neural arches in DPP were lost prior to burial, destroyed by contemporary erosion, are overlooked, or not recognized.

## Discussion

Hatchling hadrosaurs had limb bones with poorly developed (highly cartilaginous) articular ends (Horner and Weishampel 1988). These

bones would not be expected to last long in an active silt and sand-laden river system, especially in water with a higher pH caused by the acids produced by the breakdown and release of tannins into the ecosystem by the abundant local coniferous vegetation (K. Aulenback, pers. comm. 2000). In fact, some specimens do show what appears to be transport wear with ends or edges rounded to varying degrees, indicating that some of the neonate bones may have traveled unknown distances.

Sternberg (1955) suggested that juvenile carcasses may have washed down from upland nesting grounds. While this may be true in part, such carcasses surviving the ravages of crocodylians, turtles, fish, and other scavengers before arriving in DPP makes this scenario seem doubtful. More likely, those bones showing transport abrasion had been moved only short distances from the distal upland areas or from lowland nesting sites.

The presence of commonly unabraded, near perfect neonate and possible embryonic hadrosaur bones and sharp-edged hadrosaur eggshell fragments in situ indicate nesting sites must have occurred nearby the area of deposition. These findings confirm hypotheses that hadrosaurs nested in lowland environments (Carpenter 1982, 1992; Fiorillo 1987, 1989). Because hatchling hadrosaur bone occurs in bone beds and microfossil sites throughout the stratigraphic section of the Dinosaur Park Formation within DPP, it is clear that hadrosaurs nested in the area during the 2.5 million years of deposition (Eberth 1990).

Bone beds 23, 28, 47, and 50 have yielded unusually high numbers of neonate hadrosaur bones relative to other bone beds in DPP (Tanke, field observation). Several small outcrops within BB 50 are particularly rich and produce up to a dozen baby hadrosaur specimens annually (the exact GPS coordinates and photographs of these sites are on file in TMP collections). Dinosaur eggshell has not been found in these bone beds. Perhaps these higher rates of neonate bone are related to close proximity to an active hadrosaur nesting ground (Horner 1994). Certainly the uneroded nature of many of the neonate bones would indicate minimal stream transport. Collecting biases or collecting intensities in one particular site over others does not appear to be related to the abundance of bone (Tanke, field observation).

## Conclusions

Hadrosaurs apparently nested in both lowland and upland environments, dependent on their diet, soil conditions, habits, competition with other hadrosaur or dinosaurian genera, or other unknown factors. It has not been established whether a particular genus nested in a single type of environment (lowland/upland), or could have nested in both. Rare hadrosaurids in DPP (such as the lambeosaurine *Parasaurolophus* and hadrosaurine *Brachylophosaurus*) may be carcasses derived from migrating individuals. Or, they originated from upland feeding or nesting grounds, but more work in upland environment depositional systems will need to test this hypothesis. Presently, little is known of the

hadrosaurs that lived in the upland and more northern Campanian-aged facies in Alberta.

*Acknowledgments:* We have benefited from discussions with Phil Currie, Darla Zelenitsky, and Kevin Aulenback. We thank Phil for his unwavering support over the years and offer our congratulations on the occasion of his 25th anniversary of paleontological activities in Alberta and the world. We thank Kenneth Carpenter and Patty Ralrick for helping review and critique the manuscript. P. Ralrick also assisted in data recording. A final word of thanks to the overworked TMP collections staff. All figures were prepared by Rod Morgan (Calgary, Alberta).

## References

- Brett-Surman, M. K. 1989. Revision of the Hadrosauridae (Reptilia: Ornithischia) and their evolution during the Campanian and Maastrichtian. Ph.D. diss., George Washington University.
- Brinkman, D. 1986. Microvertebrate sites: Progress and prospects. In B. G. Naylor (ed.), *Dinosaur Systematics Symposium, Field Trip Guidebook to Dinosaur Provincial Park*, pp. 24–37. Drumheller: Tyrrell Museum of Palaeontology.
- Brinkman, D., D. A. Eberth, and P. A. Johnston. 1987. Bonebed 31: Palaeoecology of the Upper Cretaceous Judith River Formation at Dinosaur Provincial Park, Alberta, Canada. In D. A. Eberth (ed.), *Fourth Symposium on Mesozoic Terrestrial Ecosystems, Field Trip "A" Guidebook. Tyrrell Museum of Palaeontology, Occasional Paper 3*, pp. 12–13.
- Carpenter, K. 1982. Baby dinosaurs from the Late Cretaceous Lance and Hell Creek Formations and a description of a new species of theropod. *Contributions to Geology* (University of Wyoming) 20:123–134.
- Carpenter, K. 1987. Potential for fossilization in Late Cretaceous–Early Tertiary swamp environments. *Geological Society of America, Abstracts with Programs* 19 (5): 264.
- Carpenter, K. 1992. Behavior of hadrosaurs as interpreted from footprints in the "Mesaverde" Group (Campanian) of Colorado, Utah, and Wyoming. *Contributions to Geology* (University of Wyoming) 29 (2): 81–96.
- Carpenter, K. 1999. *Eggs, Nests, and Baby Dinosaurs*. Bloomington: Indiana University Press.
- Carpenter, K., and K. Alf. 1994. Global distribution of dinosaur eggs, nests, and babies. In K. Carpenter, K. F. Hirsch, and J. R. Horner (eds.), *Dinosaur Eggs and Babies*, pp. 15–30. Cambridge: Cambridge University Press.
- Clouse, V. R. 1995. Paleogeography of an extensive dinosaur nesting horizon in the Judith River Formation of north-central Montana. *Geological Society of America, Abstracts with Programs* 27 (4): 6.
- Currie, P. J. 1988. The discovery of dinosaur eggs at Devil's Coulee. *Alberta* 1 (1): 3–10.
- Dodson, P. 1983. A faunal review of the Judith River (Oldman) Formation, Dinosaur Provincial Park, Alberta. *Mosasaur* 1: 89–118.
- Eberth, D. A. 1990. Stratigraphy and sedimentology of vertebrate microfossil sites in uppermost Judith River Formation (Campanian), Dinosaur Provincial Park, Alberta, Canada. *Palaeogeography, Palaeoclimatology, Palaeoecology* 78: 1–36.



- Fiorillo, A. R. 1987. Significance of juvenile dinosaurs from Careless Creek Quarry (Judith River Formation), Wheatland County, Montana. In P. J. Currie and E. H. Koster (eds.), *Fourth Symposium on Mesozoic Terrestrial Ecosystems: Short Papers*, pp. 89–95. Tyrrell Museum of Palaeontology, Occasional Paper 3.
- Fiorillo, A. R. 1989. The vertebrate fauna from the Judith River Formation (Late Cretaceous) of Wheatland and Golden Valley Counties, Montana. *Mosasauro* 4: 127–142.
- Horner, J. R. 1982. Evidence of colonial nesting and “site fidelity” among ornithischian dinosaurs. *Nature* 297: 675–676.
- Horner, J. R. 1984. The nesting behavior of dinosaurs. *Scientific American* 250 (4): 130–137.
- Horner, J. R. 1994. Comparative taphonomy of some dinosaur and extant bird colonial nesting grounds. In K. Carpenter, K. F. Hirsch and J. R. Horner (eds.), *Dinosaur Eggs and Babies*, pp. 116–123. Cambridge: Cambridge University Press.
- Horner, J. R. 1999. Egg clutches and embryos of two hadrosaurian dinosaurs. *Journal of Vertebrate Paleontology* 19 (4): 607–611.
- Horner, J. R., and D. B. Weishampel. 1988. A comparative embryological study of two ornithischian dinosaurs. *Nature* 332: 256–257.
- Jepsen, G. L. 1931. Egg shells sixty million years old. *Discovery* 12: 180–183.
- Russell, L. S. 1967. Reply to J. M. Cys 1967. The inability of dinosaurs to hibernate as a possible key factor in their extinction. *Journal of Paleontology* 41 (1): 266–267.
- Sahni, A. 1972. The vertebrate fauna of the Judith River Formation, Montana. *Bulletin of the American Museum of Natural History* 147: 321–412.
- Sternberg, C. M. 1955. A juvenile hadrosaur from the Oldman formation of Alberta. *National Museum of Canada, Bulletin* 136: 120–122.

## APPENDIX 15.1.

**Embryonic, Neonate, and Small Juvenile Hadrosaur Specimens from Dinosaur Provincial Park (Dinosaur Park Fm.; Campanian), Alberta. Specimens housed in Royal Tyrrell Museum of Palaeontology (Drumheller, Alberta) collections. All specimen numbers are preceded by the acronym TMP. List compiled and updated by Darren Tanke (TMP) and Patty Ralrick; listing accurate up to March 31, 1999.**

---

*Partial skull:* 82.4.2 (cast of NMC 8917 described by Sternberg 1955).

*Basisphenoid:* 92.36.1047; 98.92.152.

*Jugal:* 92.36.428 (not neonate, but juvenile).

*Maxilla:* 80.16.1826 (fragment with 4 teeth); 81.22.6 (nearly complete, with 7 teeth); 82.16.177 (with 7 teeth; not neonate, but small juvenile); 86.36.265 (fragment); 88.36.4 (right maxilla with teeth; not neonate, but small juvenile); 88.36.10; 94.12.327 (fragment); 89.50.50; 95.134.4 (fragment).

*Surangular:* 97.12.125.

*Ceratohyal:* 98.93.165 (nearly complete; not neonate, but small juvenile).

*Right dentaries:* 67.17.4; 67.20.232 (complete); 81.16.414; 81.41.131 (fragment); 82.20.197; 82.20.202; 82.20.472; 83.67.33; 86.78.57; 87.36.386; 89.36.414; 89.50.154; 91.36.57; 93.36.662; 93.40.19; 94.12.542; 95.12.165; 96.12.9; 96.12.12 (complete); 96.12.158; 98.12.19 (complete); 98.93.146.

*Left dentaries:* 79.8.396; 79.8.588; 79.14.420; 80.13.47; 80.16.1260 (fragment); 81.19.274; 82.16.61; 82.16.259; 85.36.173; 86.36.6 (fragment); 87.48.95 (fragment); 90.50.14; 91.36.821; 92.36.12; 92.36.721; 92.36.724 (complete); 92.50.183; 93.36.69; 94.12.46; 98.68.96; 98.93.153 (complete).

*Undifferentiated dentary fragments:* 67.20.4; 92.36.127; 94.12.627 (not neonate, but small juvenile).

*Unidentified jaw fragments:* 94.12.904.

*Surangular:* 79.8.254 (not neonate, but small juvenile).

*Teeth:* 79.8.639; 90.36.3; 90.78.4 (3 teeth); 93.36.71; 94.12.552 and 94.12.579 (both not neonate, but small juvenile); 95.127.19.

*Cervical vertebrae:*

*Centra:* 96.12.166 (not neonate; but small juvenile); 96.12.171 (from cervico-dorsal transition region; not neonate, but small juvenile); 97.12.210 (not neonate; but small juvenile).

*Diapophysis:* 94.12.426 (diapophysis? Tiny = embryonic?).

*Dorsal vertebrae:*

*Centra:* 79.8.412 (not neonate, but small juvenile); 85.63.65; 91.36.206; 92.36.584; 95.127.14; 98.93.15; 98.93.161 (not neonate, but small juvenile).

*Neural arch:* 82.31.1 (not neonate, but small juvenile).

*Sacral centra:* 92.36.152 (nonhadrosaurian?); 92.50.142; 94.172.137 (embryonic?); 98.93.50 (not neonate, but small juvenile).

*Caudal centra:* 80.16.290 (medial); 80.16.1248 (proximal); 81.20.51 (proximal); 82.31.82 (medial? eroded); 83.36.112 (medial); 85.97.51 (proximal); 86.77.25 (medial); 90.50.177 (medial); 90.50.204 (medial); 92.36.166 (medial); 92.36.339 (proximal); 92.36.1171 (proximal); 94.12.431 (medial); 94.12.724 (proximal; not neonate, but small juvenile); 94.12.727 (proximal); 94.12.980 (medial; fused neural arch base); 94.112.63 (proximal); 94.112.74 (proximal; not neonate, but small juvenile); 95.12.58 (medial); 97.12.169 (proximal); 98.93.16 (proximal); 98.93.24 (proximal). 95.12.159 (2 unassociated centra, 1 posterior dorsal, and 1 proximal caudal).

*Coracoid:* 92.36.470 (nearly complete-left).

*Right humerus:* 86.49.11 (complete); 92.36.963; 93.36.386 (midshaft region—embryonic?); 94.12.676 (midshaft); 94.12.757 (shaft); 97.12.167 (complete).

*Left humerus:* 84.163.26 (?ceratopsian); 85.36.164 (shaft); 85.59.55 (shaft); 86.78.82 (shaft); 87.72.24

(midshaft section—embryonic?); 92.36.138 (complete); 92.36.371 (bears small theropod toothmarks on shaft); 92.36.1001 (distal half).

*Undifferentiated humerus*: 87.36.358 (distal end); 92.36.472 (distal end); 92.36.1064 (distal end); 97.12.154 (distal end in 3 pieces).

*Ulna*: 81.16.373 (complete); 91.36.600 (proximal end); 92.36.982 (shaft); 93.36.3 (nearly complete—in two pieces); 93.36.123 (?ulna shaft); 95.405.46 (?proximal end fragment); 96.12.168 (proximal end); 98.93.33 (shaft).

*Metacarpal*: 94.12.668 (?half metacarpal); 97.12.156 (complete).

*Manual phalanges*: 95.12.123 (manual phalanx or carpal; not neonate, but small juvenile).

*Rib*: 80.16.634 (left dorsal); 80.16.1343 (right dorsal; both not neonate, but small juvenile); 94.12.860 (right dorsal); 94.12.933 (incomplete right dorsal rib in 3 pieces).

*Right ilium*: 94.12.700.

*Pubis*: 91.36.367 (complete).

*Ischium*: 98.93.137 (complete; not neonate, but small juvenile).

*Right femur*: 73.8.360; 81.16.372 (embryonic?); 90.36.412; 92.36.112; 92.36.426 (in 2 pieces); 92.36.921 (complete); 92.40.4 (proximal end); 94.12.427 (nearly complete; in 2 pieces); 96.12.172 (complete); 96.12.175 (complete); 97.12.166 (complete); 97.12.173 (complete).

*Left femur*: 89.36.173 (complete); 89.36.415 (complete); 92.36.240 (proximal and distal ends); 92.36.600; 92.36.920; 92.36.1069 (shaft and distal end; not neonate, but small juvenile); 94.12.483 (proximal half); 98.93.132 (complete?).

*Undifferentiated femur fragments*: 87.36.375 (distal end); 92.36.130 (4 associated fragments); 92.36.471 (distal end); 92.36.1070 (distal end); 93.150.3 (shaft); 94.12.491 (distal end fragment); 94.12.492 (shaft fragment); 94.12.742 (distal end region); 95.405.50 (shaft fragment); 95.405.51 (distal fragment); 96.12.157 (distal end); 96.12.170 (distal end); 98.93.26 (distal end region).

*Right tibia*: 80.16.818 (distal end); 91.36.547 (distal end); 92.36.536 (complete); 92.36.732 (distal end); 97.12.216 (complete).

*Left tibia*: 67.20.339 (not neonate, but small juvenile); 84.67.60 (complete); 85.36.138 (complete); 87.67.60 (complete); 89.36.113; 91.36.783 (not neonate, but small juvenile); 92.36.585; 94.12.425 (distal end; non-hadrosaur?); 94.12.835 (partial tibia in 2 pieces); 94.12.956 (distal half); 94.45.8 (complete?); 97.12.126 (complete); 97.12.197.

*Undifferentiated tibia shafts*: 91.36.733 (proximal end—embryonic?); 92.36.165 (2 pieces); 92.36.804; 92.36.1048; 94.12.822; 94.12.911 (?tibia shaft, embryonic?); 95.405.38; 97.12.185; 98.93.25.

*Undifferentiated tibia shaft fragments*: 92.36.125; 94.12.485; 94.12.486; 94.12.493; 94.45.9; 94.45.10; 96.12.160; 96.12.163; 97.12.177; 98.93.32; 98.93.60; 98.93.61.

*Fibula*: 92.36.457 (distal half; possibly distal ischium?); 94.12.821 (eroded and fragmented slender limb bone—?fibula).

*Metatarsals*: 80.8.189 (distal end); 80.16.1760 (distal end); 84.163.59 (complete); 85.59.38 (complete); 85.59.274 (metatarsal in 2 pieces); 86.77.72 (nearly complete; in 2 pieces); 86.78.34; 92.36.922 (proximal end; not neonate, but small juvenile); 93.110.44 (not neonate, but small juvenile); 94.12.422; 94.12.424 (midshaft region); 94.12.939 (midshaft region); 94.45.11; 96.12.169 (complete left Mt. III); 96.12.432 (distal end; Mt. III); 97.12.168; 98.93.151.

*Pedal phalanges*: 80.16.963; 84.67.54; 87.36.358 (ungual missing tip); 92.36.121; 96.12.164 (embryonic?); 97.12.155.

*Unidentified specimens*: 92.36.490 (small bone shaft—radius?, ulna?); 93.36.73 (fragment); 94.12.810 (vial of 13 neonate hadrosaur bone fragments); 95.405.11 (bone shaft).

Unnumbered specimens for destructive histological analysis: metatarsal, distal end; small bone shaft (?fibula).

APPENDIX 15.2.

Measurements of Selected Juvenile Hadrosaur Material in TMP Collections (mm)

Phalanges are pedal elements. Abbreviations: D.= Digit; Lt.= Left; Mid.= Middle; Mt.= Metatarsal; p.= phalanx; Prox.= Proximal; Rt.= Right.

| Specimen Number | Element                     | Length | Prox. Width   | Prox. Height | Distal Width     | Distal Height |
|-----------------|-----------------------------|--------|---------------|--------------|------------------|---------------|
|                 | Cranial                     |        |               |              |                  |               |
| 98.92.152       | Basisphenoid                | 14     | Max. Width 13 |              | Condyle Width 12 |               |
|                 | Postcrania                  |        |               |              |                  |               |
| 92.36.470       | Lt. coracoid                |        | 7.5           | 14           |                  |               |
| 97.12.167       | Rt. humerus                 | 118    |               |              | 26               |               |
| 92.36.138       | Lt. humerus                 | 73     | 18+           |              | 15.9             |               |
| 87.36.358       | Humerus                     |        |               |              | 16.3             |               |
| 92.36.1064      | Humerus                     |        |               |              | 17               |               |
| 97.12.154       | Humerus                     |        |               |              | 17               |               |
| 81.16.373       | Lt. ulna                    | 107    | 21            |              | 15.5             |               |
| 91.36.600       | Ulna                        |        | 18            |              |                  |               |
| 94.170.251      | Ulna                        | 77.5   |               |              |                  |               |
| 96.12.168       | Ulna                        |        | 16.5          |              |                  |               |
| 97.12.156       | Metacarpal                  | 41.2   | 7.9           |              |                  |               |
| 96.12.164       | Rt. D. IV, p. I.            | 10.3   | 9.5           | 7.2          | 8                |               |
| 84.67.54        | D. III, p. I                | 13.2   | 13            | 8            | 10               |               |
| 97.12.155       | D. III, p. I                | 18     |               |              | 12.5             | 8.9           |
| 92.36.121       | ?Lt. D. IV, p. I.           | 16.3   | 14.5          | 10           |                  |               |
| 98.93.137       | Ischium                     | 265    | 62.8          |              | 11               | 15            |
| 90.36.412       | Rt. femur                   | 119+   |               |              |                  |               |
| 92.36.921       | Rt. femur                   | 97.2   |               |              |                  |               |
| 96.12.172       | Rt. femur                   | 155    | 37            |              | 31               |               |
| 89.36.173       | Lt. femur                   | 132    | 28            |              | 23               |               |
| 89.36.415       | Lt. femur                   | 113.5  | 24.5          |              | 20               |               |
| 92.36.240       | Lt. femur                   |        | 29.5          |              | 24               |               |
| 96.12.175       | Lt. femur                   | 125    | 28            |              | 21               |               |
| 97.12.153       | Lt. femur                   | 125    |               |              | 22               |               |
| 81.16.372       | Femur                       |        | 13            |              |                  |               |
| 81.16.375       | Femur                       |        |               |              | 23               |               |
| 92.36.1069      | Femur                       |        |               |              | 31               |               |
| 92.40.4         | Femur                       |        | 16.2          |              |                  |               |
| 97.12.197       | Rt. tibia                   |        |               |              | 24               |               |
| 97.12.216       | Rt. tibia                   | 143    | 37            |              | 39.5             |               |
| 84.67.60        | Lt. tibia,<br>tooth-marked? | 108    | 28            |              |                  |               |

## APPENDIX 15.2. (cont.)

| Specimen Number | Element          | Length | Prox. Width | Prox. Height | Distal Width | Distal Height |
|-----------------|------------------|--------|-------------|--------------|--------------|---------------|
| 85.36.138       | Lt. tibia        | 115.5  | 28.5        |              | 27+          |               |
| 94.12.956       | Lt. tibia        |        |             |              | 20           |               |
| 94.45.8         | Lt. tibia        | 124+   |             |              | 33           |               |
| 92.36.536       | Tibia            | 110    |             |              |              |               |
| 96.12.169       | Lt. Mt. III      | 46     |             | 13           | 11           |               |
| 84.163.59       | Rt. Mt. II       | 48.9   | 15          | 15.3         | 14           | 11.8          |
| 85.59.279       | Rt. Mt. II       |        | 12.8        | 15           | 15.4         | 13.9          |
| 80.16.1760      | Lt. Mt. II       |        |             |              | 13           | 11            |
| 85.59.38        | Lt. Mt. II       | 39.5   | 10.2        | 11.2         | 10.2         | 9.8           |
| 86.77.72        | Lt. Mt. II       |        |             | 13           | 12.8         | 11            |
| 80.8.189        | Mt. III          |        |             |              | 16           | 14.5          |
| 86.78.34        | Mt. III          |        |             |              | 13.8         |               |
|                 | Vertebral Centra |        | Max.Width   |              | Max.Height   |               |
| 79.8.412        | Dorsal           | 19     | 18          |              | 20           |               |
| 85.63.65        | Dorsal           | 6.2    | 7.1         |              | 7.9          |               |
| 86.77.25        | Dorsal           | 6.5    | 8           |              | 6.5          |               |
| 91.36.206       | Dorsal           | 15     | 14.5        |              | 15.2         |               |
| 92.36.584       | Dorsal           | 18.3   | 15.5        |              | 20           |               |
| 92.50.5         | Dorsal           | 13     | 12          |              | 13.3         |               |
| 95.127.14       | Dorsal           | 5      | 7.8         |              | 6.5          |               |
| 96.12.159       | Dorsal           | 11     | 10          |              | 10           |               |
| 96.12.431       | Dorsal           | 6.7    | 10          |              | 8            |               |
| 98.93.15        | Dorsal           | 10     | 16          |              | 15           |               |
| 92.50.142       | Sacral           | 13.9   | 20          |              | 14.2         |               |
| 94.172.137      | Sacral           | 5      | 8           |              | 5.8          |               |
| 90.50.177       | Mid. caudal      | 5      | 8.2         |              | 8            |               |
| 92.36.166       | Mid. caudal      | 11.3   | 11.2        |              | 10.9         |               |
| 94.12.446       | Mid. caudal      | 8.1    | 13          |              | 11           |               |
| 94.12.980       | Mid. caudal      | 5.5    | 9.5         |              | 7.5          |               |
| 80.16.1248      | Prox. caudal     | 7      | 12.5        |              | 12+          |               |
| 81.20.51        | Prox. caudal     | 10.5   | 16          |              | 15.3         |               |
| 85.97.51        | Prox. caudal     | 4.5    | 7.9         |              | 8.9          |               |
| 90.50.204       | Prox. caudal     | 5.9    | 9.7         |              | 7.2          |               |
| 92.36.339       | Prox. caudal     | 11.4   | 17          |              | 17           |               |
| 92.36.1171      | Prox. caudal     | 13     | 21          |              | 20.5         |               |
| 97.12.169       | Prox. caudal     | 4.1    | 9           |              | 8            |               |
| 98.93.16        | Prox. caudal     | 13     | 23.5        |              | 24.9         |               |
| 98.93.24        | Prox. caudal     | 12     | 27          |              | 25           |               |