DINOSAUR PROVINCIAL PARK   SEPTEMBER 24, 2011

HADROSAUR SYMPOSIUM 2011

GUIDE BOOK

INTERNATIONAL
HADROSAUR SYMPOSIUM

Post-Symposium Field Trip, September 24, 2011

Geology and Palaeontology of Dinosaur Provincial Park, Alberta

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INTRODUCTION

This field trip focuses on aspects of the geology, stratigraphy, palaeontology and biostratigraphy of Upper Cretaceous strata at Dinosaur Provincial Park (the Park), with special reference to hadrosaurs and hadrosaur localities. We will spend the day at Dinosaur Provincial Park, followed by a supper at the Patricia Steak Pit. We depart by bus from the Ramada Hotel, Drumheller, at 8:00 am and return at 8:00 pm. It is a two-hour drive to Dinosaur Provincial Park from Drumheller.

Topics and itinerary are as follows:
- Hazards
- *Historical Resources Act*
- The Park and its History
- Geologic Context
- Stratigraphy and Sedimentology
- History of Vertebrate Palaeontology at Park
- Vertebrate Fauna
- Hadrosaurs
- Dinosaur Biostratigraphy
- Preservational Patterns and Taphonomy

STOP 1: *Brachylophosaurus canadensis* **(holotype; Quarry 103).**

STOP 2: BB 50 Area
       a) *Parasaurolophus* **(Quarry 206) and Taphonomic Modes**
       b) BB 50: A Mixed, High-Diversity, Multitaxic Bonebed Complex
       c) BB 30: Mondominant Ceratopsian Bonebeds

STOP 3: *Corythosaurus* **Display (Quarry 128)**

STOP 4: Cathedral Area
       a) *Prosaurolophus maximus* **(Quarry 86)**
       b) Bearpaw Transition

OPTIONAL (if time allows):
       Juvenile *Corythosaurus* **group (Quarry 11)**
       Parasaurolophus walkeri **(Quarry 12)**

ACKNOWLEDGEMENTS

SAFETY ISSUES

Our day at Dinosaur Provincial Park will be spent outside in a modern semi-arid badlands landscape. As you can imagine there are numerous natural hazards for which we must all be prepared.

Medical Emergencies!
- For minor mishaps we are equipped with medical kits in our vehicles.
- **If a medical emergency does arise, Park staff at the Field Station will be alerted via radio and will take charge of the situation (ph: 403-378-4342)**.
- More serious emergenicies may involve a trip to the **Brooks Hospital, 45 minutes away (ph: 403-501-3232)**.

Weather!
Be prepared for hot and intensely sunny weather, even in the fall. The badlands of southern Alberta are semi-arid with daytime temperatures that routinely reach 40°C (104°F) during the summer. Deep in the badlands, highly reflective, quartz sandstones can raise local ground temperatures to 50°C (120°F). These conditions make a wide-brimmed hat, sunscreen, and water bottle a must!

Southern Alberta is also known for highly changeable weather. A clear and calm day can quickly turn into one with high winds, rain, thunder and lightning, and hail. It is always recommended that you bring a light, rainproof jacket.

Hiking Hazards!
We will be hiking in an uneven badlands landscape. Slopes littered with natural rock debris can be tricky to traverse. When wet, all bedrock surfaces in the Park can be greasy and intensely slippery due to abundant smectite clays. Large and small sinkholes are common and often hidden from view. We recommend shoes with ankle support that are tough enough to resist the many small prickly pear and pin cushion cactuses.

Plants and Critters!
- Small cactuses are common. Watch where you tread and place your hands!
- Spear grass seeds can irritate the skin if they work their way through your clothing.
- The prairie rattlesnake, *Crotalus viridis*, is a small to medium-size snake with shy habits. It will do what it can to get away from you, however, like all rattlers, it is potentially harmful if surprised. Be particularly cautious where there are large blocks of rock in dry grass; this is a favored habitat!
- Small scorpions are present and have a sting similar to that of a bee.
- Mosquitoes and other biting insects are common and seasonally abundant. We recommend liberal use of high-concentration DEET. West Nile virus (WNv) is present in Alberta.

MODERN DAY DINOSAUR PROVINCIAL PARK

Located 48 kilometres north of Brooks (Alberta), just off the Trans-Canada Highway, Dinosaur Provincial Park borders the Red Deer River for 28 km and encompasses 75 km^2 of terrain characterized by sweeping prairies, cottonwood dominated river-margin habitats, and deeply incised badlands that yield world-renowned fossils (Figs. 1-3). This unique and beautiful combination of modern and ancient resources has made the Park one of Western Canada's most popular recreation areas. Provincial Park status was granted in 1955, and worldwide recognition was officially achieved in 1979 when Dinosaur Provincial Park was designated a UNESCO World Heritage Site, joining such distinguished company as the Grand Canyon and Great Barrier Reef. The Park was also nominated in 1984 as one of the one-hundred best geological sites in the Rocky Mountains Section of the Geological Society of America—part of the Decade of North American Geology Project.

The Park is run by staff of the Provincial Parks and Protected Areas. Collecting plants, animals, rocks or fossils is strictly prohibited without a permit.

Southeastern Alberta is a vast gently undulating plain included in the Canadian prairies. Although the land surface of the prairies is generally flat to gently rolling, important exceptions exist, especially where the Red Deer, South Saskatchewan, Bow, Oldman, and Milk rivers and their tributaries sliced into the surface during the last stage of glacial wasting (~11,000 years ago). Large volumes of meltwater incised the modern river valleys and many of their coulees
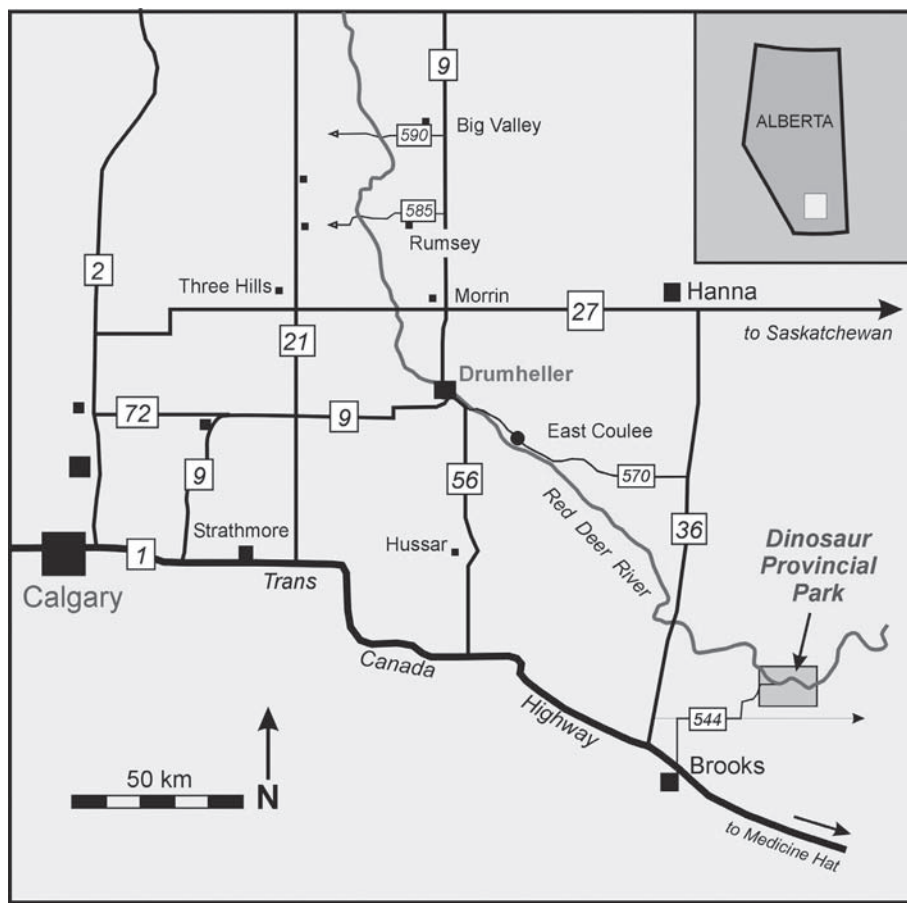

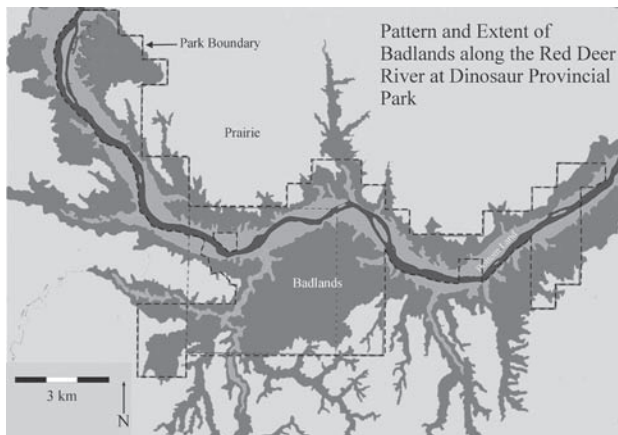FIGURE 1. Location of Dinosaur Provincial Park in southern Alberta.

FIGURE 2. The boundaries and extent of Dinosaur Provincial Park along the Red Deer River.
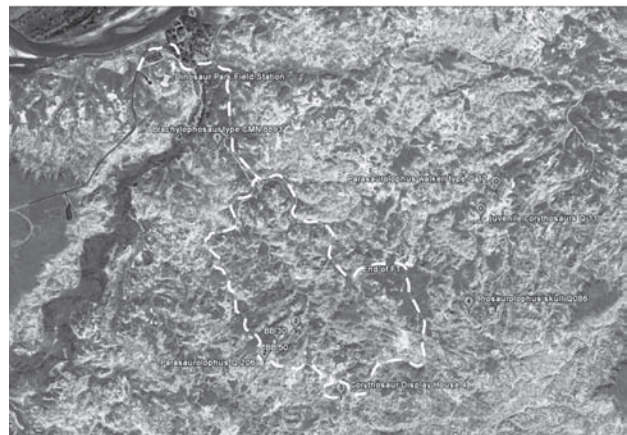

FIGURE 3. Google Earth satellite (Quickbird) image of the Park's preserve area. Numbered markers indicate localities viewed on this field trip. The white dashed line indicates the pre-serve trail. We will travel counter-clockwise.

(side branches). It is in these drainages that Upper Cretacous bedrock and fossils are most easily accessed. Although the Park's badlands (from the French, *les mauvaises terres*) were initiated by this intensive glacial wasting, today they are maintained by rapid erosion caused by rain, running water, wind, and freeze and thaw.

The Park's modern climate is cool temperate and seasonally semi-arid with an average annual precipitation of 35 cm, an average January temperature of -16°C, an average July temperature of +18°C, and an annual temperature fluctuation that ranges from +40°C to -40°C. In this strongly variable climatic setting very high intensity rainfall and wind events result in "flashy", high-discharge run-off and washouts during the spring and summer months. The smectite-rich sandstones and mudstones in the Park offer little resistance to these processes and the average rate of erosion is extraordinarily high — about 4.0 mm/year on vertical surfaces. Such high rates of erosion aid palaeontologists in their search for fossils: huge surface areas of exposure are created each year as thousands of tonnes of badlands sediment are eroded, partly washed into the Red Deer River drainage, and carried east into Saskatchewan and Manitoba.

The archaeological record in central and southern Alberta goes back ~11,000 years. For almost 10,000 years, the native economy revolved around the buffalo herds that roamed the plains. Evidence for this long period of native presence is documented in the form of isolated artifacts such as points and pounders, stone ring teepee bases, hunting sites, stone cairns, and effigy figures. All are common along the prairie edge that borders the Park.

THE HISTORICAL RESOURCES ACT OF ALBERTA

Palaeontological resources in Alberta are protected under the *Historical Resources Act* (HRA). The *Act* is administered within the Ministry of Culture and Community Spirit. The main tenet of the HRA is that all fossils collected in Alberta, whether collected on private or public land, belong to the Crown in right of Alberta (*i.e.*, all fossils collected in Alberta belong to the public trust). This ensures that all fossils of scientific, educational or display quality remain in public institutions in Alberta.

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Surface collection of fossils is allowed assuming that the collector has obtained permission from the landowner, lease holder, or proper government department. Excavating fossils requires an approved "Permit to Excavate Palaeontological Resources." Application forms can be obtained from the Royal Tyrrell Museum, and only "professional palaeontologists," (institutional affiliations and holding a Masters or Ph.D. degree) are eligible to apply. Unless alternative arrangements are made with the Minister's consent and prior to the commencement of field operations, palaeontologists associated with out-of-province institutions are required to deposit all collections in an approved Alberta public institution (Royal Tyrrell Museum, University of Alberta or University of Calgary) within 12 months of the completion of field operations.

The HRA allows for a modest trade in palaeontological resources of limited scientific, educational or display value. Palaeontological resources for which an individual can gain ownership are listed in the control list of the Dispositions Regulations and are limited to (1) ammonites, (2) oyster shell, (3) petrified wood, and (4) fossil leaf impressions. Because all palaeontological resources belong to the Crown in right of Alberta, an individual must apply to the Government of Alberta (through the Royal Tyrrell Museum) to obtain disposition (ownership) for the resources they wish to sell or trade. The Province has the right to retain any fossil that is determined to be of scientific, educational or display value. Once disposition has been granted for a fossil the applicant is the legal owner and may dispose of the fossil as seen fit. Fossils collected under scientific permit are not eligible for disposition.

Export of fossils collected in Alberta is controlled provincially by the HRA and federally by the *Cultural Property Export and Import Act*. The provincial HRA restricts the export of any palaeontological resource from Alberta without written consent of the Minister unless the exporter has been granted disposition for the fossils. A palaeontological resource listed on the *Cultural Property Export and Import Act* control list must be approved by the Canada Customs and Revenue Agency before it leaves the country.

For further information contact the Resource Management Program of the Royal Tyrrell Museum.

FIGURE 4. Western Canada Sedimentary Basin showing well bore locations and structural isopachs. From the Alberta Geological Survey website: (http://www.ags.gov.ab.ca/publications/wcsb_atlas/a_ch14/ch_14_f.html)

GEOLOGY AND STATIGRAPHY

The Park's bedrock strata were deposited in the Western Canada Sedimentary Basin (WCSB) — an elongate foreland basin bounded to the west by the front ranges of the Rocky Mountains, and to the east by the Canadian Shield (Fig. 4). The WCSB was part of the Western Interior Basin (WIB) that extended from the Arctic Ocean to the Gulf of Mexico during the Late Cretaceous. It developed in response to episodic crustal downwarping due to overthrust-induced crustal loading that, in turn, was associated with long-term docking and suturing of accretionary terranes along the western margin of Canada (Cant and Stockmal 1989; Eberth 2005).

The Park's bedrock exposures are dominated by clastics of the upper Belly River Group (sensu (Jerzykiewicz and Norris 1994; Hamblin and Abrahamson 1996; Eberth 2005). The Belly River Group is an eastward-thinning, nonmarine-to-paralic clastic wedge that interfingers with marine shales of the Western Interior Seaway and was deposited along the western margin of the Western Interior Basin during the middle to late Campanian.

In the Park area, the Belly River Group comprises three formations (Figs. 5, 6). In ascending order these are the Foremost (170 m), Oldman (40 m), and Dinosaur Park (75 m) (Eberth and Hamblin 1993; Eberth 2005). The Foremost Formation is present only in the subsurface at the Park, and only the Oldman and Dinosaur Park formations of the Belly River Group are exposed in the Park. The uppermost one-half of the Oldman Formation is exposed just above river level and large portions of the Dinosaur Park Formation are exposed throughout the Park.

The lowest ~20 m of the marine Bearpaw Formation is exposed in the eastern-most part of the Park, where it overlies the Dinosaur Park Formation. A continuous section of upper Oldman, Dinosaur Park, and Bearpaw is present on both sides of the Red Deer River in the easternmost corner of the Park, near Iddesleigh.

Radiometric Ages, Magnetostratigraphy and Biostratigraphy

The data of Thomas *et al.* (1990), Eberth *et al.* (1992), Eberth and Deino (1992), and Eberth and Deino (2005) indicate that the exposed section at Dinosaur Provincial Park spans approximately 1.5 Ma, ranging in age from ~76.5 Ma at the top of the Oldman to ~75.0 Ma near the base of the Bearpaw Formation (Fig. 5). However, there is an active program in progress to revise previously published radiometric ages for the Park and bring them in line with the revised monitor mineral ages used in $^{40}Ar/^{39}Ar$ age dating (Kuiper *et al.* 2008). These revisions will likely result in a systematic age increase of approximately 0.6% for these previously published ages. These data indicate an average sediment accumulation rate of 4.0-5.0 cm/1000 years for the entire Belly River Group and the bedrock at the Park (Eberth 2005).

At the Park, exposures of the Dinosaur Park Formation occur within the lengthy 33n magnetozone. High resolution magnetostratigraphic data suggest the presence of a brief reversal in the lower one-third of the section that has been attributed to 33n3r (Lerbekmo 2005).

Tsujita (1995) identified ammonite fragments from the "Finnegan Sandstone" (lower one-half of the Bearpaw Formation northwest of Dinosaur Provincial Park) as *Baculites compressus robinsoni*, and assigned the top of the Belly River in the Red Deer River valley to the *Baculites compressus* biozone. This interpretation corresponds well to the chronostratigraphically-calibrated biostratigraphic scheme of Obradovich (1993, fig. 2). Given the foregoing, it can be inferred that the Oldman Formation exposures at Dinosaur Provincial Park correlate with the *Didymoceras nebrascense* to *Baculites scotti* biozones, as originally suggested by Eberth *et al.* (1990). Eberth *et al.* (1990) used the first occurrence of the palynomorphs, *Mancicorpus tripodiformis* and *Expressipolis sp.* to correlate between exposures of the Belly River at Dinosaur Provincial Park and muddy lake, Saskatchewan. For an update on the utility of those taxa see Braman and Koppelhus (2005). The data and interpretations discussed here place almost all of the exposures at Dinosaur Provincial Park within the lower one-half of the informal "upper" Campanian stage.

The Foremost Formation
The paralic to nonmarine Foremost Formation (FFm) gradationally overlies marine shales of the Pakowki (Claggett) Formation and includes the MacKay and Taber coal zones at the bottom and top, respectively, and an extensive sandy zone overlying the Taber Coal Zone referred to here as the Herronton sandstone zone. None of the FFm is exposed at the Park, but the top of the Herronton zone crops out 15 km to the northeast, at Jenner Bridge. The formation reflects the regressive phase of the Belly River "wedge." It shows significant variation in lithology and facies, and consists of offlapping, progradational-to-aggrading parasequences, well-developed back-barrier coals, localized stacked shorefaces, the Taber coal zone and the overlying, stacked palaeochannels of the Herronton sandstone zone (Speelman and Hills 1980; Wasser 1988; Kwasniowski 1993; Gordon 2000). Locally thick zones of stacked shoreface sandstones indicate that shorelines shifted their positions episodically rather than continuously across Alberta (Hamblin and Abrahamson 1996). The FFm is not discussed further in this guidebook.

The Oldman Formation
The Oldman Formation (OFm) comprises a southwest-thickening unit made up of light colored alluvial sandstones and mudstones that were first referred to as the "Pale Beds" by Dowling
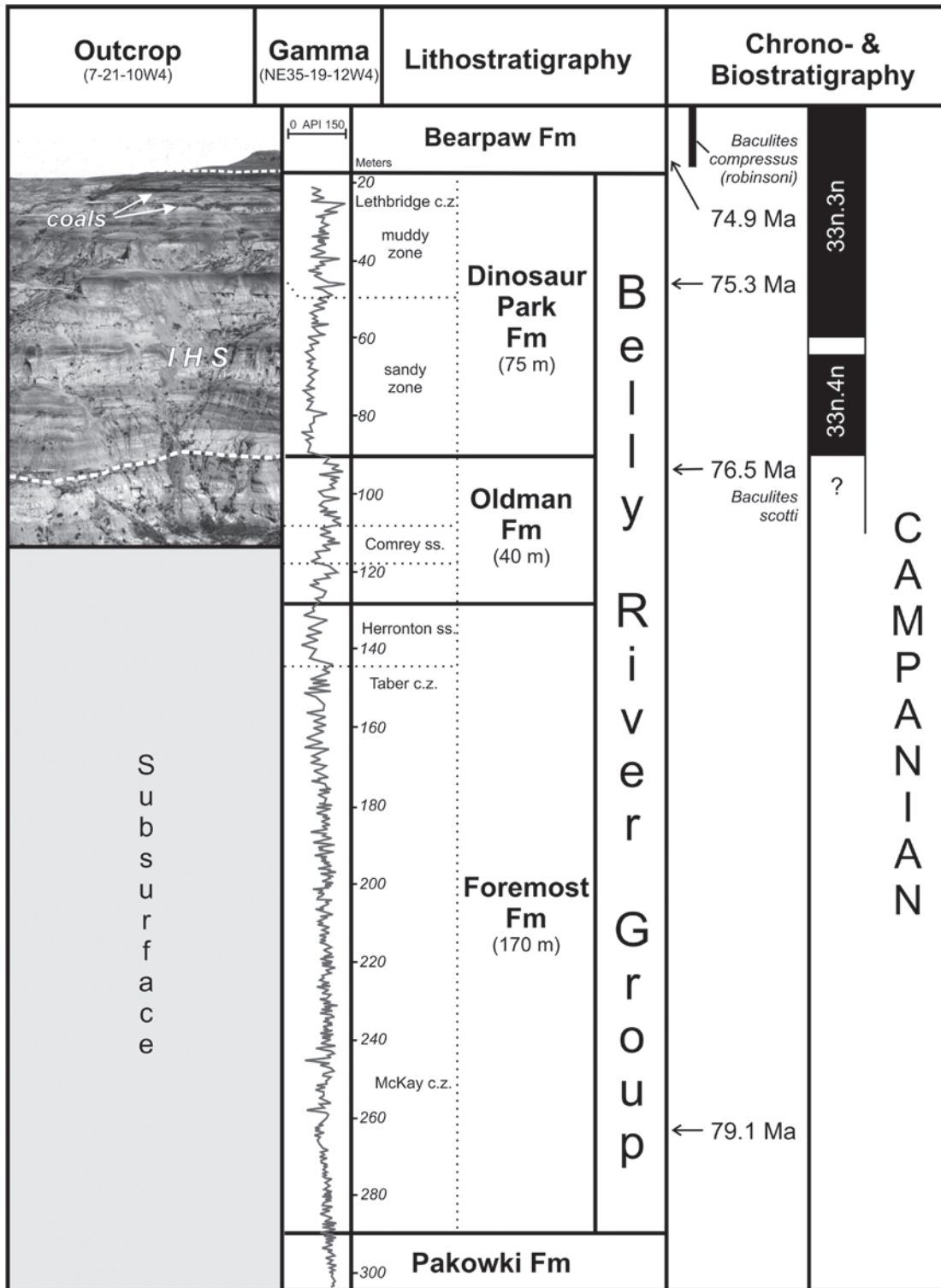
FIGURE 5. Bedrock stratigraphy at Dinosaur Provincial Park. Photograph shows an excellently exposed section of the Park's strata near Iddesleigh. Modified from Eberth (2005).

FIGURE 6. West-east (A) and north-south (B) cross-sections through the Belly River Group in southern Alberta showing basic stratigraphic architecture. Note the strongly wedge-like shapes of the Oldman and Dinosaur Park formations in B. In this case, the OFm-DPFm contact is strongly diachronous, becoming younger to the south. From Eberth (2005).

(1916, 1917). It conformably overlies the Herronton sandstone zone at the top of the Foremost but is disconformably overlain by the Dinosaur Park Formation (Eberth and Hamblin 1993; Hamblin 1997a). OFm sandstones are differentiated from sandstones in the Herronton sandstone zone and the overlying Dinosaur Park formation by their greater mature, large quartz/chert ratios (1.5-7.5), and relatively small plagioclase/k-spar ratios (0.2-2.75). Sandstones are typically very fine-to-fine grained, contain no extraformational pebbles or cobbles, and crop out as yellow, steep-faced and blocky surfaces. Ironstone staining and concretionary development are pervasive. The OFm is easily recognized in well logs by a strong increase in the gamma signature, most probably caused by an increase in the potassium-rich feldspars. The OFm records the maximum basinward extent of Belly River Group non-marine clastics and thus, a maximum late Campanian drop in relative sea level that most likely corresponds to the eustatic drop proposed by Haq *et al.* (1988) at 77.5 Ma.

Coarse and fine lithofacies of the OFm are complexly interbedded and laterally limited, exhibiting a range of grain sizes that make distinct, fine-and coarse-member divisions difficult in both outcrop and well logs. Sandstone bodies range from single to multistoried forms, up to 10 m thick, and typically comprise channel and splay sandstones with local occurrences of intraformational pebbles associated with erosional surfaces and scours. Internally, sandstone bodies are dominated by horizontal and low-angle-inclined strata, low-angle large and medium-scale trough cross-strata, and ripple lamination, including climbing ripples. Large- scale, inclined accretion surfaces and other macroforms are rare, and in this region are limited to the uppermost 10 m of the formation. Upward-fining trends are poorly developed but thinning-upward sets are common. Lateral variation in grain-size and sedimentary structures is common. In many cases, meso-scale scours are filled with climbing ripples. Palaeocurrent data from scours, trough cross-beds, and ripple lamination show an ENE, unimodal direction of flow (Eberth and Hamblin 1993).

Thin beds of heterogeneous sand-, silt- and claystone, and reddish carbonaceous shale dominate fine-grained facies of the OFm. Beds of pure claystone are rare. Mudstones are less than 1 m thick and not traceable for more than 200 m. Almost all fine-grained facies are massive and some are highly contorted. Prominent beds of massive and
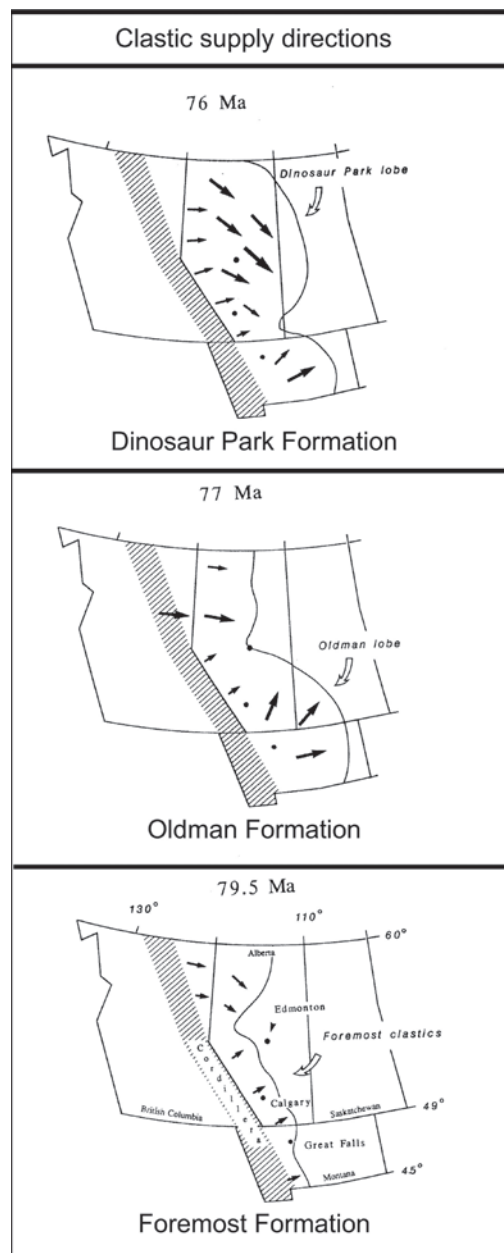

FIGURE 7. Sediment dispersal directions are significantly different in each of the three formations that make up the Belly River Group. From Eberth and Hamblin (1993).

white-grey siliceous sandy siltstone commonly occur beneath or in association with organic-rich sediments. Thin, clay-lined root traces are common in all fine grained facies and iron-replaced, concretionary root traces are present, though rare. Continental trace fossil assemblages are common and diverse,
but remain mostly unstudied.

Oldman Formation Palaeoenvironments
Palaeocurrent data and the rarity of lateral accretion surfaces through most of the formation suggest that Oldman palaeochannels were low sinuosity (straight to braided) and flowed to the northeast. Palaeochannels were typically less than 5 m deep and large portions of the channel floor may have been exposed episodically to seasonally (Noad 1993; Eberth and Hamblin 1993). Horizontal-to-low angle inclined stratification is frequently cited as evidence for shallow, high velocity, ephemeral flow in both ancient and modern low-sinuosity fluvial systems (*e.g.*, Tunbridge 1981, 1984). The abundance of internal erosional and scour surfaces, lateral and vertical variations in grain size and sedimentary structures, and wide spread occurrence of root traces, all indicate varying in-channel water levels and flow velocities, in accordance with an ephemeral flow interpretation.

The fine grained facies described above are interpreted variously as levees, splays, flood basin muds, and paleosols (Noad 1993; Eberth and Hamblin 1993). The heterogenous and sandy nature of most of these facies suggests that overbank flooding was a common occurrence, but that large lakes or ponds were not widespread. Following Eberth *et al.* (1990), white, siliceous, sandy siltstones are interpreted as albic paleosols or ganisters, formed by leaching of subaerially exposed sediments. The presence of reddish organic shales and ganisters, and the absence of coals all suggest relatively well-drained floodplain conditions.

The Dinosaur Park Formation
The Dinosaur Park Formation (DPFm) is a sandy-to-muddy, northwestward-thickening unit comprising alluvial, estuarine and paralic facies. It consists of a lower sandy zone made up of alluvial palaeochannel deposits and an upper muddy, overbank-facies-dominated succession that culminates in the Lethbridge coal zone. It rests sharply and disconformably on the OFm and interfingers with brackish and marine shales of the overlying Bearpaw Formation. The Dinosaur Park-Bearpaw contact in the Park is placed at the uppermost contact of a red-tan colored transgressive lag deposit on tabular beds of coastal plain sandstone and siltstone. The DPFm was deposited during the intial stages of the last major transgression of the Western Interior Seaway (Bearpaw Sea) in southern Alberta, and records the overall transgressive phase of the Belly River Group.

DPFm sediments are sombre grey, brown and green compared to the more light colored sediments of the OFm. Petrographically, DPFm sandstones are muddy and immature with very low quartz/chert ratios, very high proportions of volcanic rock fragments, and consistently high plagioclase/k-spar ratios. Sandstones crop out as rounded, highly-rilled surfaces and are easily distinguished from the blocky and smooth-surfaced OFm sandstones. Discrete beds of coarse versus fine grained sediment are more easily distinguished in the DPFm than in the OFm. In general, there is an increase in sandstone grain size from very fine and fine-grained sandstone to fine and medium-grained sandstone upward across the OFm-DPFm contact. Syndepositional ironstones are common throughout the formation.

Dinosaur Park Formation Palaeoenvironments
DPFm coarse units are dominated by fine-grained sandstone and are mostly interpreted as single-to-multistoried, laterally extensive palaeochannel deposits. Three primary lithofacies make up these coarse units: 1) trough cross-stratified sandstone; 2) inclined heterolithic

stratification; and 3) inclined bedded sandstone. In order these are interpreted as (1) straight channel units that equilibrate into (2 and 3) muddy to sandy meandering channel deposits. The latter two lithofacies are interpreted as the deposits of point-bar macroforms in meandering rivers. Although published palaeochannel reconstructions (Wood 1989) indicate that channels were 35-165 m in bankfull width and 5-25 m in depth, more recent evidence suggests that some palaeochannel widths may have exceeded 200 m (Eberth unpublished). Palaeoflow was generally to the southeast (Eberth and Hamblin 1993; Hamblin 1997b).

Fine grained units of the DPFm consist of grey, brown, and green massive-to-laminated, organic-rich mudstones and bentonites, and are interpreted as overbank deposits, some of which have been modified as hydromorphic paleosols. There is evidence for tidally-influenced shoreline successions in the Lethbridge Coal Zone (Eberth 1996).

Discrete, green-to-white weathering 'pure' bentonite beds are the remains of altered volcanic ashes. They typically occur in association with mudstone sequences and are up to 50 cm thick (*e.g.*, Thomas *et al.* 1990; Eberth *et al.* 1992). Some contain laminae of phenocrysts that can be dated using radiometric methods (*e.g.*, Thomas *et al.* 1990).

The Lethbridge Coal Zone (LCZ) forms the upper 15 m of the Dinosaur Park Formation. This interval also includes a variety of facies types not present in the lower strata: The most common are (1) lignitic to sub-bituminous coal beds that are <1m thick, and (2) U-shaped, mudstone-filled incised valleys (Eberth 1996). In any given vertical section through the LCZ, up to four coal beds are present. Overall, this interval indicates that extensive peat swamps were common along DPFm shorelines, and that high frequency changes in sea-level resulted in frequent episodes of channel incision and infilling/flooding by brackish to marine water.

The Oldman-Dinosaur Park Transition
Upward across the OFm-DPFm contact, changes in sedimentary characteristics (see above) record a north-to-south shift in active tectonism and, thus, an increase subsidence, in the foredeep of the southern Canadian Cordillera. This shift in tectonism and increase in subsidence resulted in a southeastward tilt in the basin. As tectonism shifted to the south, those areas of the foredeep in the central and northern Canadian Cordillera that previously had trapped clastics began to rebound, shedding coarse clastics southeastward into the basin and forming the DPFm clastic wedge (Eberth and Hamblin 1993; Fig. 7). Sediment dispersal patterns and depositional style were reorganized, as reflected by a large number of lithologic, petrographic, sedimentologic, and palaeontologic differences between the Oldman and Dinosaur Park formations. OFm clastics appear to have originated along the eastern flank of the southern Cordillera in British Columbia and northwestern Montana, and prograded northeastward. The overlying DPFm comprises a lithologically distinctive clastic wedge that originated along the eastern flank of the north and central portion of the Canadian Cordillera and prograded southeastward (Eberth and Hamblin 1993; Hamblin 1997b). This latter wedge has a restricted palaeogeographic distribution, generally limited to central and southeastern Alberta, southwestern Saskatchewan, and north-central Montana.

The Oldman-Dinosaur Park contact is regionally extensive and diachronous (north-to-south). [40]Ar/[39]Ar and K/Ar dating of Belly River Group bentonites shows that the discontinuity separating the two formations becomes younger toward the south and southeast (Eberth and Deino 1992; Eberth and Deino in preparation). These data also demonstrate that the DPFm clastics migrated southeastward at a rate of approximately 130-140 km/my, gradually overstepping the OFm clastic wedge.

Bearpaw Formation

The Bearpaw Formation (BFm) is mainly composed of dark-grey or brown-grey marine shales that are deeply weathered at surface. Numerous bentonites and a few fine-grained, clayey sandstone lenses and sheets also occur within the unit. One prominent and dated bentonite is present ~8.0 m above the contact with the DPFm in the Iddesleigh area. The transition from the DPFm to the BFm at the Park is interfingering, and numerous marine tongues/flooding surfaces have been recognized in the uppermost 15 m of the DPFm at the eastern end of the Park. The contact between the Dinosaur Park and Bearpaw formations is placed at the base of a prominent, red-brown-to-tan colored organic-fragment rich siltstone, which is interpreted as a transgressive lag (Eberth 2005).

PALAEONTOLOGY — NON VERTEBRATES

Plants

Fossil wood is common at the Park and is present in all three formations (OFm, DPFm, BFm). With few exceptions it is from conifers. Fragmented and whole twigs and leaves of conifers are also common. In contrast, angiosperm wood and leaves are much rarer. Koppelhus (2005) identified seven different gymnosperm taxa based on a study of fossil wood from the Park. Similarly she was able to identify 11 different kinds of leaves (attributable to angiosperms) and seeds, cones, twigs, stems and fronds from a variety of conifers, ferns, angiosperms, and *Equisetum*. In a few sites, there are mixtures of horsetails, ferns, angiosperms, ginkgos, and conifers with the most common leaf being *Vitis stantoni*. A new species of an aquatic monocot, *Cobbania corrugate*, has recently been described by Stockey *et al.* (2007).

Invertebrates

Invertebrate fossils, excluding microfossils, are present throughout the stratigraphic interval in all three formations. They usually occur in discrete layers or accumulations and are localized. Most prolific are the molluscs, including 14 taxa of bivalve and 10 taxa of gastropod (Johnston and Hendy 2005). Fragmentary ammonite, baculite, and crayfish remains occur patchily in outcrops of the BFm. Steinkerns of unionids are common in channel lag deposits. Invertebrate trace fossils are common in all three formations, but remain mostly unstudied. One exception is the localized high-density presence of *Lockeia* assemblages (*Fusconaia danae* escape traces; Johnston and Hendy 2005). These are present in both the Oldman and Dinosaur Park formations, and occur in iron-carbonate-cemented fine-grained sandstones of lateral accretion deposits.

Organic-Walled Microfossils

Marine dinoflagellates and acritarchs are common in the FFm, the uppermost DPFm, and the BFm. They are generally directly related to the presence of marine or marginal marine conditions. Fungal spores and algae forms occur commonly, but not in great numbers. They have only been studied in a preliminary form although more details are currently being worked out.

It is the spores and pollen that have received the most attention at the Park and across southern Alberta. This region was part of the *Aquilapollenites* floral province through the Late Cretaceous and into the Palaeocene, and has been studied by Herngreen and Chlonova (1981), Srivastava (1978, 1983), and Herngreen *et al.* (1996). Other papers that deal with some of the assemblages in the region include Jarzen (1982), Eberth *et al.* (1990), and Braman and Koppelhus (2005). Beginning in uppermost Oldman "time" and continuing through Dinosaur Park "time", there was an increase in the appearance of new taxa of spores and pollen. The Bearpaw transgression seems to represent a time of increased extinction (Braman and Koppelhus 2005).

Marine Microfossils
In general, Upper Cretaceous units of southern Alberta contain a variety of other microfossils including charophytes, ostracodes, diatoms, radiolarians, and foraminifera. With the exception of foraminifera, none of these have received much attention in the Park. Foraminifera have been successfully utilized for correlation and environmental determinations across the Western Interior Basin (Caldwell *et al.* 1978).

VERTEBRATE PALAEONTOLOGY

Historical Perspective
The media stars of the Park's fossils are the vertebrates, especially the dinosaurs. Although vertebrates have been recovered from all three formations exposed in the Park (OFm, DPFm, BFm), it is the Oldman and Dinosaur Park formations that have produced the most significant material.

Thomas C. Weston first explored the Park's badlands for dinosaurs in June 1889. A geologist with the Geological Survey of Canada, he was the first to prospect the exposures along the Red Deer River by boat. Lawrence Lambe, also with the GSC, led the first major expeditions to this rich area between 1898 and 1901. The specimens were described by Osborn and Lambe in 1902, and included the first description of *Stegoceras*. It was a decade before the next major expedition entered the region. Barnum Brown and his crew from the American Museum of Natural History had been working for several years northwest of Drumheller, but moved to what were called the Steveville badlands late in the summer of 1912. They were extremely successful over the next few years and shipped many fine skeletons back to New York. Albertan dinosaurs (including *Albertosaurus*, *Ankylosaurus*, *Centrosaurus*, *Chasmosaurus*, *Corythosaurus*, *Edmontonia*, *Euoplocephalus*, *Lambeosaurus*, *Panoplosaurus*, *Prosaurolophus*, *Struthiomimus* and *Styracosaurus*) still make up a substantial part of the Cretaceous Dinosaur Hall at the American Museum.

By 1913, the Sternberg family also moved into the Steveville badlands to collect dinosaurs for the Geological Survey of Canada, and the "Great Canadian Dinosaur Rush" was on. They successfully competed with Brown here and farther downstream in Deadlodge Canyon. By the time the dust settled in the 1920s, more than 300 significant dinosaur specimens had been collected from the Park area. These original specimens are on display in more than 35 institutions around the world, and hundreds of casts have been produced for other museums. The Sternbergs and others continued to work in this region from time to time, but dinosaurs were being collected at a much slower rate than they had been during 1912–1920. In 1955, Dinosaur Provincial Park was established, thereby protecting the Steveville Badlands, Deadlodge Canyon and adjacent regions. Field studies by Peter Dodson, Dale Russell, and others in the 1960s led to publications that were very influential in the early stages of the "Dinosaur Renaissance." In 1979, the Park became the first palaeontological site designated to UNESCO's prestigious World Heritage Site list. A few years earlier, the Provincial Museum of Alberta had started collecting dinosaurs at a scale that the region had not seen since the first golden period of collection. Their success, plus the UNESCO designation, influenced the Government of Alberta in 1981 to approve funding for the construction of what would become the Tyrrell Museum of Palaeontology. In anticipation of showcasing new specimens, Phil Currie and his crews from the Provincial Museum of Alberta (now the Royal Alberta Museum) stepped up their efforts at the Park, and began a new period of intensive research that continues to this day. The Tyrrell Museum (RTMP) opened in 1985 in Drumheller (the "Royal" designation was awarded in 1990), some two hours drive from Dinosaur Provincial Park. Part of the rationale for site selection was the sensitivity of the resources in the Park, which would have been adversely affected by the impact of half a million tourists per annum. However, in

1987, the RTMP opened its Field Station in the Park with the intention of meeting some of the needs of research, rough preparation and display in a more professional way.

Dinosaur Collecting/Research Trends
Dinosaur research programs in the Park have changed over the years. Although the earliest years produced significant fossils, they failed to demonstrate the wealth of palaeontological material the region had to offer. This changed with the advent of expeditions led by Barnum Brown and the Sternbergs. The focus then became the recovery of large, well preserved specimens suitable for description and display. Those collecting dinosaurs along the Red Deer River were aware of the isolated bones and bonebeds they were walking over on a daily basis, but gave them only cursory examination. By the end of the 1970s, the focus of dinosaur research had shifted dramatically. Large skeletons were still sought and collected, but other types of resources including bonebeds and vertebrate microfossil sites started receiving as much attention.

An interesting development in the 1930s was the initiation by Levi and Charles M. Sternberg of the practice of accurately locating and marking quarries. This culminated in the "Steveville Sheet" in 1950 a 1:31,680 map-sheet published by the Geological Survey of Canada showing the locations of 112 quarries (GSC Map 969A). The Sternberg initiative to document and mark significant quarries continues to this day augmented by efforts to relocate previously unmarked quarries (Tanke 2001), and to map the positions of all articulated specimens, microsites and bonebeds regardless of whether or not they are suitable for excavation. Survey grade GPS mapping provided by BP Resources has provided centimeter-scale accuracy in recent years (Pryor *et al*. 2001; MacDonald *et al*. 2005). Today, there are ~250 marked quarries in the Park and its immediate vicinity. Approximately 125 uncollected skeletons plus ~200 bonebeds and microvertebrate sites have also been documented.

The Park's Fauna: Taxonomic List (Appendix 1)
Appendix 1 at the end of this guidebook is an updated fossil vertebrate faunal list from the Park compiled by D.B. Brinkman. Taxa are grouped in one list and are not assigned by formation. This 'one-list-approach' reflects the overall problem with the strongly time-transgressive formational boundary between the Oldman and Dinosaur Park formations across southern Alberta (see above). For example, there is now good evidence that *Centrosaurus apertus* (common in the lower Dinosaur Park Formation at the Park) occurs in upper Oldman Formation beds in the Milk River drainage area near Manyberries. Radiometric data in the Manyberries area (DAE) indicate that upper Oldman Formation strata and fossils are time-equivalent to lower Dinosaur Park Formation strata and fossils at the Park.

A minimum of 42 different kinds of dinosaur are known from the Park, including 9 hadrosaurs and 7 ceratopsians. The vast majority of articulated and associated skeletons of dinosaurs and other macro-vertebrates come from the Dinosaur Park Formation, however, vertebrate microfossil assemblages from both formations are common and well documented.

The Park's Hadrosaurs
Hadrosaurid fossils in the Park are ubiquitous. Regardless of taphonomic mode (with the exception of monodominant ceratopsian bonebeds, see below) and stratigraphic level, hadrosaurids dominate the dinosaur assemblage (Brinkman 1990; Brinkman *et al*. 1998; Eberth and Currie 2005). Numbers of articulated skeletons and relative abundance data from microsites both suggest that hadrosaurids make up approximately 40-50% of the dinosaurs in the Dinosaur Park "ecosystem." Over 130 articulated skulls and/or skeletons have been collected since Lawrence Lambe collected the first duck-billed dinosaur material here in 1897 (Lambe 1902). Lambe noted the abundance of hadrosaurid material in the area, and named

three species of *Trachodon*, all now *nomina dubia* (Weishampel and Horner 1990). The specimens collected from the Park include some of the best-preserved and most complete hadrosaurids found to date. Preservation of articulated skeletons is often exceptional, complete with impressions of the integument, delicate bones such as the stapes and sclerotic plates, and even stomach contents (Brown 1916b; Russell 1940; Ostrom 1961; Currie *et al.* 1995). The assemblage also preserves juvenile and subadult hadrosaurid material in relative abundance, and growth series of articulated skulls are known for many taxa (Dodson 1975, 1983; Tanke and Brett-Surman 2001).

The Park preserves the most taxonomically diverse hadrosaurid assemblage known. At least nine species are present, including three hadrosaurines and possibly six lambeosaurines. Most taxa are known from more than one complete skull and at least one relatively complete postcranium. As noted below, the hadrosaur taxa from the Dinosaur Park Formation are not homogeneously distributed throughout the section, with the hadrosaurine *Gryposaurus* being confined to the lower, and *Prosaurolophus* to the upper, portion of the formation respectively. Similarly, *Corythosaurus* is confined to the lower two-thirds of the formation and is gradually replaced in the upper third by *Lambeosaurus lambei*. *Brachylophosaurus canadensis* is the only hadrosaurid known from the Oldman Formation.
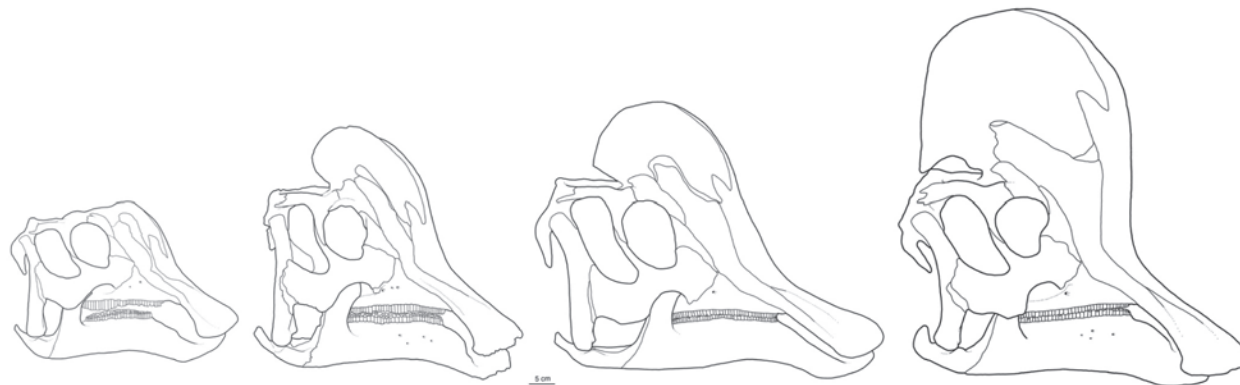

FIGURE 8. Cranial growth series of *Corythosaurus casuarius*, documenting the positive allometry of the cranial crest.

Lambeosaurinae
Lambeosaurine hadrosaurids are well represented in the DPFm and their remarkable record from the Park has contributed significantly to our knowledge about their diversity, morphological variation, and palaeobiology. No lambeosaurines are known from the OFm. There are three genera reconginzed from DPFm: the helmet-crested *Corythosaurus*, the hatchet-crested *Lambeosaurus*, and the tube-crested *Parasaurolophus*. *Parasaurolophus* is known from only a handful of specimens, most of which are fragmentary. *Lambeosaurus* and *Corythosaurus* are known from over 20 skulls representing numerous ontogenetic stages, as well as multiple complete skeletons (Ryan and Evans 2005; Evans 2007; Evans 2010; Fig. 8). The taxonomy of these lambeosaurines is historically complex. Originally, four genera and 13 species of lambeosaurines were recognized from what is now known as the Dinosaur Park Formation (Lull and Wright 1942). Early workers considered the large degree of variation in skull and crest size and shape to be too drastic to be attributable to ontogenetic processes (*e.g.* Parks 1931; Sternberg 1935; Ostrom 1963) and, instead, chose to erect a number of distinct taxa. In 1975, Dodson conducted an allometric analysis of these lambeosaurine skulls and demonstrated that the crest was a late-maturing feature, and suggested that the crest was also sexually dimorphic in shape in *Corythosuarus* and *Lambeosaurus*. Recent biostratigraphic

work has shown the putative dimorphs (*C. casuarius* and *C. intermedius; L. clavinitialis* and *L. lambei*) are stratigraphically segregated. They may represent distinct taxa, but it is possible these differences represent phyletic evolution within single lambeosaurine lineages (Evans 2007; Evans *et al.* 2008). The holotype of *Lambeosaurus magnicristatus*, the only specimen of this taxon known from the Park, is the stratigraphically highest lambeosaurine taxon in the section, and is recognized as a distinct species (Evans and Reisz 2007).

Hadrosaurinae (sensu Horner *et al.* 2004)
Hadrosaurines comprise roughly one third of DPFm hadrosaurids in terms of relative abundance (Dodson 1983). One hadrosaurine, *Brachylophosaurus canadensis*, is known from sediments of the OFm. Two hadrosaurine taxa are present in the DPFm, *Gryposaurus notabilis* and *Prosaurolophus maximus*. Within the roman-nosed *Gryposaurus*, the precise number of species is uncertain, with some workers (Horner 1992) recognizing the two morphotypes of *Gryposaurus* as distinct taxa, and others suggesting that this represents individual variation or sexual dimorphism within *G. notabilis* (Gilmore 1924; Hopson 1975). The most recent review of *Gryposaurus* argues that *G. incurvimanus* represents a juvenile *G. notabilis*, and recognizes only the latter taxon as valid (Prieto-Márquez 2010). *Prosaurolophus* and *Gryposaurus* are approximately equal in their abundance when the formation is considered on the whole, but *Prosaurolophus* is more abundant higher in the section.

DINOSAUR BIOSTRATIGRAPHY

For most of the past four decades, the Park's faunal assemblages have been assumed to represent a snapshot of a single, species-rich dinosaur ecosystem, and has been a general model for Late Cretaceous terrestrial ecosystem diversity (Dodson 1983). Renewed efforts by the RTMP to carefully document biostratigraphy at the Park, although having its roots with Sternberg (1950) and Beland and Russell (1978) and reaffirming some of their conclusions, show that the assemblage is time-averaged, and that the distribution of dinosaur taxa and microvertebrate communities is not homogeneous within the Park (Currrie and Russell 2005; Holmes *et al.* 2001; Ryan and Russell 2005; Eberth and Getty 2005: Evans 2007; Evans and Reisz 2007; Evans *et al.* 2009). The recognition of the DPFm as a distinct lithological unit from the underlying OFm clarified the faunal differences between these formations, and provided a local datum for documenting finer-scale biostratigraphic patterns.

In accordance with their temporal and lithologic differences, the better-drained OFm and the wetter DPFm appear to host different dinosaur faunas. Although the sample from the OFm is limited, none of the three documented large-bodied species (the hadrosaurine *Brachylophosaurus canadensis*, the tyrannosaurine *Daspletosaurus torosus*, and the ceratopsid *Centrosaurus brinkmani*) recovered from this formation have been found in the intensely sampled overlying sediments of the DPFm. No evidence of chasmosaurine ceratopsids or lambeosaurine hadrosaurids are known from the OFm at the Park.

Recent biostratigraphic work on DPFm assemblages indicates changes in the dinosaur fauna through the formation, as originally noted by C.M. Sternberg (1950). Sternberg used quarry location and altitude data (measured using an aneroid barometer) that he compiled and published on the Steveville Sheet map (Sternberg 1950). Sternberg (1950) noted biostratigraphic trends in both ceratopsids and hadrosaurids, which were also detected by subsequent studies (Beland and Russell 1978; Currie and Russell 2005). However, raw altitudes can be misleading because they do not control for the potentially confounding effects of the present-day structural dip of the beds, a major factor in the Park region (Beland and Russell 1978; Eberth and Hamblin 1993; Eberth 2005;), or variation in the palaeo-topography at the time of deposition.

New locality and elevation data collected with high-precision GPS technology (MacDonald *et al.* 2005) combined with the recent recognition of reasonably isochronous datums (the Oldman-Dinosaur Park and Dinosaur Park-Bearpaw formational contacts within the Park) have allowed dinosaur specimens and microvertebrate sites (Brinkman *et al.* 1998) to be placed within a much higher resolution biostratigraphic framework (Fig. 9). This approach has led to a recent focus on the biostratigraphy of the DPFm that has led to considerable ecological insights into the nature of the Dinosaur Park assemblage. Subsequent analyses of the stratigraphic distribution of ceratopsids (Holmes *et al.* 2001; Eberth and Getty 2005; Ryan and Evans 2005; Ryan and Russell 2005) and hadrosaurids (Evans 2007; Evans *et al.* 2009) has shown patterns that are generally consistent with those originally identified by Sternberg (see below for synopsis). More interestingly, this work has revealed consistency in turnover between these two major groups of ornithichians. These ongoing studies on dinosaur biostratigraphy reveal evidence for two major faunal shifts within the heavily collected DPFm.
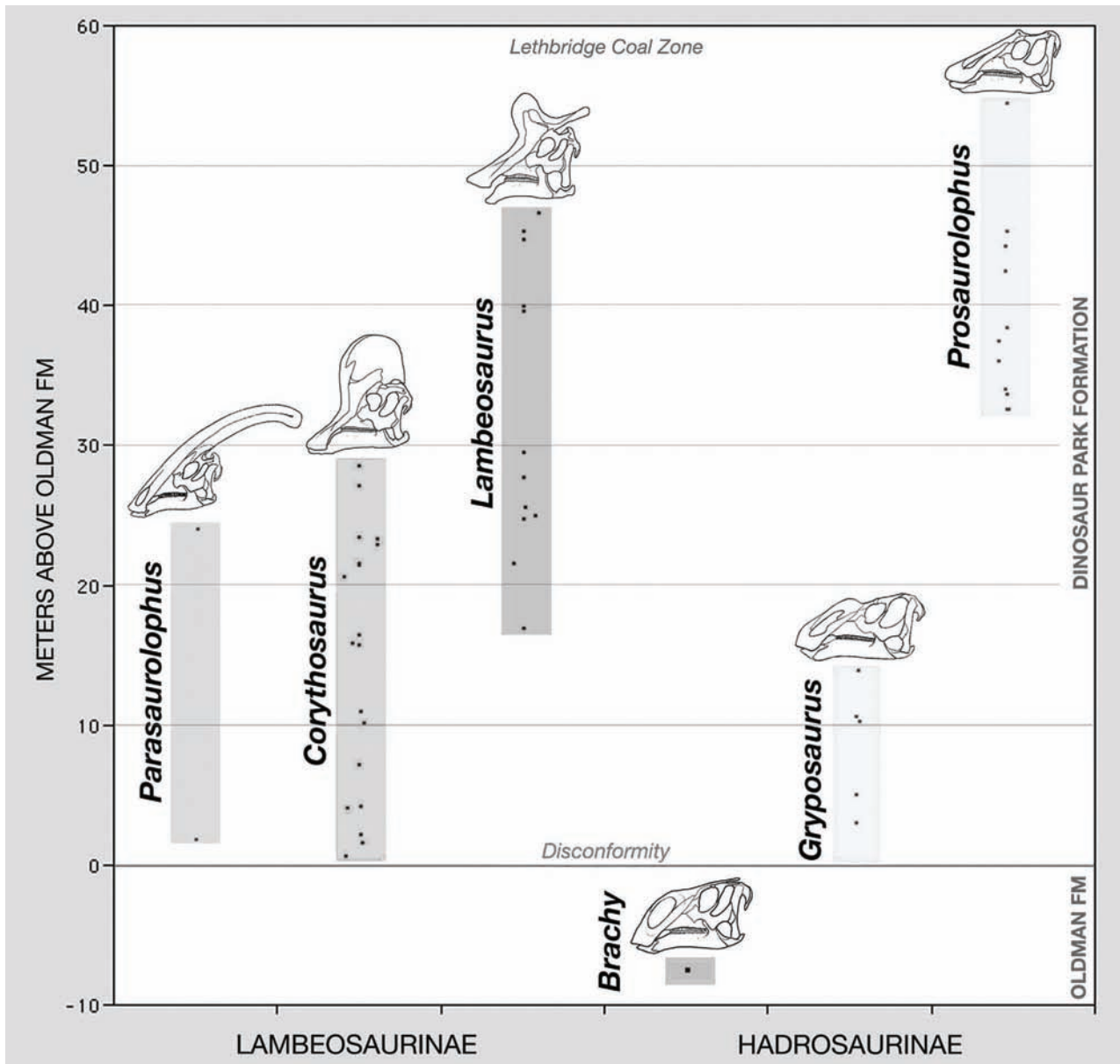

FIGURE 9. Stratigraphic distribution of hadrosaur genera at DPP. From Evans (2007).

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Based upon the abundance and distribution of ornithischian specimens in the DPFm, the lower 30 m can be characterized as the *Centrosaurus-Corythosaurus* faunal zone (Zone 1), and the upper portion as the *Styracosaurus-Lambeosaurus* faunal zone (Zone 2). The latter zone may be divisible into an uppermost third zone characterized by its centrosaurine, chasmosaurine, and lambeosuarine taxa.

Zone 1: *Corythosaurus-Centrosaurus* Assemblage
The lower 30 metres of the DPFm is characterized by the presence of the helmet-crested lambeosaurine *Corythosaurus* and the centrosaurine ceratopsid *Centrosaurus apertus*. All *Gryposaurus* material is found within this zone (within the lowermost 20 m of the formation), and *Chasmosaurus russelli* is also found only in this interval. This interval hosts the massive *Centrosaurus* bonebeds that are well-known from the Park. Ankylosaur remains are also concentrated in this zone.

Zone 2: *Styracosaurus-Lambeosaurus* Assemblage
This assemblage characterizes the upper half of the formation, and is characterized by the presence of the hatchet-crested lambeosaurine *Lambeosaurus* and the centrosaurine ceratopsid *Styracosaurus albertensis*. The vast majority of specimens of the large hadrosaurine *Prosaurolophus* are found within this zone, and are absent from Zone 1. *Chasmosaurus belli* is found only in this interval.

Zone 3: Pachyrhinosaur-*Lambeosaurus magnicristatus* association
In the uppermost portion of the formation, at or near the Lethbridge Coal Zone, most of the well-known taxa from the formation drop out and rare taxa unknown elsewhere in the formation occur here, including a pachyrhinosaur-like centrosaurine that resembles *Achelosaurus* (Ryan *et al.* 2009), the chasmosaurine *Chasmosaurus irvinensis,* and the lambeosaurine *Lambeosaurus magnicristatus. Prosaurolophus* is also persistent into this interval.

The DPFm was deposited during overall transgressive of the Bearpaw Sea. Therefore, upwards through the section, fossils were deposited increasingly closer to palaeoshoreline. It is possible that the changes in ornithischian distributions observed throughout the formation reflect differential preferences for proximity to the shoreline. The presence of distinct dinosaur palaeocommunities within the Park, based primarily on data from vertebrate microfossil assemblages, has previously been reported by Brinkman (1990), Baszio (1997a, 1997b), and Brinkman *et al.* (1998). The integration of both sets of stratigraphic data will allow for the future refinement of palaeocommunity structure within the Park, and will permit testing of the hypothesis that turnover is related to palaeoenvironomental change associated with marine transgression, and testing of a turnover pulse hypothesis (Vrba 1985) with respect to coordinated faunal turnover events.

PRESERVATIONAL AND TAPHONOMIC PATTERNS

Preservational patterns of vertebrate fossils differ between the Oldman and the Dinosaur Park formations, as well as throughout the Dinosaur Park Formation. For example, although vertebrate microfossil bonebeds are present in both units, they are typically hosted by splay sandstones in the OFm and palaeochannel lag deposits in the DPFm (Eberth 1990; Eberth and Currie 2005). Articulated-to-associated skeletal remains are rare in the OFm but uniquely abundant in the DPFm, where they often show soft tissue preservation. Similarly, vertebrate macrofossil bonebeds (multitaxic-to-monodominant) are much more abundant in the DPFm. Within the DPFm, vertebrate fossil sites, regardless of preservational mode become fewer in

number up-section, especially in the upper one-half of the formation. Also, transgressive lag vertebrate microfossil associations occur uniquely in the Lethbridge Coal Zone of the DPFm (Eberth and Currie 2005).

The Park's taphonomic modes and signatures were reviewed and discussed by Eberth and Currie (2005). Studies describing taphonomic signatures of the Park's fossil vertebrates include Dodson (1970, 1971), Currie and Dodson (1984), Getty *et al.* (1997, 1998), Ryan *et al.* (2001), and Eberth and Getty (2005). With the exception of Dodson (1971), these studies have focused on the Park's monodominant bonebeds. In each study, specimens were examined for a suite of taphonomic characteristics (*cf.* Behrensmeyer 1991). These taphonomic data were the basis for concluding that some social groups of ceratopsians had mass-drowned, and that their carcasses had experienced varying degrees of disarticulation, trampling and breakage, scavenging, chemical etching, weathering, hydraulic reworking, permineralization and diagenetic replacement of bone crystals. Further crushing and iron-oxide precipitation accompanied and followed final interment of skeletal remains in river channel and overbank palaeoenvironments.

In general, preservational quality of fossils at the Park is good to excellent, regardless of whether a specimen is a single element or a partial-to-complete skeleton. The numerous articulated skeletons and occurrences of skin impression suggest relatively rapid burial compared to most vertebrate fossil-bearing stratigraphic units. Most single elements at the Park exhibit some degree of abrasion and rounding, and it is common for delicate processes to be worn or missing. Bone surfaces show little evidence of weathering in the form of original drying and cracking, and although they are often fractured or crushed due to the influences of burial compaction, they generally appear to be unmarked and unmodified when examined macroscopically. Tooth marks are common on isolated and single hadrosaur and ceratopsian bones (Chure *et al.* 1998; Jacobsen 1998, 2003; Eberth and Getty 2005; Eberth and Currie 2005).

Eberth and Currie (2005) reviewed anecdotal and semi-quantitative data relating to the preservational patterns of different high-order dinosaur taxa (hadrosaurids, ceratopsids, ankylosaurs, pachycephalosaurs, small theropods, ornithomimids, tyrannosaurids) and non-dinosaurs. They also established a classification of taphonomic modes at the Park and discussed the origins and relationships of these modes. They concluded that the most parsimonious explanation for the origins and interrelationships of most of the Park's preservational patterns and taphonomic modes is the biological and physical response of animals, carcasses, skeletons, and bones to the frequent and severe Bangladesh-style coastal plain flooding in the region during the Late Campanian. Their data also indicated that whereas pre- and post-mortem biological and ecological controls may have influenced preservational patterns, death due to flood-induced drowning and disease was likely the primary cause of mortality among the Park's dinosaurs and other vertebrates. They also concluded that floods modified pre-existing thanatocoenoses and created the Park's characteristic taphocoenoses (preserved death assemblages).

Although it is clear that other biological and physical taphonomic factors (predation, scavenging, trampling) influenced preservation of fossils at the Park, flooding is now regarded as the primary influence because of the large number of observations and interpretations that can be potentially accounted for by this mechanism. Eberth and Currie (2005) argued that influences on preservation related to flooding (standing and flowing water) account for 15 of 18 major preservational patterns observed at the Park. Those that cannot be accounted for by flooding are potentially accounted for by pre-mortem biological-ecological controls such as some form of niche-habitat partitioning (Dodson 1983).

Hadrosaurid Preservational Patterns

A unique pattern of preservation relating to the Park's hadrosaurids was recognized by C.M. Sternberg (1970) and Peter Dodson (1983, 1987) and it continues to be confirmed by ongoing research. The pattern is made up of the following features:

- Hadrosaurs dominate in both macrofossil and microfossil assemblages;
- The degree of articulation among hadrosaur specimens ranges from isolated elements to complete skeletons;
- No complete hadrosaur "mummies" are present, but many articulated specimens include large areas of fossil skin;
- There are many headless skeletons, but relatively fewer isolated and articulated skulls;
- Hadrosaur body parts are common (*e.g.* limbs, tails, necks) and are overwhelmingly associated with palaeochannel deposits;
- Articulated juvenile specimens of hadrosaurs are present, but not abundant;
- Baby and juvenile hadrosaur elements are common at the Park (in contrast to a notable dearth of babies from other ornithischians).

FIELD TRIP STOPS

STOP 1: *Brachylopholosaurus canadensis* (holotype; Quarry 103)

Quarry 103, where the holotype specimen of *Brachylophosaurus canadensis* was collected, is marked by a prominent notch in the side of a ridge that is visible from the preserve road. The specimen was collected by C.M. Sternberg in 1936, but not described until 1953 (Sternberg 1953). This was the last hadrosaur taxon described from DPP. The skeleton consists of an excellent skull and the front half of the body, which has recently been fully described (Cuthbertson and Holmes 2010). The specimen occurs in the Oldman Formation, in a stratum 7 metres below the base of the Dinosaur Park Formation. The occurrence is significant because it is the stratigraphically lowest documented hadrosaur skeleton that can be identified to the genus-level, and it is the only hadrosaur known from the Oldman Formation at the Park.

Brachylophosaurus is unique among hadrosaurids in its possession of a wide, dorsoventrally flattened, paddle-shaped crest that extends posteriorly over the skull roof (Fig. 10; Sternberg 1953). The crest is a solid extension of the nasal bones, with associated modification of the skull roof. The forearm is proportionately longer in *Brachylophosaurus* than in any other hadrosaurine. Another well-preserved specimen of *Brachylophosaurus* was collected from the Park in the early 1920s by the Field Museum. Unfortunately, the quarry has not been relocated (Prieto-Márquez 2001).
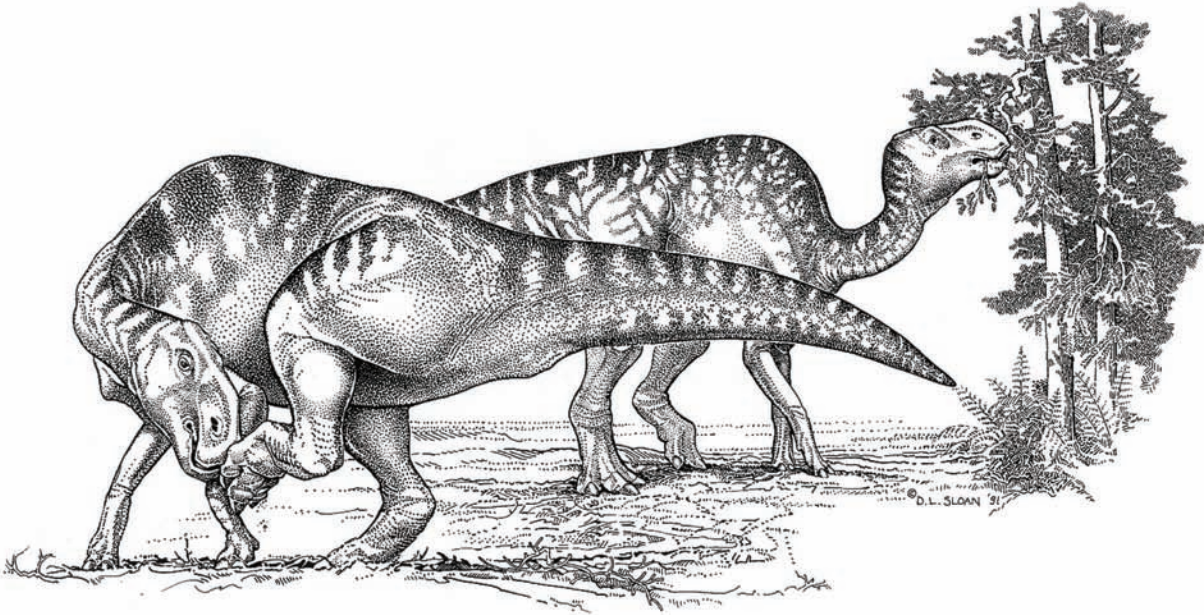
Figure 10. Life reconstruction of *Brachylophosaurus canadensis* by Donna Sloan

STOP 2: BB 50 Area

a) *Parasaurolophus* (Quarry 206) and Patterns of Preservation
This quarry was excavated under the direction of Dave Eberth in the mid 1990s. The specimen consists of a scattered, but closely associated skeleton of a large lambeosaurine hadrosaur. Unfortunately, no skull material was present, but the robustness and morphology of the pelvic elements suggest that the skeleton belongs to the rare tube-crested lambeosaurine *Parasaurolophus*. Only a handful of specimens attributable to this genus have been collected from the Park (Evans *et al.* 2009).

The detailed quantification of taphonomic modes in the Park (Eberth and Currie 2005; Eberth and Getty 2005) and their stratigraphic distribution allows for more meaningful ecological inferences about the relative abundance of taxa that are difficult to make at other localities with smaller samples sizes and less robust understanding of taphonomic biases. There are two species of lambeosaurines considered rare in the DPFm, *Parasaurolophus* and *Lambeosaurus magnicristatus* (Evans and Reisz 2007; Evans *et al.* 2009). The two skeletons of *Parasaurolophus* collected in the Park occur in the lower half of the Dinosaur Park Formation. This interval has been extensively sampled, and numerous taphonomically equivalent specimens (> 50) of hadrosaurs have been collected from it. This indicates that *Parasaurolophus* is rare not because of taphonomic biases, but because it was a rare faunal element in the Park's dinosaur community.

In contrast, such a claim cannot yet be made concerning *L. magnicristatus*. Conditions amenable to preserving articulated skulls and skeletons apparently became less favorable upwards through the DPFm and into the LCZ. Although hadrosaur teeth and other skeletal elements are present, relatively few identifiable skeletons and skull parts of hadrosaurs (and dinosaurs in general), are present. Therefore, an understanding of the relative abundance of *Lambeosaurus magnicristatus*, the other 'rare' lambeosaurine taxon known from a single good skull from the Park, is confounded by taphonomic biases against preservation of identifiable dinosaurs in the uppermost part of the DPFm section.

b) BB 50: Mixed (macrofossil-microfossil), High-Diversity, Multitaxic Bonebed Complex
Bonebed 50 is a multitaxic, high-diversity bonebed in the DPFm that comprises bones and partial skeletons of vertebrates concentrated along many different bedding planes and erosional surfaces within a stacked succession of palaeochannel sandstones. It is typical of the majority of multitaxic bonebeds in the Park and it covers many hundreds of square meters, over which it includes discrete areas dominated by either macrofossil and microfossil assemblages (mixed bonebed of Eberth *et al.* 2007). BB 50 includes a linear, NE-SW oriented 'fairway' that contains the articulated and associated partial-to-complete postcranial skeletons of at least three adult hadrosaurs. One of these has been partially excavated, perhaps by a crew from the AMNH, in the 1910s (Tanke pers. comm.).

The palaeoenvironment of BB 50 was a low-sinuosity channel that was flowing toward the east. Fossils occur in multiple lag deposits that mark erosional and bounding surfaces associated with stacked sets of trough cross-bedded sandstone (formed by sub-aqueous dunes). The co-occurrence of skeletons, isolated elements and macrofossil and microfossil remains clearly indicate that much of the fossil material in the bonebed was reworked from the surrounding Campanian landscape. The occurrence of a "string" of articulated and associated skeletons along a single surface suggests that a group of hadrosaurs were interred here at the same time.

BB 50 has not been systematically excavated or studied, and although hadrosaurid remains appear to dominate, we do not know whether the bonebed is truly a "hadrosaur bonebed" (sensu Eberth *et al.* 2011). Because of the numerical abundance of hadrosaurs in the Park's palaeoecosystems, hadrosaur remains are common in multitaxic bonebeds like this. Individual skull and postcranial bones with exquisite preservation are often recovered from these deposits, and more rarely, articulated skull or even whole skeletons can also be found. The skeletal remains at BB 50 are listed as Uncollected Articulated/Associated Dinosaurs (UADs) in collections data of the RTMP. The Park's more than 125 UADs await future study.

An area of hydraulically concentrated microfossils is well exposed at this site. The BB 50 vertebrate microfossil assemblage is dominated by aquatic vertebrates but also includes a variety of semi-aquatic and terrestrial forms (fish, amphibians, turtles, champsosaurs,

crocodiles, hadrosaurs, ceratopsians, ankylosaurs, small and large theropods, and mammals). Vertebrate microfossil sites such as this are common at the Park and have been a focus of palaeoecological studies for the past 30 years (see review in Brinkman *et al.* 2005). Sampling and screenwashing the fossils from these localities provides an efficient opportunity to examine the composition of and variation within the Park's palaeofaunas and faunal communities, and provides additional insight into the biology of some taxa. Isotaphonomic surveys show that faunal differences between sites can correlate with stratigraphy and/or facies.

c) BB 30: Mondominant Ceratopsian Bonebeds

The Park's monodominant ceratopsian bonebeds are uniquely famous and important because they provide opportunities to examine the palaeobiology and palaeoecology of the contained taxa. In particular, ontogenetic patterns, and some behaviors and ecological preferences have been documented (see Sampson 1995; Sampson *et al.* 1997; Eberth and Getty 2005; Brinkman *et al.* 2007; Eberth *et al.* 2010). They also stand out in stark contrast to the multitaxic bonebeds that contain remains of hadrosaurs.

There are now 24 monodominant ceratopsian bonebeds known from the Park (Eberth and Getty 2005 reported 20) and skeletal remains appear to be assignable to one of three species of centrosaurine — *Centrosaurus apertus*, *Centrosaurus brinkmani*, and *Styracosaurus albertensis*. Eberth and Getty (2005) report that seventeen of the twenty ceratopsian bonebeds that they examined are dominated by the remains of *Centrosaurus apertus*, with each occurring in the lowest 15 m of the Dinosaur Park Formation.

BB 30 is one of nine of the Park's mudstone-hosted (overbank muds) ceratopsian bonebeds. It occurs six metres above the base of the DPFm. The site is large and, originally, covered an area estimated at 11,000 m² (Fig. 11). The site was systematically excavated and studied in 1995 and 1996 under the direction of Dave Eberth, and is still used today for public excavation programs run by the Park's staff. Eberth and Getty (2005) described this and other sites in detail. Ryan *et al.* (2001) described the original "Centrosaurus" bonebed (BB 43), a palaeochannel sandstone hosted assemblage. Broadly similar geologic,
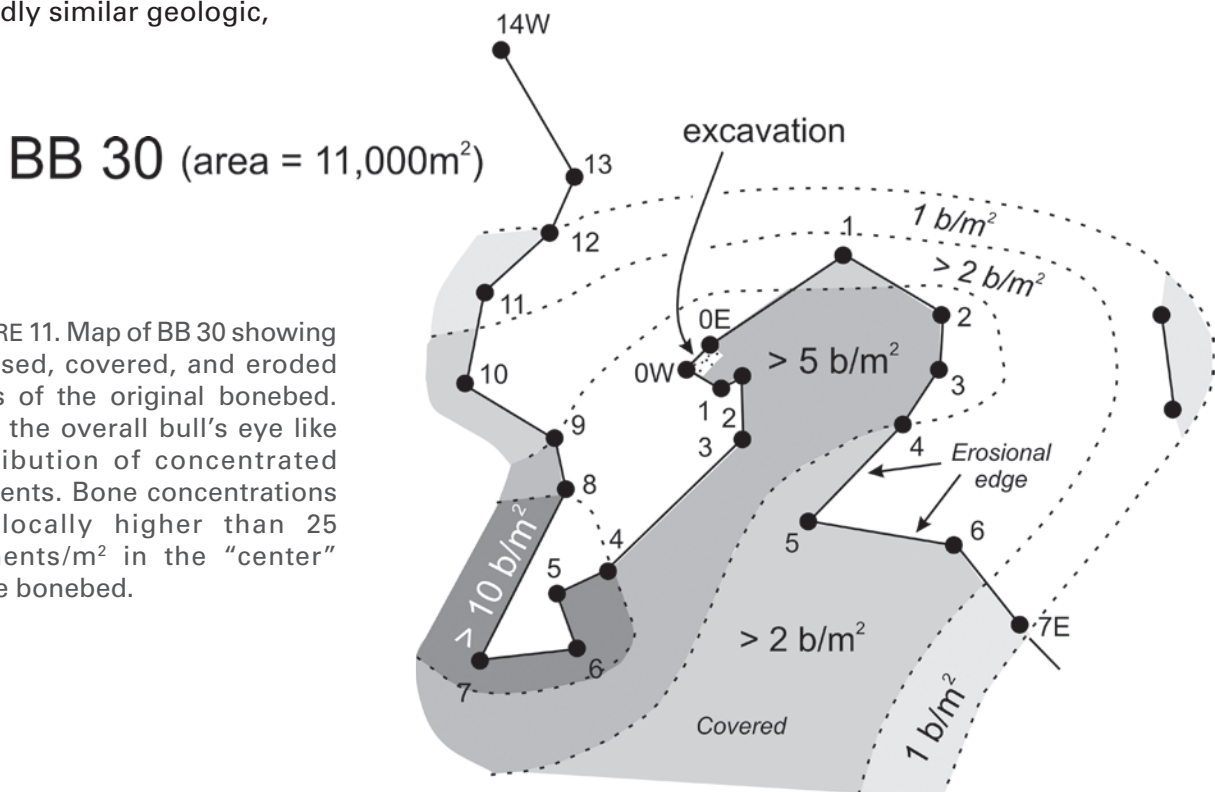

FIGURE 11. Map of BB 30 showing exposed, covered, and eroded areas of the original bonebed. Note the overall bull's eye like distribution of concentrated elements. Bone concentrations are locally higher than 25 elements/m² in the "center" of the bonebed.

compositional and taphonomic signatures among overbank- and channel-hosted ceratopsian bonebeds indicate that these assemblages had similar origins and parallel, multi-event taphonomic histories. The thorough disarticulation of carcasses, evidence for removal of trabecular bone, and absence of evidence of weathering are all consistent with the sedimentological interpretation that rotting carcasses were deposited in water-saturated reducing environments at each site, and that these environments remained wet or saturated until elements were finally interred. Bone may have been weakened and made more susceptible to fracturing and breakage due to dissolution of trabecular bone and the break down of collagen.

Unimodal and bivariate orientation data and an over-representation of large skeletal elements indicate that hydraulic sorting events occurred frequently. The presence of abundant fragmentary specimens demonstrates that hydraulic sorting events removed small skeletal elements before larger skeletal elements became broken and fragmented.

The presence of fragments, tooth marked bone, and evidence for high impact "green fractures" indicate that scavenging and trampling took place after assemblages were sorted. Whereas the pattern of abrasion and polish is compatible with an interpretation of hydraulic reworking, the association of a trampled assemblage with sandy-to-silty mudstones raises the possibility that low grade abrasion and scratches may be due to elements being trampled in an abrasive matrix over time (Brain 1967).

The large numbers of bone fragments and the specimens that exhibit fresh breaks together suggest that trampling was common at each site. The combination of breaks on fresh and older bone suggests that scavengers and tramplers of all types modified the assemblages semi-continuously, over months and, possibly, years. However, there is no necessary link between scavenging and trampling; trampling is just as likely to have resulted from large dinosaurs walking across areas of concentrated bone; the small number of tooth marked bones compared to trampled bone may reflect either a low incidence of scavenging or, alternatively, the vast abundance of 'scavengeable' specimens at each site.

An interpretation of shared taphonomic histories for palaeochannel- and overbank-hosted ceratopsian bonebed assemblages is strongly supported by the observation that palaeochannel deposits sometimes erosionally overlie and cut down through overbank-hosted bonebeds, such as at BB 30. In this latter context, some palaeochannel-hosted ceratopsian bonebeds may represent overbank-hosted assemblages that were wholly or partly reworked into channels during scouring, avulsion or channel meandering.

The minor variation in taphonomic signatures within ceratopsian bonebeds and the presence of juveniles, sub-adults and adults at each site strongly suggest that the fossil assemblage resulted from mass-kill events rather than long-term attritional processes (Eberth and Getty 2005). Whereas mass kills of ceratopsians in the Two Medicine Formation of Montana have been attributed to drought (Rogers 1990; Sampson 1995), mass kills of the Park's ceratopsians are attributed consistently to flood-induced drowning (Currie 1981; 1982; Currie and Dodson 1984; Visser 1986; Wood *et al.* 1988; Ryan 1992; Ryan *et al.* 2001; Eberth and Getty 2005).

The scenario envisaged by Eberth and Getty (2005) and accepted here explains the occurrence of both overbank- and palaeochannel-hosted ceratopsian bonebeds, as well as most of the taphonomic modes in the Park (Eberth and Currie 2005) as the result of extensive, coastal plain flooding. The low-gradient coastal-to-alluvial lowland that stretched for hundreds of kilometers across southern Alberta during the late Cretaceous afforded no significant high ground protection for groups of ceratopsians, or any large terrestrial vertebrates, during severe

seasonal-storm induced flooding. As in modern day Bangladesh, severe floods resulting in prolonged occurrences of standing water or significant water depths would have been potentially lethal to all of the large vertebrates, not only groups of ceratopsians. Such severe flooding events would have spelled death for herds but also would have culled the standing crop of large terrestrial vertebrates in the Park area, creating a lower density, multitaxic background death assemblage.

Receding floodwaters would have allowed carcasses of individuals and groups of individuals of large vertebrates to settle out across the floodplain, thus forming incipient isolated skeletal occurrences and bonebeds.

STOP 3: Display House 4 — *Corythosaurus* (Quarry 128)

When the Park was first established in 1955, it was considered important to provide visitors with a direct connection to the Park's outstanding fossil resources. Accordingly, a series of secure "display houses" were eventually constructed along a fossil trail. In each house, an "in-situ" specimen was displayed and interpreted.

Display House 4 shelters a nearly complete, articulated skeleton of a very large individual of *Corythosaurus intermedius*, displayed as it was preserved. It provides a good example of the quality of complete, articulated dinosaurs that are common in the DPFm. The specimen was found by Roy Fowler in 1964 in the sandstone ridge just outside (east) of the Display House. The specimen was collected by C.M. Sternberg, who moved it only a short distance to where you see it here. The skeleton is original, but the skull has been removed and is stored at the Royal Tyrrell Museum (TMP 1980.023.0004). The specimen represents an articulated and skin-encased carcass that was originally deposited and then reworked slightly on a sandy point bar. The specimen occurs just above an erosional surface near the top of a 20 m thick stacked palaeochannel succession. The right (down) side of the specimen is better preserved and more complete than the left. Apparently, after the carcass ruptured, the left side was exposed to currents that shifted the positions of some of the limb elements.

STOP 4: Cathedral Area

a) *Prosaurolophus maximus* (Quarry 86)

Prosaurolophus maximus occurs in the middle of the DPFm, stratigraphically above *Gryposaurus*. At least 11 articulated *P. maximus* skulls have been collected from the Park, including the holotype AMNH 5386 (Brown 1916a). These specimens exhibit a wide range of sizes and exhibit considerable morphological variation. The largest of these skulls is over 1 metre in length. Chris McGarrity (2011) recently examined the ontogeny and range of variation of *Prosaurolophus maximus* for his M.Sc. thesis. The *P. maximus* skull from Quarry 86 (CMN 2277) was collected by C.M. Sternberg in 1914. Although incomplete, it preserves the small, pocketed crest above the front of the orbits; this is diagnostic for the taxon (Figs. 12, 13).

b) Bearpaw Transition

A hike up to the top of the "Cathedral" positions us stratigraphically just above the middle of the Dinosaur Park Formation, and provides an opportunity to glimpse some of the initial stratigraphic and geologic changes that are associated with the Dinosaur Park-Bearpaw formational transition.
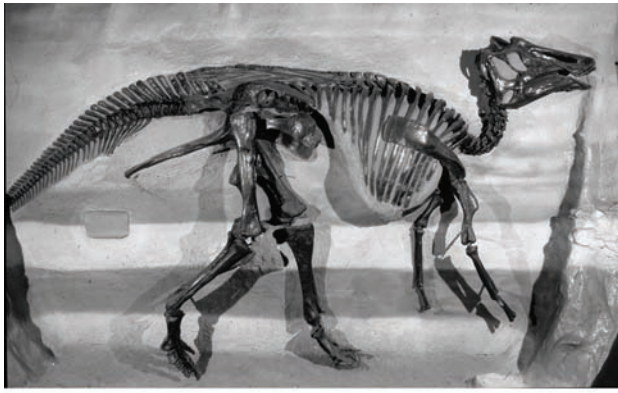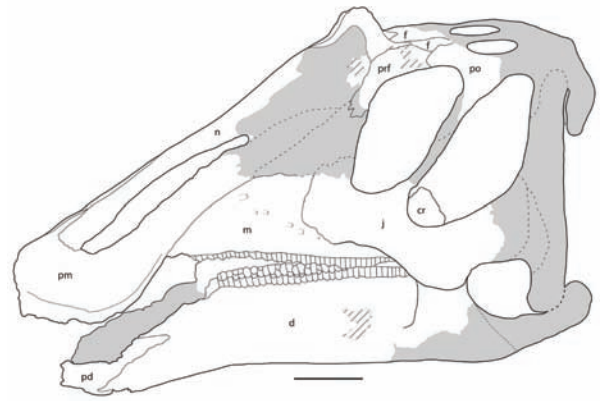
FIGURE 13. Drawing (with reconstructed areas) of the skull of *Prosaurolophus maximus* (CMN 2277) from Quarry 86 (McGarrity 2011). Scale bar is 10 cm.

FIGURE 12. Photo of *Prosaurolophus maximus* (ROM 787) and skeletal reconstruction of *Prosaurolophus* by Danielle Dufault (ROM).

There is a notable increase in mudstones (some with datable bentonites) in the stratigraphic section (Fig. 6), and a concommittant decrease in palaeochannel stacking. This change is obvious in subsurface data sets and cross-sections, and has been used to subdivide the DPFm into a lower sandy unit and an upper muddy unit. The cause of these changes is an increase in accommodation related to the relative rise in sea-level during the Bearpaw transgression (Eberth 2005). Importantly, the upsection decrease in palaeochannel stacking is positively correlated with a decrease in fossil vertebrate recovery (Eberth and Currie 2005). Thus, there is a potential preservational bias against our understanding of the vertebrates from these upper beds compared to the lower beds (see STOP 1 above).

The transition also "sees" an increase in carbonaceous shales and coals, which culminates in the occurrence of the laterally extensive Lethbridge Coal Zone. This approximately 15-20 m thick stratigraphic zone of coals, mudstones, and bentonites, and very fine grained sandstone reflects the continued rise in base level and widespread development of coastal peat swamps and small coastal channels during the transition. Our understanding of the DPFm dinosaur fauna from this interval is very limited, but new taxa continue to be discovered (*e.g.*, Ryan *et al.* 2010).

OPTIONAL STOPS

Juvenile *Corythosaurus* group (Quarry 11)

In the summer of 1920, Levi Sternberg was collecting in the Park for the University of Toronto and the Royal Ontario Museum. The field season was Levi's first without his father, the renowned fossil hunter Charles H. Sternberg. The season turned out to be particularly successful.

The first major find of the summer was the skeleton of a small hadrosaur. As Levi excavated around its exposed hind foot, he discovered that he had found not one, but two small

skeletons. Both were nearly complete and articulated, but unfortunately their skulls were missing (typical of hadrosaur skeletal preservation in the Park). Skin impressions were also present and recovered. Sixteen years later, Levi's brother Charles M. Sternberg made a remarkably similar find at the same site. His work in 1936 included an intensive project to relocate, map, and permanently identify old quarries. This project, intended to preserve contextual information for future scientists, is continued today under the direction of the Royal Tyrrell Museum, and has been instrumental in recent biostratigraphic work at DPP. While surveying Quarry 11, Sternberg found two additional small hadrosaurid skeletons in similarly close association, one lying partly on top of the other. The best specimen (CMN 34825) is virtually complete, and measures approximately 5.5 metres (17 feet) in length, half that of an adult (Fig. 14). The articluted skull is one of the best juvenile hadrosaur skulls ever collected from the Park, and it allows its identification as *Corythosaurus* (Evans *et al.* 2005). The four individuals are of similar size, and were probably approximately the same age when they died and were buried. The find is the only example of a number of articulated juvenile dinosaurs preserved together at the Park. Quarry 11 occurs near the base of the Dinosaur Park Formation.

It is possible that these dinosaurs were part of a social group that died together, supporting the idea that juveniles of some duck-bills, like *Corythosaurus*, spent considerable time in groups (Forster 1990). The four individual skeletons are now widely dispersed. Levi's specimens were sent to the Carnegie Museum (Pittsburg) and the Los Angeles County Museum of Natural History, where both specimens have been reconditioned and are on display. Sternberg's specimens have remained in Canada, and are now part of the Canadian Museum of Nature collections.

Parasaurolophus walkeri (Quarry 12)
Parasaurolopohus is characterized by a spectacular tubular crest that extends for a metre beyond the top of the skull. It is also one of the rarest duck-bills from Western Canada, with only three other fragmentary specimens known from Alberta referred to this taxon (Evans *et al.* 2009). The holotype specimen of *Parasaurolophus walkeri* was found in 1920 by an expedition from the University of Toronto. The remarkable skeleton was discovered Mr. L.W. Dippell, and its excavation and mounting in the Royal Ontario Museum of Palaeontology was conducted under the supervision of Levi Sternberg. The original description by Parks (1922) reports that the skeleton was lying on its left side with some of the bones of the right or upper side in a relatively poor state of preservation; thus the specimen is mounted showing its left side (Fig. 15). The skeleton is complete from the sacrum forward, including both forelimbs and hands, but the tail and hind limbs (with the exception of one femur) are missing, along with the posterior ends of the Ischia.

The holotype specimen from this quarry comes from near the base of the DPFm and is still the best preserved and most complete specimen of this genus in the world. Exact replicas, cast from the ROM's original skeleton, are on display in more than 30 major museums worldwide, and it is illustrated in countless books, making it one of the Canada's most widely recognized dinosaurs.

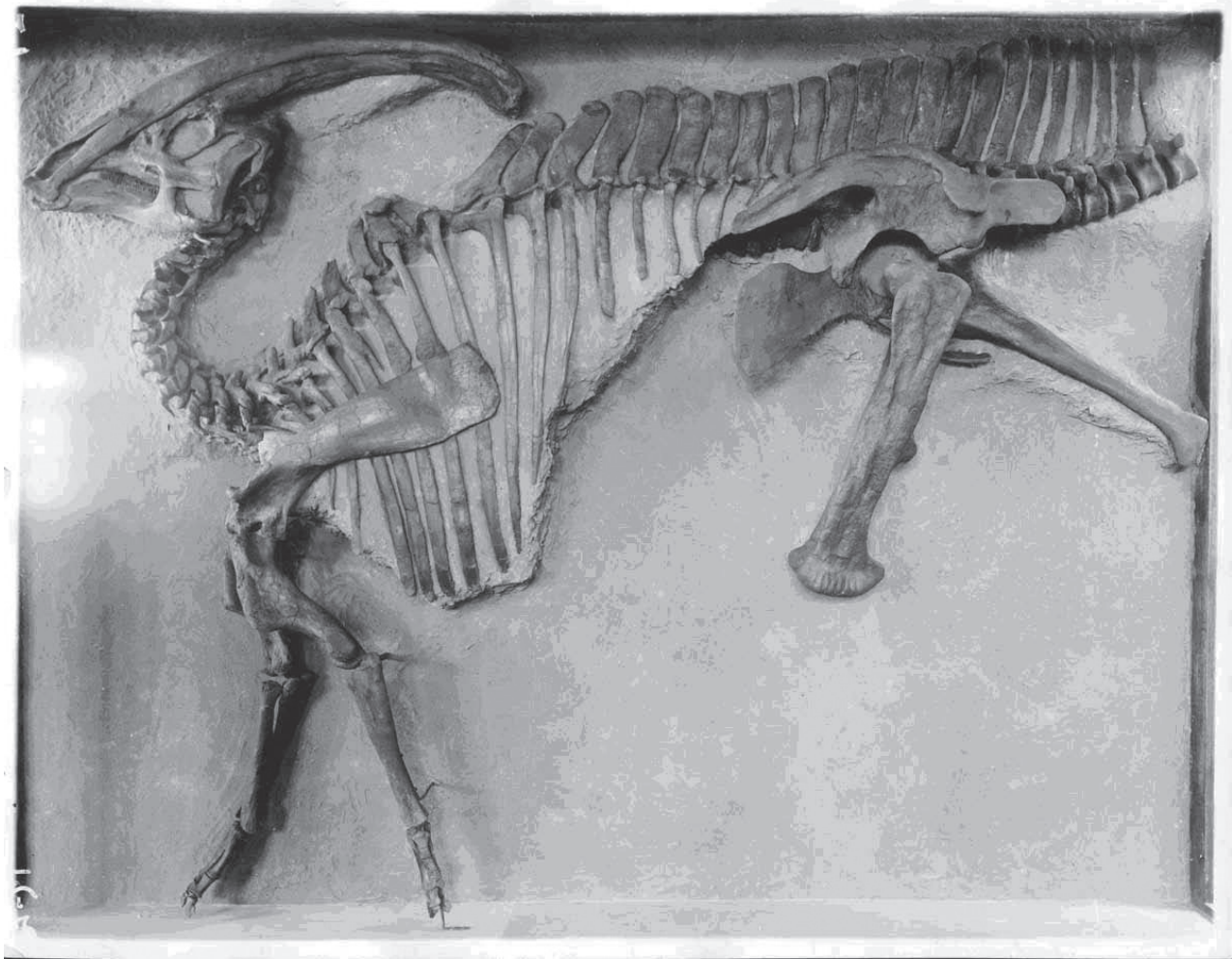FIGURE 14.Skull of a juvenile *Corythosaurus* (CMN 34825) from Quarry 11.

FIGURE 15. Articulated holotype of the tube-crested lambeosaurine Parasaurolophus *walkeri* (ROM 768) from Quarry 12.

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APPENDIX 1: List of the 145 fossil vertebrates currently known from Dinosaur Provincial Park. The assemblage includes taxa from both the Oldman and Dinosaur Park formations, and also includes brackish/marine taxa known only from transgressive lag deposits (marine interbeds of the Bearpaw Formation) that occur in the Lethbridge coal zone, uppermost Dinosaur Park Formation (e.g., *Enchodus* sp., cheloniid turtle). The vast majority of these taxa — including most of the 44 dinosaurs — are known from the Dinosaur Park Formation. List was compiled and reviewed by Donald B. Brinkman and others in August, 2011.

Class Chondrichthyes
  Subclass Holocephali
                Family Rhiochimaeridae
                    Elasmodus cf. *greenoughi*
  Subclass Elasmobranchii
                Family Hybodontidae
                    Hybodus montanensis
                Family Orectolobidae
                    Cretorectolobus olsoni
                    Eucrossorhinus microcuspidatus
                Family Odontaspididae
                    Odontaspis aculeatus
                    Carcharias steineri
                Family Archaeolamnidae
                    Archaeolamna kopingensis judithensis
                Family Otodontidae
                    Cretolamna sp.
                Family Pseudotriachidae
                    Archaeotriakis sp.
                Family Rhinobatoidei incertae sedis
                    Rhinobatos incertus
                    Myledaphus bipartitus
                Family Pristidae
                    Ischyrhize mira
                Family Hypsobatidae
                    Protoplatyrhina ranae
                Family Sclerorhynchidae
                    Ptychotrygon blainensis

Class Osteichthyes
  Subclass Chondrostei
      Order Acipenseriformes
                Family Acipenseridae
                    Acipenser albertensis
      Order Polydontiformes
                Family Polydontidae
                    gen. et sp. indet.

  Subclass Neopterygii
      Order Lepisosteiformes
                Family Lepisosteidae
                    *Lepisosteus occidentalis**
      Order ?Semionotiformes
                Family indet.
                    gen. et sp. indet. (Holostean A)
                    gen. et sp. indet. (Holostean B)
      Order Amiiformes
                Family Amiidae
                 Subfamily Amiinae
                    gen. et sp. indet.

Order Aspidorhychiformes
    Family Aspidorhynchidae
        Belonostomus longirostris
Division Teleostei
  Subdivision Osteoglossomorpha
    Order and family indet.
        Coriops sp.
        Cretophareodus alberticus

    Order Hiodontiformes
        Family Hiodontidae
           gen. et sp. indet.
  Subdivision Elopomorpha
    Order Albuliformes
        Family Albulidae
          Subfamily Phylodontinae
          Paralbula sp.
    Order Elopiformes
        Family Elopidae
          Paratarpon apogerontus
    Order Ellimmichthyiformes
        Family Sorbinichthyidae
          Diplomystus sp.
          Horseshoeichthyes sp.
  Subdivision Euteleostei
    Order indet.
        Family indet
           gen. et sp. indet. type U-4
    Order Salmoniformes
      Suborder Esocoidea
        Family indet.
          Estesesox foxi.
          Oldmanesox canadensis
    Order and Family indet
           gen. et sp. indet. type H
           gen. et sp. indet. type B
    Order Aulopiformes
        Family Enchodontidae
          Enchodus sp.
  Subdivision Neoteleostei
   Superorder Acanthomorpha
    Order ?Percopsiformes
           gen. et sp. indet.

Class Amphibia
  Order Caudata
        Family Scapherpetontidae
          Scapherpeton tectum
        Family Batrachosauroididae
          Opisthotriton kayi
  Order Allocaudata
        Family Allbanerpetontidae
          Albanerpeton gracilis
  Order Anura
        Family indet.
           gen. et sp. indet. #1
           gen. et sp. indet #2

Class Reptilia
    Order Testudines
            Family Baenidae
                Neurankylus eximius
                Boremys pulchra
                Plesiobaena antiqua
            Family Macrobaenidae
                Judithemys sukhanovi
            Family Cheloniidae
                gen. et sp. indet
            Family Chelydridae
                gen. et sp. indet.
            Family Adocidae
                Adocus sp.
            Family Nanhsiungchelyidae
                Basilemys variolosa
`   Family Trionychidae
              Subfamily Trionychinae
                Aspideretoides foveatus
                Aspideretoides splendidus
                Aspideretoides allani
                Apalone latus
              Subfamily ?Plastomeninae
                gen. et sp. indet.
    Order Squamata
            Family Borealoteiidae
                Socognathus unicuspis
                Sphenosiagon simplex
                Glyptogenys ornata
            Family Xenosauridae
                ?*Exostinus* sp.
            Family Anguidae
                Odaxosaurus priscus
            Family Necrosauridae
                Parasaniwa sp. cf. *P. wyomingensis*
            Family Helodermatidae
                Palaeosaniwa canadensis.
    Order Choristodera
            Family Cteniogeniidae
                Cteniogenys sp. cf. *C. antiquus*
            Family Champsosauridae
                Champsosaurus natator
                Champsosaurus lindoei
    Order Sauropterygia
      Suborder Elasmosauria
                gen. et sp. indet.
    Order Crocodylia
                Leidyosuchus canadensis
                Albertochampsa langstoni
    Order Pterosauria
            Family Azhdarchidae
                ?*Quetzalcoatlus* sp.
                ?*Montanazhdarcho* sp.
    Order Dinosauria
      Suborder Ornithischia
            Family indet. (basal ornithopod)
                gen. et sp. indet.
            Family Hadrosauridae
              Subfamily Hadrosaurinae
                Brachylophosaurus canadensis
                Gryposaurus notabilis
                Prosaurolophus maximus

Subfamily Lambeosaurinae
    Corythosaurus casuarius
    Corythosaurus intermedius
    Parasaurolophus walkeri
    Lambeosaurus clavinitialis
    Lambeosaurus lambei
    Lambeosaurus magnicristatus
Family Pachycephalosauridae
    Stegoceras validum
    Stegoceras sternbergi
    "Prenocephale" brevis
    gen. et sp. indet
Family Ankylosauridae
    Euoplocephalus tutus
    Dyoplosaurus acutosquameus
Family Nodosauridae
    Edmontonia rugosidens
    Panoplosaurus mirus
Family indet. (basal neoceratopsian)
    gen. et sp. indet.
Family Ceratopsidae
  Subfamily Centrosaurinae
    Centrosaurus brinkmani
    Centrosaurus apertus
    Styracosaurus albertensis
    cf. *Pachyrhinosaurus*
  Subfamily Chasmosaurinae
    Chasmosaurus belli
    Chasmosaurus russelli
    Vagaceratops irvinensis
Suborder Saurischia
Family Ornithomimidae
    Ornithomimus edmontonicus
    "Dromiceiomimus" brevitertius
    Struthiomimus altus
    gen. et sp. indet (giant ornithomimid)
Family Caenagnathidae
  Subfamily Caenagnathinae
    Chirostenotes collinsi
    Chirostenotes sternbergi
  Subfamily Elmisaurinae
    Elmisaurus elegans
Family Erlikosauridae
    cf. *Erlikosaurus* sp.
Family Troodontidae
    Troodon formosus
Family Dromaeosauridae
  Subfamily Dromaeosaurinae
    Dromaeosaurus albertensis
  Subfamily Velociraptorinae
    Saurornitholestes langstoni
  Subfamily Microraptorinae
    Hesperonychus elizabethae
Family Tyrannosauridae
  Subfamily Tyrannosaurinae
    Daspletosaurus torosus
  Subfamily Albertosaurinae
    Gorgosaurus libratus.
Theopoda incertae sedis
    Richardoestesia gilmorei
    Richardoestesia isosceles
    Paronychodon sp.
    Dromaeosaurus type A

Class Aves
                Family cf. Neognathidae
                    Palintropus A and B
                    Cimolopteryx sp.
        Euornithes
                ?*Apatornis* sp.
                Euornithes indet.
                Ornithurae indet.

Class Mammalia
  Subclass Allotheria
     Order Multituberculata
                Family uncertain
                    Cimexomys judithae
                Paracimexomys grade multituberculates
                    **cf. *Cedaromys hutchisoni*
                Family Neoplagiaulacidae
                    ***Mesodma* nov. sp.
                    ***Mesodma* sp., cf. *M. minor*
                    ***Mesodma* sp., cf. *M. archibaldi*
                Family Cimolodontidae
                    ***Cimolodon* sp., cf. *C. foxi*
                Family Cimolomyidae
                    Cimolomys primaevus
                    Meniscoessus major
                    Meniscoessus intermedius
                    **?*Meniscoessus* nov. sp.
                    **new cimolomyids A-D
  Infraclass Metatheria
    Cohort Deltatheroida
                Family Deltatheridiidae
                    cf. *Nanocuris* sp.
    Cohort Marsupialia
                Family incertae sedis
                    ***Varalphadon* sp., cf. *V. creber*
                    ***Iqualadelphis* sp., cf. *I. lacteal*
                Family Alphadontidae
                    Alphadon sp.*,* cf. *A. halleyi*
                    Alphadon sp.
                    Turgidodon russelli
                    Turgidodon praesagus
                        Family Pediomyidae
                    Pediomys sp., cf. *P. elegans*
                    Pediomys sp., cf. *P. hatcheri*
                    Pediomys sp. A
                    Aletridelphys clemensi
                    Leptalestes prokrejcii
                Family Stagodontidae
                    Eodelphis browni
                    Eodelphis cutleri
  Infraclass Eutheria
    Order Leptictida
                Family Gypsonictopidae
                    Gypsonictops lewsi
    Order ?Lipotyphla
                Family ?Nyctitheriidae
                    Paranyctoides sternbergi
    Order Cimolesta
                Family Palaeoryctidae
                    Cimolestes sp.

Comments (DBB)

James Gardner, Craig Scott, François Therrien, Andrew Neuman, Dave Eberth, and Derek Larson all helped update the list. In general, the list follows the results presented in papers included in Currie and Koppelhus (2005). Exceptions are:

The chondrichthyans were reviewed and revised by Michael Newbrey.

* Grande (2010) stated that *Lepisosteus occidentalis* is a nomen dubium, preferring this to be listed as Lepisosteidae indeterminate.

The presence of *Horseshoeichthyes* is based on centra from the Dinosaur Park Formation referred to by Neuman and Brinkman (2005) as Teleost type 1B-2, which are included in that genus by Newbrey et al (2010).

The presence of *Diplomystus* is based on centra referred to as "teleost centrum type IIB-2" by Brinkman and Neuman (2002), which is here referred to *Diplomystus* on the basis of comparison with material from the Eocene of Wyoming in the collections of the Museum of Palaeontology, U.C. Berkeley (pers. obs.).

Acanthomorphs reported from the Judith River Group by Neuman and Brinkman (2005) are tentatively referred to the Percopsiformes through comparison with extant specimens (pers. obs.).

The amphibians included here are those known to occur in Dinosaur Provincial Park. Additional taxa listed by Gardner (2005) as occurring in the Judith River Group are present in more southern localities but do not occur in the park.

The lizards included here are those known to occur in Dinosaur Provincial Park. Additional taxa reported by Gao and Fox (1996) as occurring in the Judith River Group are present in more southern localities but do not occur in the park. *Palaeosaniwa* is included in the Helodermatidae, rather than the Varanidae, on the basis of the description of associated material of this genus by Balsai (2001).

The birds included here are those known to occur in Dinosaur Provincial Park. Additional taxa listed by Longrich (2009) as occurring in the Judith River Group are present in more southern localities but do not occur in the park.

Dyoplosaurus acutosquameus is considered a valid genus following Arbour et al. (2009).

Chasmosaurus irvinensis is placed in the genus *Vagaceratops* following Sampson et al., (2010).

The mammals were reviewed and revised by Craig Scott.

** Taxa identified subsequent to Fox (2005), and as yet unpublished.

Any remaining errors are simply... regrettable.

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