The unknown giants - low-permeability shallow gas reservoirs of southern Alberta and Saskatchewan, Canada.

Shaun O'Connell*
Belfield Resources Inc., Calgary
belfield@shaw.ca

ABSTRACT

The gas reserves contained within the upper Cretaceous Milk River, Medicine Hat and Second White Specks sands in southern Alberta and Saskatchewan constitute the largest Canadian gas fields ever discovered (*figs 1 and 2*). These fields are characterised by their shallow depths, low-permeability clay-rich sands, and immature, locally generated biogenic gas.

The combined fields cover an area in excess of $35{,}000^2$ km. There are approximately 25,000 wells producing from the Milk River formation; 20,000 wells producing from the Medicine Hat formation; and 5,000 wells producing from the Second White Specks interval. These formations are usually treated as a composite play, because much of the production is commingled throughout the region. The lack of segregated production data, and the unconventional low-permeability characteristics of the producing sands, means that there are no accurate reserve estimates. It is generally accepted that Milk River reserves are in the 10-12 TCF range, the Medicine Hat contains between 4 and 6 TCF, and the Second White Specks contains approximately 2 to 3 TCF. However, recent work concentrating on detailed reserve estimates in local field areas has shown that significantly greater reserves may be present, particularly within the Milk River Formation. Within the past four years two major new gas producing trends have been discovered within these formations in Saskatchewan, far to the east of the previously existing field boundaries.

Despite their enormous economic importance, very little has been published about the geology of these fields and their internal stratigraphic framework. There are three main reasons for this neglect.

(1) The gas usually occurs in broad sheet-like sands that are distal marine in character. These sands have been regarded by many as generic, lobate offshore sands. Development of these sands has been by step-out or infill drilling and stratigraphic analysis has not usually been regarded as important for exploration success.
(2) The units are difficult to work with. The formations are very muddy and the sands are silty to very fine-grained and can be very thin. Smectitic clays often obscure the nature of the facies. Geological variations are subtle, and require a great deal of repetitive work utilizing an enormous number of well to yield insight.
(3) Due to low rates of recovery these fields were economically marginal throughout much of their history and attracted little attention. Economic

conditions have changed considerably in recent years and new exploration has opened up significant new play trends.

Production from the equivalent stratigraphic units in Montana has mainly been confined to large structural uplifts. In Alberta and Saskatchewan the fields lie downdip of the main structural uplifts and are mainly stratigraphic in origin, although local structure is extremely influential. I will briefly outline the main play types in each of the three formations with particular emphasis upon the Milk River Formation since this contains the greatest resource and is the most unconventional unit, with an apparently unique stratigraphic style.

The Second White Specks Interval

The late Cenomanian Second White Specks sands (Belle Fourche Formation) lie within the Upper Colorado Group shales of Southern Alberta and Saskatchewan. The great majority of the Second White Specks interval consists of offshore marine mudstones that are characterized by coccoliths, fish debris, and shells. The calcareous coccolithic debris gives the mudstones their characteristic white speckled appearance and this material is often concentrated at transgressive surfaces. The main reservoir facies was deposited in lower shoreface settings and consists of very fine-grained muddy bioturbated sands between 1 and 5m in thickness. Rare estuarine sands are also present.

The Second White Specks interval can be divided into two prominent stratigraphic units; the upper and the lower Second White Specks (*Fig. 3*). Both the upper and lower Second White Specks each contain progradational shoreface and high frequency lowstand deposits, with northwest-southeast shoreline trends, and each is overlain by a major transgressive surface and condensed section.

There are four Second White Specks play trends in southern Alberta and Saskatchewan (*Fig. 4*). 1) *The Hatton/Bigstick/Crane Lake trend*. These are lower Second White Specks reservoirs that are present mainly in Saskatchewan. Production is from three stacked sand units: the lowermost unit is a highstand shoreface sand that is truncated by a regional sequence boundary; the two uppermost units are transgressive shoreface sands. 2) *The Alderson/Suffield/Verger trend*. These are upper Second White Specks reservoirs and are present mainly in Alberta. Production is from a series of regionally extensive distal marine shoreline units. 3) *Senate, Merryflat, Cypress Lake, Garden Plains and in other localized areas*. Gas is trapped within elongate lowstand shoreface and estuarine, and transgressive sands incised into the top of the upper Second White Specks. 4) In several fields such as *Wymark*, *Cadillac*, *Elkwater and Monchie* there is production from muddy distal shoreface units due to local structural uplift.

The Medicine Hat Formation

The Santonian Medicine Hat Formation lies near the top of the Colorado Group in southern Alberta and Saskatchewan. The Medicine Hat interval is a predominantly marine shale section that contains a number of very fine-grained sandy progradational cycles. There are two distinct types of coarsening-upward cycle: type 1 - shaly shelfal successions that pass upwards from shales into thin heterolithic sand-shale intervals and silty sands; type 2 - sandy shoreface successions that pass upwards from shales into sands with relatively high energy shoreface characteristics.

Fig. 5 is a map of the type 2 sandy shoreface successions within the Medicine Hat Formation. These form three large isolated NW-SE trending sand bodies. The Medicine Hat A sand is 175km x 130km in size and straddles the Alberta-Saskatchewan border; a sand to the west of this measuring 150km by 130km in size is referred to as the Medicine Hat A1 sand; a third unit is present in northern Montana and southern Saskatchewan measures 50km by 100km in size, and is referred to as the Medicine Hat D unit. The cross-section in figure 6 shows the relative stratigraphic position of these sands. The Medicine Hat A, A1 and D sands are interpreted as isolated lowstand shoreface units of possible deltaic origin. The great majority of Medicine Hat production is from the A and A1 sands; trapping is predominantly stratigraphic within the isolated sand bodies. The intervening units consist of stacked type 1 units that are interpreted as distal prograding highstand systems tracts with predominantly ENE-WSW shoreline trends. These form secondary reservoir zones underlying the main type 2 reservoir sands and are of minor importance.

The Milk River Formation

The Santonian to Campanian Milk River Formation in southern Alberta and Saskatchewan forms a northward tapering sandy clastic wedge. This is the first Upper Cretaceous clastic wedge in this part of the Western Interior foreland basin, and it marks the termination of Colorado Group deposition. Shoreline and coastal plain sediments of the Milk River Formation are exposed along the Milk River near the U.S. border. These pass northwards into offshore marine shales, siltstones, and fine-grained sandstones of the Alderson Member, which hosts the Milk River gas field.

In outcrops the Milk River Formation forms a shallowing-upward facies succession from offshore sands and shales to shoreface and shoreline sandstones, and coal-bearing, non marine coastal plain deposits. Subsurface correlations of these units show that they form a series of seaward stepping shorefaces that downlap to the northeast and are interpreted as a northeasterly prograding highstand systems tract of probable third order frequency. This Milk River succession is non-productive in Alberta and Saskatchewan.

There is a major unconformity separating the shoreline sediments of the Milk River Formation from the shelfal deposits of the Alderson Member. Palynological evidence shows that the Alderson Member is younger than the rest of the Milk River formation and that the sequence boundary represents a hiatus of approximately 3 million years (O'Connell et al., 1992). The unconformity is marked by a distinct lag with chert pebbles and concretions. Little truncation is observed below the unconformity, but well log markers show an onlapping relationship above.

An isopach of the Alderson Member (*Fig. 7*) shows that it thickens from 110 m in the southwest to 200 m to the east in Saskatchewan. The Alderson is very fine grained and homogenous with two broad subdivisions: a lower sandy interval containing multiple, irregular graded sandy units between 4m and 10m thick; and an upper Alderson which is more shaley with fewer graded units (*Fig. 8*).

Alderson Member Lithologies

Alderson Member lithofacies can be classified on the basis of four characteristics:
1. Lithological composition; all Alderson Member lithofacies contain very fine-grained sand, silt, and mud in varying proportions, and all three components are always present.
2. Degree of stratification; Alderson Member sediments, with the exception of the most distal shales, are highly mixed. This mixing results from a combination of the primary compaction of the muddy sediments, and bioturbation.
3. Sedimentary structures; A limited range of sedimentary structures are present. Deposition was in a wave-dominated environment, and preserved structures are wave-ripples, low-angle to undulating sand and silt laminae, and graded units.
4. Ichnology; Alderson Member sediments have been bioturbated by an abundant, though limited, ichnoassemblage. This is a stressed Cruziana assemblage dominated by grazing and deposit feeding organisms. Dwelling and suspension feeders were supressed by the high proportion of mud in the water column.

Typical Alderson lihofacies are: silty and muddy sandstones; sandy and muddy siltstones; and sandy and silty mudstones. Each of these may have a predominantly laminated or mixed texture.

Stratigraphic unconformities

There are many stratigraphic unconformity surfaces within the Alderson Member, indicating significant sea-level variations and many periods of depositional hiatus. There was subaerial exposure during the mid-Alderson, indicated by a thin pedogenic surface. Chert and quartz pebble layers are present at regionally extensive unconformity surfaces. Intraformational pebble conglomerates occur at irregular intervals in the upper part of the lower Alderson. These layers are up to 50cm in thick and consist of large clasts of sandstone, siltstone, and reworked sideritic nodules. There are also accumulations of glauconitic greensands several tens of cm thick, indicating significant depositional hiatus.

Alderson Member Stratigraphy

Alderson stratigraphy is summarised in *Fig. 8*. The Alderson Member is interpreted as a lowstand systems tract of probable third order origin. The lower Alderson is a broadly progradational unit that onlaps the basal unconformity from north to south. The sandy graded units with the lower Alderson do not have a predictable stacking pattern but form imbricate layers several townships in size. The upper Alderson is a composite unit . The lower part of the upper Alderson succession consists of a series of shoreface sands (developed well to the south of the field area and non-productive) and their offshore marine equivalents that downlap onto the top of the lower Alderson. The lower part of the upper Alderson succession was truncated by a later stratigraphic unconformity or upper sequence boundary. The succeeding upper Alderson deposits are distal marine in character, with no preserved shoreline sediments. They appear to onlap the upper sequence boundary and are truncated by the transgressive surface at the top of the Milk River.

The most likely depositional setting for the Alderson Member sediments is that they are offshore marine, silt-dominated delta-plume deposits. The stratigraphic equivalent of the Alderson Member to the south in Montana is the Upper Eagle Formation. The Upper Eagle consists of sandy shoreline sediments dominated by a series of large, stacked deltaic systems that appear to have directly sourced the Alderson Member (Payenberg, 2002). The Alderson Member is the offshore equivalent of a series of Eagle Formation deltas that were established in northern Montana during the Campanian. These deltas provided a continuous supply of fine-grained sand, silt, and mud to the marine basin to the north. There were many episodes of relative sea-level fall and rise during this time, but the deltas were re-established following each such episode.

The trapping mechanism for the Milk River gas field (*Fig. 10*) is highly variable and not fully understood. The eastern edge of the main producing trend is structural, since the Milk River drops off into the Moose Jaw syncline. Recent discoveries have shown that the Milk River is capable of production to the east of the Moose Jaw syncline. Local structural trends have also influenced the location of the southern edge of the field in Saskatchewan. The northern and western limits of the field are economic edges that are formed by the gradual northward decrease in sandy and silty lithologies. To the south the field limits are partly determined by updip stratigraphic pinchout and partly by hydrodynamic influences, especially in the upper Alderson.

References

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Payenberg, Tobias H.D. 2002
Litho-, chrono- and allostratigraphy of the Santonian to Campanian Milk River and Eagle Formations in southern Alberta and north-central Montana: implications for differential subsidence in the western interior foreland basin. University of Toronto Ph.D. Thesis.

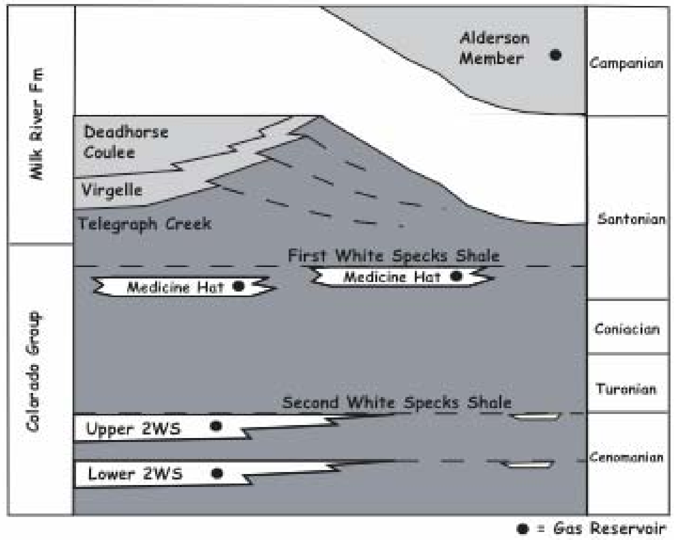


Figure 1 - Shallow gas stratigraphy southern Alberta and Saskatchewan

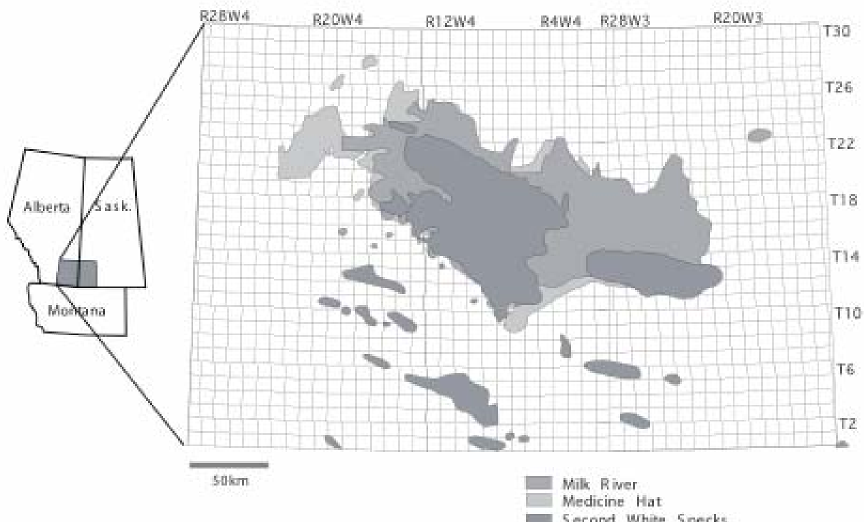


Figure 2 - Shallow Gas fields

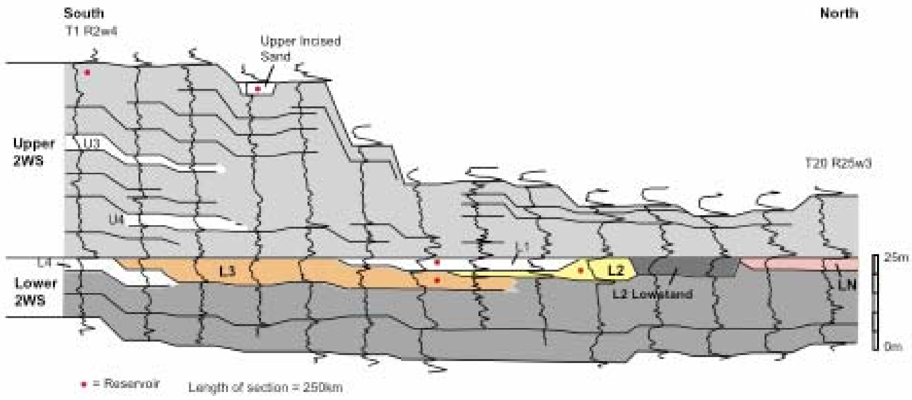


Figure 3 - Gamma log cross-section of the Second White Specks (Belle Fourche) interval - Alberta and Saskatchewan

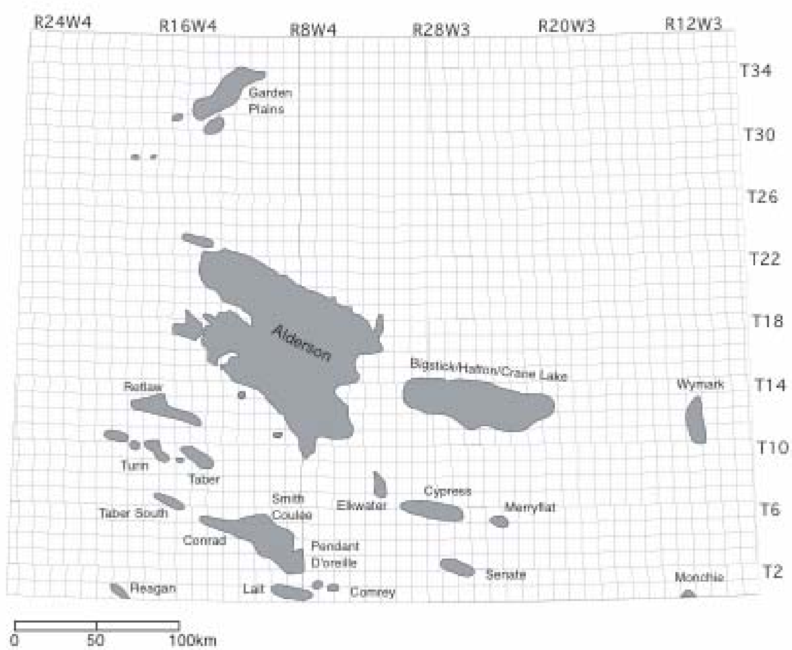


Figure 4 - Second White Specks fields

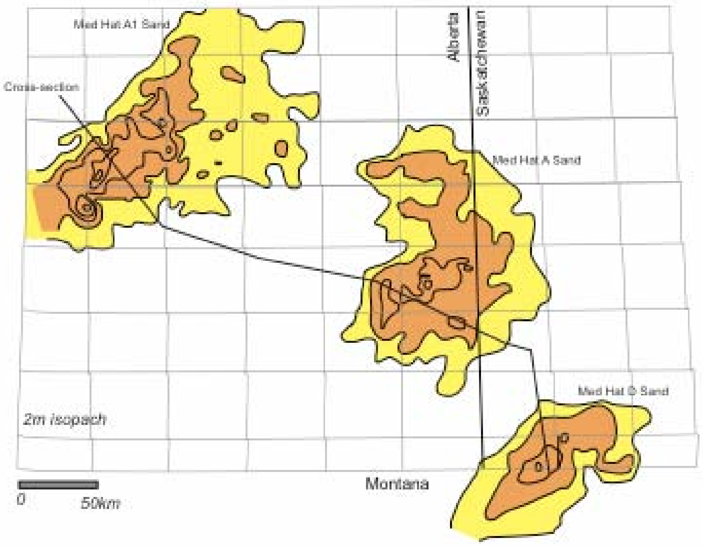


Figure 5 - Net sand isopach: Medicine Hat type 2 (lowstand) sands

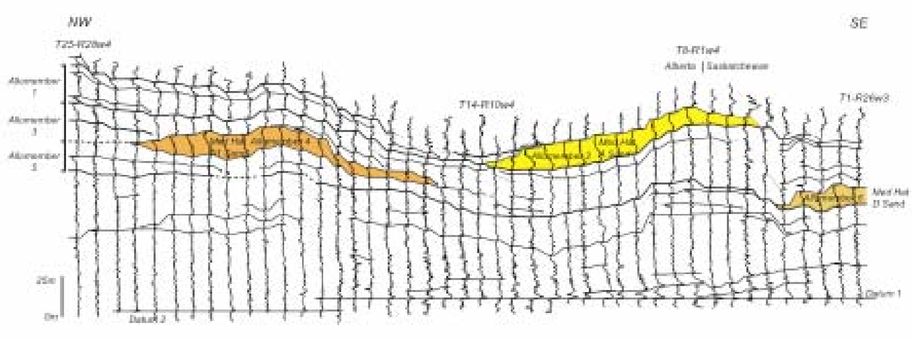


Figure 6 - Medicine Hat Formation
NW-SE regional stratigraphic gamma-log cross-section
showing allostratigraphic framework (see figure 4 for location)

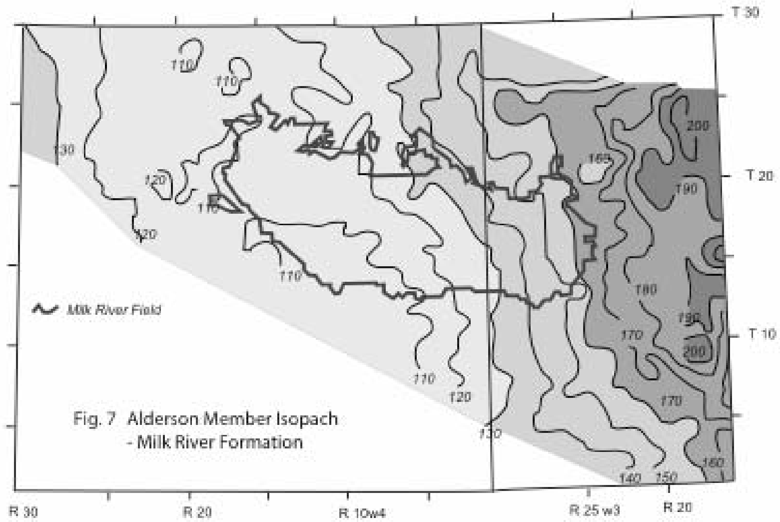
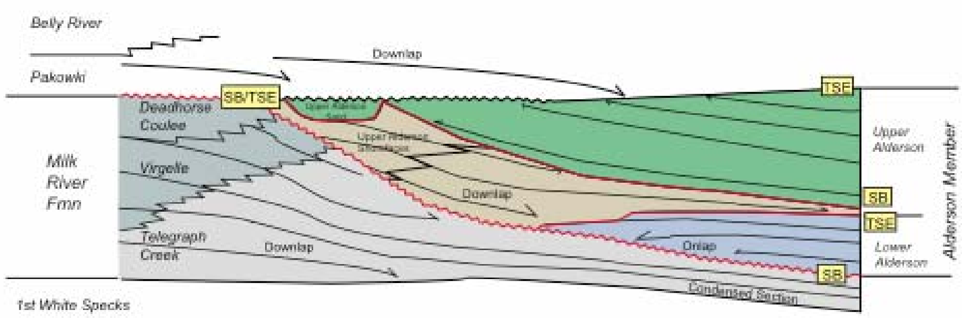


Fig. 7 Alderson Member Isopach
- Milk River Formation



TSE = Transgressive Surface of Erosion
SB = Sequence Boundary

Fig 8 - Regional Milk River / Alderson Stratigraphy