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Stratigraphic response to sedimentation in a net-accommodation-limited setting, Lower Cretaceous Basal Quartz, south-central Alberta

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ABSTRACT

Based on differences in mineralogy, paleovalley morphology, hydrocarbon production history and crosscutting stratigraphic relationships, the subsurface Basal Quartz in the study area is interpreted to comprise four paleovalley fills consisting of braided-fluvial strata overlain abruptly by meandering fluvial strata. Significantly these strata accumulated in an accommodation-limited part of the basin where **net** sedimentation rate was only about 1 m/m.y. Accordingly, stratal characteristics contrast markedly with those in more extensively studied nonmarine successions that accumulated in high net-accommodation basins, and include (1) each unconformity bounded sequence is significantly thinner, (2) the upward change from braided-fluvial to meandering-fluvial or tidal strata occurs abruptly, and (3) a general lack of fine-grained floodplain mudstone, which improves significantly the lateral connectivity of reservoir sandstones. A long-term effect of limited net accommodation, and the consequent slow aggradation of the sedimentary pile, is the repeated cannibalization of older valley-fill deposits by younger paleovalleys. This creates a stratigraphy consisting of laterally and vertically consistent stratal assemblage dominated by a single, typically the youngest, paleovalley fill. In places, however, parts of older paleovalley fills are preserved as localized remnants surrounded on most sides by younger strata. On a local scale, this results in the development of a significantly more complicated stratigraphy marked by rapid lithological changes, and similarly reservoir quality, even over short horizontal distances. On a more regional scale, the complex crosscutting of different-aged paleovalley fills, in addition to the tendency for each paleovalley to incise from a similar stratigraphic level, makes stratigraphic correlation difficult. Together, these characteristics can have significant stratigraphic and economic ramifications.

RÉSUMÉ

En se basant sur des différences dans la minéralogie, la morphologie de paléo-vallée, l'histoire de production des hydrocarbures et les relations de recoupement stratigraphiques, le Quartz de Base de la région d'étude est interprété comme comprenant quatre remplissages de paléo-vallée, consistant en des strates d'environnement fluvial-anastomosé, recouvertes abruptement par des strates fluviales à méandres. Significativement, ces strates se sont accumulées dans une partie à espace d'accommodement limitée du bassin ou le taux de sédimentation net n'avait seulement qu'environ 1 m/ma. En conséquence, les caractéristiques des strates contrastent de façon marquée avec celles de successions non-marines étudiées de façon plus étendue qui se sont accumulées dans les bassins à accommodement net élevé, et incluent (1) chaque séquence limitée par une discordance est significativement plus mince, (2) le changement vers le haut de strates fluviales anastomosées à fluviales à méandre ou de marée se présentent abruptement, et (3) un manque général de mudstone à grain fin de plaine d'inondation, qui améliore significativement la connectivité latérale des grès de réservoir. L'effet à long terme de cet accommodement net limité, et de la conséquente aggradation lente de la pile sédimentaire, est une cannibalisation répétée des dépôts de remplissage de vallée plus anciens par des paléo-vallées plus jeunes. Ceci crée une stratigraphie qui consiste en des assemblages de strates latéralement et verticalement uniformes, dominés par un seul remplissage de paléo-vallée, typiquement le plus jeune. En certains endroits toutefois, des parties des paléo-vallées plus vieilles sont préservées comme des restants localisés qui sont entourés sur la plupart de leurs faces par des strates plus jeunes. À une échelle locale, ceci donne pour résultat le développement d'une stratigraphie plus compliquée marquée par des changements lithologiques rapides, et à une qualité de réservoir similaire, même sur de courtes distances horizontales. À une échelle plus régionale, le recoupement complexe de remplissages de paléo-vallées de différents âges, en plus de la tendance de chaque paléo-vallée à inciser à partir d'un niveau stratigraphique similaire, rend les corrélations stratigraphiques difficiles. Ensemble, ces caractéristiques peuvent avoir des ramifications stratigraphiques et économiques importantes.

Traduit par Lynn Gagnon

Introduction

As noted by many early workers, fluvial systems are highly complex and dynamic systems that respond on all time scales to the myriad of variables that control them (cf. Gilbert, 1877; Mackin, 1948; Lane, 1955; Schumm, 1977, 1981, 1993; Andrews, 1979; Leopold and Bull, 1979). Work during the past decade has significantly improved our understanding of these systems, and in particular how adjustments to fluvial systems are manifested in the stratigraphic record. Of particular note is the understanding of the fundamental relationship between changes of relative sea level, controlling fluvial base level, and fluvial architecture (e.g. Blakeney et al., 1990; Krystinik and Blakeney, 1990; Gibling, 1991; Shanley and McCabe, 1991; Törnqvist, 1993; Myøs and Prestholm, 1994; Zaitlin et al., 1994; Olsen et al., 1995; Burns et al., 1997; Martinsen et al., 1999). Other workers, however, have shown that changes in climate, and related changes in sediment and fluid supply, can elicit similar changes in fluival sedimentation and erosion patterns, and hence the makeup of the stratigraphic column (e.g. Schumm, 1981; Hall, 1990; Saucier, 1981; Autin et al., 1991; Blum, 1994; Blum et al., 1994). At present, differentiating the stratigraphy of fluvial systems controlled by climate versus changes in relative sea level is problematical. In addition, most ancient fluvial stratigraphic models are based on observations of successions that accumulated in high net-accommodation settings (i.e. sedimentary basins where long-term accommodation is high). Stratal discontinuities in these strata are widely separated and generally easily identified. However these models may not be representative of net-accommodation-limited settings where rates of stratal aggradation, although potentially similar during the short term, differ significantly over the long term, and stratal discontinuties are narrowly spaced or, in many places, merged into a single surface. Furthermore, because the stratigraphy of low net-accommodation settings is far less affected by long-term changes of relative sea level, does the stratigraphic column resemble that in the better known high net-accommodation basins, or are there important differences? The aim of this paper is to address these questions as we interpret the temporal and spatial patterns of deposition of the Upper Jurassic to Lower Cretaceous Basal Quartz in southern Alberta (Fig. 1) — a mostly nonmarine siliciclastic succession that accumulated in a severely net-accommodation-limited part of the Western Canada Sedimentary Basin.

Regional Geology

In the Western Canada Sedimentary Basin (WCSB) strata of the Mannville Group overlie the regional sub-Cretaceous unconformity and in turn are unconformably overlain by shale of the Colorado Group, which in this part of the WCSB comprises the Joli Fou Shale (Leckie et al., 1997; Leckie and Smith, 1992) (Fig. 2). In general, the Mannville Group has been subdivided into two units: the lower and upper Mannville successions (Fig. 2). The lower Mannville occurs between the sub-Cretaceous unconformity and the post-Ostracode to pre-Glauconite unconformity, and ranges in age from Tithonian (about 148 Ma) to latest Aptian (113 Ma). The upper Mannville succession overlies the lower Manville and is capped unconformably by the Colorado Group (Middle Albian). Compared to the approximately 18–32 m.y. represented by the lower Mannville (Leckie et al., 1996; Leckie et al., 1997), the upper Mannville represents only about 10 m.y. of geological time.

In southern Alberta, the lower Mannville succession comprises the Basal Quartz (also referred to as BQ) and the overlying Ostracode Formation. Basal Quartz is a purely descriptive lithological term used for the predominantly quartzose sandstones that occur near the base of the lower Mannville Group (Glass, 1990). Recent work, for example Zaitlin et al. (1999), Zaitlin et al. (this issue), has shown the Basal Quartz to consist of a highly complex stratigraphy that in large part is made up of various-aged incised valley fills and generally thickens to the north and northwest of the study area. Following from this work, and the stratigraphic nomenclature developed in an earlier paper (Arnott et al., 2000), the Basal Quartz in the study area has been subdivided into four informal stratal units, but for simplicity has been reduced to three units in this paper: "weathered" sandstone, "Horsefly" sandstone, and "BAT" sandstone (Figs. 2, 4).

Study Area and Data Base

The study area is in south-central Alberta and generally is bounded north–south by Townships 6–9 and east–west by Ranges 13–17 west of the fourth meridian (Fig. 1). This approximately 550 km^2 area was part of an expansive subsurface regional study by PanCanadian Petroleum in 1998 that encompassed an area of approximately 147,500 km^2 in southern Alberta. The study area is located on the northwestern limb of the northeast–southwest-trending Sweetgrass Arch, and, as a consequence, strata dip consistently toward the northwest. Within the study area six pools currently produce from strata of the BQ (Fig. 1). The principal BQ pools are Horsefly, Chin Coulee and Mannville A pools. A detailed description and interpretation of geological controls on reservoir distribution can be found in Arnott et al. (2000).

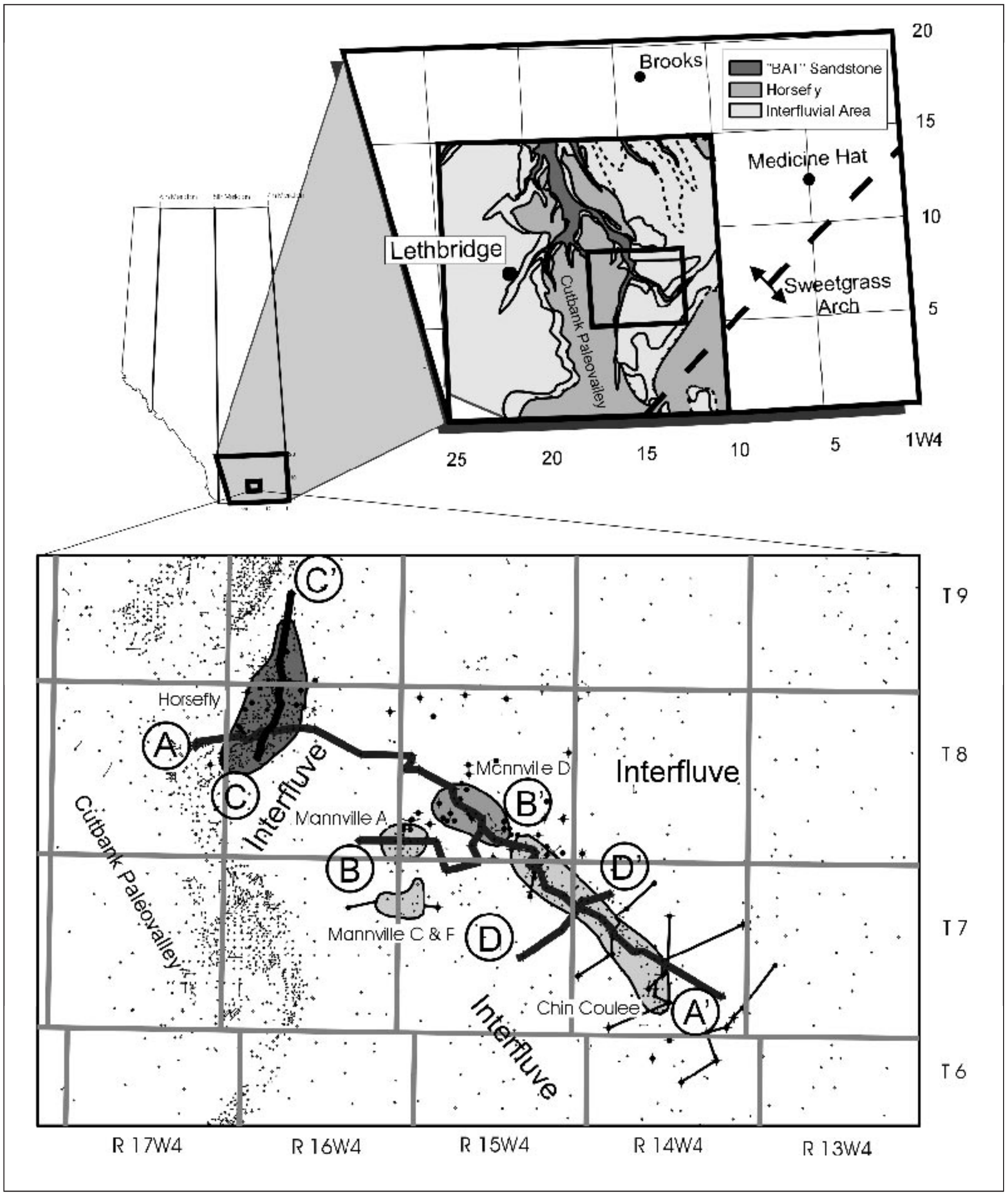

Fig. 1. Location map of the study area in south-central Alberta. On all maps, each square represents an area of 36 square miles (92 km^2). Names and general outlines of each of the pools discussed in the text are shown. In addition, stratigraphic cross-sections constructed in this study are shown, those that are labelled (e.g. A–A′) are presented in Figure 5A–D. Wells designated with large grey dots represent data points for this study, which in some cases represent wells that were not included on the stratigraphic cross-sections. Shown in the upper right panel is the general outline of the north-trending Cutbank Paleovalley, several tens of kilometres wide. The study area is along the eastern margin of the paleovalley.

Data for the study included detailed description of 52 cores, petrographic analysis of 75 thin sections, and the construction of 16 wireline log cross-sections comprising 157 wells (Fig. 1). Logs were correlated using the base of the few-metre-thick Bantry/Ostracode unit as the stratigraphic datum, which in this area immediately overlies the BQ succession (see discussion in Arnott et al., 2000).

Six unique lithofacies were identified based on sediment grain size, vertical changes in grain size, and type and abundance of physical sedimentary structures (Table 1; Fig. 3A–F; see also discussion in Arnott et al. 2000). All lithofacies, except Lithofacies 7, indicate deposition under fully nonmarine conditions. Only Lithofacies 7, which occurs in the youngest paleovalley fill, contains physical and biogenic evidence suggestive of marine-influenced sedimentation.

Valley-Fill Characteristics and Stratal Architecture

Based on sedimentological, mineralogical, and production characteristics, strata of the Basal Quartz succession in the study area have been subdivided into three distinct units — weathered

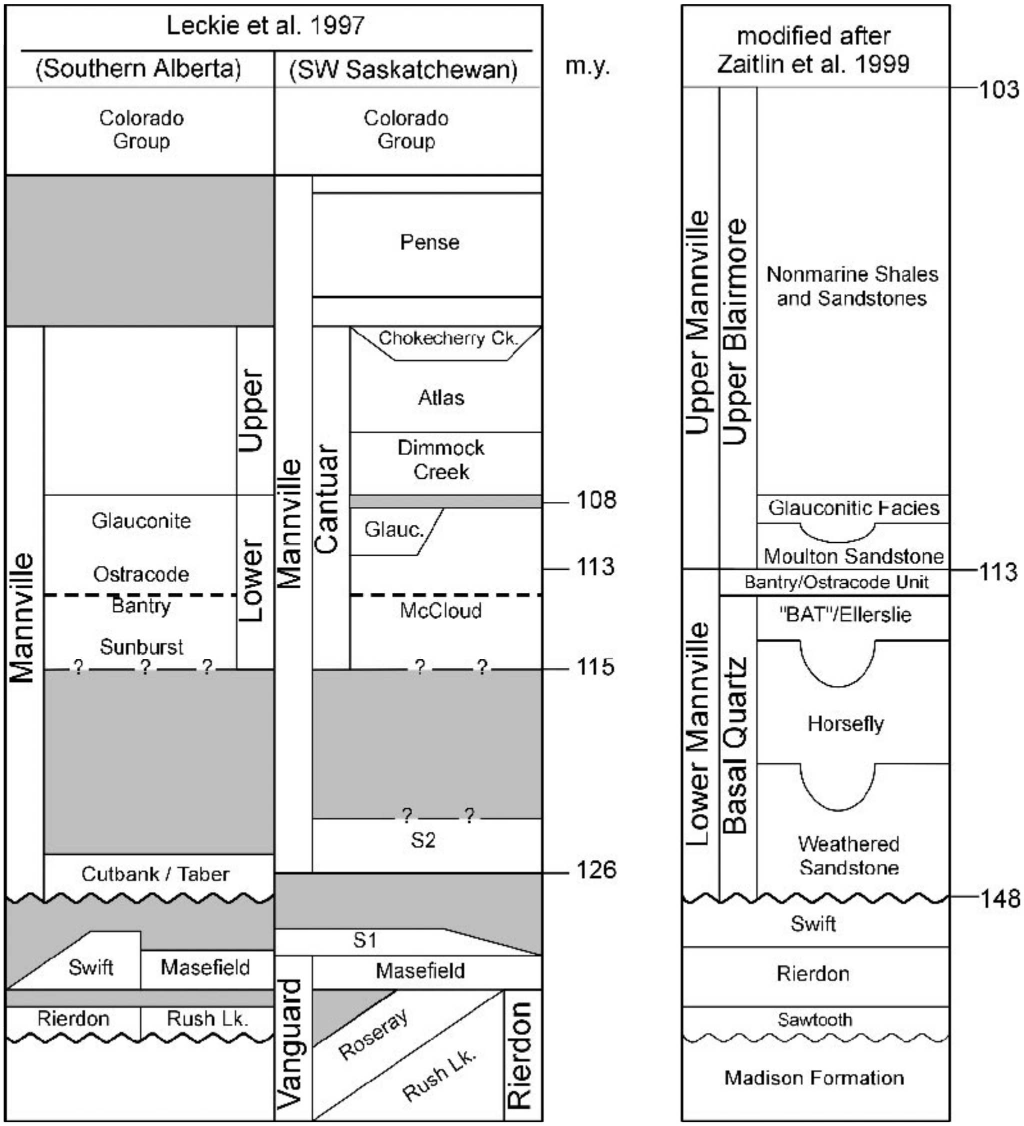

Fig. 2. Stratigraphic framework of Lower Cretaceous strata in southern Alberta based on the recent work of Zaitlin et al. (1999) and Leckie et al. (1997).

sandstone, Horsefly sandstone, and BAT sandstone (see discussion in Arnott et al., 2000; Fig. 4). Furthermore, based on stratigraphic correlation, these units are interpreted to form four successively-younger incised-valley and valley-fill successions (Figs. 4, 5), which notably incise from a similar stratigraphic level (Fig. 5A–D). In the study area, valleys were eroded into Rierdon Shale or previously deposited Basal Quartz sediment, and in most cases were filled subsequently with nonmarine deposits (Fig. 5A–D). Only strata in Mannville A Pool show evidence of marine-influenced sedimentation (Lithofacies 7).

Crosscutting channel relationships and also the degree of pedogenic alteration indicate that the oldest BQ strata in the study area consist of Lithofacies 2, termed the weathered sandstone (Fig. 5A, B); this succession comprises the A sandstone and weathered Horsefly sandstone of Arnott et al. (2000). Recent work by Zaitlin et al. (this issue) suggest that these strata form part of a complex, areally extensive alluvial succession that, because of prolonged subaerial exposure and attendant pedogenic alteration, are generally considered as non-reservoir. Younger successions in the study area include the Horsefly sandstone and younger BAT sandstone, which respectively makeup the Horsefly Pool, and Chin Coulee and Mannville A pools. Regional mapping by Lukie (1999) and Zaitlin et al. (this issue) suggest that the Horsefly sandstone forms a laterally and longitudinally extensive stratal unit within the several tens of kilometre-wide, northward-trending Cutbank trunk paleovalley. In contrast, the BAT sandstone in this study area, and also elsewhere in southern Alberta (Ardies, 1999), forms the fill of significantly narrower paleovalleys — Chin Coulee and Mannville A pools occur in paleovalleys that are 2 and 7 km wide, respectively.

Although of different stratigraphic age, the three youngest valley fills, represented by Horsefly, Chin Coulee and Mannville A pools, show a generally similar vertical stratal

Table 1. List of lithofacies, their distinguishing characteristics and depositional interpretation. See Arnott et al. (2000) for more detailed description of lithofacies. Present/absent indicates that the characteristic is or is not present, which, as outlined in the text, depends on the sandstone unit present (e.g.Horsefly sandstone, BAT sandstone etc.).

Lithofacies	Lithofacies Description	Trace Fossils	Depositional Environment	Evidence of Pedogenesis	Carbonaceous material
1	poorly bedded matrix- and clast-supported conglomerate with interbedded sandstone	absent	regolith	present	present/absent
2	massive sandstone, siltstone, mudstone	absent	weathered alluvial strata	extensive	absent
3	medium-scale cross-stratified sandstone	absent	braided fluvial	absent	present/absent
4	Fining-upward succession; medium- to small-scale cross-stratified sandstone to massive silt-/mudstone	absent	meandering fluvial	absent	present/absent
5	planar and small- to medium-scale, low-angle cross-stratification	absent	lacustrine	absent	absent
6	interstratified siltstone/sandstone fining upward to mudstone	uncommon *Planolites*	floodplain	present/absent	absent
7	medium-scale cross-stratified sandstone fining upward to interstratified sandstone/mudstone	low to moderate bioturbation: *Planolites, Arenicolites, Skolithos*	tidal channels and tidal-flat strata	absent	present

succession (Figs. 5, 6A, B). Sandstone-dominated braided-fluvial deposits form a sheetlike deposit, several metres thick, in the lower part of the paleovalley fill. Except in Mannville A pool, braided-fluvial strata are overlain abruptly by meandering-fluvial deposits, which in most places consists of a single channel-fill succession. In core, the base of the meandering succession is marked by abundant mudstone/siltstone intraclasts and also an abrupt increase in grain size (up to very coarse sandstone with dispersed coarser clasts). Typically the contact shows little relief, but locally, for example in the Chin Coulee Pool, meandering-fluvial channels have incised deeply into the underlying braided-fluvial succession (Fig. 5A, D), and, as a result, significantly thinned the primary reservoir unit. Planar-tabular and trough cross-stratified sets are common in the meandering-fluvial succession but planar-tabular sets predominate in the underlying braided-fluvial succession. Also, like the underlying braided-fluvial succession, meandering-fluvial strata are laterally extensive in the valley fill, and, therefore, have good lateral connectivity (good channel body continuity).

In Mannville A Pool the vertical succession of lithofacies is somewhat different. Here, braided-fluvial strata are overlain by a siltstone/mudstone floodplain succession, several metres thick. Because of the small size of the study area, plus poor local well control, the origin of this unit is equivocal. One possibility is that the floodplain deposits aggraded locally following a major avulsion of the braided-fluvial system (e.g. Burns et al., 1997). Nevertheless, sharply overlying this floodplain succession is a succession of Lithofacies 7 strata, several metres thick (Figs. 5B, 6B). In contrast to all other Basal Quartz strata in the study area, these strata are in places moderately bioturbated and display tidal sedimentary structures. These features are interpreted to represent the first direct sedimentological evidence for marine influence during Basal Quartz sedimentation in the study area. Moreover, this observation is consistent with the long-term, regional rise of relative sea level that occurred during much of Basal Quartz time (Cant and Abrahamson, 1996) and suggests that the Mannville A Pool occurs in the youngest Basal Quartz valley within the study area. Transgression eventually flooded the study area and deposited strata of the Bantry Shale/Ostracode unit.

Sequence Stratigraphic Framework and Depositional Controls

Although of different age, the stratal architecture of Horsefly, Chin Coulee and Mannville A pools are similar, particularly Horsefly and Chin Coulee. Previous workers have observed a similar upward change from braided- to meandering-fluvial deposits, and have attributed this consistent vertical stratal assemblage to changes in relative sea level and associated accommodation space (Fisk, 1944; Blakeney et al., 1990; Krystinik and Blakeney, 1990; Gibling, 1991; Törnqvist, 1993; Myøs and Prestholm, 1994; Shanley and McCabe, 1991, 1994; Zaitlin et al., 1994; Olsen et al., 1995; Burns et al., 1996; Martinsen et al., 1999). In this study, however, net-accommodation space in this part of the Basal Quartz sedimentary basin was most probably always limited and changed little on both short or long time scales (see below). Accordingly, unlike many other

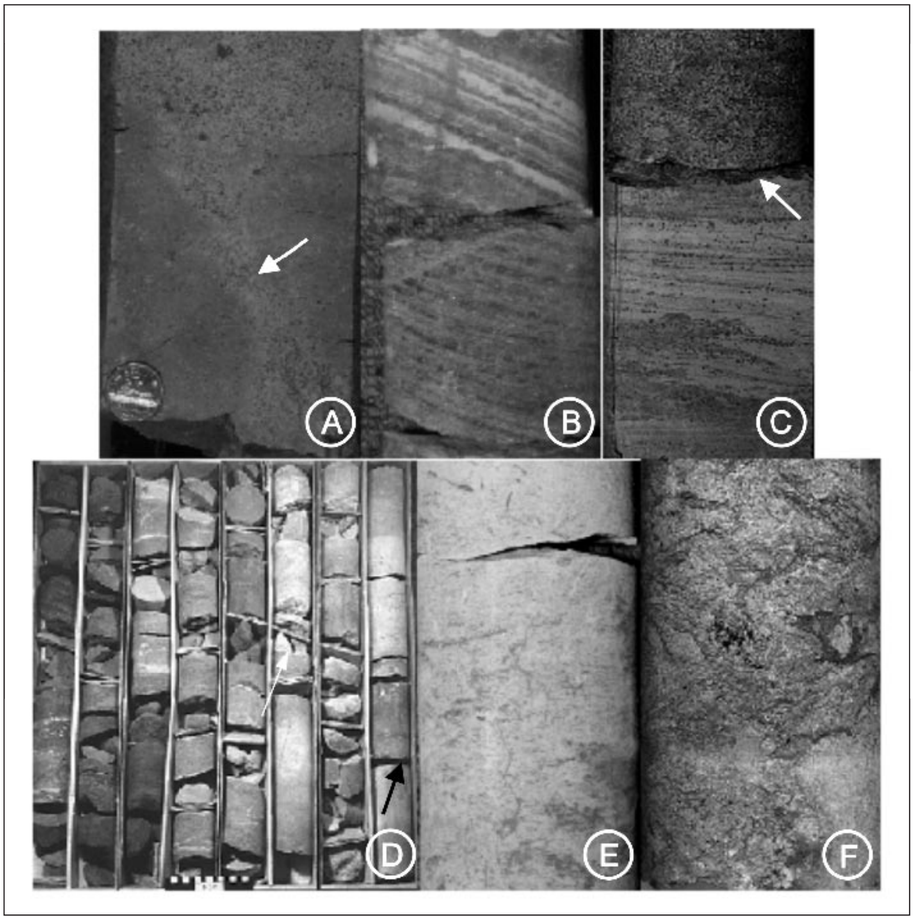

Fig. 3. Basal Quartz lithofacies; all cores are 10 cm wide. (**A**) pedoturbated strata of Facies 2. Note sandstone-filled root trace (arrow) crosscutting silty mudstones (well location: 8-17-8-15W4); (**B**) planar-tabular (2D dune) cross-stratified sandstone of Facies 3 — principal reservoir strata in the study area (well location: 3-5-9-16W4); (**C**) abrupt contact (arrow) between well sorted fine-grained, wave-ripple cross-stratified sandstone (Facies 5: floodplain lacustrine deposits) and upper-medium, meandering-fluvial sandstone (Facies 4) (well location: 3-5-9-16W4); (**D**) stacked fining-upward meandering-fluvial deposits (base of upper channel fill indicated by the white arrow). The upper black arrow indicates the abrupt contact between sandstone and silty mudstone interpreted to be the result of channel abandonment (well location: 10-35-7-15W4); (**E**) rooted siltstone (floodplain strata) of Facies 6 (well location: 10-35-7-15W4); (**F**) marine-influenced, moderately bioturbated sandstone of Facies 7 (well location: 11-19-8-15W4).

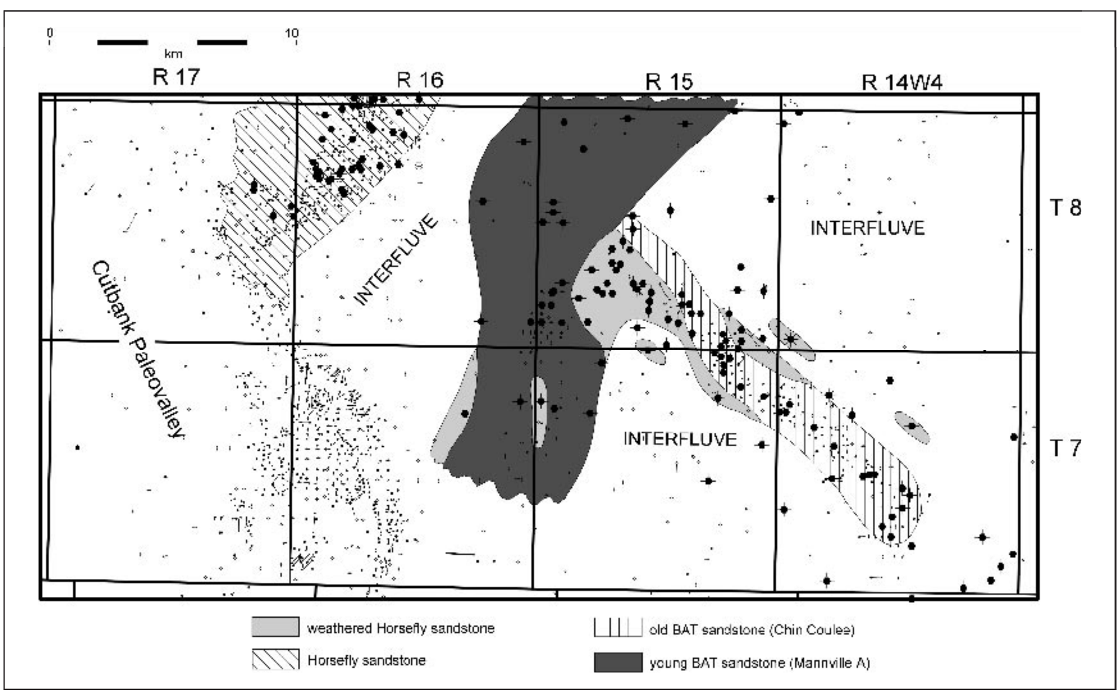

Fig. 4. Map of differentiated Basal Quartz strata, showing that, within the study area, the Basal Quartz succession consists of parts of four incised valley fills that are bounded on most sides by Rierdon Shale (interfluve).

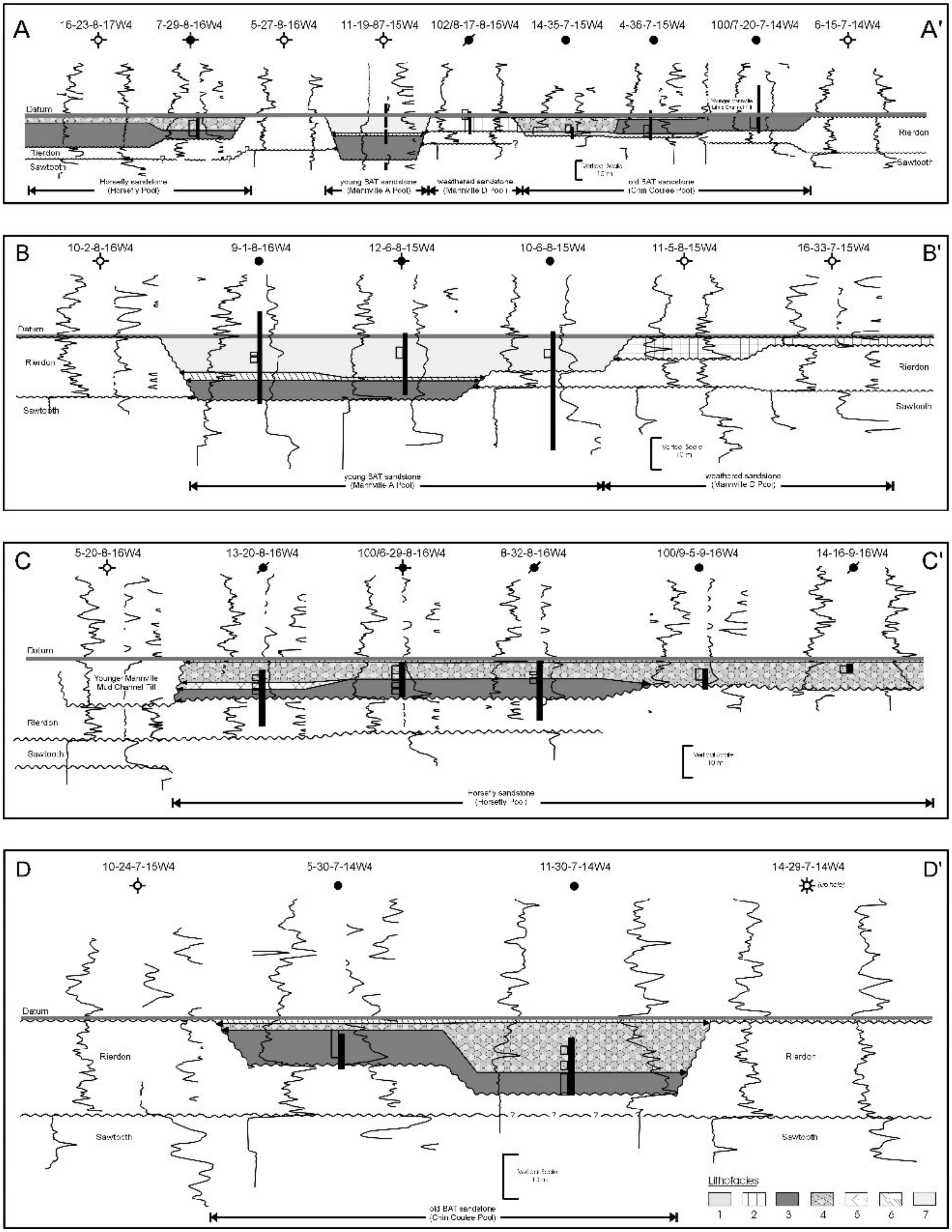

Fig. 5. (A–D) Stratigraphic cross-sections using gamma-ray and resistivity geophysical logs (in each well the left- and right-hand trace, respectively). Patterned infills indicate different lithofacies (see legend); lithofacies are discussed in text and presented in Table 1. The stratigraphic datum is the Bantry/Ostracode unit, which, in the study area, marks the top of the Basal Quartz succession. Black vertical bars indicate cored intervals; open bars indicate perforated zones. See Figure 1 for location of wells and lines of cross-section. Although the Basal Quartz consists of multiple incised valley fills, there is a consistent lithofacies-stacking pattern in most valley fills (see text for details). See Table 1 for lithofacies descriptions and interpretations.

earlier stratigraphic models (e.g. Olsen et al., 1995), upward changes in fluvial style are probably unrelated to changes of accommodation space or fluvial gradients related to tectonism, but instead to temporal changes in sediment supply. On a regional scale changes in sediment supply can be attributed to two forcing mechanisms: tectonism or climatic changes (glaciation is a third possible mechanism, but most workers believe it had a negligible effect on Cretaceous stratigraphy). In this study, like most others, deciphering the forcing mechanism that caused sediment supply to vary is problematical. In foreland basins, like the basin in which the Basal Quartz was deposited, episodes of tectonic uplift result in isostatic subsidence in the upland area, which in turn causes coarse detritus to be trapped in proximal alluvial fan environments (Heller et al., 1988; Heller and Paola, 1996; Burns et al., 1997), and starves downdip sedimentary systems of coarse bed-load sediment. During intervening periods of tectonic quiescence, however, these coarse-grained deposits are uplifted, eroded and transported basinward (Heller et al., 1988; Heller and Paola, 1996; Burns et al., 1997). Such temporal changes in the makeup of the sediment load would significantly, but also consistently, affect the nature of the stratigraphic column. Nevertheless, similar changes also can be the result of climate change causing variations in sediment flux and also fluid discharge (Hall, 1990; Saucier, 1981; Autin et al., 1991; Blum, 1994; Blum et al., 1994). Episodes of net alluvial sedimentation, or conversely channel erosion, are controlled by changes in sediment flux and available stream power, which in turn are controlled by a complex assemblage of geological, climatic, and antecedent conditions (Schumm, 1977; 1985). However as pointed out by Blum (1994) and Blum et al. (1994), the response of drainage basins and their constituent fluvial systems to climate change may be highly variable, not only in adjacent, coeval systems, but also in different reaches of the same system, and even for the same climate change. Intuitively, therefore, the consistent stratigraphic architecture within, and also between each of the different valley fills, even though each paleovalley fill was deposited over a significant length of geological time and also differ significantly in age (possibly by as much as millions of years), suggests that tectonism is a more tenable forcing mechanism.

In this scenario, coincident with a major tectonic uplift event, was a regional rejuvenation of the drainage basins within the regional Basal Quartz drainage system. Fluvial channels, starved of bed-load sediment trapped in upland areas, actively eroded and lowered their bases (Fig. 7A). Additionally, if the study area were an appropriate distance from the orogen, erosion would have been augmented by uplift of the flexure-related peripheral bulge (e.g. Quinlan and Beaumont, 1984; Cant and Stockmal, 1989; Stockmal et al., 1992). Subsequent erosion in the orogen, and accordingly isostatic uplift in the upland areas, caused a significant increase in sediment flux, particularly the bed-load fraction, down dip. Fluvial systems now overwhelmed with coarse sediment favoured the development of braided-fluvial systems (e.g. Cant, 1982). These systems deposited the (reservoir) sheet sandstones at the base of each paleovalley fill, which consist of highly interconnected, bed-load-dominated channel deposits with only minor preserved overbank mudstone (Fig. 7B). The paucity of preserved fine-grained sediment improves significantly the reservoir quality and vertical continuity in these strata. With time, sediment calibre and probably also sediment flux decreased. A fining and reduction of the sediment load would have enhanced channel-bank stability, and accordingly inhibited lateral channel migration and promoted the development of meandering-fluvial channels (e.g. Schumm, 1981) (Fig. 7B). Also if sediment flux remained reasonably high (but not necessarily), higher sedimentation rates in channels compared to laterally adjacent floodplains would have caused frequent channel avulsions (Bryant et al., 1995). Because the fluvial channels in this study were confined within a wider incised valley complex, exacerbating the limitation of accommodation (see below), newly formed channels migrated only locally and eroded deeply into previously deposited, fine-grained floodplain and, in places, channel deposits. Over the long term this resulted in the merging together of the lower, coarser-grained part of meandering-fluvial channel fills, forming a more sheetlike deposit, and the preferential removal of fine-grained floodplain deposits. Thick floodplain deposits are preserved mostly at the top of the youngest meandering-channel fills (i.e. those not eroded by younger channels).

At the same time, but in more distal areas closer to the paleoshoreline and influenced by marine processes, tidal channel and tidal flat deposits (Mannville A succession) would have stacked upward. Although generally similar, the Mannville A succession differs only because of its more basinward paleogeographic position, which can be accounted for by the long term transgression. In the study area, although transgression signficantly changed the characteristics of sedimentation, it had negligible effect on accommodation space, and accordingly stratal architecture.

Related also to the long term transgression is the marked difference in valley morphology between the weathered sandstone and Horsefly sandstone (Horsefly Pool), and the BAT sandstones (Chin Coulee and Mannville A pools). Along a fluvial profile, the greatest amount of incision typically occurs near the distal end of the system (Begin et al., 1981; Arnott, 1992; Shanley and McCabe, 1994; Olsen et al., 1995; Burns et al., 1997). Headward-migrating knickpoints incise valleys that generally shallow and widen upstream as the integrity of the knickpoint is progressively lost (if no other local knickpoints were encountered) (Shepherd and Schumm, 1974; Arnott, 1992). Given sufficient time and/or low topographical gradient, headward-migrating incision may extend a significant distance up the fluvial system, although the length of the affected reach is presently the source of much debate. The wide, relatively flat-based paleovalleys of the weathered and Horsefly sandstones may have formed well landward of the fluvial reach affected by downdip knickpoint erosion. Also, the long term tendency of fluvial channels to adjust by migrating laterally, rather than incising vertically (Yoxall, 1969), suggests that the wider weathered and Horsefly paleovalleys may also represent a longer period of time compared to the younger BAT paleovalleys. More significantly, however, the narrow paleovalleys that contain Chin Coulee and Mannville A pools were most likely located in a more basinward position, and therefore directly affected by downdip knickpoint erosion.

Consequences of Low Net-Accommodation on Fluvial Stratigraphy

In general the stratigraphic record and its internal characteristics reflect the interaction of sediment supply and accommodation space. In the case of nonmarine stratigraphy, most published stratigraphic models are based on observations of ancient stratal successions from high net-accommodation settings (cf. Gibling, 1991; Myøs and Presholm, 1994; Shanley and McCabe, 1994; Olsen et al., 1995; Burns et al., 1997). In this study, however, the mostly nonmarine Basal Quartz succession is about 20–25 m thick (compared with several tens of metres thick to the north and northwest of the study area), but represents approximately 18–32 m.y. of geological time (Leckie et al., 1996; 1997). This indicates that within the study area the **net** sedimentation rate was extremely low, only of the order of about 1 m/m.y. (although it is well understood that actual local sedimentation rates were temporally significantly higher). This indicates that strata in this study accumulated in a severely net-accommodation-limited

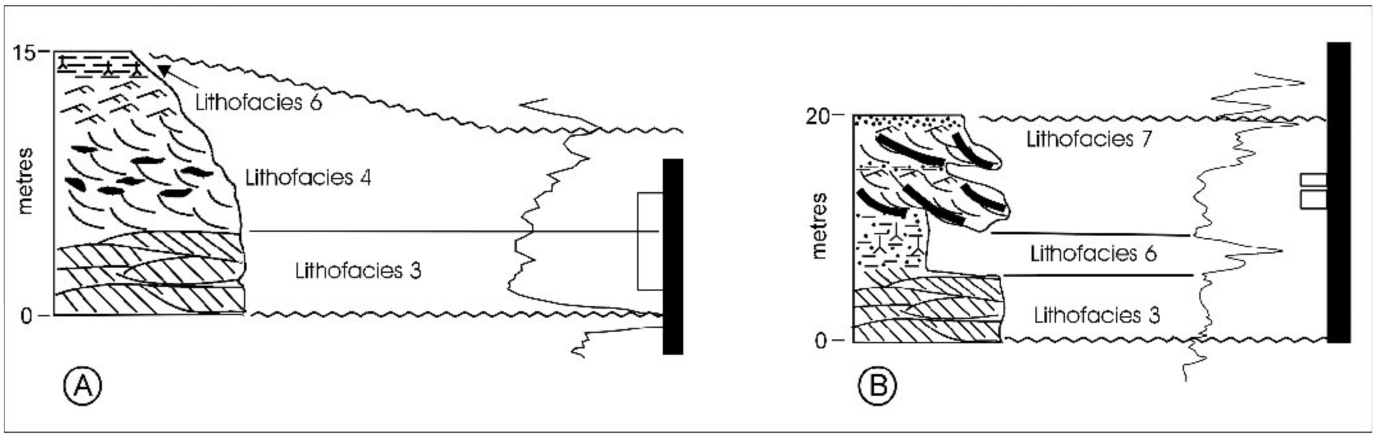

Fig. 6. Schematic line diagram with representative gamma-ray geophysical well log (vertical black bars indicate cored interval; open bars indicate perforated hydrocarbon producing interval). (**A**) braided-fluvial strata (Lithofacies 3) overlain abruptly by a meandering-fluvial succession consisting of Lithofacies 4 and 6 (well log from 6-29-8-16W4). (**B**) braided-fluvial strata overlain by floodplain deposits in turn abruptly overlain by tidally-influenced strata of Lithofacies 7 (well log from 9-01-8-16W4). This succession makes up the youngest paleovalley fill in the study area.

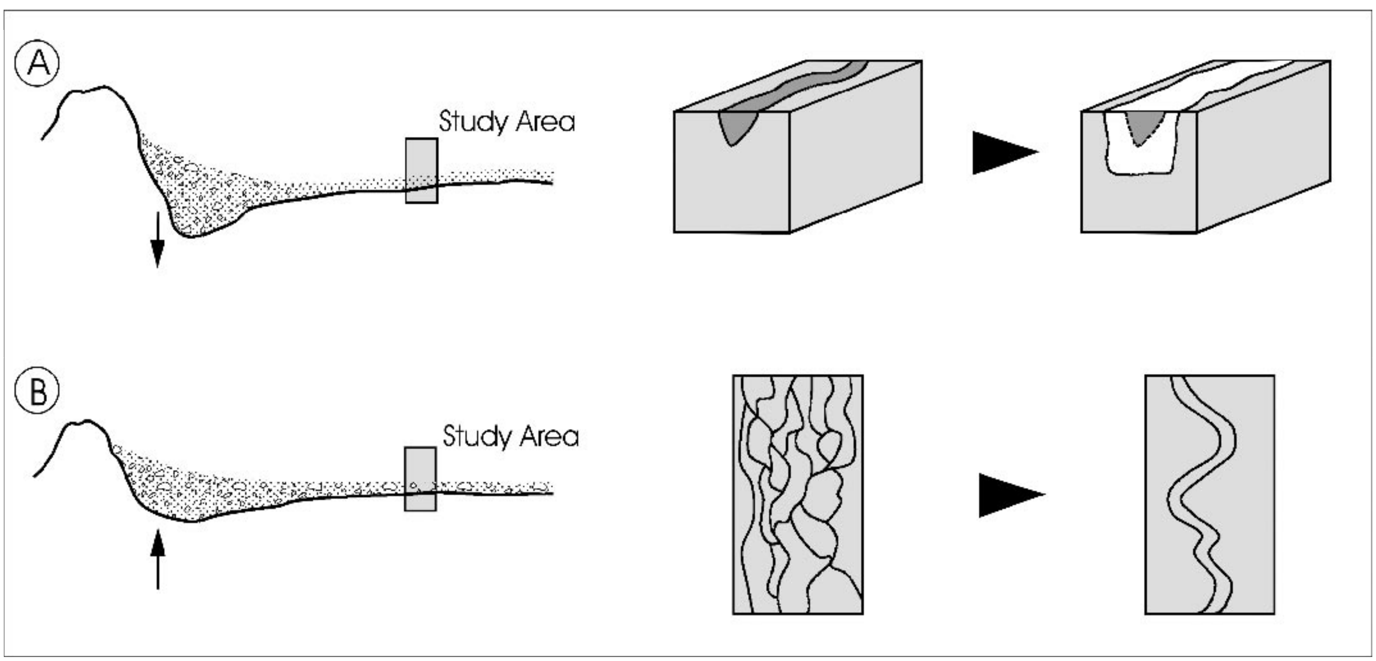

Fig. 7. Schematic diagram illustrating the fluvial response within the study area to changes in sediment flux and grain size related to tectonism. (**A**) coincident with a tectonic pulse and lithospheric flexure, fluvial systems in the study area enlarge by eroding their bases and sides; (**B**) with later tectonic quiescence and related uplift in the orogen, an initial increase followed by a decrease in sediment flux and grain size in the study area results in braided- fluvial followed by meandering-fluvial conditions.

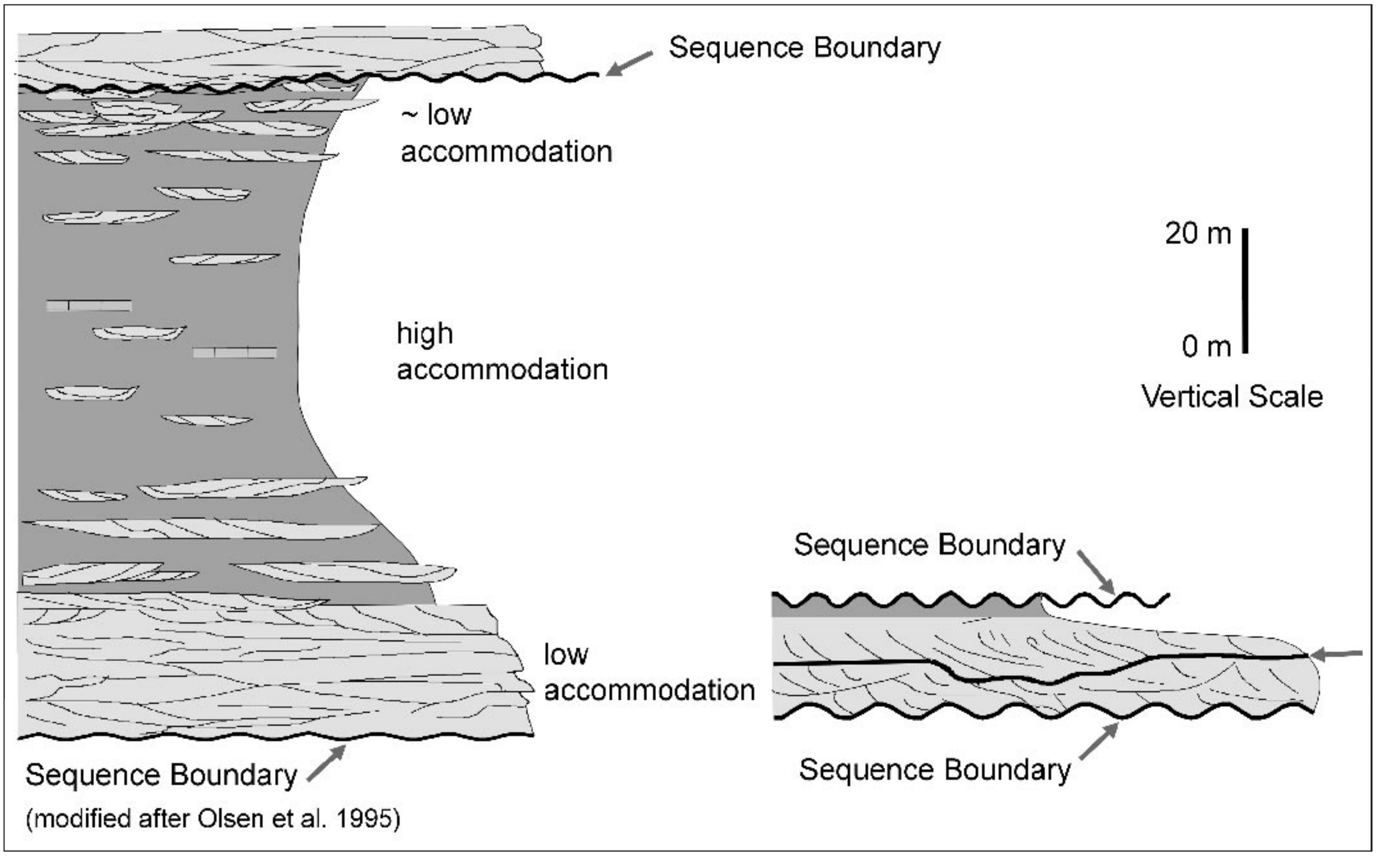

Fig. 8. Schematic diagram, illustrating the difference in an idealized nonmarine sequence in a high versus low net-accommodation setting. In high net-accommodation basins the succession consists of a basal low-accommodation braided-fluvial succession that with increasing accommodation space grades upward into meandering-fluvial deposits with progressively more thickly preserved overbank strata. Further upward, and thus closer to the upper bounding sequence boundary, fluvial channels become progressively more amalgamated laterally and overbank deposits become more poorly preserved. In contrast, the stratal succession in low net-accommodation is significantly thinner and because of the low sedimentation rate is dominated by channel deposits; fine-grained overbank deposits are typically well developed (preserved) only at the top of the succession. Channel deposits consist of braided-fluvial overlain abruptly by meandering-fluvial strata (arrow at right), but, as noted in the text, a single, slowly aggrading fluvial planform would produce a similar stratal assemblage.

part of the BQ basin. Despite this, there are some striking similarities with stratal successions that formed in high net-accommodation settings. Most notably is the consistent upward change from braided- to meandering-fluvial deposits (Fig. 8). In high net-accommodation settings this upward change is attributed to upward changes (increase) in accommodation space. In low net-accommodation settings, on the other hand, the short- and long-term lack of accom-modation space requires that stratal changes be related to temporal changes in other controls, like characteristics of sediment supply. Also the abrupt change from braided- to meandering-fluvial sedimentation is a consequence of low net sedimentation rate and repeated cannibalization by laterally migrating fluvial channels; the most completely preserved channel fills are those deposited last. Alternatively, it could be argued that the entire fluvial succession was deposited by a single planform fluvial system. Under conditions of very low net sedimentation, both laterally migrating braided or meandering channels would preferentially preserve the lowermost (high-energy) parts of a channel fill, which with time would stack vertically upward. Only late-stage channel fills, which subsequently were not eroded by younger channels, would preferentially preserve the fine-grained upper parts of the channel fill. Although appealing, observed changes in grain size, clast composition, and upward change from principally planar-tabular to common trough crossbedding is more consistent with a change from high width-to-depth braided-fluvial channels to low width-to-depth meandering-fluvial channels. Nevertheless, in spite of these potentially equivocal differences, the fluvial stratigraphy deposited in a low net-accommodation basin by a single channel planform, or by a system that evolved from braided to meandering channels would, for all intents and purposes, be similar.

In high accommodation basins, because **net** sedimentation rates are high and the sedimentary section aggrades quickly, the preservation potential of most stratal units is high and each younger unconformity-bounded paleovalley tends to incise from a discernibly higher stratigraphic level. Accordingly, erosion by younger paleovalley systems is generally unable to remove completely the record of older paleovalley fills, thereby forming a stratigraphy consisting of stacked, but generally distinguishable paleovalley fills. In low

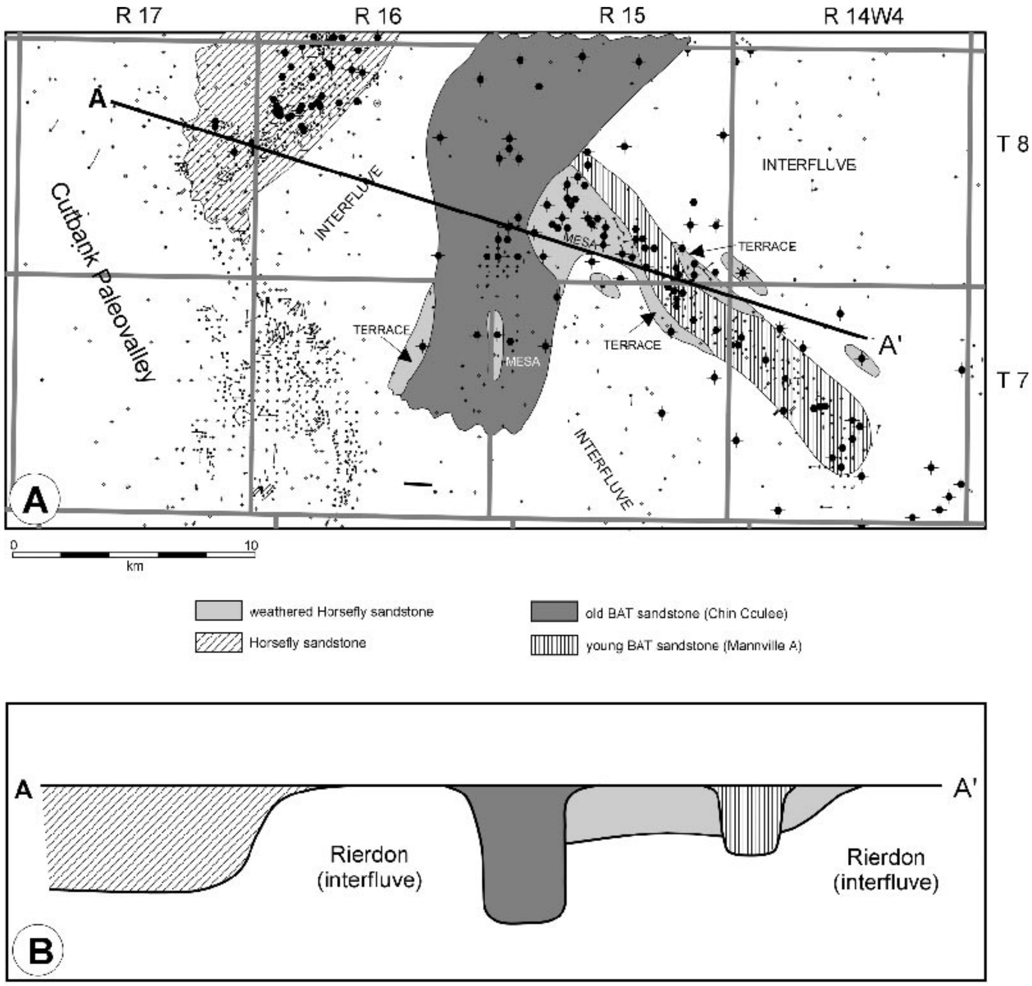

Fig. 9. (**A**) Map illustrating the complex stratigraphic architecture in a low net-accommodation basin. Because of common crosscutting of different-aged paleovalleys, localized preservation (remnants) of older paleovalley strata occur along the margins (valley terraces) and between (mesas) younger paleovalley fills. In addition, successive paleovalleys tend to erode from a similar stratigraphic horizon, which makes stratigraphic correlation in these kinds of basins difficult. (**B**) Schematic cross-section A–A′ (see Fig. 9A) illustrating the complex stratigraphy of the Basal Quartz in the study area (see also Fig. 5A).

accommodation settings, on the other hand, low **net** sedimentation rates cause younger paleovalley systems to incise from a similar stratigraphic level and to extensively cannibalize previously deposited paleovalley fills — this would be especially profound where fluvial drainage patterns were structurally controlled and fluvial systems consistently reoccupied older fluvial fairways. Older (deactivated) valley fills are therefore extensively eroded and their sediment made available for younger valley fills. As a consequence, much of the stratigraphic column is made up of the youngest valley fills, which consist of areally extensive, lithologically consistent stratigraphic units. In places, however, the preservation of parts of older paleovalley fill successions, either as outliers, mesas separating younger paleovalleys, or as terraces along the walls of younger paleovalleys results in a significantly more complicated local stratigraphy (Fig. 9 A, B). Here the vertical, but more typically lateral, juxtaposition of old and young paleovalley successions results in a complicated local stratigraphy characterized by significant vertical and lateral heterogeneity, variations which can have very significant economic ramifications.

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References

Andrews, E.D. 1979. Hydraulic adjustment of the East Fork River, Wyoming to the supply of sediment. In: Adjustments of the Fluvial System. D.D. Rhodes and G.P. Williams (eds.). Tenth Annual Geomorphology Symposia Series, Binghamton, New York, p. 69-94.

Ardies, G.W. 1999. Sedimentology, depositional environments, and high-resolution stratigraphy of the Horsefly, BAT and Ellerslie (Basal Quartz) incised valleys, south-central Alberta, Canada. Unpublished M.Sc. thesis, Queens University, Kingston, Ontario, 359 p.

Arnott, R.W.C. 1992. The role of fluvial processes during deposition of the (Cardium) Carrot Creek/Cyn-Pem conglomerates. Bulletin of Canadian Petroleum Geology, v. 40, p. 356-362.

______, Zaitlin, B.A. and Potocki, D.J. 2000. Geological controls on reservoir distribution in the Lower Cretaceous Basal Quartz, Chin Coulee–Horsefly Lake area, south-central Alberta. Bulletin of Canadian Petroleum Geology, v. 48, p. 212-229.

Autin, W.J., Burns, S.F., Miller, R.T., Saucier, R.T. and Snead, J.I. 1991. Quaternary geology of the lower Mississippi valley. In: Quaternary nonglacial geology; conterminous U.S. R.B. Morrison (ed). The Geology of North America, Volume K-2. Geological Society of America, p. 547-582.

Begin, Z.B., Meyer, D.F. and Schumm, S.A. 1981. Development of longitudinal profiles of alluvial channels in response to base-level lowering. Earth Surface Processes and Landforms, v. 6, p. 49-68.

Blakeney, B.A., Krystinik, L.F. and Downey, A.A. 1990. Reservoir heterogenity in Morrow valley fills, Stateline Trend: implications for reservoir management and field expansion. Bulletin of the Rocky Mountain Association of Geologists, p. 131-142.

Blum, M.D. 1994. Genesis and architecture of incised valley fill sequences: a Late Quaternary example from the Colorado River, Gulf Coastal Plain of Texas. In: Siliciclastic Sequence Stratigraphy: Recent Developments and Applications. P. Weimer and H.W. Posmentier (eds.). American Association of Petroleum Geologists, Memoir 58, p. 259-283.

______, Toomey, R.S. and Valastro, S., Jr. 1994. Fluvial response to Late Quaternary climatic and environmental change, Edwards Plateau, Texas. Paleogeography, Paleoclimatology, Paleoecology, v. 108, p. 1-21.

Bryant, M., Falk, P. and Paola, C. 1995. Experimental study of avulsion frequency and the rate of deposition. Geology, v. 23, p. 365-368.

Burns, B.A., Heller, P.L., Marzo, M. and Paola, C. 1997. Fluvial response in a sequence stratigraphic framework: example from the Montserrat fan delta, Spain. Journal of Sedimentary Research, v. 67, p. 311-321.

Cant, D.J. 1982. Fluvial facies models and their application. In: Sandstone depositional environments. P.A. Scholle and D. Spearing (eds.). American Association of Petroleum Geologist, Memoir 31, p. 115-137.

______ and Stockmal, G.S. 1989. The Alberta foreland basin: relationship between stratigraphy and Cordilleran terrane-accretion events. Canadian of Journal Earth Sciences, v. 26, p. 1964-1975.

______ and Abrahamson, B. 1996. Regional distribution and internal stratigraphy of the Lower Mannville. Bulletin of Canadian Petroleum Geology, v. 44, p. 508-529.

Fisk, H.N. 1944. Geological investigation of the alluvial valley of the Lower Mississippi River. Mississippi River Commission, Vicksburg, Mississippi, 78 p.

Gibling, M.R. 1991. Sequence analysis of alluvial-dominated cyclothems in the Sydney Basin, Nova Scotia. In: Proceedings of the 1991 NUNA Conference on High Resolution Sequence Stratigraphy. Geological Association of Canada, p. 15-19.

Gilbert, G.K. 1877. Report on geology of the Henry Mountains. United States Geographical and Geological Survey of the Rocky Mountain Region, 160 p.

Glass, D.J. (editor) 1990. Lexicon of Canadian Stratigraphy, Volume 4, Canadian Society of Petroleum Geologists, Calgary, Alberta, 772 p.

Hall, S.A. 1990. Channel trenching and climatic change in the southern United States Great Plains. Geology, v. 18, p. 342-345.

Heller, P.L., Angevine, C.L., Winslow, N.S. and Paola, C. 1988. Two-phase stratigraphic model of foreland-basin sequences. Geology, v. 16, p. 501-504.

______ and Paola, C. 1996. Downstream changes in alluvial architecture: an exploration of controls on channel-stacking patterns. Journal of Sedimentary Research, v. 66, p. 297-306.

Krystinik, L.F. and Blakeney, B.A. 1990. Sedimentology of the upper Morrow Formation in eastern Colorado and western Kansas. Bulletin of the Rocky Mountain Association of Geologists, p. 37-50.

Lane, E.W. 1955. The importance of fluvial morphology in hydraulic engineering. American Society of Civil Engineering Proceedings, v. 81, Paper 795, p. 1-17.

Leckie, D.A. and Smith, D.G. 1992. Regional setting, evolution and depositional cycles of the Western Canada Foreland Basin. In: Foreland Basins and Fold Belts. R.W. Macqueen and D.A. Leckie (eds.). American Association of Petroleum Geologists, Memoir 55, p. 9-46.

______, Rosenthal, L. and James, D.P. 1996. Sedimentology of clastic reservoirs in southern Alberta: the Blairmore-Mannville Groups and bounding strata. Geological Survey of Canada, Open File 3322, 108 p.

______, Vanbeselaere, N.A. and James, D.P. 1997. Regional sedimentology, sequence stratigraphy and petroleum geology of the Mannville Group, southwestern Saskatchewan. In: Petroleum Geology of the Cretaceous Mannville Group, Western Canada. S.G. Pemberton and D.P. James (eds.). Society of Petroleum Geologists, Memoir 18, p. 211-262.

Leopold, L.B. and Bull, W.B. 1979. Base level, aggradation and grade. American Philosophical Society Proceedings, v. 123, p. 168-202.

Lukie, T.D. 1999. A study of the sedimentology, geochemistry and stratigraphic organization of the Lower Cretaceous Horsefly (Basal Quartz) Valley (Taber-Cutbank), southern Alberta and northern Montana. Unpublished M.Sc. thesis, Queens University, Kingston, Ontario, 290 p.

Mackin, J.H. 1948. The concept of the graded river. Geological Society of America Bulletin, v. 59, p. 463-512.

Martinsen, O.J., Ryseth, A., Helland-Hansen, W., Flesche, H., Torkildsen, G. and Idil, S. 1999. Stratigraphic base level and fluvial architecture: Ericson Sandstone (Campanian), Rock Springs Uplift, SW Wyoming, USA. Sedimentology, v. 46, p. 235-260.

Myøs, R. and Prestholm, E. 1994. The geometry and organization of fluviodeltaic channel sandstones in the Jurassic Saltwick Formation, Yorkshire, England. Sedimentology v. 40, p. 919-935.

Olsen, T., Steel, R., Hogseth, K., Skar, T. and Roe, S.L. 1995. Sequential architecture in a fluvial succession: sequence stratigraphy in the Upper Cretaceous Mesaverde Group, Price Canyon, Utah. Journal of Sedimentary Research, v. 65, p. 265-280.

Quinlan, G.M. and Beaumont, C. 1984. Appalachian thrusting, lithospheric flexure, and Paleozoic stratigraphy of the Eastern Interior of North America. Canadian of Journal Earth Sciences, v. 21, p. 973-996.

Saucier, R.T. 1981. Current thinking on riverine processes and geologic history as related to human settlement in the Southeast. Geoscience and Man, v. 22, p. 7-18.

Schumm, S.A. 1977. The Fluvial System. John Wiley and Sons, New York, 338 p.

______ 1981. Evolution and response of the fluvial system, sedimentologic implications. In: Recent and Ancient Non-Marine Depositional Environments: Models and Exploration. F.G. Ethridge and R.M. Flores (eds.). Society of Economic Paleontologists and Mineralogists, Special Publication 31, p. 19-29.

______ 1985. Explanation and extrapolaton in geomorphology: seven reasons for geologic uncertainty. Transactions of the Japanese Geomorphological Union, v. 6, p. 1-18.

______ 1993. River response to baselevel change: implications for sequence stratigraphy. Journal of Geology, v. 101, p. 279-294.

Shanley, K.W. and McCabe, P.J. 1991. Predicting facies architecture through sequence stratigraphy - an example form the Kaiparowits Plateau, Utah. Geology, v. 19, p. 742-745.

______ and ______ 1994. Perspectives of the sequence stratigraphy of continental strata. American Association of Petroleum Geologists Bulletin, v. 78, p. 544-568.

Shepherd, R.G. and Schumm, S.A. 1974. Experimental study of river incision. Geological Society of America Bulletin, v. 85, p. 257-268.

Smith, D.G. 1994. Paleogeographic evolution of the Western Canadian Foreland Basin. In: Geological Atlas of the Western Canadian Sedimentary Basin. G. Mossop and I. Shetsen (comps.). Canadian Society of Petroleum Geologists and Alberta Research Council, p. 272-316.

Stockmal, G.S., Cant, D.J. and Bell, J.S. 1992. Relationship of the stratigraphy of the Western Canada Foreland Basin to Cordilleran tectonics: insights from geodynamic models. In: Foreland Basins and Fold Belts. R.W. McQueen and D.A. Leckie (eds.). American Association of Petroleum Geologists, Memoir 55, p. 107-124.

Törnqvist, T.E. 1993. Holocene alternation of meandering and anastomosing fluvial systems in the Rhine-Meuse delta (central Netherlands) controlled by sea-level rise and subsoil erodibility. Journal of Sedimentary Petrology, v. 63, p. 683-693.

Yoxall, W.H. 1969. The relationship between falling baselevel and lateral erosion in experimental streams. Geological Society of America Bulletin, v. 80, p. 1379-1384.

Zaitlin, B.A., Dalrymple, R.W. and Boyd, R. 1994. The stratigraphic organization of incised-valley systems associated with relative sea-level change. In: Incised-Valley Systems: Origin and Sedimentary Sequences. R.W. Dalrymple, R. Boyd and B.A. Zaitlin (eds.). SEPM (Society for Sedimentary Geology), Special Publication 51, p. 45-60.

______, Potocki, D., Warren, M.J. and Boyd, R. 1999. Sequence stratigraphy in low accommodation foreland basins: an example from the Lower Cretaceous "Basal Quartz" Formation of southern Alberta. Canadian Society of Petroleum Geologists Reservoir, v. 26, p. 12-13.

______, ______, ______, Rosenthal, L. and Boyd, R. (this issue). Stratigraphic organization of the Basal Quartz (Lower Cretaceous) in southern Alberta: controls and reservoir implications. Bulletin of Canadian Petroleum Geology.

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