

# Lithofacies Architecture of the Milk River Formation (Alderson Member of the Lea Park Formation), Southwestern Saskatchewan and Southeastern Alberta – Its Relation to Gas Accumulation

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Ridgley, J.L. (2000): Lithofacies architecture of the Milk River Formation (Alderson Member of the Lea Park Formation), southwestern Saskatchewan and southeastern Alberta – its relation to gas accumulation; in Summary of Investigations 2000, Volume 1, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2000-4.1.

## 1. Introduction

Large accumulations of biogenic gas are known to occur in shallow (<1000 m) Cretaceous reservoirs of the Northern Great Plains (mainly Montana) and southeastern Alberta and southwestern Saskatchewan, Canada. The 1995 U.S. Geological Survey national oil and gas assessment made a mean estimate of 1.15 to 1.18 x 10<sup>12</sup> m<sup>3</sup> (41 to 42 trillion cubic feet) of potential additions to reserves of continuous-type (unconventional) gas in Cretaceous shallow biogenic gas plays of northern and central Montana (Rice and Spencer, 1995). About 90 percent of the 1995 gas

estimate was in hypothetical plays, and of this percentage, over one-half was based primarily on similarity of the potentially productive facies in Montana to the facies that host large shallow biogenic gas resources in southeastern Alberta and southwestern Saskatchewan. The controls on the hypothetical play boundaries were poorly understood in 1995. Sedimentologic, structural, and hydrologic studies of the important shallow gas-producing formations in southwestern Saskatchewan and southeastern Alberta have been undertaken in order to better understand the relative importance of each of these parameters as a control on the site of the shallow gas accumulation.

The objective of this research is to apply the Canadian model to Montana where gas might be expected to occur.

The Milk River Formation is one of the principal formations that yields shallow gas in the large southeast Alberta gas field (Alberta and Saskatchewan) (Figure 1). Gas in the Milk River occurs in interbedded, very fine-grained sandstone and shale reservoirs. In contrast, shallow gas production in the correlative Eagle Sandstone in Montana is from fine- to medium-grained sandstone reservoirs. Gas in both the Milk River and Eagle Sandstone is of biogenic origin. Whereas gas in the Eagle Sandstone reservoirs has been assessed as a conventional gas accumulation, gas in the Milk River Formation would be considered a type of unconventional gas accumulation that fits the “continuous-type” gas accumulation category first defined and used in the 1995 U.S.G.S. national assessment (Schmoker, 1995). Continuous-type accumulations are

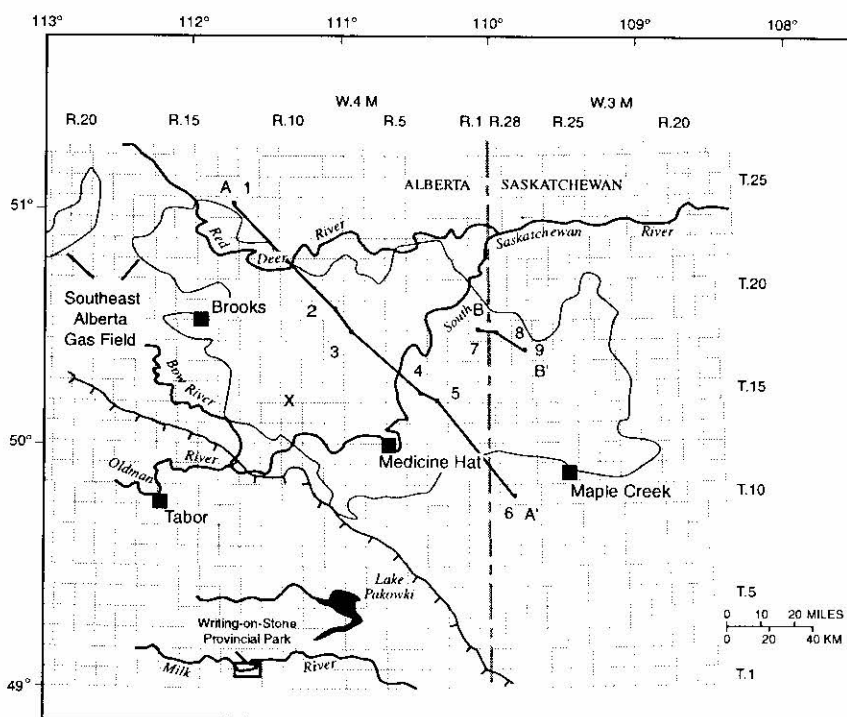


Figure 1 - Map showing location of core holes and cross-section A-A' and B-B', depositional extent of Virgelle Sandstone (hachured line), Writing-on-Stone Provincial Park, and location of southeast Alberta gas field (Alberta and Saskatchewan). Type Alderson section ARCO Alderson well 10-14-15-10W4 is shown as X.

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considered to be large, low-grade, non-conventionally reservoir (i.e. not bounded by a downdip water contact) gas concentrations that crosscut lithologic boundaries on a regional scale. Where they occur, continuous-type gas accumulations are thought to be mostly gas-charged everywhere in the gas-bearing interval, although the gas may not always be economic. Other characteristics of continuous-type gas accumulations include an updip water contact, the insignificance of conventional traps and seals, a close association of reservoir with source rock, and low reservoir permeability in facies that have large areal extent. Application of the concepts of continuous-type gas accumulations to the area of the Northern Great Plains (Montana) and southeastern Alberta and southwestern Saskatchewan indicates that gas resources should be present over an area greater than that in which this commodity is currently being exploited. This report presents preliminary correlations of lithofacies along two strike-oriented transects (Figure 1) within the Milk River depositional system and examines the relative control of lithofacies on sites of gas accumulation. This summary represents work in progress on the sequence stratigraphic characterization of the Milk River Formation.

## 2. Regional Stratigraphy

The Santonian-Campanian Milk River Formation in Canada and its regionally correlative Eagle Sandstone in Montana (Figure 2) form the basal part of the Montana Group. The Milk River is composed of three members, from base to top, the Telegraph Creek Member, the Virgelle Member, and the Deadhorse Coulee Member. The Virgelle is often informally subdivided into a lower and upper part; the boundary is placed where a pronounced change in depositional environment is evident. In Montana, the correlative Eagle Sandstone is subdivided into the Virgelle Member and unnamed rock units of alluvial origin. The Telegraph Creek is placed stratigraphically below the Eagle. In both Canada and north-central Montana, the base of the Telegraph Creek is placed at the top of the Niobrara Formation of the Colorado Group. The Niobrara Formation is a calcareous, coccolithic-bearing shale and thus, in core, the top of the formation is an excellent marker horizon separating rocks of the Montana Group from those of the Colorado Group. The Milk River is overlain by the Pakowki Formation and the Eagle Sandstone is overlain by the Claggett Shale (Figure 2). The Ardmore bentonite beds, found in the lower part of the Pakowki and Claggett, provide an excellent upper marker unit. Thus, the two lithologic markers can be used to provide boundaries to the Milk River Formation depositional system.

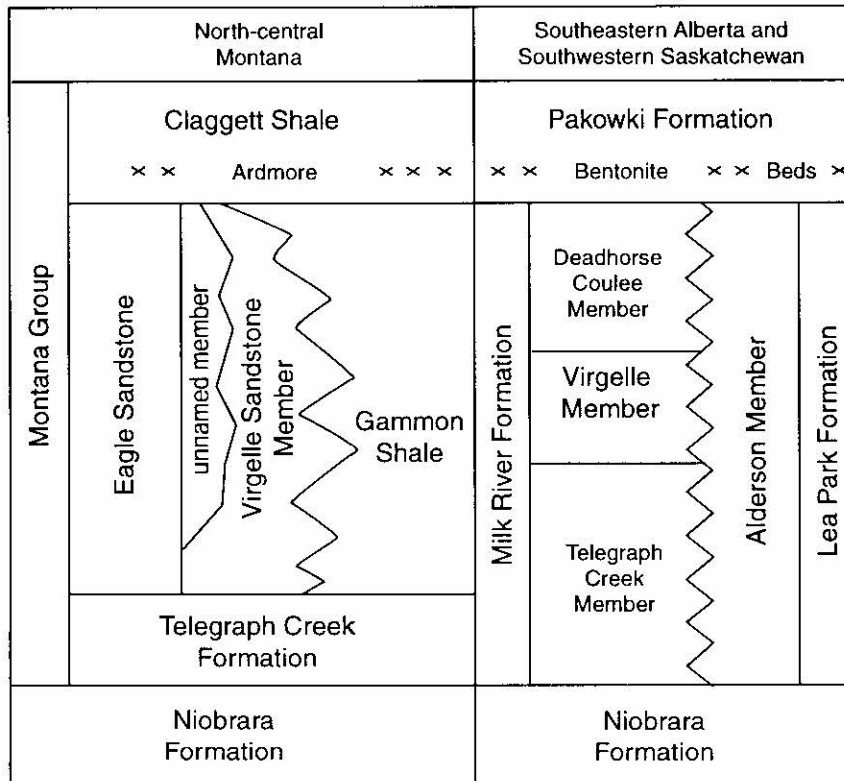


Figure 2 - Stratigraphic chart showing correlation of members of the Milk River Formation, Alderson Member of the Lea Park Formation, Saskatchewan and Alberta, Canada, and members of the Eagle Sandstone, Montana, U.S.A.

In Montana, rocks assigned to the Virgelle Member are, in part, older than those assigned to the Virgelle in Canada. The Milk River and Eagle have generally been considered to represent a mainly progradational, wave-dominated depositional system within the Cretaceous Interior seaway of North America. The Virgelle in Canada represents the later part of the main seaward-stepping progradational event and is correlative to the wedge of marine sandstone in the middle part of the Eagle (Gill and Cobban, 1973, p16).

## 3. Previous Studies

The principal study area for the current investigation is between longitude 108° and 113° and latitude 49° and 51° in southwestern Saskatchewan and southeastern Alberta. Within this area, only a few detailed facies architecture studies of the Milk River Formation have been made (limited to Alberta). Outcrops of the Milk River Formation are confined to the vicinity of the Writing-on-Stone Provincial

Park, Alberta, (Figure 1) where the Milk River has dissected outcrops of this rock unit, providing excellent three-dimensional exposures for stratigraphic and sedimentologic analysis. Three detailed studies of these exposures have resulted in three slightly different interpretations of the origins of the formation (McCrorry and Walker, 1986; Cheel and Leckie, 1990; Meyer *et al.*, 1998). Each of the studies interpreted the Telegraph Creek to have been deposited in the offshore-transition zone below shoreface sands of the lower part of the Virgelle Member. All three studies subdivided the Virgelle Member into an upper and lower part based on a distinct paleodepositional environment break. The lower part of the Virgelle was interpreted to have been deposited primarily as lower shoreface to middle shoreface sands along a wave-dominated coastline. The upper part was interpreted to have been deposited in a complex tidal setting. The models for the tidal processes vary somewhat between the three reports. The tidal complex models will not be reviewed here because the link between these outcrop facies and the subsurface facies in the distal offshore has not been completed. All three studies of the Milk River outcrops interpret the Deadhorse Coulee Member (Figure 2) to have been deposited in fluvial-alluvial plain environments.

Principal published subsurface characterizations of the Milk River Formation are limited to studies by Meijer-Drees (1972) and Meijer-Drees and Myhr (1981). In cross-sections, the succession of facies (discussed above) was shown to change laterally down dip to the north into fine-grained facies. The upward succession of these facies was divided into offshore, subtidal, nearshore, and intertidal and subtidal. These facies were interpreted from core from the ARCO Alderson well 10-14-15-10W4 (Figure 1) and were calibrated to wireline logs. From their subsurface studies, Meijer-Drees and Myhr (1981) plotted the depositional extent of shoreface sandstone in the Virgelle. The sandstone trends northwest-southeast (Figure 1), and is believed to approximate the orientation of Milk River Formation shorelines in Alberta and Saskatchewan. Where the facies that characterize the Virgelle and Deadhorse Coulee members are no longer recognizable (i.e. they pass laterally into fine-grained facies), the stratigraphic succession has been redefined as the Alderson Member of the Lea Park Formation (Figure 2) (Meijer-Drees and Myhr, 1981). Detailed information on the Milk River sedimentology is not reviewed here, but where appropriate has been incorporated into the discussion of the facies determined along the two transects described in this paper. Facies reported herein are for the Alderson Member of the Lea Park Formation, although this terminology has not been universally adopted as a replacement for the Milk River Formation or Milk River equivalents. For the purposes of this report, the discussion refers to this stratigraphic succession as the Milk River Formation.

#### 4. Methods

Most of the Milk River Formation occurs in the subsurface. The formation is characterized by low-

contrast response on wireline logs due to the shaly nature of the rocks throughout much of the depositional system. Detailed observations of selected cores, logged at a scale of 0.3 m (one ft), from Saskatchewan and Alberta have been used to calibrate wireline log responses to depositional facies. Principal observations included sedimentary structures, lithologies, trace fossil and macrofossil assemblages, and major diagenetic changes (mostly the presence of siderite and glauconite). Preliminary results of the detailed description of the Milk River are presented in two strike-oriented cross-sections through the main part of the Milk River gas field (Figures 3 and 4). The detailed observations permit lateral correlation of lithofacies and of significant erosion surfaces between wells, and serve as a basis for evaluation of gas productive facies. The datum used in the cross-sections is a prominent bentonite bed in the lower part of the Pakowki Formation.

#### 5. Lithofacies Architecture

Seven distinct lithofacies and their preliminary inferred depositional environments are summarized below and are shown on Figures 3 and 4. One additional facies that is thought to be present is not described because no representative core has been examined. This facies is designated as F? and occurs only at the base of the Milk River Formation in well 6 (Figure 3). It could represent fluvial rocks. Siderite is locally present throughout all lithofacies except I and II. Its position within the described sections on Figures 3 and 4 is not shown except where it occurs at erosional surfaces. Likewise, nondescript burrows and areas of bioturbation are not shown on Figures 3 and 4 because they are pervasive throughout all lithofacies. The discussions of the lithofacies below are listed from deeper to shallower water environments.

##### I: Offshore Facies

This facies is dominated by calcareous, coccolithic mudstone (>90 percent) that is interbedded with thin (millimetre scale) siltstone. This facies coincides with the upper part of the Niobrara Formation. Strata in this facies were deposited below storm wave base.

##### II: Offshore-Transition Facies

Mudstones and siltstones of the offshore facies grade vertically into centimetre- to decimetre-thick, very fine-grained sandstone that is interbedded with siltstone and mudstone. The mudstone and overlying sandstone form vertically stacked couplets within which both the proportion and thickness of the sandstone interbeds increase and the intervening siltstone and mudstone beds decrease in thickness upwards through this facies. The sandstones have sharp bases and tops. In the lower part of this facies, they are relatively clay rich and are commonly parallel laminated. In the upper part, they typically exhibit hummocky cross-stratification. The top of this facies is generally characterized by thick (metre-scale) amalgamated, hummocky cross-stratified sandstone

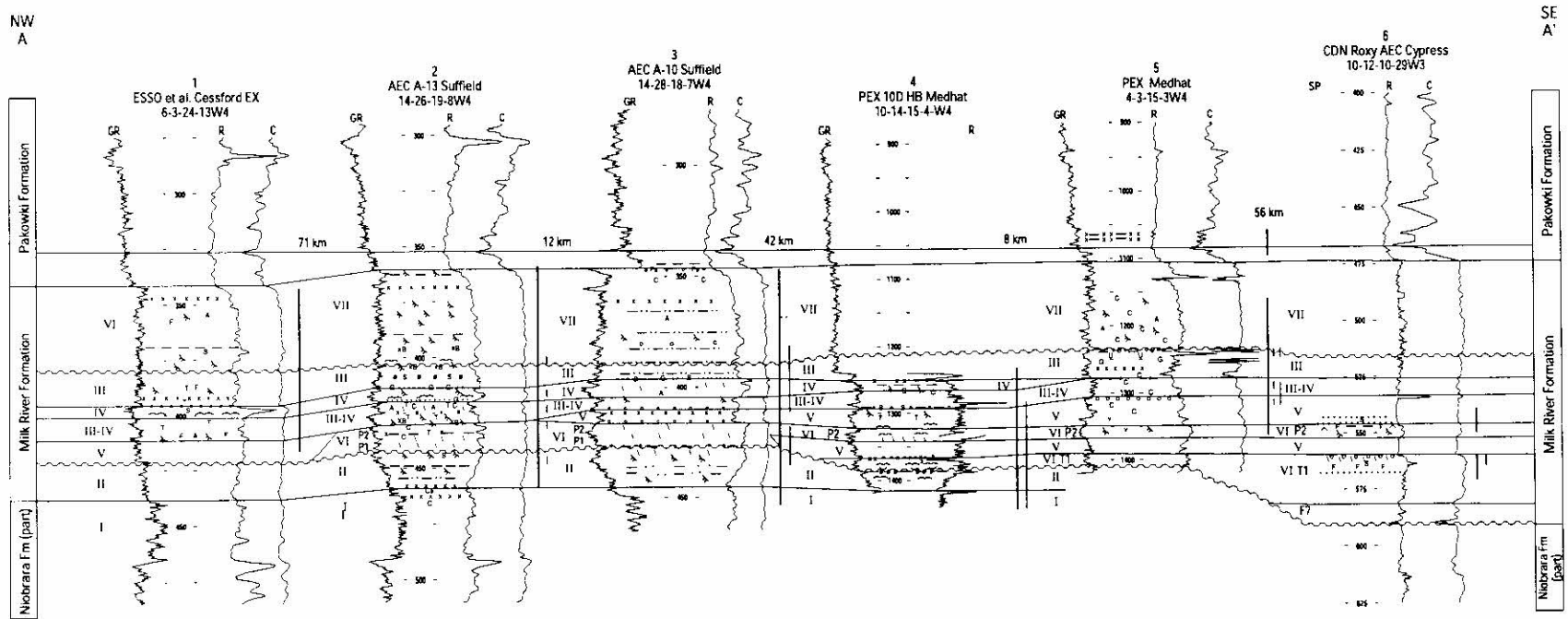
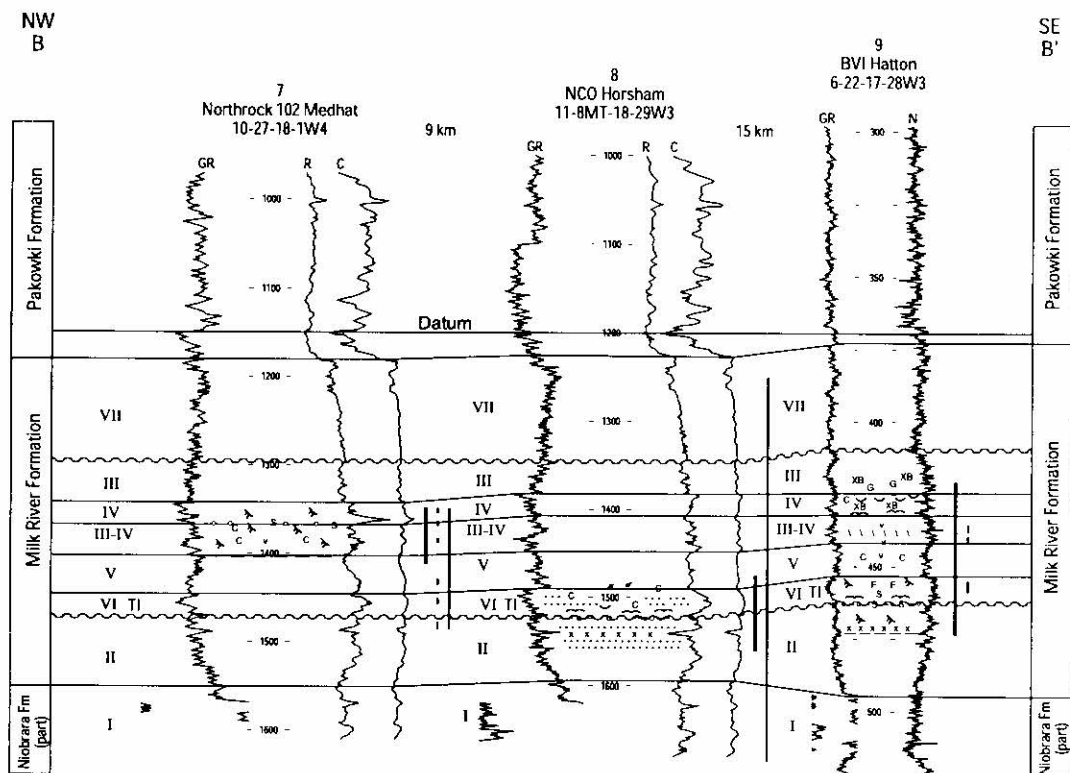


Figure 3 - Cross-section A-A', showing correlation of lithofacies I to VII, and simplified sedimentary structures in the Milk River Formation. Tested and cored intervals shown to the right of each well. Depths for wells 1 to 3 and 6 are in metres. Depths for wells 4 and 5 are in feet. Locations of wells are shown in Figure 1. (Gr, gamma ray; R, resistivity; C, conductivity; and SP, spontaneous potential). Explanation of symbols is shown on Figure 4.



**EXPLANATION**

- |       |  |       |   |
|-------|--|-------|---|
| ~     | Hummocky cross stratification                | o o o | Siderite clasts or conglomerate clasts              |
| ~     | Swaley cross stratification                  | • • • | Intraformational siderite clasts                    |
| \\    | Indeterminate low angle cross stratification | ^     | Fractures   |
| ➤     | Current ripples                              | A     | Coiled ammonite fragments                           |
| F     | Flaser bedding                               | u     | <i>Arenicolites</i> burrows                         |
| ...   | Coarse sandstone layers                      | T     | <i>Terebellina</i> sp. burrows                      |
| —     | Mudstone                                     | Fa    | Fish fragments                                      |
| - - - | Siltstone                                    | • • • | Chert grains or coarse grit                         |
| ca    | Coccolithic shale                            | I     | Offshore facies                                     |
| v     | Vuggy  | II    | Offshore-transition facies                          |
| x     | Bentonite                                    | III   | Inner to outer shelf facies                         |
| xb    | Biotite-rich rocks                           | IV    | Shelf sandstone facies                              |
| c     | Carbonaceous                                 | V     | Inner shelf to outer estuarine facies               |
| g     | Glaucanite                                   | VI    | Coastal sandstone facies                            |
| s     | Siderite                                     | VII   | Amalgamated shoreline sandstone and mudstone facies |
| ~     | Unconformity                                 | Ff    | Fluvial facies                                      |
|       | Cored interval                               |       | Tested interval                                     |
| T 1   | Transgressive shoreface sand                 | P 1   | Regressive shoreface sand                           |

**Figure 4 - Cross-section B-B', showing correlation of lithofacies I to VII, and simplified sedimentary structures in the Milk River Formation. Tested and cored intervals shown to the right of each well. Depths for wells 7 and 8 are in feet. Depths for well 9 are in metres. Locations of wells are shown in Figure 1. (Gr, gamma ray; R, resistivity; C, conductivity; and N, neutron).**

that is commonly current rippled at the top. No distinct trace fossil assemblages were observed. Bioturbation is locally pronounced with many thinner sandstone beds intensely to thoroughly bioturbated. Deposition of this facies is interpreted to have taken place under alternating storm and quiet-water conditions between fair-weather and storm wave base (Howard and Reineck, 1981; Dott and Bourgeois, 1982).

### III: Inner to Outer Shelf Facies

This facies is characterized by very fine- to fine-grained sandstone with some coarse-grained sandstone and grit layers. The topmost sandstones are locally very glauconitic (as pellets) and contain abundant green-grey clay clasts and mud drapes. Flat and current ripple laminations are the dominant sedimentary structures. Maximum thickness of this interval is 9 m; the most glauconitic sandstone, which is at the top of this facies, is commonly less than 0.2 m thick. The sandstones are locally bioturbated; *Terebellina* burrows were observed in one core. Ammonite fragments and indeterminate coiled specimens have been found in this interval from the lowermost current ripple-laminated to low-angle cross-bedded sandstone. Strata in this facies are interpreted to have been deposited in inner to outer shelf, shallow-water environments as required for the development and preservation of the glauconite (Stonecipher, 1997). Glauconite typically develops in areas of low sediment input in the inner to outer shelf. High concentrations of glauconite pellets such as those observed in the cores form through winnowing under shallow-water, non-oxidizing conditions. The presence of the coiled ammonites suggest water depths somewhat deeper than those of the middle shoreface.

### IV: Shelf Sandstone Facies

This sandstone facies is superficially similar to the coastal sandstone facies described below. The sandstones tend to be clean, although carbonaceous material is locally present at the top or base of the sandstone. Sedimentary structures include hummocky or swaley cross-stratification that is overlain by ripple laminations. Coiled ammonite fragments have been found at the base of the shelf sandstone in well 3 (Figure 3). The sandstones are bounded by mudstone that commonly contains glauconite. The vertical succession of sedimentary structures and the apparent encasement of the sandstones in marine siltstones and mudstones, some of which are glauconitic, suggest that this facies was deposited as shelf sandstone. This facies is interbedded with the inner to outer shelf facies and may form stacked sequences as much as 12 m thick.

### V: Inner Shelf to Outer Estuarine Facies

This heterolithic facies is characterized by interbedded very fine-grained sandstone, siltstone, and mudstone of centimetre to decimetre to metre thickness. There is no upward thickening of the sandstone-mudstone beds to form couplets like those observed in the offshore-transition facies. Shell fragments, unidentified pelecypods, and fragments of *Baculites* sp. are scattered throughout the facies. The facies is

commonly very carbonaceous. Ripple and flat laminations are the most prominent sedimentary structures, although flaser bedding is locally well developed. The base of this facies may be marked by a thin (<3 m thick) hummocky cross-stratified sandstone. Bioturbation is locally intense, commonly destroying sedimentary structures. Burrows, most prominently *Terebellina*, are abundant. The interbedded, relatively flat nature of the sandstone and mudstone units that show no preferred upward thickening of sandstone-mudstone couplets suggests tidal influence (Greb and Archer, 1998; Adkins and Eriksson, 1998). The preservation of shelly fauna suggests a somewhat quieter depositional setting than that observed for a storm-dominated coastal setting. Although its lateral relationships have not been fully determined, this facies appears to lie lateral to the coastal shoreface sandstones of lithofacies VI as well as overlie them. It is provisionally interpreted to have been deposited in the distal end of estuaries where there was interaction between tidal and inner shelf processes.

### VI: Coastal Shoreface Sandstone Facies

Lithofacies II, the offshore-transition facies, is overlain by thick (up to 15 m), very fine- to medium-grained sandstone. In vertical succession, from the base to the top, sedimentary structures consist of poorly preserved low-angle cross-stratification, swaley cross-stratification, and current ripple or flat laminations. Bioturbation, mostly *Terebellina* burrows, is randomly distributed within this facies, but is most intensely developed in the upper current-rippled and laminated sandstone. Although carbonaceous material is found throughout the facies, it is most concentrated in the upper few metres. The vertical succession of sedimentary structures is similar to that found in the middle to lower shoreface sandstones and to that described from the lower Virgelle (McCrary and Walker, 1986; Meyer *et al.*, 1998) at Writing-on-Stone Provincial Park. *Terebellina* burrows are thought to occur in shoreface to nearshore (shoreface toe) depositional environments (Chamberlain, 1978). Meyer *et al.* (1998, Table 1) reported the presence of *Terebellina* in their middle shoreface facies. Preserved fossils are generally lacking due to the high energy within the depositional environments. Strata are provisionally interpreted to have been deposited between fair weather base and mean low water in a high-energy, storm-dominated nearshore environment.

### VII: Amalgamated Shoreline Sandstone and Mudstone Facies

This facies, which is up to 42 m thick, is an amalgamation of stacked fine-, to very fine-grained, clean to muddy sandstone beds deposited in channels of undetermined size. The basal sandstone tends to be coarser grained (fine size range) than sandstone (very fine size range) of the underlying facies. Where they occur, mudstone layers and drapes are most common in the upper parts of individual channel sandstones. Rarely, black mudstone caps sandstone units. The sandstones are carbonaceous, and locally contain

woody fragments where they occur at the base of a channel. The sandstones are dominantly flat to ripple laminated. Bioturbation is locally intense. Shell fragments, unidentified pelecypods, and large baculitids and coiled ammonite fragments are common throughout. Gastropods have been observed in the upper part of this facies. This unit is widespread in the subsurface (Gilboy, 1996); however, it is not observed at the outcrop at Writing-on-Stone Provincial Park.

The base of the unit, as determined in the two cross-sections, is undulatory. It cuts into the underlying inner to outer shelf facies. Although additional work is needed to determine fully the spatial geometry of this facies and hence its depositional environment, these sandstones and thin mudstones are believed to be the result of deltaic deposition with their geometry modified by coastal longshore or storm processes to form sheetlike bodies. Similar thick, stacked sandstones in the middle Eagle Sandstone, Montana, were interpreted by Rice and Shurr (1983) to represent deposition by deltaic processes. Neither rooting nor bleaching of the top sandstones in this facies was observed. The top of this facies, which represents the top of the Milk River Formation, is overlain unconformably by the Pakowki Formation. Grit, black chert pebbles, and concentration of fish fragments mark the contact between the Milk River and Pakowki.

## 6. Discussion

The vertical stacking of the lithofacies shown in cross-section A-A' (Figure 3) and B-B' (Figure 4) describes a different model for deposition of the Milk River than is commonly proposed. Two major erosional surfaces have been recognized. When tied to unpublished dip-oriented cross-sections, each suggests a drop in sea level, a basinward shift in facies, and creation of accommodation space during the ensuing sea-level rise. This accommodation space appears to have been greater in Saskatchewan, where the Milk River thickens (well 6, Figure 3). The controls for this shift are unknown, but are speculated to be related to tectonic activity to the southwest. The basal erosion surface cuts out parts of the Telegraph Creek (lithofacies II). In several of the cores, this surface is marked by a transgressive lag consisting of black, red, and tan cherts along with angular to subangular rock fragments of undetermined composition (Figures 5A and 5B). The configuration of this surface has not been fully determined but, based on work in progress, beveling of the Telegraph Creek appears to increase irregularly to the southeast, east of the South Saskatchewan River. The Milk River is thicker in cross-section B-B' than it is in A-A'; the difference in thickness is attributed to differential subsidence. The upper erosional surface occurs between the amalgamated shoreline sandstone and mudstone facies and the inner to outer shelf facies. This surface is, in places, marked by a lag consisting of siderite clasts set in green-grey clay matrix (Figure 5C).

The type of lithofacies that overlies the basal erosional surface varies depending on the position of the facies on the incised surface. The juxtaposition of facies of

shallower water origin deposited after a sea-level fall to deeper water facies deposited during a previous regression suggests that the basal erosional unconformity that separates these facies represents a sequence boundary. The deepest incision by the unconformity occurs in well 6 (Figure 3). Here, the unconformity is overlain by an undefined unit (no cores through this unit have been examined, but its log response indicates that it could possibly be of fluvial origin). The overlying facies have sedimentary characteristics of shoreface sands and are interpreted to represent lowstand or transgressive shoreface deposits (VI T1). The vertical stacking of facies of the fluvial and overlying shoreface sandstone is indicative of marine lowstand to transgressive deposits filling an incised valley.

The coastal shoreface sandstone facies (VI T1) in well 6 (Figure 3) is overlain by inner shelf to outer estuarine facies (V) that pinch out laterally into a stacked sandstone sequence (VI) that is interpreted to represent younger shoreface sandstones of two progradational events (VI P1 and VI P2). Both upper shoreface sandstones (VI P1 and VI P2) wedge out between A-A' and B-B', and shoreface sandstone VI P2 thins to the southeast. These shoreface sandstones are laterally replaced and in some cases overlain by a thinly laminated sandstone-mudstone sequence of the inner shelf to outer estuarine facies (V). The lateral cut-out of the shoreface sandstones and infill of the erosional surfaces by inner shelf to outer estuarine facies are similar to the situation observed in offshore sand bodies in the Gulf of Lions in the western Mediterranean (Berne *et al.*, 1998), interpreted to represent prograding shoreface sands deposited during a forced regression. The coastal shoreface sandstone (VI P1 and VI P2) and inner shelf to outer estuarine facies (V) represent marine regression.

Overlying the regressive succession of facies is another transgressive sequence represented by mixed inner to outer shelf facies and shelf sandstone (III and IV), shelf sandstone facies (IV), and an overlying outer shelf facies (III). The base of this transgressive package of rocks in many of the cores is defined by a reworked zone of siderite clasts (Figure 5D). The outer shelf facies (III) of the transgressive succession is glauconitic and, in several cores, a coarse grit, siderite concretion and pebble lag set in green-grey clay matrix (Figures 5E and 5F) and glauconitic sandstone occur at the contact with the underlying shelf sandstone facies (IV). The coarse interval represents a transgressive lag as the deeper water outer shelf units migrated landward over the shelf sandstone, which may have built up into the fair weather base zone.

The outer shelf facies (III) is erosionally overlain by the amalgamated shoreline sandstone and mudstone facies (VII). The configuration of this incised surface is unknown, but from reconnaissance studies and published cross-sections (Meijer-Drees, 1972; Meijer-Drees and Myhr, 1981; Gilboy, 1996), the depth of incision is considerably less than that observed for the lower erosional surface. The relationship of this facies to outcrop units of the Milk River Formation has not

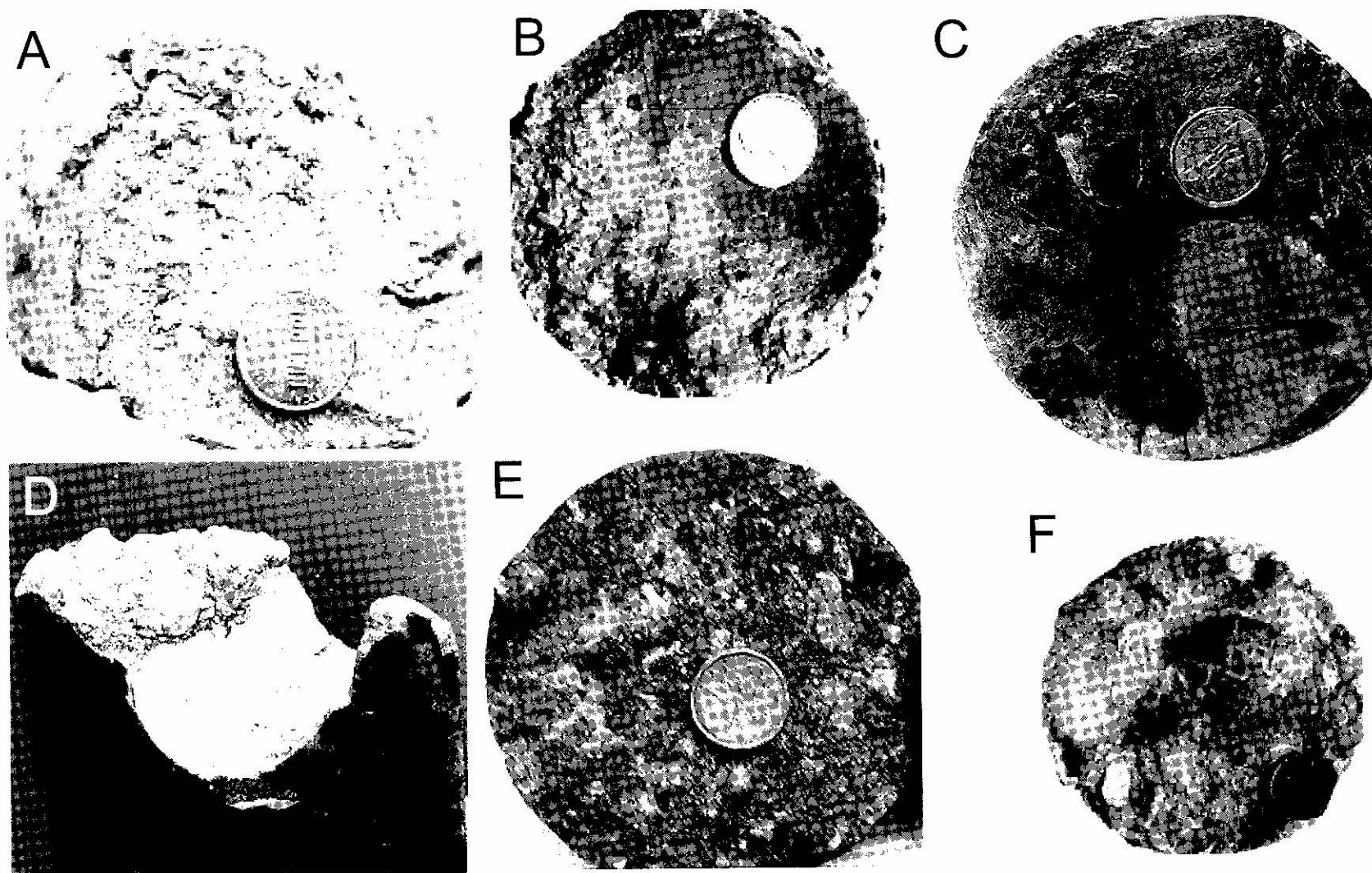


Figure 5 - Photographs of conglomerates in the Milk River Formation, Alberta and Saskatchewan. A) Conglomerate from 463.3 m (1520 ft) depth, NCO Horsham 11-8-18-29W3 well. Clasts consist of tan, red, and black angular to subangular chert pebbles up to 1.5 cm long. Conglomerate zone is 15 cm thick. B) Siderite-cemented clast conglomerate from 460 m depth BVI Hatton 6-22-17-28W3 well. Clasts consist of red and black chert, quartz, and green(?) pebbles, and rock fragments up to 0.6 cm long set in a grey-green clay matrix. C) Siderite-cemented clast conglomerate from 374.5 m (1228.6 ft) depth, PEX Medhat 4-3MR-15-3W4 well. Clasts are black chert and clear quartz pebbles up to 2.5 cm long and are set in green-grey clay matrix. D) Siderite-cemented clast conglomerate from 391.7 m (1285 ft) depth, PEX IOD HB Medhat 10-14MR-15-4W4 well. Clasts are black and cream siderite nodules up to 1.3 cm long and are set in green-grey clay matrix. E) Conglomerate from 391.3 m (1283.9 ft) depth, PEX Medhat 4-3MR-15-3W4 well. Clasts are black and tan chert pebbles, indeterminate subangular rock fragments up to 1.2 cm long and are set in a green-grey clay matrix. F) Siderite-cemented intraclast conglomerate from 413.3 m (1356 ft) depth, Northrock 102 Medhat 10-27-18-1W4 well. Clasts are siderite nodules or small concretions up to 20 cm in length. Coins are approximately 1.8 cm diameter.

been determined; however, this facies may form the basal transgressive unit of the Pakowki transgression. Lag deposits between the Pakowki and Milk River may represent a transgressive surface of erosion.

O'Connell *et al.* (1999) also recognized the presence of two erosional (sequence) boundaries, but it is not clear how their boundaries conform to those discussed above, especially in the manner in which they tie the boundaries to the Milk River outcrop succession. They suggested that the Alderson Member is depositionally unrelated to the Milk River succession observed in outcrop and that the member rests on a third-order sequence boundary. The depositional models suggested by this study and by O'Connell *et al.* (1999) indicate that additional work needs to be done on the Milk River depositional system. Redefinition of the facies relationships through analysis of vertical stacking sequences can provide predictive models for the best targets for gas accumulation.

## 7. Age Relationships

An understanding of the age relationships of the units comprising the Milk River Formation is an important component of the sequence stratigraphic modelling. The age of the Milk River is commonly thought to span the Santonian-Campanian boundary, based on its correlation to the Eagle Sandstone in Montana. Dating of the Eagle has been based on ammonite zones (Gill and Cobban, 1973); however, datable ammonite specimens from the Milk River are lacking. An upper age limit to the Milk River of 80.71 Ma is based on  $^{40}\text{Ar}/^{39}\text{Ar}$  dating of sanidine in the Ardmore bentonite

(Hicks *et al.*, 1995). This bentonite (actually a series of bentonites) occurs in the lower part of the Pakowki and its correlative Claggett Shale in Montana and is a widespread regional marker unit. Two bentonites in the Ardmore unit in well 5 (Figure 3) provide calibration of the bentonite markers to wireline log responses. There are scattered bentonites in the Milk River Formation, some of which can be correlated between wells as discrete bentonites or as biotite-rich sandstone or mudstone beds. None of these bentonites has been dated. As part of this project, several bentonites of the Milk River were collected for age dating; however, no sample has contained sanidine suitable for the argon-argon laser fusion dating method (Obradovich, 1993). One bentonite sample from the upper part of the Eagle Sandstone in the Elk Basin, Wyoming, yielded a  $^{40}\text{Ar}/^{39}\text{Ar}$  date of  $81.14 \pm 0.51$  Ma, but it is unknown how this bentonite correlates within the Milk River (Hicks *et al.*, 1995).

Ammonites have been used to subdivide the Montana Group into incremental time zones (Gill and Cobban, 1973) which, where possible, have been tied to  $^{40}\text{Ar}/^{39}\text{Ar}$  radiometric dates of sanidine from bentonites. The Santonian-Campanian boundary has been dated at  $83.5 \pm 0.5$  Ma, which occurs between the *Desmoscaphites bassleri* and *Scaphites leei* III ammonite zones (Figure 6). The top of the Milk River Formation and the correlative Eagle Sandstone is within the *Baculites* sp. (smooth) or *Baculites* sp. (weak flank ribs) zones. Ammonites collected from Milk River core included two that could be identified with some certainty (W.A. Cobban, pers. comm., 2000). Numerous large (up to 4 cm wide by 12 cm long), smooth-shelled baculitids are present in several

cores in the amalgamated shoreline sandstone and mudstone facies (Figure 7A). They have been identified as *Baculites* sp. (smooth) (W.A. Cobban, pers. comm., 2000) and are characterized by simple sutures and lack flank rib ornamentation. In the upper part of the amalgamated shoreline sandstone and mudstone facies (VII), these large smooth-shelled baculitids are also associated with large baculitids showing some weak flank ribs, but specimen preservation was too poor to permit identification.

Coiled ammonites have also been observed in several cores from the inner to outer shelf facies (III) and from the amalgamated shoreline sandstone and mudstone facies (VII). Preservation of most is too poor to permit identification. However, one specimen (Figure 7B) at 424.39 m in the inner to outer shelf facies, below the amalgamated shoreline sandstone

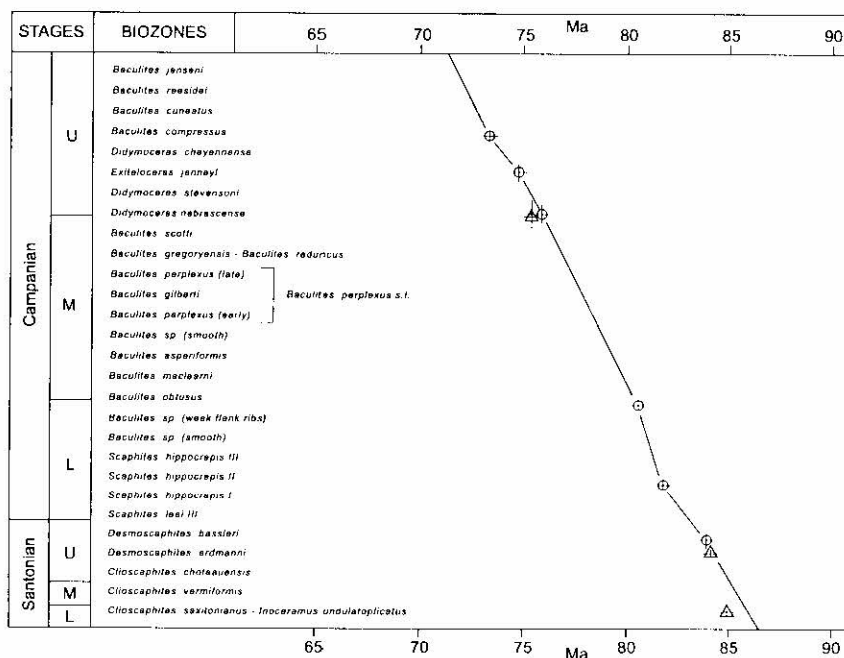
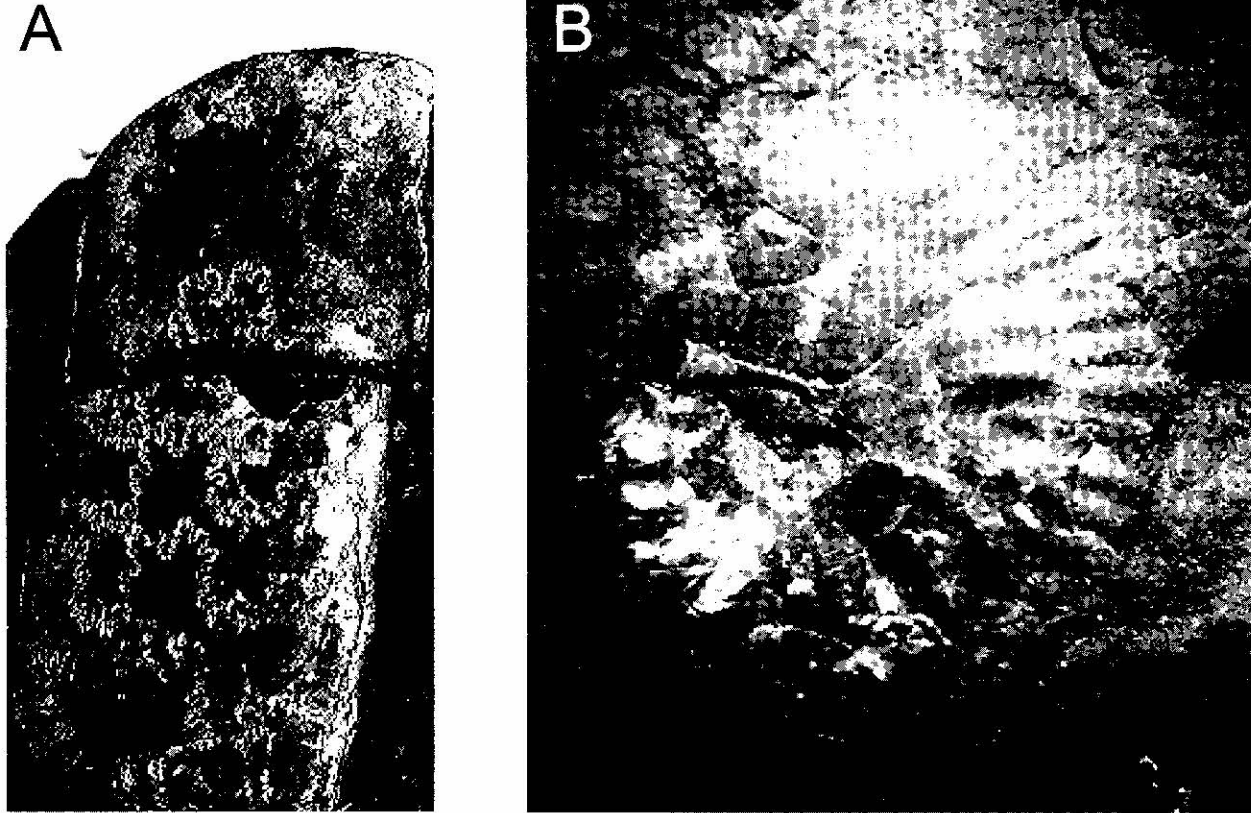


Figure 6 - Biostratigraphic chart showing ammonite zonation and their relative ages based on  $^{40}\text{Ar}/^{39}\text{Ar}$  radiometric dates of sanidine from bentonites (from Obradovich, 1993).



**Figure 7 - Photographs of ammonites in the Milk River Formation, Saskatchewan. A) *Baculites* sp. (smooth) from 721.17 m depth in the Seagull Staynor Hall 6-27-1-23W3 well. Note the simple suture pattern. Ammonite is 10.1 cm long by 3.05 cm wide. B) *Scaphites hippocrepis* sp. from 424.39 m depth in the Antelope et al. Smiley 12-28-30-25W3 well. Ammonite is 3.8 cm high by 3.3 cm wide. Identifications provided by W.A. Cobban, U.S. Geological Survey.**

and mudstone facies, in the Antelope et al. Smiley 12-28-30-25W3 well has been identified as a *Scaphites hippocrepis* sp. (W.A. Cobban, pers. comm., 2000), but the exact species (I, II, or III) could not be determined.

In general, age-diagnostic palynomorphs from the Milk River are lacking. Palynomorph assemblages have been reported from two intervals in the City of Medicine Hat Hatton 8-15-16-28W3 well (Gilboy and Nambudiri, 1991). The lower sample at 500.3 m is from the lowest part of the inner shelf to outer estuarine facies (V) of this report. Lack of characteristic index species from this sample prevented age and depositional environment interpretation. The upper sample at 436.61 m is from the amalgamated shoreline sandstone and mudstone facies (VII) of this report. The lithofacies described from this interval (Gilboy and Nambudiri, 1991; this study) is similar to that of the amalgamated shoreline sandstone and mudstone facies shown on the two cross-sections. The palynomorph assemblage indicated a Campanian age, which is in agreement with the *Baculites* sp. (smooth) fossils found in this lithofacies in other core.

Magnetostratigraphic dating of the Pakowki and Milk River has resulted in an equivocal age for the Milk River Formation when the results are interpreted within

the context of ammonite and foraminiferal zones (Leahy and Lerbekmo, 1995). The contact of polarity chron 33r-34n is placed within the Deadhorse Coulee, approximately 38 m above the contact with the Virgelle Member. This part of the Deadhorse Coulee was correlated to the middle and upper members of the Eagle Sandstone in Montana by Meijer-Drees and Myhr (1981). As such, the base of the polarity chron 33r should be somewhere within the *Scaphites hippocrepis* III and the *Baculites* sp. (weak flank ribs) zones. Leahy and Lerbekmo (1995) placed the base of the chron 33r within the lower part of the *Baculites* sp. (smooth) zone, which would make the contact between the 33r-34n in the Campanian. This age assignment is, however, at odds with magnetostratigraphic results in Europe where the Santonian-Campanian boundary is placed in the lower part of chron 33r (Perchersky et al., 1983). These inconsistencies indicate that the Milk River has a much more complex depositional history including the possible presence of internal sequence boundaries (O'Connell et al., 1999) than has been previously recognized. Until the complex facies relationships are completely worked out within a sequence stratigraphic context, the relationship of the polarity chron 33r-34n contact to the ammonite zones is in flux.

## 8. Gas Production

The Milk River Formation is the most underexplored of the three formations that characterize the southeast Alberta gas field (Figure 1). Currently all gas production is assigned to the Alderson Member of the Lea Park Formation; however, for discussion purposes, the term Milk River will be used to refer to the gas-bearing strata. Table 1 summarizes information on lithofacies, tested zones, initial production where available, drillstem tests, and current status of the wells shown in cross-sections A-A' and B-B'. The tested intervals are also shown on the two cross-sections (Figures 3 and 4). In many instances, because multiple zones within the Milk River were tested, it is impossible to tell which intervals are actually productive. In addition, other formations such as the Medicine Hat and the Belle Fourche (drillers' Second White Specks) are often tested at the same time and production is not always isolated to a particular formation. This makes it difficult to assess the actual productive potential and productive facies of the Milk River Formation.

In cross-sections A-A' and B-B', the main zones tested are within the inner to outer shelf facies (III), shelf sandstone facies (IV), and coastal sandstone facies (VI). On the wireline logs, targets appear to be the thin, cleaner looking sandstones that are interbedded with sandstones that are quite clay rich or are overlain and underlain by mudstone units. In the gas-bearing interval, some of the sandstones examined in core are very friable and vuggy (shown in Figures 3 and 4) indicating a lack of cementation. Both the clean and clay-rich sandstones are often carbonaceous, contain finely comminuted organic matter, and can have good porosities (12 to 20 percent) (Meijer-Drees, 1972; unpublished data this study). RockEval analyses of some of these sandstones (not the shales) indicate a total organic carbon content from 0.4 to 1.5 percent, although the average is from 0.4 to 0.6 percent. This low level of organic matter content is believed to be sufficient for generation of biogenic gas; only 0.5 percent is thought to be required (Clayton, 1992). Only wells 2 and 3 on cross-section A-A' (Figure 3) tested the amalgamated shoreline sandstone and mudstone facies (VII) of the Milk River. The productive potential of this facies has not been adequately tested. The amalgamated shoreline sandstone and mudstone facies (VII) is gas productive in some wells in the Medicine Hat area (Meijer-Drees, 1972), but the most productive facies at that location are in the inner shelf to outer shelf (III) and shelf sandstone facies (IV) described in this report. The lack of gas productivity in the amalgamated shoreline sandstone and mudstone facies (VII) may reflect the general lack of interbedded carbonaceous mudstones which are thought to be the main source for the gas (Meijer-Drees, 1972).

Figure 8 shows the main gas producing area in the Milk River Formation and areas where Milk River and Medicine Hat gas is commingled. This production appears to be disconnected from the seaward pinch out of the sands that define the Virgelle Member (Figures 8A and 8B). However, along the west margin of the

current gas field on a line between Brooks and Medicine Hat, many of the productive wells produce water, suggesting at least some link to the updip recharge area to the south and southwest. The current extent of the Milk River gas field might simply reflect past drilling practices, having grown by step-out drilling from productive single completion wells. Some of the scattered wells, which have been tested between the main gas field and the Virgelle sandstone pinchout, do contain gas (Meijer-Drees, 1972); however, the current practice of testing only a few thin, isolated sandstone beds, based on their geophysical log characteristics, suggests that pay zones may have been overlooked. The shaly nature of the rocks (this study; Meijer-Drees and Myhr, 1981) also suggests that wireline log responses may not adequately reflect the presence of gas. Subsurface cross-sections (Meijer-Drees, 1972; Meijer-Drees and Myhr, 1981; unpublished sections this study) indicate that facies similar to those described herein extend updip to the south.

Gas production in the Milk River does not appear to be solely controlled by orientation of depositional facies. The trend of production occurs at an oblique angle to the inferred northwest-southeast-trending shoreline as suggested by the depositional limit of the Virgelle Sandstone. O'Connell *et al.* (1999) suggest that: a) the gas in the Alderson Member was trapped in offshore sandstones encased in shelf mudstones above a third-order sequence boundary, and b) this sequence boundary provided a discontinuity between these units and the shoreline sandstones of the Milk River, thus preventing the gas from migrating updip. Although two sequence boundaries or principal erosion surfaces may be present within the Milk River, the boundary itself is not the barrier to gas migration. The nature of the various lithofacies comprising the Milk River and their lateral and vertical juxtaposition in relation to the depth of incision of the erosional surfaces will determine the extent of gas accumulation, gas migration, and hydrologic connectivity. Thinly bedded sandstones are not necessarily impervious to gas or water migration. Hydrologic models that will examine the connectivity of groundwater flow in the outcrop succession of the Milk River to adjacent lithofacies that rest on the erosional surfaces in the subsurface are required before the extent of gas and water migration is known. Modeling should focus on the time of gas exsolution and migration and not on the present-day hydrologic regime.

Drilling may ultimately extend the Milk River gas field to the south (based on similarity of facies) modifying its current configuration. However, another control on the current position of the gas field should also be considered. This is the relationship of the position of the most favourable facies (inner to outer shelf (III), shelf sandstones (IV), and the coastal sandstones (VI) described in this report) in the Milk River Formation to the part of the Sweetgrass Arch where the structure contours flatten. The Sweetgrass Arch, a periodically active structure, achieved its present configuration during the Laramide orogeny (Thomas, 1974, 1979;

**Table 1 - Lithofacies, tested zones, initial production (or average daily production during first year when initial production is not available), drillstem test interval and results, and current status of wells listed in cross-sections A-A' and B-B'. Lithofacies tested are listed from top to bottom in the well. (IP), initial production; (F), average daily production during first year; (C), commingled average daily production during first year. Test intervals of wells A4, A5, B1, and B2 shown in feet and A1 to A3, A6; and B3 in metres. Producing = production from Milk River; Standing = well completed, cased, and ready for production. Data are from a database leased from Datashare International, Inc. and are current through June 1996.**

Well	Cross-section Location	Lithofacies	Tested Interval	Initial Production 10 <sup>3</sup> m <sup>3</sup> /d	Drillstem Test Interval and Results	Current Status
Esso et al. Cessford EX 6-3MH-24-13W4	A 1		Not tested		No Data	Produces from Medicine Hat
AEC A-13 Suffield 14-26-19-8W4	A 2	VII IV III-IV VI P1 P2	403.0 - 404.0 415.6 - 417.6 424.0 - 425.0 431.9 - 433.0 448.5 - 449.5	1.12 (F)	416.0 - 416.1 416.0 - 416.1 416.5 - 416.5 417.6 - 417.6 426.7 - 426.7 431.3 - 431.3 No Results	Producing
AEC A-10 Suffield 14-28-18-7W4	A 3	VII III IV III-IV VI P1 P2 II	379.1 - 379.6 380.3 - 381.0 390.8 - 391.4 393.7 - 394.1 400.4 - 402.8 404.4 - 405.0 407.6 - 408.4 409.1 - 410.0 416.8 - 419.0 420.1 - 421.5 422.3 - 423.0 429.2 - 429.7 432.5 - 433.4	4.40 (IP)	No Data	Producing
PEX IOD HB Medhat 10-14MR-15-4W4	A 4	III-IV V VIP2 II I	1290.0 - 1450.1	2.12 (F)	No Data	Producing
PEX Medhat 4-3MR-15-3W4	A 5	III III-IV V	1237.9 - 1248.0 1337.9 - 1341.9 1354.0 - 1359.9 1337.9 - 1359.9	3.74 (F)		Producing
CDN Roxy AEC Cypress 10-12-10-29W3	A 6	IV T1	561.0 - 565.0			Abandoned
Northrock 102 Medhat 10-27-18-1W4	B 1	IV III-IV V VI T1 II	1349.1 - 1350.1 1362.9 - 1363.8 1382.9 - 1383.9 1437.0 - 1438.0 1452.1 - 1453.1 1481.0 - 1482.0 1349.1 - 1482.0	11.69 (F)	No Data	Producing
NCO Horsham MT 11-8-18-29W3	B 2		1250.0 - 1685.0		No Data	Standing Production from Medicine Hat
BVI Hatton 6-22-17-28W3	B 3	III-IV VI T1	436.0 - 437.0 438.5 - 440.5 455.0 - 458.0	8.07 (C)	No Data	Combined Milk River and Medicine Hat

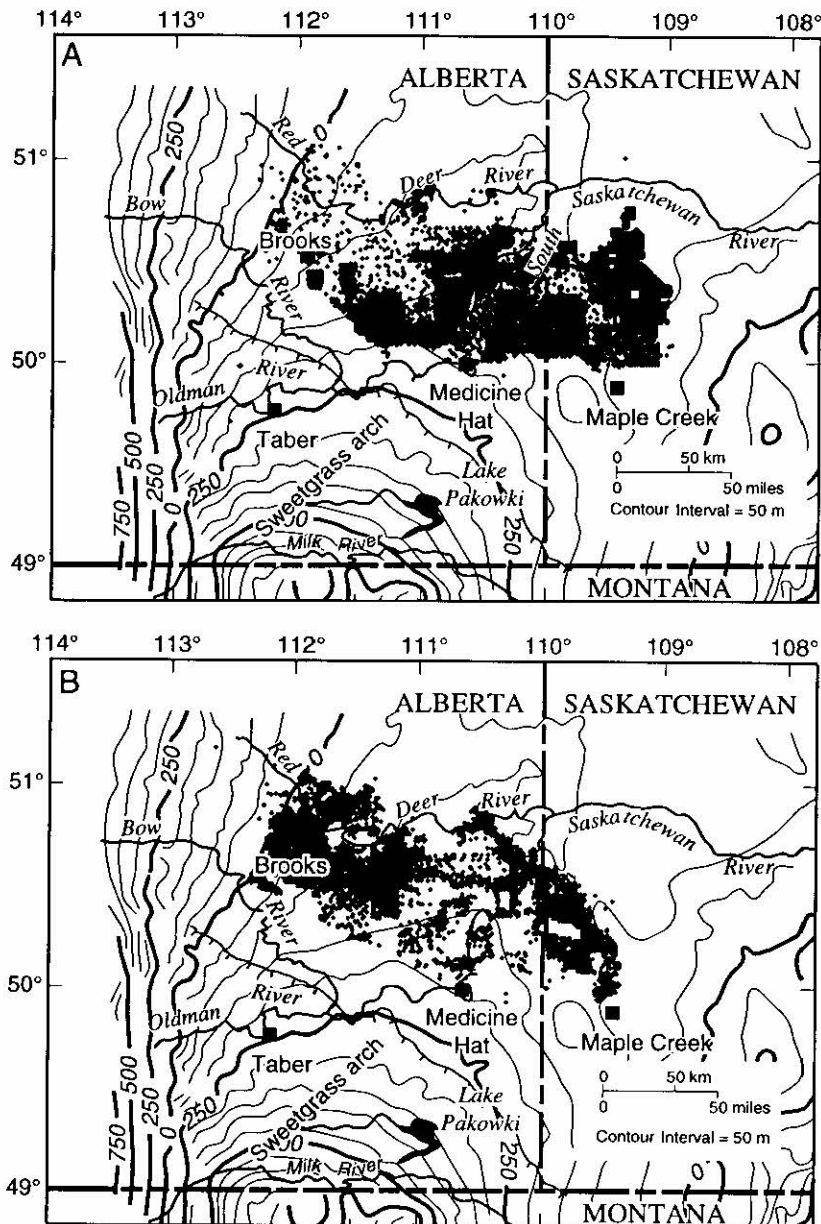


Figure 8 - Maps showing location of Milk River gas production and depositional extent of Virgelle Sandstone (hachured line). A) Gas wells producing only from the Milk River. B) Commingled Milk River and Medicine Hat producing gas wells.

Lorenz, 1982). Uplift of the arch placed the most favourable facies for gas generation and trapping in the Milk River Formation in a down-structure position on the arch. During the Laramide orogeny, when the Sweetgrass Arch was forming, a decrease in hydrologic gradient followed by a decrease in pressure due to subsequent erosion, permitted gas in solution or as a free phase to migrate. The gas was trapped in downdip parts of the arch where pinch out or truncation of facies occurs. Individual accumulations may have been locally sourced and eventually coalesced to form larger accumulations and permeability barriers to downdip water migration. During this process, gas exsolved and filled available pore space. Growth of the gas

accumulation occurred in the upstructure direction through permeable facies or laterally as waters were diverted around permeability barriers. The extent of the gas accumulation upstructure or laterally and the duration of gas migration and exsolution are not known.

## 9. Future Studies

Future studies will further refine the depositional model for the Milk River within a sequence stratigraphic context. These data will be incorporated with studies of the Eagle Sandstone in Montana (Rice and Shurr, 1983) and will form the geologic framework for future gas assessments of shallow biogenic gas in the Northern Great Plains.

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