3rd-order sequence stratigraphy and lithostratigraphy of the Bearpaw–Horseshoe Canyon transition, Alberta plains

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Summary

The regional-scale delineation and modelling of upper and lower boundaries and zero edges for the Bearpaw Formation tongues in southern and central Alberta forms an important component of a wider AGS project to construct a digital 3D geological framework for the Alberta subsurface. Core and high-quality wireline logs, generated to a large extent by recent coal-bed methane drilling, permit the establishment of a 3rd-order sequence stratigraphic framework. This provides a context within which lithostratigraphic boundaries of the Bearpaw Formation with laterally equivalent and overlying Horseshoe Canyon and St. Mary River formation strata can be more rigorously mapped. Lower boundaries of the Bearpaw tongues are 3rd-order transgressive, or more proximally, maximum flooding surfaces, and upper boundaries are highly diachronous facies contacts within successive regressive systems tracts.

Introduction

The complex nature of the intertonguing relationship between Campanian-Maastrichtian (Upper Cretaceous) Bearpaw Formation marine shale and fluviodeltaic nonmarine and shoreline deposits of the Horseshoe Canyon and St. Mary River formations in central and southern Alberta has long been recognized (e.g. Russell, 1932; Irish, 1970). Following earlier work focused on high-resolution, 4th-order sequence analysis of the stratigraphically limited part of the Bearpaw–Horseshoe Canyon transition exposed along the Red Deer River valley (e.g. Rahmani, 1988; Ainsworth, 1994), the first regional sequence stratigraphic study of the succession was undertaken by Catuneanu et al. (1997). In that study increasing and decreasing trends in wireline gamma-ray response were used to delineate up to 11 3rd-order transgressive-regressive (T-R) sequences within the Bearpaw Formation. However, the subsurface correlations of Catuneanu et al. (1997) could not be replicated by the present author, and the sequence architecture proposed here is substantially different. Hamblin (2004) mapped contacts of informally defined lithostratigraphic tongues of the Horseshoe Canyon Formation with upper, middle and lower Bearpaw Formation marine tongues. In that study T-R cycles were not rigorously defined, although they were discussed and schematically illustrated (Hamblin, 2004, Fig. 80). Subsequently, Eberth and Braman (2012) presented a revised lithostratigraphy for the Horseshoe Canyon Formation, including formal definitions of constituent members. Their stratigraphic scheme, which differs from that of Hamblin (2004) in a number of important respects (notably Hamblin's 'upper Bearpaw tongue' is not recognized), is followed here. Eberth and Braman (2012, p. 1071) noted that their data did not allow them to present detailed sequence stratigraphic models, suggesting that this would likely require extension of their study eastward into marine shale, and this is the essential focus of the work presented here.

Method

Subsurface mapping was carried out using down-hole gamma-ray, resistivity, neutron and sonic logs, together with drillcore where available, and ties to selected outcrop sections with hand-held scintillometer gamma-ray curves (e.g. Hathway et al., 2011). Regionally mappable 3rd-order maximum flooding (MFS) and transgressive (TS =maximum regressive) surfaces were defined on the basis of observed stratal stacking patterns and lapout relationships, rather than the vertical trends in gamma-ray response used by Catuneanu et al. (1997) and others (e.g. Chen et al., 2005). 4th-order flooding surfaces defining clinoforms or parasequence tops within 3rd-order systems tracts have also been mapped at a more local scale.

Example

The sequence stratigraphy and lithostratigraphy of the Bearpaw–Horseshoe Canyon transition are illustrated using the NW-SE stratigraphic cross-section A–A' in the Drumheller area (Figures 1, 2 and 3), with an overall trend perpendicular to the dip (used to refer to depositional dip throughout this abstract) of upper Bearpaw clinoforms. This area has a high well density, with a number of recent, high-quality cores (cored intervals in cross-section A–A' wells are indicated in Figure 2), and lies close to well exposed outcrop sections along the Red Deer River valley.

Lower Bearpaw (LB) tongue strata are assigned to four 3rd-order sequences, here denoted LB sequence A to D from top to bottom (Figs 2 and 3). The base of the Bearpaw Formation closely approximates the MFS (downlap surface) in LB sequence D, and the trangressive systems tract (TST) of this sequence is considered to be developed within the upper part of the underlying Belly River Group (Lethbridge coal zone). Within the overlying LB sequence D regressive systems tract (RST), 4rd-order parasequence-bounding flooding surfaces define SE-dipping clinoforms. The three overlying LB sequences consist mainly of RST intervals similar to that in LB sequence D, and TSTs are thin and generally below the limit of well-log resolution. In cross-section A–A', the best developed TST is at the base of LB sequence B (in the 16-15-028-20W4 core this consists of a 2.5 m thick interval of sandy mudstone to muddy glauconitic sandstone underlying the MFS/downlap surface). Clinoforms in lower Bearpaw RSTs are more gently dipping than those in the upper Bearpaw tongue described below, but in places they can be traced to downlap terminations at the MFS. Upper parts of the RST parasequences generally pass updip into relatively thin intervals of interbedded marine sandstone and mudstone, which are overlain further updip to the NW by paralic to nonmarine carbonaceous mudstone and/or coal. Thicker shoreface sandstone intervals are generally present at the tops of the RSTs. These include relatively sharp-based sandstone intervals in the distal, southeastern parts of LB sequence B (the Finnegan sandstone exposed along the Red Deer River) and LB sequence D, which are detached from more proximal sandstone intervals to the NW and may represent lowstand shoreface deposits, and the Dorothy sandstone at the top of LB sequence A , which marks the maximum regression at the top of the lower Bearpaw tongue, as noted by Eberth and Braman (2012).

Eberth and Braman (2012) defined a stratotype for the boundary between the lower Bearpaw tongue and the overlying Strathmore Member of the Horseshoe Canyon Formation in the cored well CPOG Strathmore 07-12-25-25W4 (Figure 1 shows location). The boundary is placed at the top of a sandier-upward interval of thinly interbedded mudstone and low-angle cross-laminated very fine grained sandstone to silt which gradationally overlies bioturbated marine mudstone, and is overlain by 1.2 m of carbonaceous mudstone, overlain in turn by coal. The boundary is interpreted as a marine (regressive shoreface) to nonmarine (backshore/coastal plain) facies change by Catuneanu et al. (1997, the Bearpaw-Horseshoe Canyon contact at 1645' measured depth in their Fig. 6 log). In cross-section A–A' (Figure 3) this time-transgressive lithostratigraphic contact can be seen to step upsection to the SE from sequence to sequence, and from parasequence to parasequence within the 3rd-order sequences.

Upper Bearpaw (UB) tongue strata in cross-section A–A' are assigned to three 3rd-order sequences, denoted A to C from top to bottom (Figures 2 and 3). In the central part of cross-section A–A', the basal TST of UB sequence C consists of a thick (up to 30 m) backstepping (retrogradational) set of individually progradational parasequences which coarsen up to include upper intervals of bioturbated shoreface sandstone up to 13 m thick (e.g. core 16-15-028-20W4). To the northwest, intervals of carbonaceous mudstone and coal form the upper parts of these parasequences, indicating a transition to coastal plain facies of the upper Strathmore Member. Basinward to the SE, the bounding surfaces of the TST parasequences terminate against the overlying MFS/downlap surface (backlap), and in the southeasternmost well the TST consists of a 5 m thick mudstone interval with an upward-increasing gamma-ray signature. Clinoforms in the overlying UB sequence C RST are significantly steeper than those in the lower Bearpaw RSTs, and shoreface sandstone intervals in the proximal and upper parts of the RST parasequences are generally much thicker. In the southeast part of cross-section A–A', the RST clinoform geometry is well delineated by the anomalously thick Dorothy bentonite (Figure 2), which thickens from ~1.5 m on the topset to 12 m on the clinoform foreset, and thins again as it approaches the underlying downlap surface (bottomset). In the central part of cross-section A–A', log markers in the upper part of the UB sequence C RST are truncated at the base of a sandy interval with an upward-increasing (fining upward) gamma-ray signature, which may represent an incised valley or deltaic distibutary fill (Figure 2). The middle UB sequence B is broadly similar to sequence C, although the basal TST is less well developed. As in the upper part of UB sequence C, log markers in the upper part of the sequence B RST are locally truncated at the base of a fining upward interval in the central part of the cross-section (Figure 2). This represents the erosionally based interval mapped and interpreted as an estuarine channel fill by Rahmani (1988). The uppermost UB sequence A, present in the shallow subsurface at the southeastern end of cross-section A–A', is penetrated by far fewer wells than the underlying sequences, but appears to be similar to UB sequence B.

The lithostratigraphic boundary between the upper Bearpaw tongue and the underlying Strathmore Member is placed at the base of the UB sequence C TST (the transgressive surface) to the southeast (and in the CPOG Strathmore stratotype well), rising through a transitional interval, where it may best be placed at the top of the uppermost coal in the TST, to coincide with the MFS in the northwestern part of cross-section A–A' (Figure 3). The lithostratigraphic boundary between the upper Bearpaw tongue and the overlying Drumheller Member of the Horseshoe Canyon Formation steps up-section to the southeast in a similar manner to that at the top of the lower Bearpaw tongue (Figure 3). However, unlike that boundary it is not placed at the marine-nonmarine facies change, but "at the base of the lowest thick sandstone body that is associated with coal, above the chocolate-brown mudstone of the Bearpaw Formation" (Irish, 1970, p. 134; see also Hamblin, 2004; Eberth and Braman, 2012). The thick basal Drumheller Member sandstone interval thus defined consists of shoreface and/or estuarine channel deposits (e.g. Ainsworth, 1994), and the marine-nonmarine facies change lies within, or at the top of that interval. As the basal boundaries of the Strathmore and Drumheller members step up-section, a number of nonmarine 'tongues' which lie basinward of lithostratigraphic vertical cutoffs, including the 'Dorothy tongue' of Eberth and Braman (2012) at the top of UB sequence C and an interval at the top of LB sequence C, are necessarily included within the lithostratigraphic Bearpaw Formation.

Conclusions

Data from downhole wireline logs, core and outcrop sections are used to establish a 3rd-order sequence stratigraphic framework for the offshore to fluviodeltaic Bearpaw–Horseshoe Canyon transition in southern and central Alberta. This provides a context for the more rigorous mapping of the complex, diachronous lithostratigraphic boundaries between the two units. In the Drumheller area, lower Bearpaw tongue and laterally equivalent Horseshoe Canyon formation strata are assigned to four 3rd-order sequences, typically with thin TSTs, and RSTs dominated by low-angle clinothems. Upper Bearpaw tongue strata are assigned to three 3rd-order sequences. The lower two of these have thicker TSTs, consisting of backstepping progradational parasequences in the nearshore area, and RSTs are proximally more sand-rich and show a steeper clinoform geometry.

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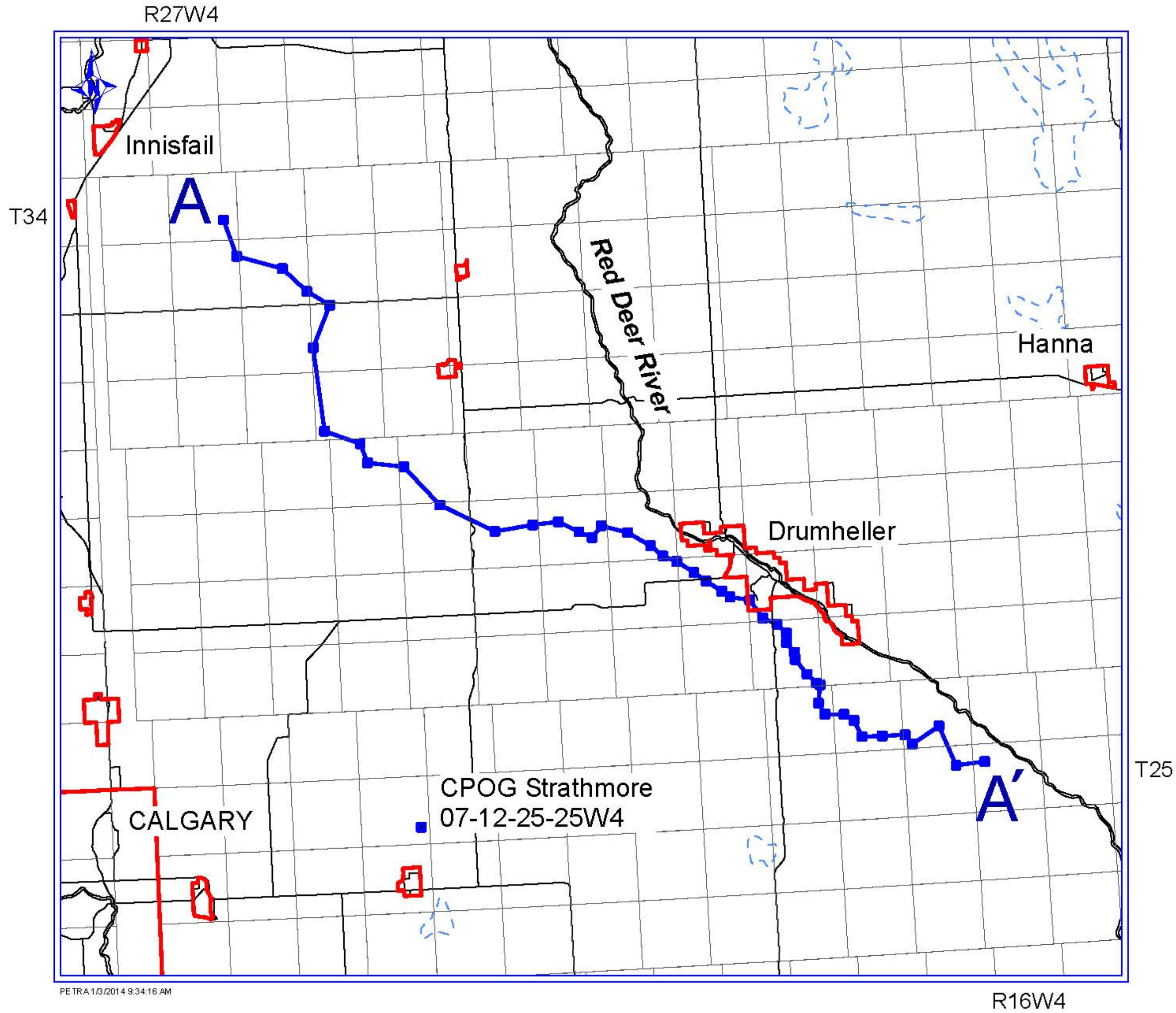
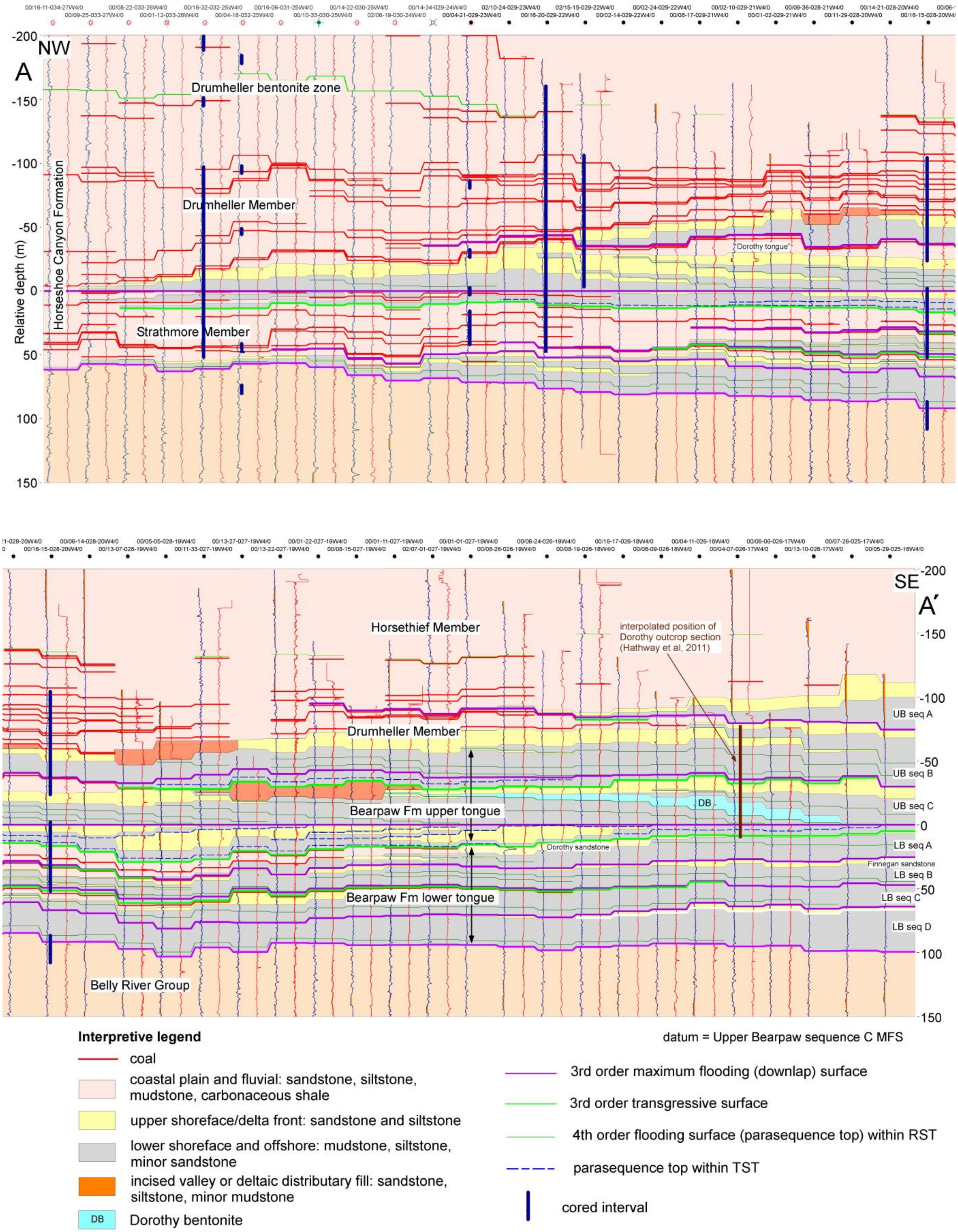


Figure 1 (above). Location map for cross-section A–A'. Straight-line distance from A to A' is 133 km.

Figure 2 (below). Stratigraphic cross-section A–A' (shown split into two panels) with interpretive legend. Datum is the maximum flooding (downlap) surface in upper Bearpaw sequence C. Wireline logs shown are gamma-ray (in blue) and resistivity (in red).


NW
A
Drumheller bentonite zone
Drumheller Member
Horseshoe Canyon Formation
Relative depth (m)
Strathmore Member
"Dorothy tongue"
SE
A′
Horsethief Member
interpolated position of Dorothy outcrop section (Hathway et al, 2011)
Drumheller Member
Bearpaw Fm upper tongue
DB
Dorothy sandstone
Bearpaw Fm lower tongue
Belly River Group
UB seq A
UB seq B
UB seq C
LB seq A
Finnegan sandstone
LB seq B
LB seq C
LB seq D
-200
-150
-100
-50
0
50
100
150
Interpretive legend
coal
coastal plain and fluvial: sandstone, siltstone, mudstone, carbonaceous shale
upper shoreface/delta front: sandstone and siltstone
lower shoreface and offshore: mudstone, siltstone, minor sandstone
incised valley or deltaic distributary fill: sandstone, siltstone, minor mudstone
DB
Dorothy bentonite
datum = Upper Bearpaw sequence C MFS
3rd order maximum flooding (downlap) surface
3rd order transgressive surface
4th order flooding surface (parasequence top) within RST
parasequence top within TST
cored interval

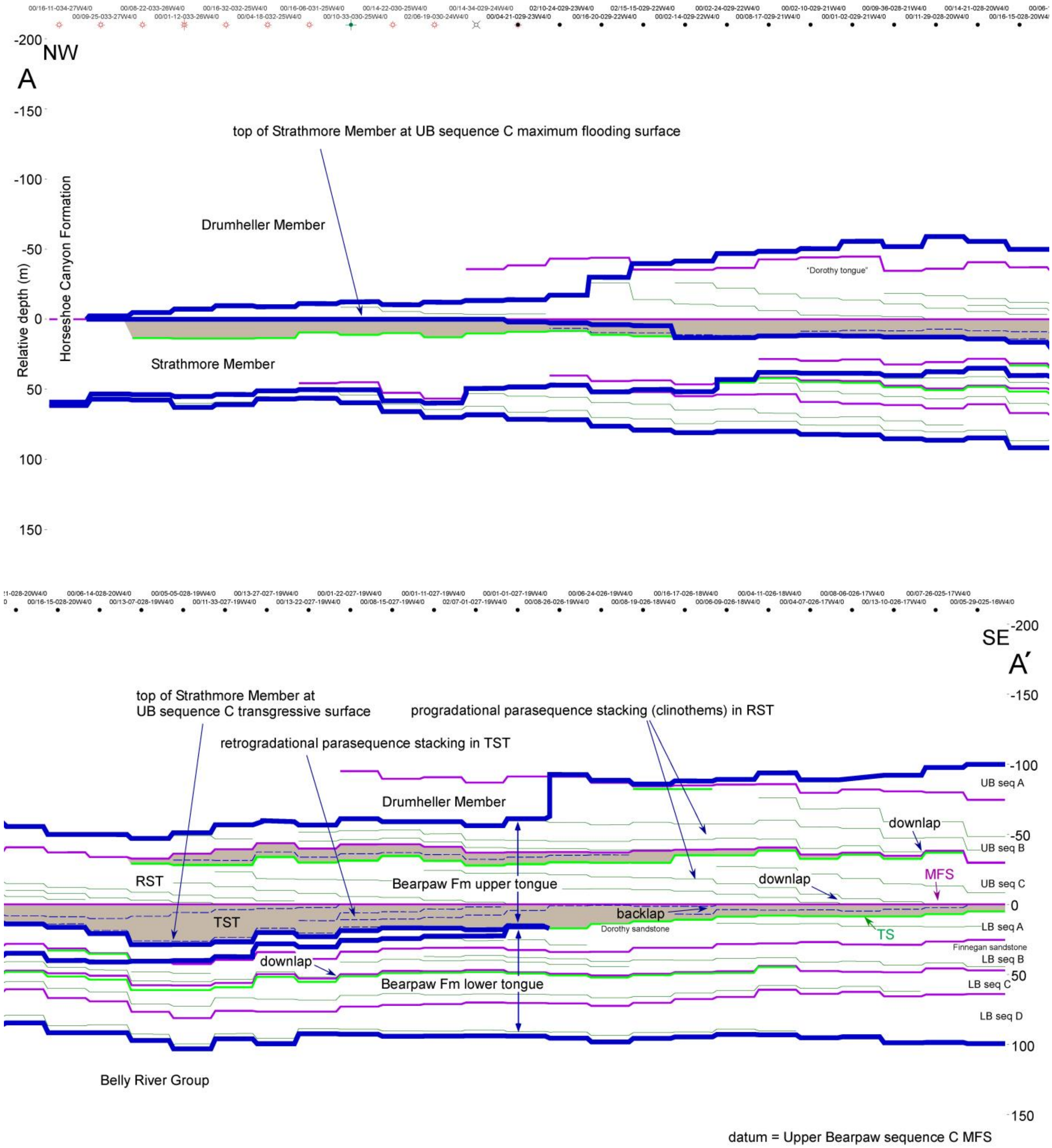


Figure 3. Stratigraphic cross-section A–A' with sequence stratigraphic surfaces shown, but interpreted lithofacies and wireline logs shown in Figure 2 omitted for clarity. Bold blue lines mark lithostratigraphic boundaries of the Bearpaw Formation. The UB sequence B and C transgressive systems tracts (TSTs) are shaded in grey.