Osteology and variation of Brachylophosaurus canadensis (Dinousauria, Hadrosauridae) from the Upper Cretaceous Judith River formation of Montana
by Albert Prieto-Marquez

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
The recovery of an adult articulated, complete skeleton and more than 1,300 specimens from a bonebed of the hadrosaurid dinosaur Brachylophosaurus canadensis allowed a reexamination of the morphologic features of this taxon. The fossils were recovered from Upper Cretaceous (Campanian) Judith River of northeastern Montana. The bones were first described element by element in order to produce a complete redescription of the whole skeleton. Secondly, a systematic analysis of the morphological variation present in each element was conducted. Finally, a revision of the systematic position of this taxon was undertaken.

B. canadensis is rediagnosed on the basis of a subrectangular skull with a relatively deep snout; nasals greatly developed into a paddle-like solid crest that extends caudodorsally overhanging the dorsal region of the skull; nasals possessing an anteroposteriorly-oriented groove terminating in an elongated foramen, located medial to the prefrontal; prefrontal projected posteriorly, resting dorsomedially over the anterior process of postorbital and, more posteriorly, extending ventromedially underlying the nasal; jugal with a ventrally projected semicircular flange, being deeper element than in Maias aura; depressed dorsal surface of the frontal between the nasal joint and the postorbital suture; anteroposteriorly short exoccipital-supraoccipital roof posterior and dorsal to the foramen magnum; sternals with a compressed, oval “paddle”; and very elongated, slender forearm due to elongation of radii and ulnae. The species B. goodwini is considered a junior synonym of B. canadensis. The completeness of the new specimens from Malta complements our knowledge on hadrosaur anatomy.

The available specimens of B. canadensis show individual, ontogenetic, and dimorphic variation. At least four subadults and two adults are represented in the bonebed as deduced from the maximum number of specimens of the same side of a single element. Most remarkable is the dimorphic variation, which is here explained either as sexual dimorphism or size and ontogenetic changes.

The phylogenetic analysis agrees with previous hypothesis that placed B. canadensis as the sister taxon of Maiasaura peeblesorum. Both taxa form a relatively basal clade in relation to the successive more derived Gryposaurus, Prosaurolophus, and Edmontosaurus.

OSTEOLOGY AND VARIATION OF *BRACHYLOPHOSAURUS CANADENSIS* (DINOSAURIA, HADROSAURIDAE) FROM THE UPPER CRETACEOUS JUDITH RIVER FORMATION OF MONTANA

by

Albert Prieto-Márquez

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Earth Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

April 2001

APPROVAL

of a thesis (dissertation) submitted by

Albert Prieto-Marquez

This thesis (dissertation) has been read by each member of the thesis (dissertation) committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

John R. Horner [signature] 4/17/01
(Signature) Date

Approved for the Department of Earth Sciences

James G. Schmitt [signature] 4/17/01
(Signature) Date

Approved by the College of Graduate Studies

Bruce McLeod [signature] 4-18-01
(Signature) Date

STATEMENT OF PERMISION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under the rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Signature ______________________

Date April 17, 2001

Acknowledgements

I would like to thank my major advisor, Dr. John R. Horner, for opening the door and offering me the opportunity to come to Montana to work on this project and form part of one of the leading paleontologic institutions of the country, the Museum of the Rockies. No words can express how thankful I am to Mr. Terry and Mrs. Mary Kohler, who fully funded two years of tuition and living expenses through their Windway Foundation. Thanks also to them for the exciting trip to Argentina and Chile. Thank you also to my co-advisor, Dr. James G. Schmitt, for his expert advises, friendship, kindness, and support. To Dr. David J. Varricchio, who had the patience to answer all my anatomy questions and inquiries, and for his fresh and interesting discussions on dinosaur morphology. To my fellow graduate students who offered advise, sympathy, and English lessons along the way, including Jeff LaRock, for his help in the taphonomy and sedimentology of the "Brachy" sites, Ben Shoup for the horse ride, Chuck Lindsey for saving the format of this thing. The paleo crew deserves a special mention, including Cynthia Marshal for daring to read my first draft, Celeste Horner for computer and digital assistance, Bob Harmon, Carrie Ancell and various volunteers for the exquisite preparation of the specimens, and of course the Malta field crew for digging the specimens and take me to the hospital when, you know, I started to throw out things and get sicker and sicker… in my first North American dinosaur experience ever… Special thanks to Frankie Jackson and Mary Schweitzer for sharing their knowledge of dinosaurs, eggs, and biochemistry.

Most importantly I would like to thank my Mom and Dad, and my sister "La Chera" and the babies for all the support they have been giving to me over the years. Without them I would never have made it this far. My good friend Dr. Carlos Bonet Betoret provided additional funding and called me every three weeks. Cyberfriend Desiel Parra, who add a lovely Venezuelan taste to my hadrosaur delusions. And to my sweetie, Erika Maticorena Coronatta, for so much love and emotional support.

Finally, to Steve Roach, Robert Rich, Michael Stearns, Lustmord, Vir Unis, Vidna Obmana, and many other sound sculptors for carving all those deep soundworlds that provided the environment where I dwelled to produce the thesis you have in your hands.

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

The recovery of an adult articulated, complete skeleton and more than 1,300 specimens from a bonebed of the hadrosaurid dinosaur *Brachylophosaurus canadensis* allowed a reexamination of the morphologic features of this taxon. The fossils were recovered from Upper Cretaceous (Campanian) Judith River of northeastern Montana. The bones were first described element by element in order to produce a complete redescription of the whole skeleton. Secondly, a systematic analysis of the morphological variation present in each element was conducted. Finally, a revision of the systematic position of this taxon was undertaken.

B. canadensis is rediagnosed on the basis of a subrectangular skull with a relatively deep snout; nasals greatly developed into a paddle-like solid crest that extends caudodorsally overhanging the dorsal region of the skull; nasals possessing an anteroposteriorly-oriented groove terminating in an elongated foramen, located medial to the prefrontal; prefrontal projected posteriorly, resting dorsomedially over the anterior process of postorbital and, more posteriorly, extending ventromedially underlying the nasal; jugal with a ventrally projected semicircular flange, being deeper element than in *Maiasaura;* depressed dorsal surface of the frontal between the nasal joint and the postorbital suture; anteroposteriorly short exoccipital-supraoccipital roof posterior and dorsal to the foramen magnum; sternals with a compressed, oval "paddle"; and very elongated, slender forearm due to elongation of radii and ulnae. The species *B. goodwini* is considered a junior synonym of *B. canadensis.* The completeness of the new specimens from Malta complements our knowledge on hadrosaur anatomy.

The available specimens of *B. canadensis* show individual, ontogenetic, and dimorphic variation. At least four subadults and two adults are represented in the bonebed as deduced from the maximum number of specimens of the same side of a single element. Most remarkable is the dimorphic variation, which is here explained either as sexual dimorphism or size and ontogenetic changes.

The phylogenetic analysis agrees with previous hypothesis that placed *B. canadensis* as the sister taxon of *Maiasaura peeblesorum*. Both taxa form a relatively basal clade in relation to the successive more derived *Gryposaurus*, *Prosaurolophus*, and *Edmontosaurus*.

CHAPTER 1

INTRODUCTION

The dinosaurs of the family Hadrosauridae have been more intensely studied and we possess more fossil evidence about them than on any other dinosaur group. Yet, despite the current amount of data available, there are still gaps concerning the current knowledge of these creatures. For example, relatively little attention has been paid to their postcrania (Brett-Surman, 1976; Maryañska and Osmolska, 1983; Maryañska and Osmolska, 1984) in relation to the amount of work carried out on their cranial material. Thus, most diagnosis and studies have been focused on the skull (Ostrom, 1961; Heaton, 1972; Hopson, 1975; Maryañska and Osmolska, 1979; Weishampel, 1981b; Horner, 1992), plus some features of the appendicular skeleton (Chapman and Brett-Surman, 1990; Weishampel and Horner, 1990), probably because it is the most easily distinctive part of their anatomy. Likewise, a detailed morphological description of all the skeleton elements is not common in the literature, in spite of the vast quantity of specimens collected since the middle of the nineteen-century (Lull and Wright, 1942; Colbert, 1984). Abundant hadrosaurid remains, including complete and partial skeletons, eggs, nests, babies and even integument (Horner, 1984) remains have been collected during the past hundred and fifty years in North and South America (Lull and Wright, 1942; Dodson, 1971; Horner, 1983; Bonaparte et al., 1984; Head, 1998), Europe (Weishampel et al., 1993; Laurent et al., 1997; Company et al., 1998; Casanovas et al., 1999) and Asia (Maryañska and Osmolska, 1982; Buffetaut and Tong-Buffetaut, 1993). Thus, we not only have information on hadrosaur anatomy and evolutionary history (Hopson, 1975; Weishampel, 1981b; Horner, 1990), but also on behavior and life strategies (Horner and Makela, 1979; Horner, 1982; Horner and Currie, 1994; Cooper and Horner, 1999), functional morphology (Galton, 1970; Weishampel, 1981a; Norman and Weishampel, 1985), paleoecology (Weishampel and Norman, 1989; Chin and Gill, 1996) and taphonomy and sedimentology of its fossil occurrences (Dodson, 1971).

Morphological differences in some areas of the hadrosaurid skeleton are so subtle that preservational effects can easily obliterate them. Hence it is usually difficult to use some skeletal elements (especially those that are evolutionary conservative) for diagnosis, variation and generally any study emphasizing fine morphological observation, in the hadrosaurid material available.

In 1996 a practically complete, fully articulated skeleton of an adult "duck-billed" dinosaur of the genus *Brachylophosaurus,* was excavated from Judith River Formation strata near Malta, northeastern Montana (Harmon, 1997; Horner and Dobb, 1997). Posteriorly, the articulated hindquarters of a subadult were uncovered, but never prepared. In the summers of 1998 and 1999, a paucispecific, multiindivual bone bed was excavated in the vicinity of the other two sites (LaRock, 2000). Detailed sedimentologic and taphonomic studies were conducted on the bonebed (LaRock, 2000).

The purpose of this study is first to redescribe *Brachylophosaurus* on the basis of the new material. Specific goals of this research include: (1) to provide a descriptive model of a hadrosaurid dinosaur, (2) determine the degree and type of morphologic variation existing among the available specimens, and (3) reassess the phylogenetic position of this taxon, as well as the characters useful for hadrosaurid phylogenetic systematics. It is hoped that the osteology and variation presented in this thesis will contribute to the detailed undertanding of hadrosaur anatomy, providing a complete description to be used in further anatomical studies on "duck-billed" dinosaurs.

General Geologic Context

The Judith River Formation forms a terrigenous wedge west of the front of the Rocky Mountains with its contemporaneous counterpart, the western Two Medicine Formation. The Two Medicine Formation - Judith River clastic wedge (fig. 1), located in the Western Interior of the United States and the southern Western Canada sedimentary basin, has been a major source of dinosaur and other Late Cretaceous fossil remains and information for the past century (Currie, 1987; Eberth, 1997). The sites to be studied in project belong to this clastic wedge.

These nonmarine sediments are interpreted as the remains of an extensive alluvial plain that stretched from the west rising front of the Cordilleran thrust belt to the western shoreline of the Western Interior Seaway. The lowest deposits may be Santonian in the westernmost outcrops and the youngest are early Maastrichtian (Rogers et al., 1993). The wedge formed as the result of the deposition of terrigenous material shed from the thrust belt front into its foreland basin, during a major regressive-transgressive cycle of the Western Interior Seaway (Kauffman and Caldwell, 1993). The wedge thins eastwards and interfingers up section with the transgressive, marine Bearpaw Formation, and down section with the marine, regressive Clagget Formation (Montana) and the Pakowki-Lea

Park Formation (southern Alberta). Below the lower nonmarine sandstones of the Eagle Formation in Montana and the Milk River Group in southern Alberta are present (Eberth, 1997). The middle portion of that broad alluvial plain is lost due to the erosion of strata from the Sweetgrass Arch. In fact, this post-Cretaceous erosional event isolated the Two Medicine Formation in western Montana from its correlative strata to the east, the marine Clagget Formation, nonmarine Judith River Formation and the marine Bearpaw Formation (Rogers, 1994). The Two Medicine-Judith River wedge and its interfingered marine correlatives are overlaid by the Maastrichtian Saint Mary River Formation in the west and the Hell Creek Formation in the east.

Stratal packages range from mudstones to litharenites and volcanic litharenites, and represent a wide array of paleonvironments – beach and barrier island complexes, deltas, lakes, floodplains and fluvial channel systems (Eberth, 1997).

The strata of the Judith River Formation represent the more distal portion of the alluvial plain and thin eastwards towards the Cretaceous shoreline of the Western Interior Seaway. The deposits formed as the result of an eustatic fall of the sea level during Campanian time. The formation correlates in southern Alberta with the Belly River Group and the Judith River Group (Foremost, Oldman and Dinosaur Park Formations) (fig. 2) (Eberth, 1997). The outcrops of the Judith River Formation can be found in central Montana and south Alberta, and represent a coastal plain with fluvial, lacustrine and deltaic environments developed under a subtropical to temperate climate (Horner, 1989). The terrigenous material is chiefly composed of grayish to brownish siltstone and mudstones interbedded with medium-grained sandstone (Rogers, 1993).

Hadrosaur remains from the Judith River Formation are rather fragmentary in Montana, in contrast to the more complete and articulated specimens found in Alberta (Waldman, 1969; Horner, 1988; Currie, 1987; Weishampel, 1990). The material described here, recovered from Malta, may well be among the most complete and beautifully preserved hadrosaurid remains ever collected.

Location and taphonomy of the bone-bearing strata

The specimens herein studied were recovered from sites located in Phillips County, about 15 miles north of Malta, and 50 miles south of the Canadian border. The strata correspond to the lower portion of the Judith River Formation, in the Upper Cretaceous (Campanian). The Malta bonebed lies stratigraphically close to the underlying marine Clagget Shale, suggesting that these dinosaurs may have lived relatively near the shore of the Western Interior Seaway (LaRock, 2000).

In this area, the Judith River Formation outcrops are exposed in badlands located on the Bureau of Land Management lands. The tan-colored sandstones that entombed the Malta hadrosaurs are medium grained and well sorted. In the field area the Judith River Formation is composed by interbedded quartz rich, fine to medium grained sandstones and mudstones (LaRock, 2000). Fossil plant material is common and consists of isolated wood fragments, and interbedded plant material and sand layers (LaRock, 2000).

The taphonomy and sedimentology of the Malta bonebed,conducted by Jeff LaRock (2000), indicates that the deposit accumulated in a shallow sandy meandering channel under lower flow regime conditions. Likewise, the channel, which is of rather small scale and nine meters from the underlying shoreface Parkman Sandstone, may have been a distributary one close to the paleoshoreline (LaRock, 2000). A tree trunk was found lying across the bonebed. The high degree of association coupled with the lack of hydraulic equivalence between the bones and the grain size of the sediment led LaRock to suggest that "the hadrosaurs arrived in the quarry as bloated carcasses and accumulated on the unpstream portion of a fallen tree" (LaRock, 2000). This logjam was subsequently scavenged, disarticulated and slightly weathered. The accumulation of the hadrosaur remains probably represents a period not surpassing five years, based on the presence of bark on the tree (LaRock, 2000). The bonebed represents the remains of at least four subadults and two adult *Brachylophosaurus*. No evidence suggests herding behavior or that the animals were together at the moment of death.

Material and Methods

The complete list of the specimens studied can be found in Appendix A. In brief, the redescription, variation, and taxonomy of *Brachylophosaurus canadensis* is based on complete adult, articulated skeleton MOR 794, the more than 1,000 prepared specimens from the Malta bonebed (MOR 1071), a few cranial elements collected in the early twentieth century in Alberta, Canada (PB 862), and a fragmentary nasal UCB 130139.

The bone material of MOR 1071 and MOR 794 shows minimal weathering, none or very slight abrasion, some fractures, crushing, and a few tooth marks. MOR 794 is mediolaterally compressed due to lithostatic pressure probably, but otherwise is exquisitely preserved.

MOR 1071 includes complete and partial cranial elements such as premaxilla, nasal, prefrontal, frontal, lacrimal, postorbital, jugal, maxilla, pterygoid, ectopterygoid, palatine, predentary, dentary, quadratojugal surangular, splenial, squamosal, including two articulated braincases in partial skulls (nearly complete roof skulls); and either complete or partial postcranial elements including cervical, dorsal, sacral and caudal vertebrae, sternals, scapula, coracoid, humerus, ulna, radius, pubis, ilium, ischium, femur, tibia, fibula, carpals, tarsals, metacarpals, metatarsals, manual and pedal phalanges, including unguals.

The MOR 794 and 1071 specimens were hardened with vinac and were prepared duting the last five years. In fact, as this manuscript is written, more jackets are still being opened providing more elements from the Malta bonebed that will not be included here due to the limitations of time.

The bones are characteristically tan-colored and show minimal permineralization or infilling. The immense majority of specimens fall in the 0 and 1 weathering stages of Behrensmeyer (1978). The stage 1 of weathering is seen in the form of mosaic-cracking patterns on the articular surface of mostly vertebrae (especially caudals) and distal limb elements such as phalanges and unguals (LaRock, 2000, fig. 10A). Spiral fractures are also present in some specimens and are interpreted by LaRock (2000) as prefossilization breakage. A few specimens, dentary (MOR 1071-8-15-98-574), a partial nasal (MOR 1071-7-12-99-76), and two vertebrae, show deep grooves possibly indicative of tooth marks. The case of the dentary is very compelling, as it includes two deep and sharp grooves plus a puncture mark in its vicinity. Eight bones from the bonebed show pathologies (Hanna et al., 1999). Perhaps the most remarkable is a subadult metacarpal II with a bone overgrown.

This work was accomplished by first describing the skeleton of *Brachylophosaurus* in a rather systematic way, starting for the postcrania and ending up in the braincase. For organization purposes, the description is arranged in cranial and postcranial (appendicular and axial) osteology. Within the cranial description, the skull is organized in facial, palatal, mandibular and neurocranial segments or regions. The facial elements are those exposed externally and around the maxilla, a major bone in the skull. The neucranial complex includes the braincase and the frontal and parietal, which are intimately related to the former.

Once the dinosaur was fully described, attention was paid to the analysis of the variation present among the fossil material. The two age classes found in the bonebed represent ontogenetic variation. Individual and, possibly dimorphic, variations were also studied and described.

Finally, a new diagnosis of the taxon was established, along with a revision of the systematic position of *Brachylophosaurus*. It should be emphasized that the phylogeny here presented is rather limited by the time and taxonomic sample size available to me, and is intended only as a way to provide a phylogenetic context to *Brachylophosaurus*. Most of the characters employed were taken from a recent list by Horner, Weishampel and Forster (personal communication). Some characters were modified, several others deleted, and a few ones added to the list used here. The resulting matrix was input into MacClade 3.0 and PAUP, to obtain the tree herein presented.

The hadrosaur fossil material is here assigned to the species *Brachylophosaurus canadensis*. All the hadrosaur non-diagnostic elements from the Malta sites are also placed in this taxon, assuming that they follow the diagnosis suggested by the other elements. This is considered here the most parsimonious and probable hypothesis on the taxonomic precedence of these remains.

Numerous measurements were taken of several dimensions and features of the osteologic elements, whenever the landmark was complete enough. Linear measurements were taken with a caliper, while a few angular measures were taken with a conventional protractor. The measurements are intended to provide an idea of the dimensions of the different features of the skeletal elements. Although very precise figures are given, they should not be taken as the actual measures of the features, since breakage, abrasion, crushing, concealing by articulation and other preservational artifacts commonly affect the remains.

CHAPTER 2

SYSTEMATIC PALEONTOLOGY

Ornithopoda Marsh, 1871

Iguanodontia Dollo, 1888

Hadrosauridae Cope, 1869

Brachylophosaurus Sternberg, 1953

Brachylophosaurus canadensis (Sternberg, 1953)

(= *B. goodwini* Horner, 1988)

Revised Diagnosis

Hadrosaurid possessing a subrectangular skull, with a relatively deep snout; nasals greatly developed into a paddle-like solid crest that extends caudodorsally overhanging the dorsal region of the skull; nasals possessing an anteroposteriorly-oriented groove terminating in an elongated foramen, located medial to the prefrontal; prefrontal projected posteriorly, resting dorsomedially over the anterior process of postorbital and, more posteriorly, extending ventromedially underlying the nasal; jugal with a ventrally projected semicircular flange, in overall a deeper element than in *Maiasaura*, but more lightly built than in gryposaurs, saurolophs and edmontosaurs; extremely elongated, rod-like anterodorsal process of the maxilla projecting medial to the narial cavity along most of the anteroposterior length of the external naris; depressed dorsal surface of the frontal between the nasal joint and the postorbital suture; anteroposteriorly short exoccipital-supraoccipital roof posterior and dorsal to the foramen magnum; sternals with a compressed, oval "paddle"; and very elongated, slender forearm due to elongation of radii and ulnae.

Referred Specimens

MOR 794, a complete adult articulated skeleton lacking only the distal part of the tail; MOR 1071, more than 800 subadult and adult specimens from a paucispecifc bonebed, including disarticulated or partially articulated and/or associated coracoids, scapulae, sternals, ilia, pubes, ischia, cervical, dorsal, sacral and caudal vertebrae, ribs, humeri, radii, ulnae, carpals, metacarpals, phalanges, femora, tibiae, fibulae, tarsals, metatarsals, pedal phalanges, premaxillae, maxillae, a partial nasal, prefrontals, postorbitals, jugals, quadratojugals, quadrates, dentaries, a predentary, splenials, surangular, angulars, articulars, pterygoids, ectopteyrgoids, palatines, frontals, and two articulated skull roofs with preserved braincases, plus an articulated partial subadult skull. PR 862 is a partial skull roof with associated jugals, dentaries, pterygoid, nasals, right surangular, angulars, and left quadrate. UCB 130139, a partial nasal from the holotype of *B. goodwini* (Horner, 1988).

Locality

The adult quarry of MOR 794 (MOR locality JR-168) and the bonebed of MOR 1071 (MOR locality JR-224) correspond to two sites located in Phillips County, about 17 miles north of Malta, northeastern Montana, 54 miles from the Canadian Border (LaRock, 2000). PR 862 was found in 1922 by the Elmer S. Riggs expedition, in the Red Deer River area, north of Medicine Hat, Alberta, Canada. The nasal UCB 130139 is part of the material found by Mark Goodwin in 1981 in the Judith River Formation, UCMP locality no. V83125, Canadian Creek, Hill County, Montana.

Horizon

MOR 794 and MOR 1071 correspond to the Judith River Formation. PR 862 was unearthed from strata pertaining to the Two Medicine Formation. Both formations are Campanian in age.

Discussion

Sternberg (1953) originally named and described briefly *Brachylophosaurus canadensis* on the basis of a complete skull, cervical and anterior dorsal vertebrae, ribs, scapulae, coracoids, humeri, left ulna, and radius. These specimens came from the Oldman (Judith River) Formation of southern Alberta. In 1988 Horner emended Sternberg's diagnosis, characterizing *Brachylophosaurus* by the possession of a solid and low, sheet-like, nasal crest caudally directed, a nasal depression that do not extends to the crest, lightly constructed jugal with a ventrally projecting boss and an craniocaudally short supraoccipital-exoccipital roof caudal to the foramen magnum (Horner 1988, emended diagnosis). This diagnosis is here enhanced to accommodate a few more characters.

In the same 1988 paper, Horner described and named a new species of *Brachylophosaurus*, *B. goodwini*, from fragmentary cranial elements from the Judith River Fm. of Montana. This taxon is here considered invalid and a junior synonym of *B. canadensis*. Horner diagnosed *B. goodwini* on the basis of a deep and rounded dorsal depression or pit at or near the junction of the frontal and postorbital, dorsally concave upper process of the nasal, posterolateral surface of nasal reaching orbital rim, and quadratojugal process of the jugal parallel with postorbital process (Horner, 1988).

The depression on the dorsal surface of the frontal near the postorbital joint has been also found in the Malta specimens. The subadults MOR 1071-7-13-99-87-I and MOR 1071-6-30-98-4 show depressed areas near the postorbital suture. These depressions are elongated, but individual and/or ontogenetic variation might account for that discrepancy with Horner's observation.

The nasal characters are probably resulting from the wrong reconstruction of the fragmentary remains of this element studied by Horner. Horner interpreted the nasal UCB 130139 as having a concave relief, in contrast to the arched relief of the holotype and the other specimens of *Brachylophosaurus canadensis*. However, a closer comparison with the MOR 794 and MOR 1071 specimens shows that the UCB nasal was oriented in the opposite direction. When correctly oriented, the UCB nasal fragment corresponds probably to the supra to preorbital region of the skull and follows the outline of the typical *Brachylophosaurus* skull. The only difference is the large size of the UCB specimen. The parallel quadratojugal and postorbital process of the jugal is a case of individual variation. MOR 794 shows jugals with postorbital processes only slightly divergent. Among the bonebed specimens of available there is a degree of variation in the divergence between the postorbital and quadratojugal processes, coupled with a remarkable variation in the size and shape of the quadratojugal process (but see variation).

CHAPTER 3

OSTEOLOGIC DESCRIPTION

This chapter, the major section of this project, is intended as a redescription, as detailed as possible, of *Brachylophosaurus canadensis*. It revises and enhances the account given by Sternberg in his original paper in 1953, in the light of the new, more diverse and complete specimens. The text is organized in cranial and postcranial osteologies. The postcrania is split into appendicular and axial skeletons. The appendicular skeleton includes all the elements excluding the vertebral column and the ribs, being more or less related to the limbs. The cranial section is mainly divided into mandibular, facial, palatal, and neurocranial complexes, in a similar, but not exact, way of Ostrom (1961). Facial complex is preferred here instead of maxillary complex (Ostrom, 1961; Horner, 1992), since, although the maxilla is the major element in that segment of the skull, not all the elements included in that area contact the maxilla. Facial complex elements here are those exposed externally on the skull, exception made of the ones associated with the braincase and the mandibular segment. The other cranial complexes considered here follow the organization of Ostrom (1961).

General Description of the Skull

The skull of *Brachylophosaurus canadensis*, as exemplified by MOR 794 (Fig. 1) and the MOR 1071 specimens, is about two and half times longer than deep. The skull is relatively broad mediolaterally, especially across the postorbital width and the paroccipital processes, where the skull is one third as wide as it is long. In lateral view, the dorsal border of the skull is anteriorly arched and sloping along the anterior third, close and from the nasal-premaxilla joint. Along the posterior two thirds of the dorsal border the skull is rather straight, only rising posterodorsally very gently due to the projection of the nasal crest. The ventral border of the skull is also rather straight and mainly formed by the ventral edge of the dentary, the anteroventral deflection of which is slight in MOR 794, but much more remarkable in PR 862.

Brachylophosaurus shows a ellipsoidal, anteroposteriorly elongated and large external naris. The premaxilla forms the anterior edge of the narial cavity, while the nasal forms a lunate posterior border. The ventral border of the external naris is formed by the dorsal edge of the posteroventral process of the premaxilla. The dorsal border of the narial cavity is mostly formed by a laterally convex anterodorsal process of the nasal. The anterodorsal process of the maxilla can be seen crossing almost all the narial cavity anteroventrally as a narrow and long rod-like projection. A relatively large maxillary foramen opens anterolaterally, its anterior edge bounded by the lateral border of the posteroventral process of the premaxilla. The orbit is oval, relatively more elongated dorsoventrally. The longest axis of the orbital cavity extends in a dorsoposterior to anteroventral direction, about 20-25 degrees from a vertical line. The orbit is relatively very large and its anterodorsal edge is sharp and rugose, formed by a prefrontal that overlaps the dorsal face of the anterior process of the postorbital to underlie the nasal. Likewise, the posterodorsal and posterior edges of the orbit, formed by the postorbital, are still more rugose, notched and mediolaterally expanded at the dorsal area of the jugal