The ichnology, sedimentology, and stratigraphy of the upper Belly River Group in southeast Alberta were investigated to develop an integrative model for better understanding the transition from continents to marginal marine areas, through subaerial plains and freshwater fluvial to tidally influenced channel systems. The well exposed strata in Dinosaur Provincial Park record a complex, low-gradient, low-accommodation succession during the Campanian expansion of the Bearpaw Sea as it flooded fluvial systems in southern Alberta. Sedimentary facies are dominated by trough cross-stratified sandstones, inclined heterolithic stratification, coal, and several mudstone facies. Together, these facies and their stratigraphic packaging are comparable to other fluvially dominated, tidally influenced units of the Alberta Cretaceous (e.g., McMurray Formation).

The Oldman and Dinosaur Park formations of the Belly River Group, separated by a sequence boundary, represent the most basinward progradation of the clastic wedge followed by the transgression of a low-gradient region supplied by abundant clastic material. Trace fossils produced by unionid bivalves and by air-breathing organisms (e.g., *Taenidium, Skolithos* likely produced by beetles) are associated with paleosols, crevasse splay sandstones, and freshwater fluvial channels. This assemblage characterizes the coastal plain environments of the Oldman Formation. The Dinosaur Park Formation, in contrast, preserves a high density, low diversity assemblage of very simple types of bioturbation (e.g., cryptic bioturbation) throughout most of the succession. Roots and plant material are preserved throughout, but do not necessarily accompany paleosol development or freshwater environments. Higher diversity and potential brackish-water trace fossils (e.g., *Teichichnus*) appear abruptly above the Lethbridge Coal Zone at the top of the succession, in sedimentary facies nearly identical to those below. Above the Lethbridge Coal Zone, diminutive *Skolithos* burrows and abundant terrestrial plant detritus are present within thin coarsening-upwards units of siltstones and very fine-grained sandstones that prograded into the advancing Bearpaw Sea. Finally, the dark grey shales of the Bearpaw Formation evidence rapid transgression in this low-gradient setting.
Introduction

Badland erosion of the upper Belly River Group (Campanian) at Dinosaur Provincial Park, southeast Alberta (Fig. 1), provides exceptional outcrop exposure of laterally variable fluvial to estuarine, but likely very low salinity, deposits, well known for their inclined heterolithic stratification (sensu Thomas et al., 1987). The Dinosaur Park Formation of the uppermost Belly River Group, in particular, is an ideal case study for the transition from freshwater fluvial to potentially fluvially dominated, tidally influenced marginal marine depositional systems during transgression.

Inclined heterolithic stratification is also a common bedding style associated with other economic fluvio-tidal deposits of Alberta (e.g., McMurray Fm., Gething Formation, Ostracod Formation) that, like the upper Belly River Group, also show a transition from freshwater fluvial to tidally influenced channel systems, and contain abundant incision surfaces apparently produced as a result of both channel migration and downstream controls on base level.

The ichnological and sedimentological results of this study can be applied to helping recognize the position of these deposits relative to the shoreline and identifying the hydrochemical conditions within the channels. Future work will address the application of this data to the finer-scale prediction of mud-bed distribution and architecture in both mudstone and heterolithic facies of these types of systems. Although not typically investigated in detail, mudstone facies provide valuable information for understanding these depositional systems because they vary in their composition, thickness, lateral extent, and style of contacts with adjacent sandstones.

Fig. 1. Map of the Dinosaur Provincial Park area.
Methods

Outcrop and core studies to date include measured stratigraphic sections and logged core, and use gamma ray spectra, petrography, bulk geochemistry (XRF), and bulk X-Ray diffraction to help identify sedimentary facies and understand depositional processes.

Summary of ichnological and sedimentological results

The sedimentary facies and ichnology of the Oldman Formation together represent a coastal plain, with paleosols, bioturbated crevasse splay sandstones, and laterally accreting freshwater fluvial deposits containing unionid bivalves, whose biogenic structures (e.g., Johnston and Hendy, 2005) demonstrate short-term variability in sediment accumulation within channels systems. The sharply contrasting channel sandstone deposits of the overlying and downcutting Dinosaur Park Formation preserve a high density, very low diversity assemblage of small, simple biogenic structures (e.g., Planolites) and cryptic bioturbation that is commonly associated with shallow marine and brackish-water settings (e.g., MacEachern and Gingras, 2007; Pemberton et al. 2008). Drapes of clay and small plant fragments on rhythmic laminae are associated with high-density, very small horizontal burrows (Planolites).

Both the sedimentological and ichnological data recorded in these trough cross-stratified sandstone units are consistent throughout the entire thickness of the Dinosaur Park Formation in the Dinosaur Provincial Park area. As the relative proportion of laterally equivalent units dominated by inclined heterolithic stratification increases upwards, and the trace fossil assemblage shows evidence of brackish water in relatively muddy channels (e.g., Teichichnus), the trough cross-stratified facies remain relatively unchanged. Similarly, other sedimentological features, such as siderite nodules and abundant muddy intraclasts, are associated with the IHS units throughout the Dinosaur Park Formation. The appearance of a brackish assemblage of trace fossils within clayey IHS-dominated channel deposits above the Lethbridge Coal Zone in the northeastern part of the Park helps to demonstrate the importance of trace fossils in recognizing changing hydrochemical conditions. This highlights the potential of trace fossils to identify regions where marginal marine depositional systems are overwhelmed by freshwater input and/or sediment supply. In contrast, a thin unit of low-angle cross-bedded sandstones above the Lethbridge Coal Zone elsewhere within the Park are interpreted as upper shoreface to foreshore deposits. These deposits preserve Macaronichnus and large Skolithos, and are clearly marine.

Examples

A stratigraphic section of the upper Oldman Formation, the entire Dinosaur Park Formation, and the lowermost Bearpaw Formation measured at 7-18-T21-R10-W4 will be presented in detail. Additional photographic field examples showing the lateral and vertical relationships of facies will also be presented. The Alberta Research Council Coal Core (ARC CH 1-83 “NE 35-T19-R12 W4” or 1-2-T20-R12-W4) drilled near Dinosaur Provincial Park will be on display.
Discussion and future directions

The ichnology and sedimentology vary significantly between the Oldman Formation, interpreted as coastal plain deposits, and the overlying Dinosaur Park Formation, comprising mainly sandstones and IHS-containing heterolithic channel deposits. The Dinosaur Park Formation represents deposition in fluvial and fluvially dominated, tidally influenced environments of a low-gradient, low-accommodation setting during transgression (e.g., Eberth and Hamblin, 1993; Eberth, 1996). As such, the stratigraphic relationships among sandstones and the different mudstone facies are complex and require detailed mapping in future research. Incision surfaces are numerous, and scoured and sharp contacts between both sandstones and mudstone facies appear to be much more common than gradational, as is suggested by traditional interpretations of the Dinosaur Park Formation (Fig. 2).

Two depositional scenarios of the IHS units at Dinosaur Provincial Park are observed: 1) the gradual transition from trough cross-stratified sandstones to the lateral accretion deposits of meandering river point bars; and 2) the sharp incision between trough cross-stratified sandstones representing channel thalwegs and overlying tidally influenced muddy and heterolithic channel deposits that may represent rising sea level (Fig. 3; Eberth, 1996). The recognition of these stratigraphic relationships is especially important for interpreting the significance of inclined heterolithic stratification within fluvial systems that are influenced by rising sea levels.
Future research that will help to distinguish between these two scenarios includes the characterization of mudstone and heterolithic facies in terms of their lithology, associated microfossil assemblages, clay mineralogy, 3-D architectures, and position within the stratigraphic succession. Biogenic structures will remain a focus of study because they are helpful for recognizing the stratigraphic transition point between a system that is overwhelmed with sediment and freshwater supply and one influenced by relatively saline marine waters.

Sedimentary facies that dominate the Dinosaur Park Formation (e.g., trough cross-stratified sandstones, IHS units, and several mudstone facies), also comprise other successions in the Cretaceous of Alberta (e.g., McMurray Formation; Wightman and Pemberton, 1997; Musial et al., in press). Future research will place emphasis on comparisons between the Dinosaur Park Formation, the
McMurray Formation, and other similar petroleum producing successions of the western margin of the Cretaceous seaway in North America with inclined heterolithic stratification.

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