The Cenomanian–Santonian Colorado Formations of Eastern Southern Saskatchewan and Southwestern Manitoba

Jim Christopher[1], *Melinda Yurkowski*[2], *Michelle Nicolas*[3], *and Jim Bamburak*[3]

Christopher, J.E., Yurkowski, M., Nicolas, M., and Bamburak, J. (2006): The Cenomanian–Santonian Colorado formations of eastern southern Saskatchewan and southwestern Manitoba; *in* Gilboy, C.F. and Whittaker, S.G. (eds.), Saskatchewan and Northern Plains Oil & Gas Symposium 2006, Saskatchewan Geological Society Special Publication 19, p299-318.

Abstract

The Cenomanian–Santonian Colorado formations of eastern southern Saskatchewan and southwestern Manitoba comprise (from oldest to youngest), (1) the Belle Fourche Formation (predominantly greyish black shale with basal "Fish Scales" zone, medial quartzose Okla Sandstone and upper Ostrea calcarenite, bentonite and black shale), (2) the Second White Specks or Favel Formation (Keld and Assiniboine members) of coccolithic and shell calcarenite with subordinate marlstone and shale, (3) the Carlile Formation, inclusive of the Morden black shale and Boyne repetitive sequences of coccolithic and shell calcarenite with subordinate marlstone and shale, and (4) in eastern Saskatchewan, the erosional remnant of the Santonian argillaceous Niobrara Formation of western Saskatchewan under the Campanian Milk River (Gammon) Formation. All units below the Niobrara crop out in the bluffs of the Manitoba escarpment in the east of the study area and are traceable westward through cored and geophysical well log sections. Current usage in Saskatchewan treats the 'Fish Scales' as a formation separate from the Belle Fourche. In Manitoba it is a basal marker bed of the Belle Fourche, and, in view of its less than 10 m thickness, is treated as such in this study. The Belle Fourche upper contact is drawn on the 'X' Bentonite, which in this study is taken as the uppermost of a series of thin bentonites above the Ostrea beloiti beds. The Okla Sandstone is prominent above the Fish Scales zone in the northern part of the study area and is developed as graded laminae of fine grained, quartzose sand and black shale.

The Belle Fourche shale is thickest in southwestern Manitoba, and is transitional through the 'X' Bentonite bed into the Keld Member of the Favel formation by means of upward-shallowing sequences of black, noncalcareous shale, calcareous shale and coccolithic calcarenite. The Keld Member can be divided into three downlapping sequence sets which appear to be imbricate clinoforms that attenuate to the west and northwest in Saskatchewan. The basal set, Keld A, is capped by a subaerial unconformity in the east and a patterned hardground in the west. Keld B and C are likewise differentiated on the basis of sharp, irregular contacts as well as by changes in depositional pattern. The Assiniboine Member is recognized by its multiple, sharp-based, thin sequences of bituminous black shale, inoceramid-dominant bioclastic limestone with intercalated bentonites. It is partially truncated to the north and west in Saskatchewan under the black shale of the Morden Member of the Carlile Formation. The Morden is thickest in the eastern half of the study area, but attenuates westward into the lower third of the dark grey, argillaceous Carlile Formation of western Saskatchewan, and everywhere is in erosional unconformity on the Second White Specks Formation. Conversely, the Boyne parasequence sets of coccolithic calcarenite and marlstone thicken westward, but likewise grade into the dark grey shale of the western Carlile Formation. In the study area, the Morden – Boyne pair is a stratigraphic and sedimentological re-iteration of the underlying Belle Fourche–Second White Specks (Favel) parasequence sets. The Turonian Carlile Formation on a west to east transect, underlies the Santonian Niobrara Formation in the extreme west of the study area, and, toward the east, the Campanian Milk River (Gammon) and Lea Park (Pierre) formations by virtue of their off-lapping basal unconformities.

Keywords: Upper Cretaceous, Upper Colorado, Cenomanian, Turonian, Coniacian, Santonian, Campanian, Belle Fourche, Second White Specks Formation, Carlile, Morden, Boyne, Niobrara, Milk River Formation, Favel Formation, First White Specks, Amaranth Successor Sub-basin, Punnichy Arch, Swift Current Platform.

[1] Geological Consultant, 252 Coldwell Road, Regina, SK S4R 4L2
[2] Petroleum Geology Branch, Saskatchewan Industry and Resources, 201 Dewdney Avenue East, Regina, SK S4N 4G3;
E-mail: myurkowski@ir.gov.sk.ca
[3] Manitoba Industry, Economic Development and Mines, Petroleum Branch, 360-1395 Ellice Avenue, Winnipeg, MB R3G 3P2;
E-mail: mnicolas@gov.mb.ca or jbamburak@gov.mb.ca.

1. Introduction

Mapping of the Phanerozoic formations in the eastern half of southern Saskatchewan and southwestern Manitoba was initiated in 2003 as part of a larger project known as the Williston Basin Architecture and Hydrocarbon Potential Targeted Geoscience Initiative (TGI 2) Project. This trans-provincial mapping project is a collaborative undertaking by Saskatchewan Industry and Resources, Manitoba Industry, Economic Development and Mines, and the Geological Survey of Canada aimed, in part, at providing correlatable continuity for all the major Phanerozoic stratigraphic units present in the region. The overall context for this component of the project is, in essence, the furtherance of objectives for oil and natural gas exploration in the Cretaceous. Because of the great distances between Upper Colorado sections sited in different regions of an active, partially compartmented, orogenic Western Interior Basin, transfer of formation names from one location to another carries risks attributable to facies changes and dynamic sea-floor accommodation space. Thus classic names such as Mowry, Fish Scales, Belle Fourche, Second White Specks, Carlile and Niobrara have been transferred to other localities by a succession of authors, commonly with different results. The present paper may not be an exception to this process. Its scope is, however, limited to the establishment of stratigraphic equivalencies across the study area of eastern southern Saskatchewan and southwestern Manitoba in the context of reference sections established in southwestern Saskatchewan and the eastern outcrop belt.

The nomenclatural history of Colorado Group strata in the outcrops of southwestern Manitoba since the time of Dawson (1859), who first dated them as Cretaceous, is detailed in McNeil and Caldwell (1981) and therefore is not pursued further in this paper. These strata were laid down in the eastern part of the Western Interior Seaway, a distal sedimentary region controlled by broad, shallow, bathymetric surfaces supported by differentially re-activated craton blocks, and are, in general, sourced from the east. The counterpart Colorado Group strata of southwestern Saskatchewan are deposits on the western flank of the seaway, a region immediately outlying the orogenic Rocky Mountain belt and therefore western sourced. Correlation of the eastern outcrops with the reference sections of southwestern Saskatchewan has been largely accomplished by faunal extrapolation across a vast *terra incognita*. The more recent major papers (Bloch *et al.*, 1999 and Schröder-Adams *et al.*, 2001*)* dealing with correlation of the Manitoba outcrops to the western sections are amplifications of the faunal and stratigraphic syntheses of North and Caldwell (1975) and McNeil and Caldwell (1981). All of the foregoing authoritative sedimentological, faunal, floral, and geochemical studies utilize essentially, the same basic core and outcrop data, and therefore serve as the reference framework for this paper. The area of study (Figure 1) is situated between Range 4W3 in Saskatchewan and the outcrop belt of southwestern Manitoba, and between the International Boundary with North Dakota and Montana and the edge of the subcrop north of Township 52 in Saskatchewan. More than 36,000 bore holes penetrate the Colorado Group in the region, but only 20 are cored.

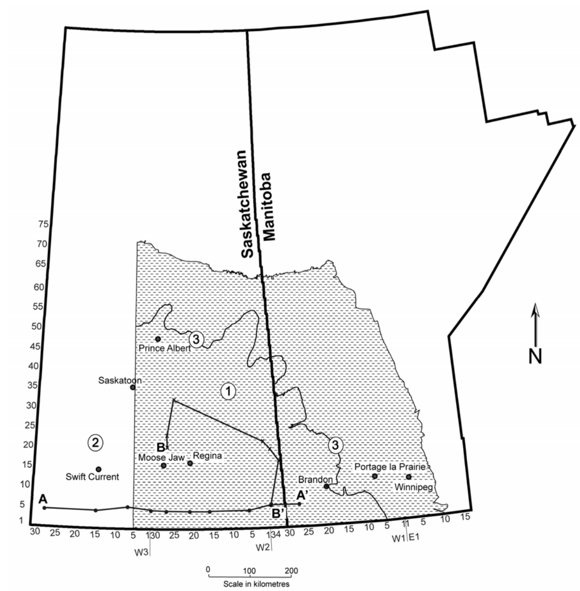

Figure 1 - Map of eastern southern Saskatchewan and southwestern Manitoba showing (1) the study area; (2) adjacent western area of Saskatchewan to the Alberta Boundary; (3) approximate northern and eastern erosional limit of the Upper Colorado subgroup in the study area, and (4) locations of stratigraphic cross-sections A–A' and B–B'.

The strata of interest comprise (oldest to youngest):

(1) the Belle Fourche Formation (predominantly greyish black shale with basal "Fish Scales" zone, medial Okla Sandstone and upper black shale with *Ostrea beloiti* and bentonites),

(2) the Second White Specks or Favel Formation (Keld and Assiniboine members) of chalk-speckled (coccolithic) and bioclastic calcarenite with subordinate inoceramid coquina, marlstone and shale,

(3) the Carlile Formation, inclusive of the Morden black shale and Boyne repetitive sequences of coccolithic and bioclastic calcarenite with subordinate marlstone and shale, and

(4) in the southwest of the study area, the erosional remnant of the Santonian argillaceous Niobrara Formation of western Saskatchewan under the Campanian Milk River–Gammon Formation (Yurkowski *et al*., 2006, Christopher *et al*., 2006).

The nomenclatural and chronostratigraphic settings of these formations are illustrated in Figure 2. All , other than the Niobrara of western Saskatchewan, crop out in the bluffs of the Mesozoic escarpment in the east of the study area, and are traceable westward through stratigraphic cross-sections based on core and geophysical well logs (Figures 3 and 4). Current usage in Saskatchewan treats the 'Fish Scales' as a formation separate from the Belle Fourche. In Montana to the south, it is incorporated as the uppermost unit of the

Mowry Formation (Ridgley *et al.,* 2001). In Manitoba, the Fish Scales is a basal marker bed of the Belle Fourche Formation and is utilized as such by McNeil and Caldwell (1981, p78). In view of the less than 12 m regional thickness, this usage is followed in the present study. The Belle Fourche upper contact in the east is drawn on the 'X' Bentonite (Collom, 2000; Schröder-Adams *et al*., 2001*)*, which in this study is taken as the uppermost of a series of thin bentonite beds, 3 to 11 in number, superjacent to the *Ostrea beloiti* zone.

2. Stratigraphic Setting

a) Belle Fourche Formation

Though generally categorized as homogeneous dark grey shale, the Belle Fourche stratal sequence is variously punctuated by high concentration of fish and reptilian bone debris, quartzose sandstone, *Ostrea* debris layers, bentonite, and in the uppermost part of the section, coccolithic marlstone. The Fish Scales marker bed by its high gamma count on the geophysical logs is readily traced across the study area, but its identity in core is more problematic in that the expected lithological character of black shale with associated fish bone and scale detritus is not exclusive to it. The presence of "sandy laminae" in association with such detritus (McNeil and Caldwell, 1981) is not helpful in precisely defining the unit in that quartzose sand is also widespread in the underlying Westgate Formation. However, Simpson (1979) describes and names the Okla Sandstone as a body possibly equivalent to the Fish Scales. The type section is the Imperial Okla 1-29-35-8W2 well at 372 to 380 m depth. The sandstone is quartzose, micaceous and kaolinitic, and has gently inclined and horizontal laminated layers ranging in thickness from a few millimetres to several centimetres. It is associated with several thin beds of bentonite and layers of concentrated fish debris, and grades downward into dark grey mudstone. The Okla Sandstone is traceable southward to Sohio Baysel Foam Lake No. 3 (Lsd. 4-6-26-9W2) and southeastward to Sylvite Ste Marthe 13-22-17-30W1 (Figure 3). The Belle Fourche Formation at the latter site lies at 304.8 to 266.2 m below Kelly bushing, (*i.e*., is 38.60 m thick) and is divisible into six units (bottom to top):

(1) The 11 m thick Fish Scales marker bed (depth 304.8 to 293.8 m) incorporating a basal 2.4 m thick, dark grey and greenish grey mudstone with intercalated yellow-green bentonite (0.16 m and 0.05 m thick), a medial 4.9 m thick, medium grey shale, and a 3.7 m thick, upper dark grey mudstone intercalated with cm-scale black shale and scattered concentrations of fish debris;

(2) the Okla equivalent bed (293.8 to 281.9 m) of medium grey, faintly laminated, graded, argillaceous, quartzose siltstone and shale, 11.9 m thick;

(3) dark grey mudstone (281.9 to 276.6 m), 5.3 m thick, grading upward by sporadic increase of pelecypod shell fragments into a

(4) 5 m thick *Ostrea beloiti* zone (276.6 to 271.6 m) of dark grey shale with abundant oyster shells and scarce fish scales;

(5) 6 m thick, dark grey mudstone (271.6 to 267.6 m) with scattered concentrations of white coccoliths; and a

(6) 1.4 m thick, greyish black shale intercalated with six bluish grey bentonites, 0.05 to 0.1 m thick, representative of the so-called 'X' Bentonite (interval 267.6 to 266.2 m).

A contact with the Second White Specks Formation, though picked at 266.2 m, is not identified in core. It is noted, however, that the sequence ending with the Keld A parasequence set of the Second White Specks formation is initiated at unit 5 above; *i.e*., on the *Ostrea beloiti* zone.

An excellent reference section for the Okla Sandstone is provided by the recently extracted core from the LMLE Simpson 6-28-29-24W2 well in the northwestern part of the study area, where the unit overlies the Fish Scales marker bed as a conspicuous, 22.3 m thick, graded, laminated fine-grained, quartzose sandstone and black shale unit, described as follows:

465.00 - 453.05 m:	Siltstone: argillaceous, dark grey; faintly laminated and current laminated in cm-scale truncation sets with mm-scale, dark grey mud caps; graded lenticles of light grey, very fine-grained, quartzose sandstone at 460.3 to 461.8 m (recovery *ca.* 35%).
453.05 - 446.00 m:	Mudstone: dark grey, scattered, starved ripples of laminated, quartzose siltstone at 446.8 m (remainder of unit broken up, with 100% loss between 446.8 and 453.0 m).
446.00 - 442.70 m:	Sandstone: quartzose, fine grained, light grey, calcareous to noncalcareous, friable; laminated as cm-scale ripple beds with minor bedding-aligned bioturbation pods and subordinate greyish black shale; sand content decreases upward as laminae become lenticular, starved-ripple layers, and section grades into mudstone and black silty shale against a sharp contact.

The *Ostrea beloiti* zone fossils are not present here, but the 6.81 m thick interval above 442.70 m is occupied by two upward-shallowing coccolithic shale to calcarenite sequences, continuous through the 'X' Bentonite zone, and transitional to the limestone of the Second White Specks, as follows:

442.70 - 441.35 m:	Mudstone: greyish black, laminated with about 20% quartzose, argillaceous siltstone and about 5% mudstone speckled with white, fine-grained, chalk.

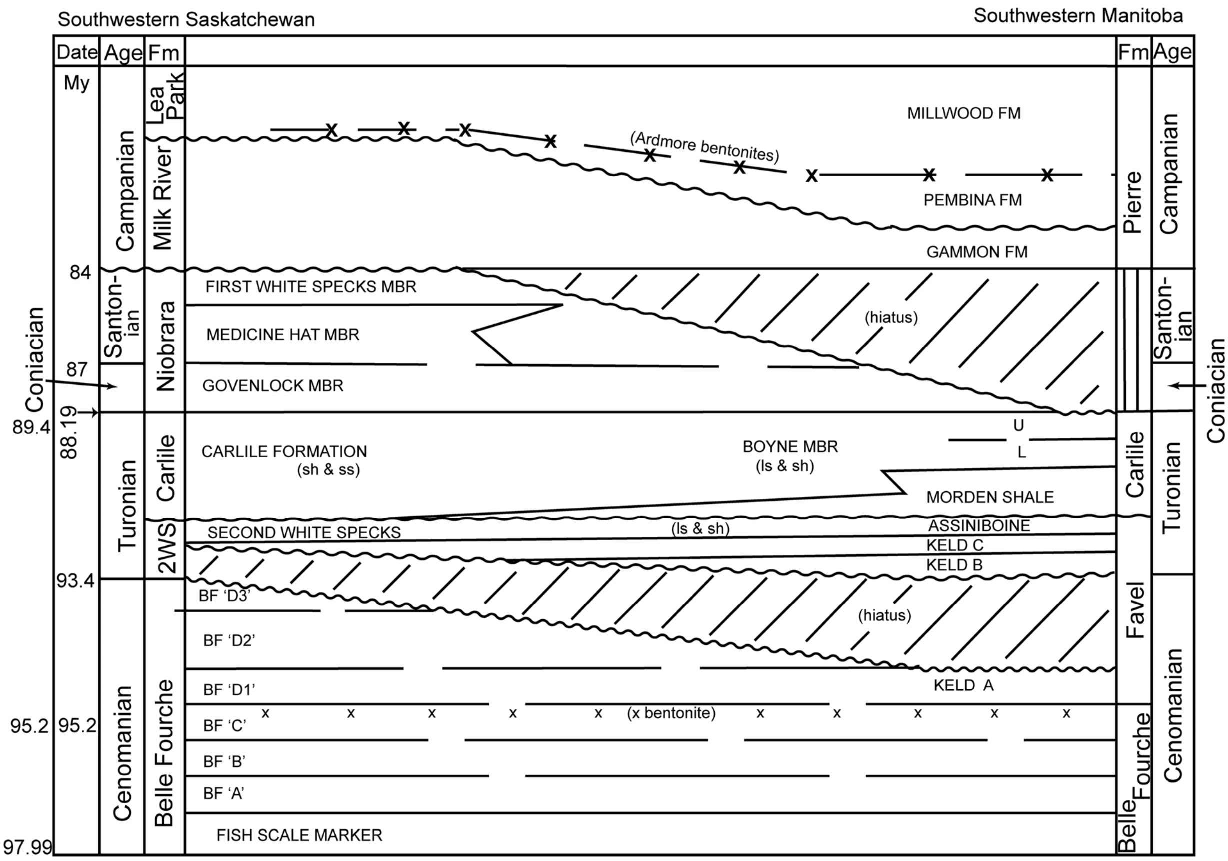

Figure 2 - Nomenclatural setting of the Cenomanian–Campanian formations of southwestern Saskatchewan with respect to the study area of eastern southern Saskatchewan and southwestern Manitoba. References: Ridgley et al. (2002); Collum (2000); Bloch et al. (1993); McNeil and Caldwell (1981); Caldwell et al. (1978).

441.35 - 438.80 m: Shale: greyish black, with about 5 to 7% silty partings; about 5% laminae include concentrated fish debris.
438.80 - 438.75 m: Bentonite: bluish grey.
438.75 - 438.25 m: Shale: as at 441.35 m.
438.25 - 437.76 m: Bentonite: bluish grey.
437.76 - 437.36 m: Calcarenite: light grey, laminated with fish-scale-strewn black shale; decreases above basal 0.1 m into greyish black shale with scattered coccolithic stringers.
437.36 - 437.26 m: Bentonite: light grey, interbedded at cm-scale with greyish black shale.
437.26 - 436.00 m: Shale: dark grey, calcareous upward; thin laminae of *Inoceramus* at decimetre-scale intervals; scattered laminae with high concentrations of fish debris.
436.00 - 435.89 m: Bentonite: bluish grey, massive ('X' by virtue of its position).

Second White Specks Formation

Keld B

435.89 - 434.45 m: Limestone: argillaceous, coccolithic, laminated, white- and brown-speckled; coccolithic laminae increase upward; abundant inoceramid shells. (Core continues).

Ridgley *et al.* (2001) in their study of the contiguous region of Montana, southwestern Saskatchewan and southeastern Alberta created a four-fold stratigraphic sub-division of the Belle Fourche labeled (oldest to youngest) A, B, C and D above a Fish Scales–Mowry Formation. In the west, the Middle Cenomanian 'X' Bentonite is included in Belle Fourche C, and therefore the subjacent Okla Sandstone equates with their "lower Belle Fourche sandstones" of units A and B. The three units constitute a Lower Belle Fourche (Figure 2). The Upper Belle Fourche D in their nomenclature comprises (oldest to youngest) subunits D1, D2 and D3, as parasequence sets truncated eastward successively beneath a Late Cenomanian, sub-Second White Specks unconformity. The D subunits at full section constitute more than half of the Belle Fourche thickness. In the eastern part of the Belle Fourche depositional basin, represented by the present study area, only the lower units of the Belle Fourche (A, B and C) and the basal portion of D1 above the 'X' Bentonite remain of units terminated northeastwardly against the Keld coccolithic marlstone and calcarenite. Northward truncation of the Belle Fourche argillaceous beds is also recognized by McNeil and Caldwell, 1981,

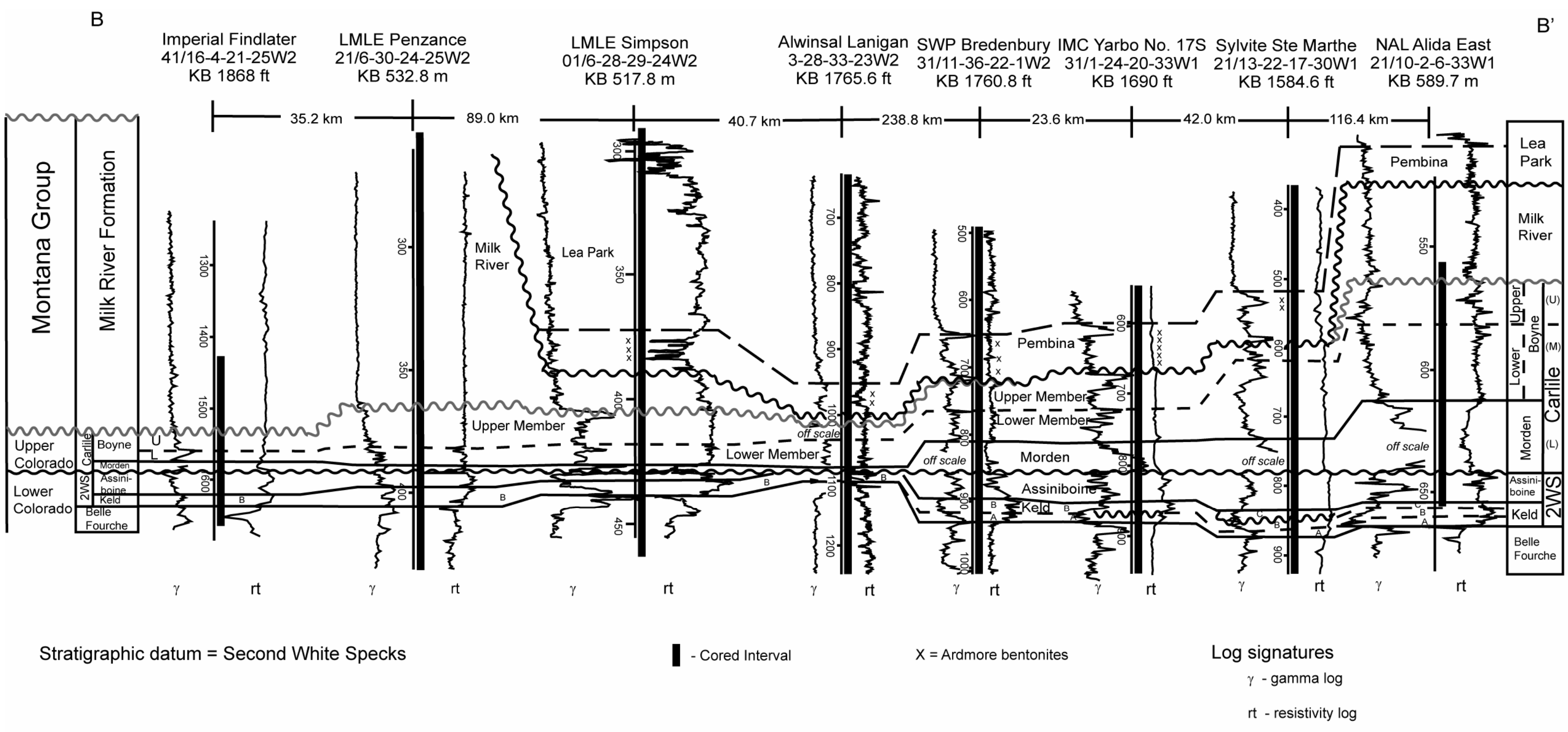

Figure 3 - Geophysical log stratigraphic section B–B′ of selected cored wells in eastern Saskatchewan.

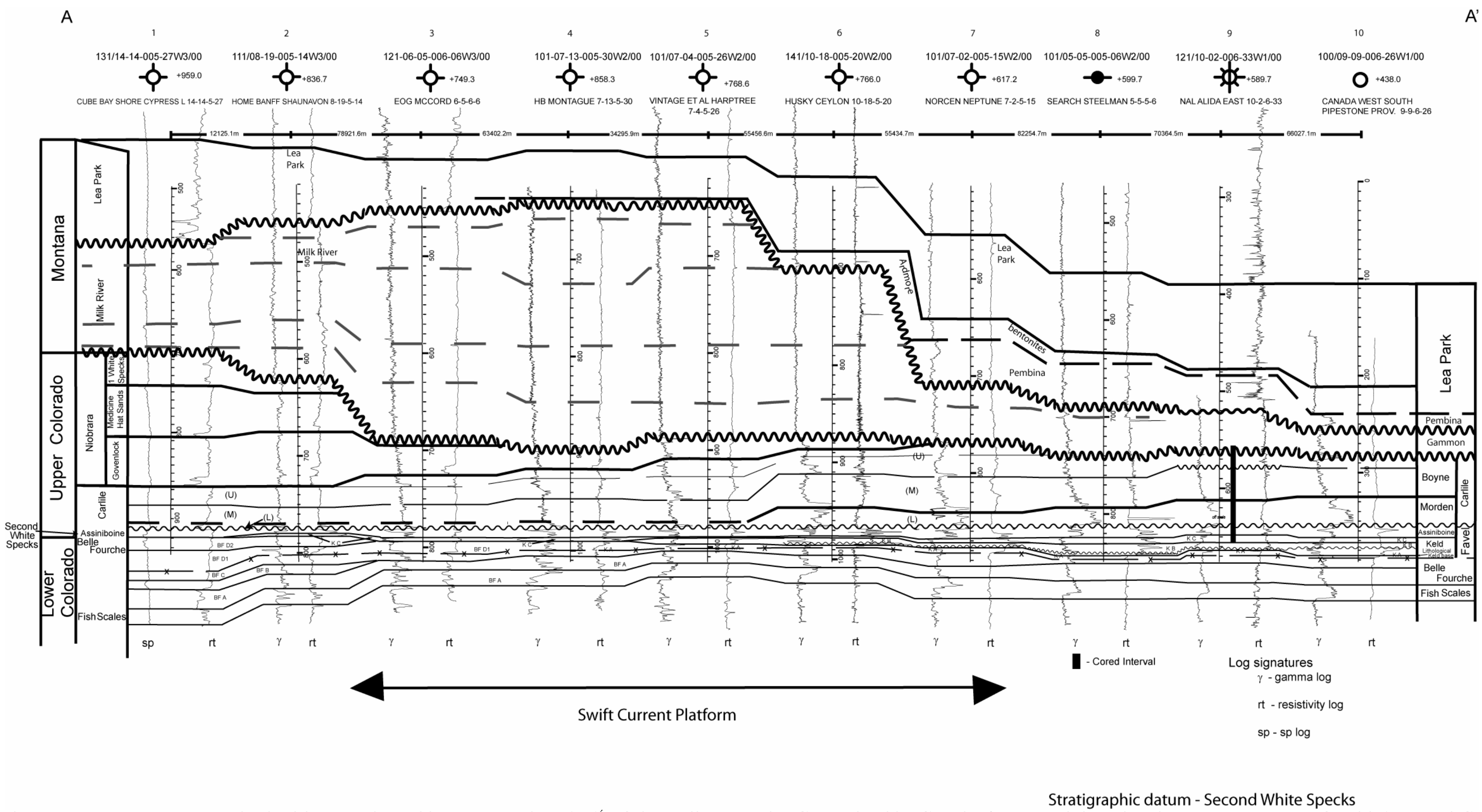

Figure 4 - West to east geophysical log stratigraphic cross section A–A´ of the Belle Fourche, Second White Specks (westward downlapping sequence sets of Keld A, B and C and Assiniboine), Carlile (Morden, Boyne), Milk River (Gammon) and Lea Park formations along townships 5 and 6, southern Saskatchewan and southwestern Manitoba. Datum is on the Second White Specks–Favel Formation).

p79) in the Manitoba escarpment where, in the south, the 'X' Bentonite lies 9 to 10 m below the calcareous Keld, but rises northward to within 5 m against an apparent sharp contact with the very calcareous and resistive Keld limestone. The core evidence for this erosion surface is apparent at the Yarbo 17S (Lsd. 1-24-20-33W1) well, where a regolith of kaolinitic seat earth and coal (described below) associated with this unconformity is preserved on a partially truncated Keld A marlstone that is transitional to the dark grey shale of the Belle Fourche through the 'X' Bentonite beds. Although the contact of the Belle Fourche with the Keld is picked at the base of the carbonate facies of the Favel Formation, the unconformity at the top of Keld 'A' in the study area renders Keld 'A', by virtue of its position on the 'X' Bentonite, a stratigraphic equivalent of the Belle Fourche Middle Cenomanian subunit D1. As illustrated in Figure 2, this unconformity rises stratigraphically, westward on the Belle Fourche to underlie the western Second White Specks Formation on subunit D3. Thus regionally, the Belle Fourche at the Second White Specks contact is Middle Cenomanian in eastern southern Saskatchewan and southwestern Manitoba (Collom, 2000), and Upper Cenomanian in southwestern Saskatchewan, where the Belle Fourche D unit overlies the 'X' Bentonite (Ridgley *et al*., 2001). The unconformity is therefore Late Cenomanian in age (Figure 2).

Depositional Basin

The Belle Fourche of the study area is thickest in the eastern half of the study area, where it forms a vast triangular wedge along the interprovincial boundary region (Figure 5). It thins northward from 52 m in the Williston Basin of North Dakota and Montana to less than 22 m in the vicinity of Township 44. The shale body is abruptly terminated to the east at the Cenozoic erosion front, where it thins sharply from a thickness of 32 m. The northern portion is elongated north–south, from Township 44 to Township 18 between ranges 2W2 and 29W1. Farther to the south, it expands to the southwest and southeast. The region contains a sub-basin that was a rejuvenation of the Jura-Triassic Amaranth Sub-basin and is hereinafter referred to as the Amaranth Successor Sub-basin, which was extant for the remainder of Colorado times. It apparently conforms to a Precambrian Superior Province block of north–south and east–west trends which, having undergone Jura-Cretaceous uplift, was depressed against outlying linear trends toward the west, namely the Tabbernor lineament belt (2) and the Moosomin–Hudson Bay structural belt (Churchill–Superior Boundary Zone [Li *et al*., 2005]) (3). The Amaranth platform was apparently tilted toward the southwest in response to deepening of the Williston Basin in North Dakota and eastern Montana. To the northwest of the Amaranth Successor Sub-basin, the Belle Fourche isopach pattern in Saskatchewan is shaped by local thickening in salt dissolution sinks of the Middle Devonian Prairie Evaporite, and thinning on draped peaks of the buried Paleozoic limestone topography between townships 20 and 40. Downwarp of the Williston Basin appears to have up-tilted the Punnichy Arch to form a shallow shelf flat, on which accumulated graded, fine-grained, quartzose Okla sand as submarine banks , probably by density currents from a distant estuary to the northeast of the study area. A similar region of thinning to the south of the Punnichy Arch, framed in part by the Prairie Evaporite salt-dissolution edge (6), apparently corresponds to an uplifted eastern front of the Swift Current Platform. The presence of upper Belle Fourche units southwestward into central Montana suggests that these units were preserved in an expanded Late Cenomanian Rocky Mountain foreland basin, and that there was a Late Cenomanian regional uplift of the study area across which the Upper Belle Fourche was truncated (Figure 4).

b) Second White Specks (Favel) Formation

Commonly referred to as shale or limestone, the Turonian Second White Specks Formation is used in the restricted sense of Ridgley and Gilboy (2001) to delineate that lithological unit made up of bituminous, bioclastic and calcarenitic limestone and marlstone and calcareous grey and black shale that is in unconformity with both the subjacent black and bentonitic shale of the Belle Fourche Formation and the superjacent black, carbonaceous shale in the lower part of the Carlile (Morden) Formation (Figure 2). Thus the Second White Specks Formation equates stratigraphically with the outcropping Favel Formation of Manitoba, which is sub-divided into the limestone-dominant, coccolithic Keld and the overlying inoceramid-dominant shaly Assiniboine members. The Favel members loose their individuality westward across the study area by depositional thinning, facies change, and truncation under the Morden Member of the Carlile Formation (Christopher and Yurkowski, 2005). A characteristic contact between the members is lacking, so picking of the member boundary on geophysical logs tends to be based on interpretation of the resistivity signature, the Keld being the more resistive lower unit (Figure 3). At Bainbridge Creek in the Pasquia Hills of eastern Saskatchewan, the Keld calcarenite is dominated by comminuted pelecypod shells and foraminiferal tests, and the 'white specks' include some 54 nannofossil species of coccolithic and rhabdolithic algae (Bloch *et al*., 1999; Schröder-Adams *et al*., 2001). The lower contact is lithological, and arbitrarily placed on the so-called "'X' Bentonite", as the defined top of the Belle Fourche Shale. However, the bentonite laminae of this series, displayed in all cores of the study area, are intercalated with a bedding sequence that grades from noncalcareous black shale of the Belle Fourche to the calcareous speckled shale characteristic of the Second White Specks. However, an unconformity at the base of the Second White Specks is described as present in southwestern Saskatchewan (Bloch *et al*., 1993, Ridgley and Gilboy, 2001). A comparable unconformity in the study area is apparently that on the westward attenuating, basal Keld A parasequence described below. Bedding sequences characterize the Keld. These are generally thin and cyclic (from deeper water greyish black shale upward to shallower water calcarenite and bioclastic limestone or the reverse), and number as many as 17. The Keld cycles reflect far-

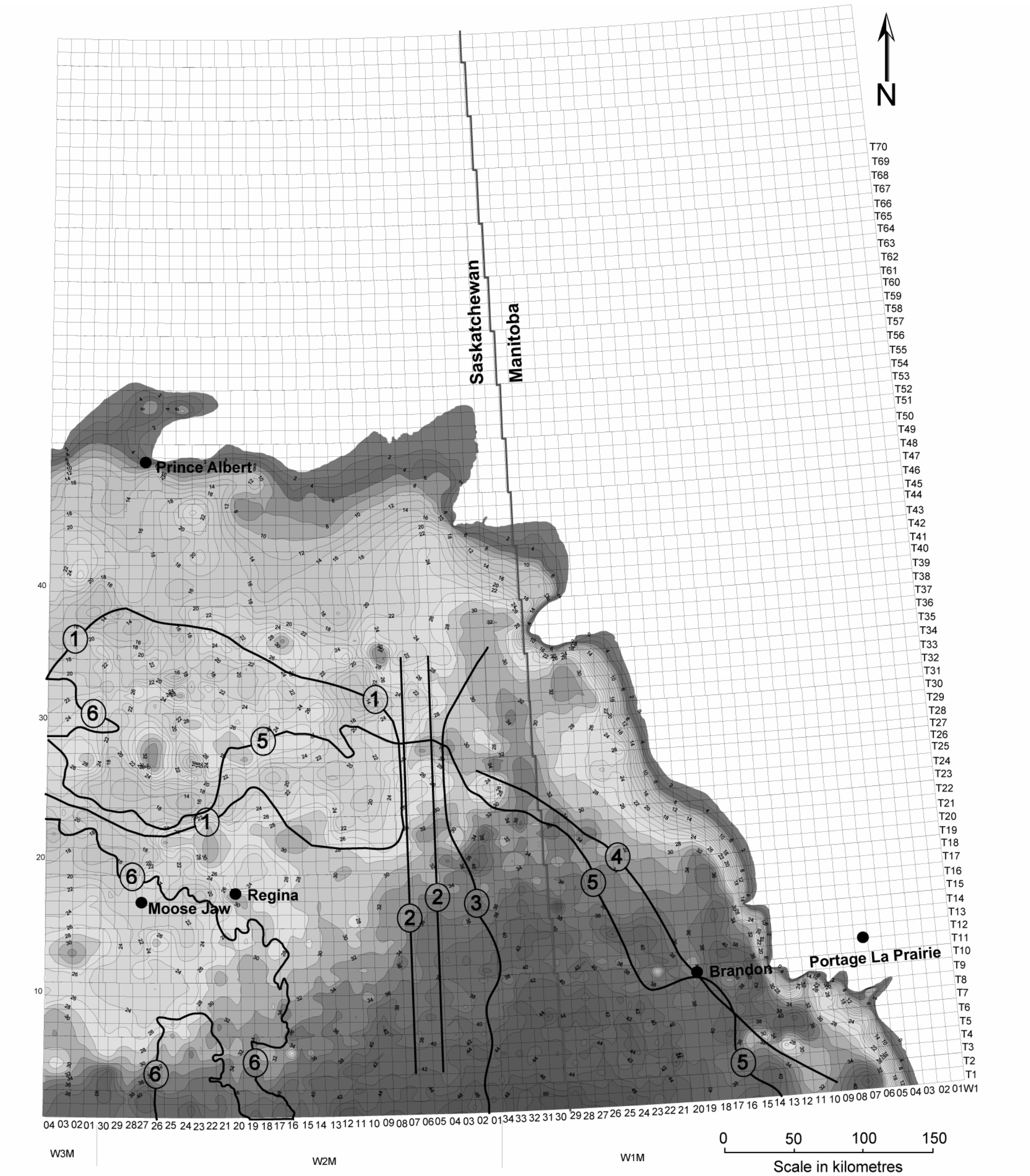

Figure 5 - Isopach map of the Belle Fourche Formation, eastern southern Saskatchewan and southwestern Manitoba. Contour interval is 2 m; also depicted: (1) Punnichy Arch (Christopher, 2003); (2) projection of the Precambrian Tabbernor lineament belt; (3) Moosomin–Hudson Bay structural belt (Churchill–Superior Boundary Zone [Li et al., 2005]), (4) axis of the Colorado sub-basin that, as a rejuvenation of the Jura-Triassic Amaranth Sub-basin, is referred to as the Amaranth Successor Sub-basin, (5) buried subcrop of the Mississippian Lodgepole Formation, (6) Prairie Evaporite salt-dissolution front.

ranging clinoforms and, in the study area, belong to three southwesterly downlapping parasequence sets (Wagoner *et al*., 1987), named (oldest to youngest) Keld A, Keld B and Keld C (Christopher and Yurkowski, 2005), see Figures 3 and 4. Bedding cycles of the Assiniboine represent a deeper water phase of the Keld. They are apparently distal tongues of submarine banks lost beyond the outcrop in Manitoba, in that they attenuate and increase in number southeastward into the Amaranth Successor Sub-basin. In the northwest of the study area the Assiniboine is truncated at the sub-Morden disconformity. The upper contact of the Favel (Second White Specks) Formation with the Morden Member of the Carlile Formation is seen as erosional in all cored sections except that in IMC Yarbo 17S (Lsd. 1-24-20-33W1), where the material representing the contact zone is apparently lost. The truncation of the Favel under the Morden in the outcrop belt is also described by McNeil and Caldwell (1981, p80).

Regional Lithological Relationships

The reference sections of the Keld and Assiniboine members of the Favel Formation in the outcrop belt of Manitoba are labeled 81 and 80 by McNeil and Caldwell (1981, pp368, 369) in Townships 23 and 24, Range 20Wl. At the first, 8.98 m of the Belle Fourche is exposed as greyish black shale grading into the olive-black, calcareous, chalk-speckled shale of the overlying 16.54 m thick Keld Member. It should be noted, however, that the lower 9.95 m of the type Keld is dominated by speckled shale intercalated with 11 bentonite seams, the uppermost of which is taken in this study as the 'X' Bentonite. The remaining section, *i.e*., 6.59 m, displays the more carbonate-rich, speckled, shaly and bioclastic limestone and marlstone with abundant Early Turonian pelecypods (*Mytiloides labiatus, Pseudoperna congesta,* and *Inoceramus corpulentus*), and the less abundant ammonites (*Tragodesmoceras carlilense and Collignoniceras woollgar, Scaphites larvaeformis,* and *Baculites yokoyamai*) and rare *I. cuvieri* characteristic of the Second White Specks Formation, and mapped as 'Keld' in this study. The Assiniboine Member at section 80 is 15.69 m thick, and largely made up of dark, olive-grey, calcareous, speckled shale which, above the lower 10.24 m, is calcarenitic with abundant fish fragments, calcareous worm tubes and pelecypods, and includes the 1.2 m thick, cemented 'Marco calcarenite' with fauna consisting of *Actinocamax manitobensis, Inoceramus cuvieri, Psuedoperna bentonensis* and *Serpula semicoalite*.

Parallel subsurface stratigraphic control, about 116 km to the west-southwest of the type outcrops, is provided by the line of fully cored wells in or about the Second Meridian in Saskatchewan (Figures 1 and 2) anchored by the section in the IMC Yarbo 17S (Lsd. 1-24-20-33W1) well. Here, the Second White Specks Formation is 23.75 m thick and partitioned between the 9.75 m thick Keld and the 14 m thick Assiniboine. The 'X' Bentonite is the uppermost of four bentonites, and is intercalated with calcareous marlstone over an interval of 1.8 m. The Keld displays bedding sequences which, on the basis of sharp, irregular contacts, are grouped into the three parasequence sets (Wagoner *et al*., 1987), represented by units Keld A, B and C. There are seven cyclic beds of which sequences 2 to 6 are upward transitions of marlstone to very fine-grained calcarenite, averaging 0.78 m in thickness, and lacking erosional upper and lower boundaries. These sequences are assigned to Keld B. The underlying Keld A is represented by sequence 1, which differs from the others in that, as a 4.3 m thick transition through the 'X' Bentonite from the black shale of the Belle Fourche to the marlstone of the Keld, it terminates at a 0.04 m thick, kaolinitic seat earth and remnant coal bed at an erosional surface. It also includes layers of fish-bone and fish-scale hash above the bentonite. The capping unconformity, although clearly delineated in only two of the seven cores examined, is traced regionally in the well logs, and appears in core at the Imperial Oxbow 15-36-2-3W2 well, 180 km to the south, as burrowed hardground near the base of the Keld. The Assiniboine Member at Yarbo 17S displays five sequences averaging 2.8 m in thickness, sharp contacts between beds, and a varied depositional style. Sequences 1 and 2 deepen upward from current-bedded, fine-grained calcarenite, laminated with subordinate marlstone, into marlstone laminated with subordinate greyish black, white-speckled shale. Sequences 3, 4 and 5 are upward-shallowing from greyish black shale to shaly calcarenite and bioclastic limestone dominated by *Inoceramus* and subordinate fish-bone and fish-scale debris. There are also five beds of yellowish green bentonite, 0.01 to 0.02 m thick, the first of which is basal to the Assiniboine. The member underlies the Morden Member of the Carlile Formation at an erosional contact.

The cyclic format and thickness of the Second White Specks remain consistent to the north and south of the Yarbo 17S reference well, as seen at SWP Bredenbury 11-36-22-1W2 and Sylvite Ste Marthe 13-22-17-30W1 respectively, but differ internally in number and thickness of bedding sequences, and the presence or absence of bentonitic laminae (Christopher and Yurkowski, 2005). Accordingly, at SWP Bredenbury 11-36-22-1W2, the 9.6 m thick Keld displays three rather than seven sequences and, overall, shallows upward from marlstone-dominant in the lower half of the member to medium-grained calcarenitic and coccolithic limestone-dominant in the upper half. Keld A, *i.e*., sequence 1, is a 4.7 m thick, bituminous, dark grey, coccolithic marlstone with abundant fish scales and bone fragments. It grades upward into medium-grained, current-bedded, well indurated, coccolithic calcarenite. Keld B incorporates sequences 2 and 3, calcarenitic limestone with thin concentrations of fish debris, respectively 1.7 m and 3.2 m thick. Both parasequences include bentonite partings. The 14.9 m thick Assiniboine Member displays five sequences, the basal of which is an upward-deepening, 6.4 m thick transition from dark grey, bituminous, coccolithic and pelecypod-rich, bioclastic limestone into argillaceous limestone with dispersed coccoliths, a compressed tree limb, and a bentonite. Sequence 2, similar in thickness, includes five bentonite laminae, but shallows upward through coccolithic and inoceramid-rich marlstone into cemented, bioclastic limestone of interlaminated inoceramid shell debris and calcarenite. Vestigial sequences of marlstone, calcarenitic limestone and cemented inoceramid coquina complete the section, ending at a pyrite-lined unconformity with the Morden Shale.

Both members of the Second White Specks thicken southward, but Keld A thins and Keld C emerges from under an Assiniboine contact. Keld A, 3.8 m thick at Sylvite Ste Marthe 13-22-17-30W1, is made up of upward-shallowing, dark grey, argillaceous, coccolithic and inoceramid-rich calcarenite. Keld B is represented by sequences 2 and 3, 2.9 m and 1.8 m thick respectively, each exhibiting transition from marlstone to coccolithic calcarenite. Keld C is bipartite and in erosional contact with Keld B. Its lower sequence, 1.4 m thick, grades upward from a permeable, medium- to fine-grained, calcite-cemented, quartzose sandstone and inoceramid gritstone into sandy, calcareous mudstone with abundant fish scales. The 2.1 m thick upper bed is upward shallowing, an argillaceous limestone marked by increase of shell calcarenite and coccoliths. The 17.4 m thick Assiniboine Member incorporates five sequences, of which 1 to 4 are upward transitions from dark grey marlstone to coccolithic and shelly bioclastic limestone with intercalated bentonites. Sequence 5 is upward deepening, 7.6 m thick, includes three bentonites, and is mostly made up of bituminous, greyish black and dark grey marlstone that contains abundant fish bones and teeth and is interbedded with subordinate cm-scale, white, coarsely crystalline, inoceramid-rich, bioclastic limestone. Forming the top of sequence 5 is a 1.6 m thick bed of black, noncalcareous shale with abundant fish bones. The contact with the Morden Shale is irregular and marked by a 0.03 m thick rubble of pyrite-encrusted nodules, green and tan mudstone flakes and granules, and black mudstone granules.

Southward from Township 13 into the Williston Basin, the 23.6 m thick Keld, as seen at Imperial Oxbow 101/15-36-2-3W2 , acquires a dark grey mudstone and inoceramid-dominant bioclastic limestone facies, similar in character to the Assiniboine. Additionally, the member is dominated by a 13 m thick Keld B and a 9.9 m thick Keld C. It displays 11 bedding sequences which, on the basis of sharp, irregular contacts, are grouped into the three parasequence sets Keld A, B and C. Except for sequence 2, the 11 sequences are upward shallowing; five of them are each less than a metre thick. Keld A is a single bed, 0.7 m thick, of well cemented, dense, medium-grained, coccolithic calcarenite, penetrated by vertical burrows, and intercalated at decimetre spacing with greyish black shale partings. The basal contact is on the 'X' Bentonite of the Belle Fourche Formation (core termination), and the upper contact lies at an unconformity corresponding to that on Keld A at IMC Yarbo 17S. Keld B incorporates sequences 2 to 6, and is terminated by medium grey, argillaceous bioclastic limestone and its cap, 0.07 m thick, of burrowed (*Glossifungites*), calcite-cemented, very fine-grained, quartzose sandstone. Keld C (sequences 7 to 11) comprises mostly marlstone to calcarenite transitions in the lower half, and marlstone to bioclastic limestone in the upper. Inoceramid shells, up to 15 percent by volume, appear in all beds, and two bentonitic laminae are present in sequence 7. The basal contact of Keld C is sharp and irregular, and the upper contact is at a green bentonite that is basal to the Assiniboine Member. The latter retains the thin-bedded, sharp-contact-bounded, inoceramid-rich bioclastic, cyclic bedding character of the northern wells.

The Second White Specks Formation thins onto the Punnichy Arch in the northwest of the study area. At Imperial Findlater 16-4-21-25W2 on the southern flank of the arch, the absence of Keld A is attributed to westward downlap and erosional truncation of that unit onto the Belle Fourche C unit (Ridgley *et al*., 2001). Keld B, as the basal parasequence, overlies a 0.3 m thick 'X' Bentonite of the Belle Fourche series at 502.3 m depth. The Keld sequences are initiated below the 'X' Bentonite by Keld A (equivalent), a 3.6 m thick, greyish black, noncalcareous shale grading upward into calcareous and coccolithic shale with abundant inoceramid fragments. Above the 'X' Bentonite, Keld B consists of a lower 6.2 m thick bed, upward deepening from coccolithic, current-bedded, inoceramid-rich, bioclastic calcarenite into argillaceous limestone and interbedded calcareous shale; and superjacent, upward-shallowing vestigial (0.8 m and 0.4 m thick) sequences 2 and 3 of calcareous shale transitional into argillaceous limestone. The overlying 7.3 m thick unit shares the characteristics of both Keld C and the Assiniboine. It comprises seven beds of coccolithic and calcarenitic limestone gradational into black, coccolithic marlstone, and four bentonite beds, two of which are in the 0.8 m thick first sequence. Although originally assigned to the Assiniboine Member by Christopher and Yurkowski (2005), reassigning them to Keld C eliminates the necessity of a sub-Assiniboine unconformity to account for the absence of Keld C from the section. The contact with the Morden Member is sharp and irregular. Attenuation of the Second White Specks Formation to the northwest occurs by sub-Morden erosional overlap down to the basal Keld B bed, as seen at Alwinsal Lanigan 3-28-33-23W2, some 65 km away. Again, the calcareous phase of the Keld is initiated in the Belle Fourche, between the uppermost and penultimate bentonites, by the presence of a 0.4 m thick, dark grey, laminated argillaceous limestone and coccolithic shale, attributable to Keld A. Keld B is 4.3 m thick, rests on the 'X' Bentonite, and displays two upward-deepening sequences, 2.4 m and 1.9 m thick, of well cemented, dark grey and greyish black, current-bedded, coccolithic calcarenite and bioclastic limestone transitional into dark grey, argillaceous, coccolithic limestone. Keld B is terminated by a sharp, irregular contact with the Morden Shale.

The Keld A and B parasequences are present in all the eastern wells, as represented by Imperial Oxbow 101-15-36-002-03W2, NAL East Alida 121/10-02-006-33W1, Sylvite Ste Marthe 13-22-17-30W1, IMC Yarbo

17S (Lsd.1-24-20-33W1) and SWP Bredenbury 11-36-22-1W2. Parasequence C, however, is traceable north only to Sylvite St Marthe 13-22 and is either overlapped by, or has undergone facies change into, the Assiniboine Member to the north and west. The cyclic beds differ in number, thickness and facies distribution from well to well, and so indicate imbricate, lenticular forms. However, their attenuations extend from the main body for many kilometres. For instance, westward from the Imperial Oxbow well, where Keld A is thinned to 0.7 m from the 3.8 m at Ste Marthe 13-22, the top of the parasequence is traceable some 175 km westward along Township 3 to Range 20W2, as a thinning eroded pavement basal to the Keld (Figure 4). Thus westward along the international border, the Second White Specks Formation rests on an unconformity basal to onlapping Keld B, Keld C and, in the far west, the Assiniboine (Figures 2 and 4). The Keld parasequences, though interrupted by erosional unconformities, is an eastern and later offset of those expressed by the 'D' subunits of the Upper Belle Fourche (Ridgley *et al*., 2001). The westward younging of the Second White Specks is also hypothesized by Buckley and Tyson (2003) from their geochemical analysis of the Upper Colorado in the Western Canada Sedimentary Basin. As developed in the discussion of the Belle Fourche Formation, Keld A is significantly older than the overlying Keld units, so much so that Collom (2000) identified it as a Cenomanian Keld Member, assigning the overlying calcareous facies with its Turonian fauna to the Assiniboine Member. The constancy of the Keld stratigraphic position above the 'X' Bentonite across the study area in the cross-section of Figure 4 merely reflects the alignment of the section with the east-west sedimentary strike on the south-dipping depositional slope of a low-relief region. West of Range 14W3 (*i.e*., beyond the study area) the slope abruptly steepens and the 'X' Bentonite dips beneath the erosion surface to underlie the D1 sub-unit of the Belle Fourche.

Depositional Basin

The isopach map of the Second White Specks Formation (Figure 6) depicts an eastern region of thickened sediments which more or less conforms to the Belle Fourche isopach pattern (Figure 5), and reflects a rejuvenated Amaranth Successor Sub-basin as a northward embayment of the Williston Basin from the south. The Favel Formation thickens rapidly westward to 24 m from its eastern Cenozoic erosion edge, and from 28 m to 44 m, north to south, in the keel (4) of the Amaranth Successor Sub-basin. The sub-basin is framed to the west by the Moosomin–Hudson Bay structural belt (3) from Township 26 to Township 10. A northwesterly zone of thinning to 22 m, widening from 20 km in the south to 100 km in the north, separates the Second White Specks Amaranth Successor Sub-basin from the northern part of the Williston Basin, wherein the Second White Specks thickens sharply to 38 m. The northeastern cored sections are located on the northwestern front of the buried Precambrian Superior Province as delineated by the Moosomin–Hudson Bay structural belt (3), and on which thickness of the Second White Specks Formation mostly ranges between 24 m and 27 m. The thickened sediments of the Amaranth Successor Sub-basin represent, in part, the accumulation of more argillaceous sediments in the trough of the sub-basin(4) and, in part, the build-up of Keld limestone on the accentuated draped highs of the buried Mississippian limestone escarpment (5). The latter coincidence suggests control of the Keld depositional base by draped pre-Mesozoic topography, whereby the Paleozoic ridges correspond to Keld bathymetric highs on which generation of limestone deposits in the photic zone of the marine environment was facilitated. The repetitive depositional breaks in the Favel suggest corresponding episodes of emergence and scouring. Argillaceous content increases eastward in the sub-basin in response to deeper water depositional conditions. There, the more irregular, but parallel, outlying pattern of thinner deposits (13 to 40 m) indicates both drape of similarly buried topography (but on Devonian strata) and Cenozoic incision.

West of the Amaranth Successor Sub-basin, the region is one of thinned Second White Specks sedimentary rocks, ranging through a narrow spread of 12 to 18 m. From a 23 m thickness in the Williston Basin of southeastern Saskatchewan, the Second White Specks Formation thins northward to less than 5 m on the Punnichy Arch (1). North–south lineament control is suggested by the coincidence of thinned Second White Specks strata along the eastern side of the Punnichy Arch and the Tabbernor lineament belt (2). Curvilinear bands of 4 m thickening accompany the trace of the Lodgepole buried cuesta (5) on the southern flank of the Punnichy Arch. Northerly and southwesterly bands of thinning on the arch and in the region to the north reflect pre-Morden erosion of the Second White Specks Formation on a mildly uplifted Punnichy Arch. At IMC Yarbo 17S (Lsd. 1-24-20-33W1), the submarine bank representing Keld A had shallowed sufficiently to permit island coastal facies, culminating in prolonged exposure, pedosol and coal development. The region to the south and west, as indicated by the westward younging parasequences, would have been slightly raised relative to the eastern Amaranth Successor Sub-basin, and on-lapped by the Keld B and Keld C parasequences. The general loss and attenuation of the Favel units northwestward also indicate episodic uplift of the Punnichy Arch, sediment starvation and pre-Morden truncation. The Assiniboine multiple inoceramid death assemblages alternating with black shale may indicate stressing of the ecological environment by repeated freshening of the seawater (see Bloch *et al*., 1999). Correspondingly, southward thickening of the Second White Specks Formation implies tectonic subsidence of the Williston Basin and the re-entrant Amaranth Successor Sub-basin in Manitoba, especially during post-Keld A and Assiniboine time. At Imperial Oxbow 101-15-36-002-3W2, the parasequences are twice as thick as their equivalents to the north on the Moosomin–Hudson Bay structural belt (3). Pre-Morden uplift and truncation of the Second White Specks in the interprovincial boundary region between the Williston Basin (proper) and the Amaranth Successor Sub-basin are suggested

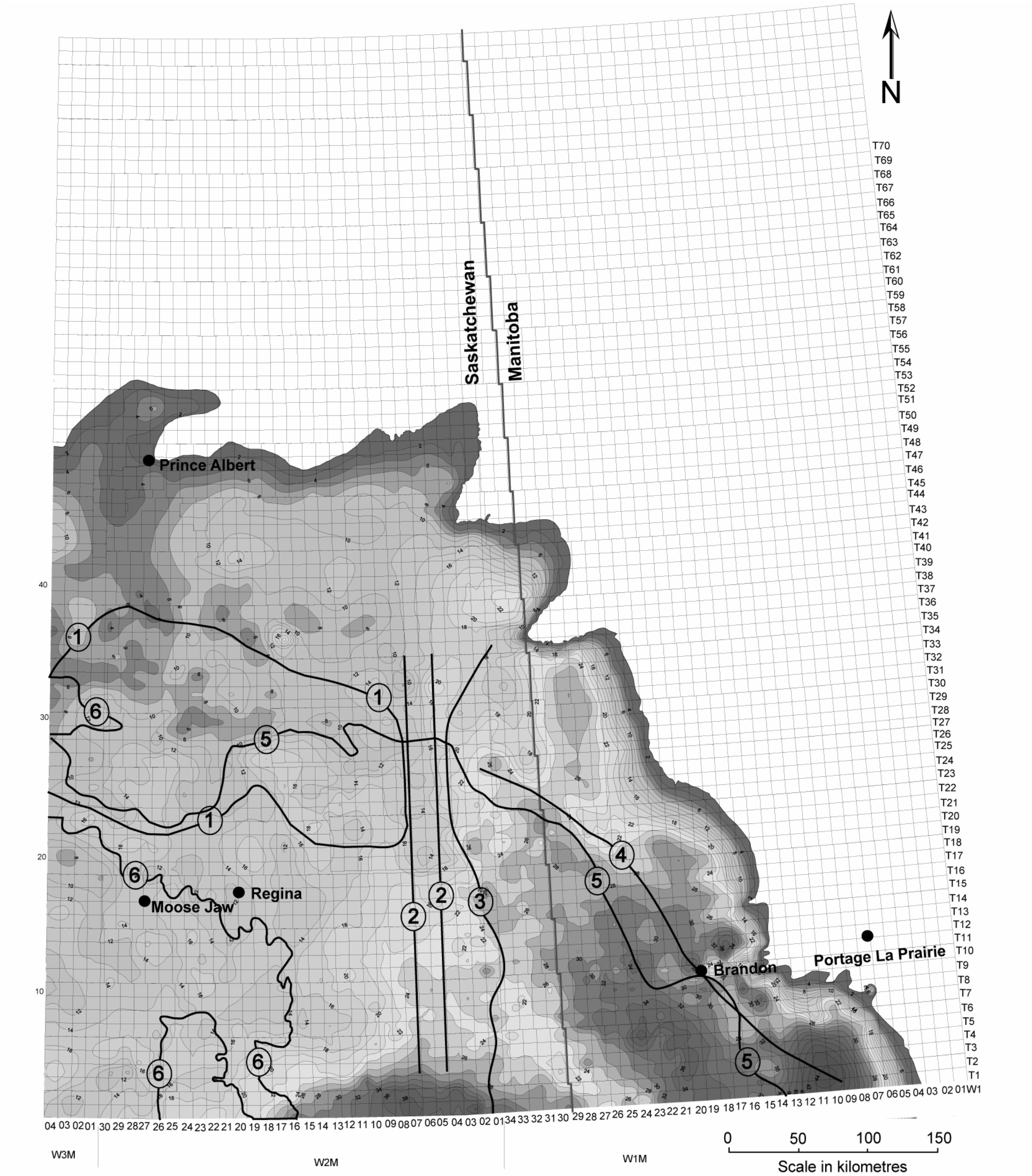

Figure 6 - Isopach map of the Favel–Second White Specks Formation, eastern southern Saskatchewan and southwestern Manitoba. Contour interval is 5 m; Also depicted: (1) Punnichy Arch (Christopher, 2003); (2) projection of the Precambrian Tabbernor lineament belt; (3) Moosomin–Hudson Bay structural belt (Churchill–Superior Boundary Zone [Li et al., 2005]), (4) axis of Upper Colorado Amaranth Successor Sub-basin, (5) buried subcrop of the Mississippian Lodgepole Formation, (6) Prairie Evaporite salt dissolution front.

by the northwesterly trend of thinning south of Township 12.

c) Relationship Of The Carlile Formation Of Southwestern Saskatchewan To The Morden And Boyne (Niobrara) Members Of The Vermilion River Formation Of Southwestern Manitoba

General

The Carlile of southwestern Saskatchewan and southeastern Alberta is divisible into three un-named members (Gilboy, 1993, 1996; Nielsen *et al.*, 2003), and is recognized as a Turonian, largely grey, argillaceous and quartzose sandy formation between the coccolith-speckled calcareous shale of the Second White Specks Formation below, and the argillaceous and quartzose, sandy and coccolithic Niobrara Formation above. In the outcrop belt of southwestern Manitoba, a similar stratigraphic arrangement is that of the Morden Shale, the colour of which is predominantly black, medial to the buff coccolithic marlstone and grey shale of the underlying Favel (Second White Specks) Formation and the overlying buff and grey, coccolithic limestone, marlstone and shale representing the Niobrara Formation of McNeil and Caldwell (1981), *i.e.,* Boyne Member of the Vermilion River Formation of earlier usage (North and Caldwell, 1975, p315).

The Morden is distinct westward across eastern southern Saskatchewan, even as the black shale attenuates as basal tongues into the Carlile Formation, and west of Range 15W2 grades into noncalcareous grey mudstone and coccolithic marlstone of the Middle Carlile (Figure 4). Northward onto the Punnichy Arch of Saskatchewan, the Morden is erosionally overlapped by the Boyne marlstone and limestone (Figure 3). Thus the Morden is a black shale facies of the early Carlile in the interprovincial boundary region of Saskatchewan and Manitoba, and an equivalent grey, calcareous to noncalcareous shale in the extreme southwest of the study area.

The Boyne in the interprovincial boundary region consists of calcareous facies marked by upward-shallowing sequences of dark grey, noncalcareous and calcareous mudstone, greenish grey and buff, coccolithic marlstone, and coccolithic, calcarenitic and bioclastic, argillaceous and cemented limestone. It is traced westward on capping cemented limestone pavements that coincide with sharp electric-log resistivity increases, beneath a higher count gamma-ray signature at the base of the Milk River Formation, where present, or on the top calcarenite of the upward-shallowing shale to carbonate cycles above the Morden high-gamma count black shale. In this context, the Boyne is the upper member of the Carlile and the Morden the lower. However, with attenuation of black shale westward across the study area, the Boyne calcareous content increases to dominant, and quartzose, sandy, argillaceous mudstone becomes significant in the upper part of the section. The upper and lower units of the Boyne, as described in outcrop by McNeil and Caldwell (1981), are seen in core from the Sylvite Ste. Marthe 13-22-17-30W1 well in the interprovincial boundary district of Saskatchewan, and are described and called such by North and Caldwell (1975, p318).

As a formal lithologic description of a Carlile reference section in southwestern Saskatchewan does not exist, no attempt has been made to characterize in the east the informally designated upper, middle and lower members of Nielsen *et al*. (2003) using geophysical well logs. Accordingly, the Carlile Formation of the study area is traced into the reference Carlile of southwestern Saskatchewan as delineated on the west-to-east geophysical log section constructed by Pedersen (2004, Figure 3) and, in this study, the stratigraphic cross-section of Figure 4. The Morden is unconformable with respect to the Second White Specks Formation. This relationship is in keeping with observations of the Morden Member in the outcrops of the Cretaceous escarpment in eastern Saskatchewan and in Manitoba (Schröder-Adams *et al.*, 2001), and with the base of the Carlile in southeastern Alberta at G Basin BVX Medhat 6-22-11-6W4 (Ridgley *et al.*, 2001, p259). The Carlile is in unconformity with respect to the Milk River Formation, as indicated by not only the absence of the western Niobrara, but also presence of calcite-cemented and joint-inlaid calcarenite beds capping the Boyne Member throughout the study area. It is presently presumed to be in conformity with the Niobrara of western Saskatchewan.

d) Carlile (Morden And Boyne Members) Formation

The Morden Member, 4 to 5 m in thickness, crops out in the Cretaceous escarpment of southwestern Manitoba and, as described by McNeil and Caldwell (1981, p354), consists of soft, flaky, greyish black shale to black shale with abundant fish scales and bone debris, and intercalated bentonite seams toward the base. Contacts are obscured by creep of surface debris. Their Niobrara Formation (Boyne Member) on a tributary of the Boyne River (McNeil and Caldwell, 1981, p384) comprises a lower “Chalky Member”, 9.68 m thick, interbedded at metre intervals or less, with dark grey, fine-grained speckled, chalky shale and olive-black, calcareous and noncalcareous shale with three intercalated bentonites also present, and an upper “Calcareous Member”, 12.19 m thick, of dark olive-grey, calcareous shale with fine- to medium-sized chalk specks. This “Calcareous Member” contains two bentonite seams and is bioturbated in its upper 1.83 m. As observed in the cored wells, the Upper Boyne is transgressive with respect to the Lower Boyne, and in all of the wells features basal upward-deepening beds that are on a sharp contact, an erosive conglomeratic contact, or an erosional contact marked by a basal sand veneer. Like the sub-Morden unconformity, the regional tectonic significance of the sub-Upper Boyne disconformity remains undetermined. It leaves open the possibility that it represents a 'sub-Niobrara unconformity', and that the upper Boyne is an eastern limestone facies of the western, basal-Niobrara, argillaceous Verger Member of Nielsen *et al.*, (2001). The correlation pursued in this study is that the lower unit of the Boyne is correlative as a middle member of the Carlile and the upper Boyne is an equivalent upper member of a tripartite Carlile Formation. The contact of the Boyne with respect to the Morden is transitional, usually by decrease in carbonaceous aspect of the Morden.

The foregoing stratigraphic trichotomy is exhibited in core from wells in eastern southern Saskatchewan (Figures 1 and 3). At NAL Alida East 121/10-02-006-33W1, the Morden Member is 28.19 m thick. Above a basal 0.2 m thick, inoceramid-rich, coccolithic, light grey, cryptocrystalline limestone in erosional contact with the Second White Specks Formation, the Morden is composed of a 21.69 m thick, black, carbonaceous, shaly mudstone with five bentonite laminae and a capping 6.5 m thick, dark greenish grey mudstone, speckled with white coccoliths, interlaminated with black shale and intercalated with abundant inoceramid bioclasts. The Lower Boyne (Middle Carlile), 34.5 m thick, comprises 24.05 m of dark grey, variably calcareous, shaly mudstone that grades into bioturbated marlstone with scattered inoceramid fragments, overlain by four beds of medium grey, current-bedded and burrowed, sandy, argillaceous limestone 1.01 m, 1.32m, 2.30 m, and 5.32 m thick respectively. A 0.5 m thick, grey-white, cryptocrystalline limestone, with calcite-veined solution pipes, 0.3 m deep, terminates the unit . The 9.15 m thick Upper Boyne (Upper Carlile) displays similar mini-transitions of marlstone into bioturbated, inoceramid-rich, argillaceous limestone, and a solution-pitted limestone 2.55 m below the top at 570.35 m. Only the basal 8.35 m of the overlying Milk River Formation is cored in this well. The contact is erosional, marked by a thin layer of pisolites, overlain by flasered and current-bedded, very fine-grained, quartzose, sandy to silty mudstone with laminae of bentonite, grading upward into dark grey and greyish black, variably calcareous, silty mudstone.

At the Sylvite Ste Marthe 13-22-17-30W1 well, some 110 km to the north-northeast, the Morden thins to 14.6 m (236.8 to 222.2 m depth), but displays the characteristic black shale interspersed with laminae of yellow jarosite, green bentonite, and a coal, and a basal zone, 0.03 m thick of pyritic mudstone granules and flakes on an irregular contact. The overlying beds (222.2 to 198.9 m depth) of the Middle Carlile, correlated with the lower unit of the Boyne Member and dated Middle Turonian by North and Caldwell (1975, p318), feature two subunits. The lower comprises 23.3 m thick, dark grey and greyish black, calcareous mudstone with thin *Inoceramus* shells, transitional into massive, noncalcareous mudstone with scattered fish scales, and a capping marlstone with abundant carbonized plant fragments and large *Inoceramus* ending at a sharp contact. The upper subunit is 5.8 m thick, and is made up of dark grey, calcareous mudstone, transitional into coccolith-speckled, calcite-cemented, laminated, quartzose siltstone and marlstone; it terminates at a sharp contact. The upper unit of the Boyne, *i.e.,* Upper Carlile, features a basal 2.6 m thick, dark grey and medium grey, calcareous mudstone and marlstone with an intercalated bentonite, and an overlying 10.1 m of interbedded coccolithic marlstone, calcareous mudstone and intercalated biotitic bentonite. The Carlile is terminated under the Pembina, at 180.4 m depth, by the sub-Lea Park (sub-Pierre) unconformity.

The 13.12 m thick Morden Member at IMC International Yarbo 17S (Lsd.1-24-20-33W1) retains its black shale character as displayed at depths 245.67 to 232-56 m (McNeil and Caldwell, 1981). The strata between the Morden and the sub-Lea Park unconformity at 202.8 m., *i.e.,* the Niobrara Formation of the aforementioned authors, are in this study re-designated the Boyne Member of the Carlile Formation. Above the Morden at 232.56 m, the Lower Boyne displays, over a 15.56 m interval, four upward-shallowing sequences comprising (1) dark grey and greyish black mudstone transitional into very calcareous mudstone and marlstone with scattered pelecypod shell fragments and indurated limestone (7.93 m thick), (2) medium grey, calcareous mudstone with scattered fish scales grading into argillaceous, very fine-grained calcarenite (2.74 m thick); (3) black, upward to greyish black shale with abundant fish teeth and mm-scale fish remains transitional into limonite-yellow, very fine-grained, bioturbated calcarenite with abundant pelecypod shell hash, (0.89 m thick), and (4) dark grey, very calcareous shale, white-speckled at the base, capped by dark grey, cemented limestone with scattered fish scales (4.00 m thick). Above a sharp contact at 217.0 m, the 14.92 m thick Upper Boyne exhibits a basal, thin, calcareous, very fine-grained quartzose sandstone succeeded by predominantly medium grey, calcareous and noncalcareous mudstone, and a capping, 5 m thick, coccolithic limestone intercalated with pelecypod (including *Inoceramus*) fragments, and a bentonite lamina. The Colorado section is terminated at 202.08 m depth by the sub-Pierre unconformity at the Pembina Formation.

Attenuation, lenticular bedding and erosional contacts proliferate in all of the units at SWP Bredenbury 11-36-22-1W2. The 4.9 m thick, unconformity-bounded, Morden black shale is carbonaceous, noncalcareous, fissile, and sulphurous. The thinly bedded, 12.2 m thick lower unit of the Boyne, *i.e.,* the Middle Carlile, comprises (1) sharp-based and -capped, dark grey, slightly argillaceous, cryptocrystalline limestone, 0.4 m thick and veined with coarsely crystalline calcite; (2) noncalcareous, greyish black mudstone, 6.0 m thick, with basal inoceramid shell debris on a sharp, irregular contact, overlain by 2.4 m thick coccolithic and calcarenitic, argillaceous, greyish brown, shaly limestone; and (3) a 3.4 m thick, dark brownish grey, noncalcareous but calcite-veined mudstone on bentonite, grading upward to medium grey, coccolithic and fish-scale-strewn limestone interbedded with calcareous mudstone. The 14.36 m thick upper unit of the Boyne, *i.e.*, Upper Carlile Member, displays a basal erosional contact under a 0.1 m thick, porous, coarse- and medium-grained, quartzose sandstone with abundant green lithic fragments, biotite, fish teeth and black chert. This sandstone is sharply terminated by bentonite under a dark brownish grey, noncalcareous mudstone, 0.2 m thick. A superjacent 3.7 m thick, argillaceous, fine-grained, coccolithic limestone with two laminae of bentonite is succeeded by 10.3 m of noncalcareous, medium brownish grey mudstone, grading by intercalation into coccolithic marlstone and capping coccolithic limestone. A sharp based, irregular, coccolithic, calcarenite pavement, 0.06 m thick, terminates the Carlile succession. The succeeding 0.9 m thick dark grey marlstone with about 15% white specks, grading upward into dark grey, noncalcareous mudstone terminated by the sub-Lea Park unconformity, are mapped as basal Milk River strata.

Apart from general attenuation, the Carlile Formation in the western part of the study area displays lithological characteristics similar to those in the east, but with higher noncalcareous, argillaceous content. At Alwinsal Lanigan 3-28-33-23W2, the Carlile is attenuated to 23.10 m. The 2.1 m thick Morden is greyish black mudstone intercalated with two coarse-grained, white-speckled, coccolithic, argillaceous calcarenite beds, 0.2 m and 0.15 m thick, bounded by sharp, irregular contacts, and two beds of bentonite, the upper of which is 0.3 m thick. As elsewhere, the contact on the Second White Specks is erosional. The Lower Boyne incorporates two shallowing-upward marlstone to coccolithic calcarenite transitions, 7.9 m and 4.8 m thick. The Upper Boyne includes an 8.3 m thick, coccolithic calcarenite featuring cm-thick coquinas of *Ostrea,* three bentonite laminae, and a basal, fish-bone-rich calcarenitic marlstone on a sharp, irregular contact marked by black mudstone fragments. An overlying 3.4 m thick, dark grey, calcareous mudstone with scattered bands of coccoliths, like that at SWS Bredenbury 11-36-22-1W2, is taken to represent the Milk River Formation beneath the sub-Lea Park unconformity.

At LMLE Simpson 6-28-29-24W2, the 2.43 m thick Morden Member comprises greyish black mudstone, seven intercalated bentonites, 0.01 to 0.17 m thick, and a basal pisolitic layer in erosional contact with the Second White Specks Formation. The Lower Boyne, 7.76 m thick, shallows upward overall, through three shallowing-upward marlstone to quartzose, sandy marlstone sequences with *Ostrea* and intercalated bentonite. The Upper Boyne is 14.12 m thick, and consists of sharp-based, lime-mud indurated, fine-grained, coccolithic, brown-speckled with white, current- and wavy-bedded calcarenite with scattered layers of *Ostrea* and five bentonites. It terminates at the sub-Lea Park unconformity.

At LMLE Penzance 21/06-30-24-25W2, the Morden attenuates to a 0.16 m thick, unconformity-bounded, lithic conglomerate. The Lower Boyne includes six bentonites and is 9.64 m thick across three shallowing-upward sequences, 4.39 m, 2.45 m, and 2.8 m thick, composed of greyish black, noncalcareous mudstone with scattered white specks, gradational into dark greenish grey, calcareous mudstone with about 10% coarse-grained feldspar, and greyish black, laminated and current-bedded, silty marlstone and argillaceous limestone with abundant biotite and muscovite. The 13.43 m thick Upper Boyne features an upward-deepening lower bed, 3.95 m thick, of dark greenish grey, sandy marlstone, small-scale current-bedded and channeled in part, transitional into dark grey, patchily calcareous to noncalcareous mudstone with abundant white pelecypod fragments; and an upward-shallowing upper bed, 9.48 m thick, of current-bedded and thinly cross-bedded argillaceous calcarenite with about 15% fine-grained white specks, scattered laminae of pelecypod clasts, and a seventh bentonite. It is terminated by a sharp contact with the Milk River Formation.

Basin Setting

The consistent lithological format of the Carlile members across the study area shows the Morden–Boyne stratigraphic couple to be a more eastward reiteration of the southwest-centred, subjacent Belle Fourche–Second White Specks (Favel). It indicates that no major tectonic change in basin geometry occurred in this region over the time represented by the two formation sets. The stratigraphic relationships of the Upper Colorado and Montana Group formations (along section, Figure 4) between the reference region of southwestern Saskatchewan and the outcrop belt in Manitoba are diagrammatically illustrated in Figure 7a using the low-relief sub-Carlile unconformity as datum. This unconformity gently truncates the Second White Specks Formation from east to west, and thereby indicates mild post-Second White Specks uplift in the west. The diagram also depicts the truncation of the Niobrara Formation on to the Carlile Formation by over-step of the Campanian Milk River Formation in western southern Saskatchewan. The Milk River is similarly over-stepped by the Lea Park at the sub-Pierre unconformity, but more as a high-relief cut antecedent to the northwesterly front of the Cenozoic Missouri escarpment at about Range 14 W2 (Christopher and Yurkowski, 2003). To the east, the unconformable surface is essentially low in relief, and supported by a veneer of Milk River Formation on the Boyne, *i.e.*, the Gammon Shale of Manitoba (McNeil and Caldwell, 1981). Both the Niobrara and Milk River formations are western-sourced foreland-basin deposits laid in active depocentres, as is the Carlile in southwestern Alberta (Nielsen *et al*., 2003). Thus the pattern appears to be one of eastward-advancing, episodic down-warps creating accommodation for Upper Cretaceous depositional bodies. A more dynamic portrayal of these events is presented in Figure 7b, wherein the cross-section of Figure 7a is reformatted to a datum on the sub-Milk River unconformity. Accordingly, the Colorado formations are portrayed as down-warped in the west under a progradational Milk River body, and there preserved, while truncated across the eastern shelf. Accordingly, the Boyne carbonates, like the Second White Specks, represent shelf (Niobrara facies) coccolithic and bioclastic carbonates built up on the broad, episodically emergent, marine platform of eastern southern Saskatchewan and southwestern Manitoba, in counterpoint to the differentially subsiding tectonic depocentre of the Carlile in southeastern Alberta. By the same argument, the Morden Amaranth Successor Sub-basin in Manitoba represents an early Carlile repeat of early Belle Fourche subsidence in the eastern Williston Basin.

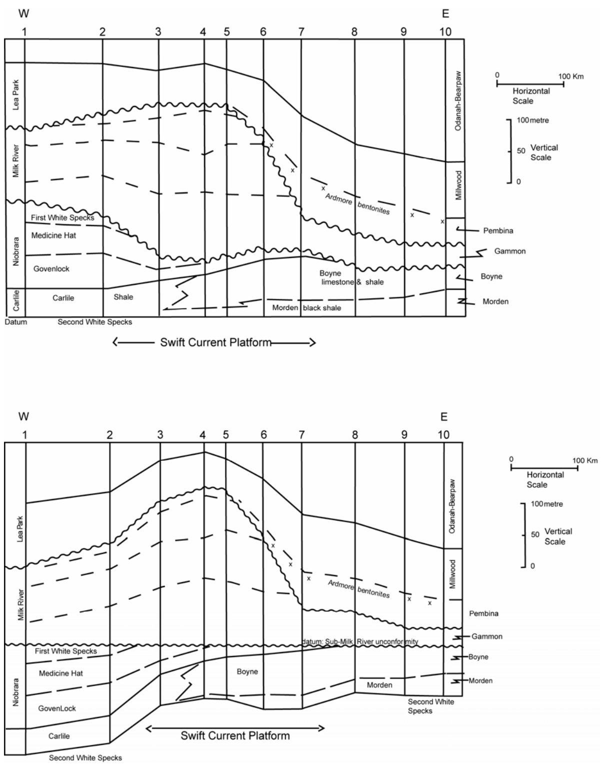

Figure 7 – A) West to east panel diagram of the formations of the Upper Colorado and Montana Groups along Township 5, southwestern Saskatchewan to southwestern Manitoba; datum on the Second White Specks–Favel Formation; wells numbered as on Figure 4; B) Same, but with datum on the sub-Milk River unconformity.

The configuration of the Carlile depositional basin (Figure 8) is formatted similarly to that of the Second White Specks (Figure 6) in its tripartite arrangement of an Amaranth Successor Sub-basin in southwestern Manitoba, the Williston Basin in southern Saskatchewan and a broad central and northern area of isopach values below 40 m. The axis (4) of the Carlile Amaranth Successor Sub-basin (Figure 8) is elongated north-northwest, parallel to, but generally outside the buried edge of the Mississippian Lodgepole Formation (5). The Morden black shale is at its thickest in the sub-basin, *i.e.*, 60 m in the southern region of the trough, where it constitutes half the total thickness of the Carlile. As a whole, thickness of the Carlile in the sub-basin ranges from 50 m in the interprovincial boundary region at Township 30, where the trough (4) of the sub-basin terminates against the Moosomin–Hudson Bay structural belt (3) at Range 3W2, to 120 m southeastward into the Williston Basin at the international border. Like the Favel, Carlile-equivalent strata of Manitoba are truncated by Cenozoic erosion along the front trending northwest from Range 8W1 at the international border to the Pasquia Hills in Saskatchewan near the interprovincial boundary at Township 50. Immediately to the west of the Moosomin–Hudson Bay structural belt (3), local sites of thickening to between 30 and 45 m are north-aligned between Ranges 3W2 and 5W2. These are probably related to tectonic movements projected from the Precambrian basement along linear structures such as the Tabbernor lineament belt (2). In the northwest of the study area, isopachous thins in the range of 17 to 25 m thick are associated with the buried subcrop of Mississippian strata (5), and so reflect drape over sub-Mesozoic buried hills on a rising Punnichy Arch (1). North of Township 8 and west of Range 3W2, the Carlile thins to 40 m, and ranges in thickness between 20 and 35 m over the Punnichy Arch (1). North of Township 42, general values below 20 m prevail. Expansion of the Williston Basin is indicated south of Township 8 in Saskatchewan by the relatively abrupt thickening of the Carlile from ~70 m to ~106 m at the international boundary. North of the edge of the Milk River Formation, the Carlile Formation underlies the Campanian Pembina Formation at the sub-Lea Park (sub-Pierre) erosion surface.

The depositional style of the Carlile Formation is a more elaborate repeat of that of the Second White Specks Formation. It begins with black shale sedimentation, controlled by downwarp and restricted circulation in the Morden Amaranth Successor Sub-basin in Manitoba. Cyclic build-ups of black and grey shale to marlstone and calcarenitic limestone followed, which spread to the low-relief platform region of eastern southern Saskatchewan and extreme southwestern Manitoba. The erosional basal contact of the Carlile indicates extensive emergence and mild erosion of the Second White Specks Formation toward the west and north. Four or more parasequences of the Carlile, including the upper contact zones of both the Middle and Upper Carlile members, are capped by widespread calcite-cemented pavements indicating exposure surfaces, the last of which resisted pre-Milk River erosion in the western part of the study area, and an additional episode of widespread pre-Lea Park (Pierre) erosion in the northeast. The post-Morden Carlile depositional style in the study area appears to reflect multiple sea-level oscillations on an open marine, relatively shallow, flattish sea bottom, which was built up by weak sediment incursions from distant sources and the growth of indigenous bioclastic banks. Multiple emergences of the seafloor occurred at higher eminences of the depositional basin such as the Punnichy Arch, the eastern front of the Precambrian Superior Province (represented by the Moosomin–Hudson Bay structural belt), and the compactional highs above the buried Mississippian escarpment. However, the expansion of the northern flank of the Williston Basin into embayments represented by the Carlile Amaranth Successor Sub-basin and the down-set Swift Current Platform lay outboard to deepening of the foreland basin in the Western Interior Colorado

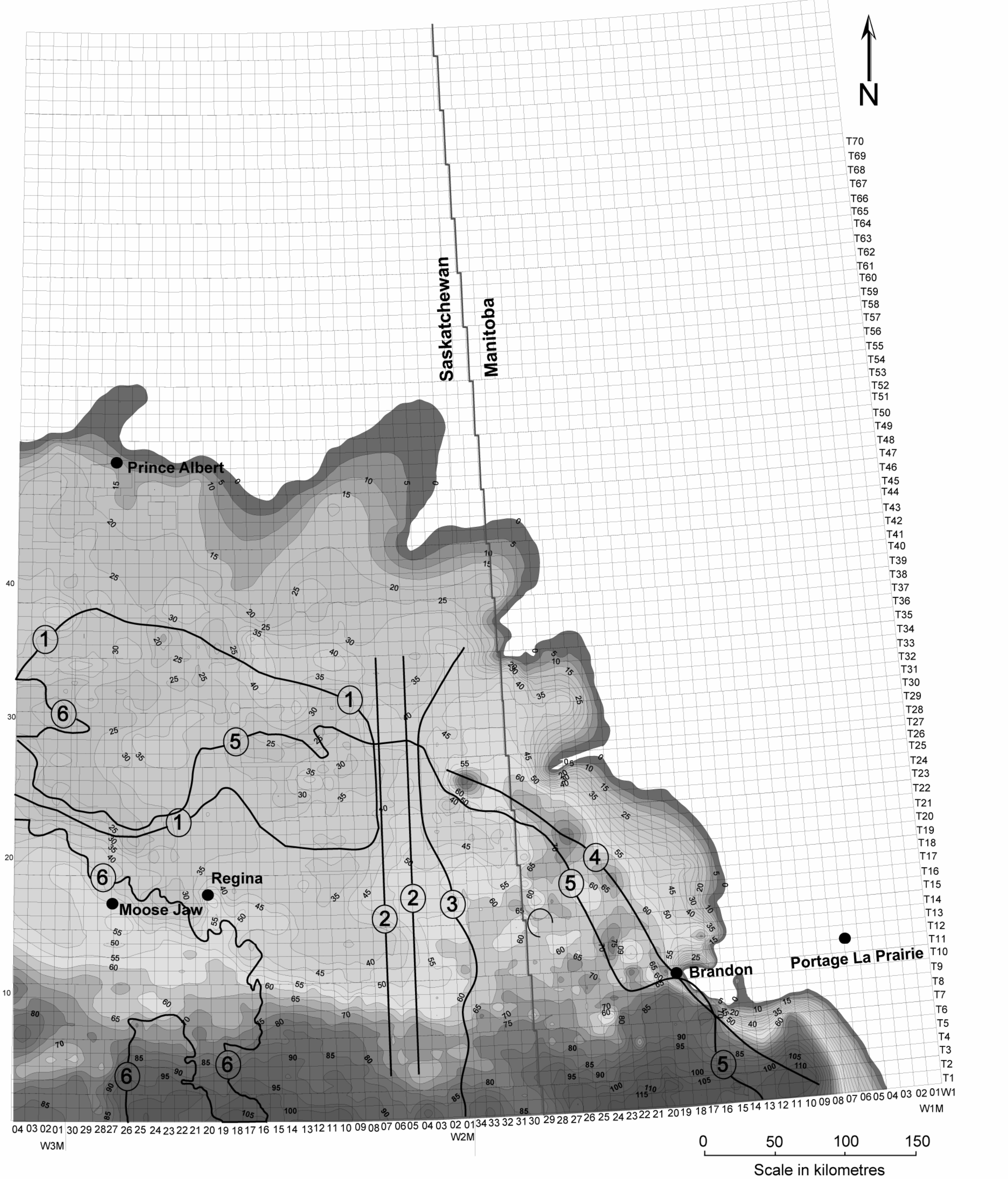

Figure 8 - Isopach map of the Carlile Formation, eastern southern Saskatchewan and southwestern Manitoba. Contour interval is 5 m. Also depicted from Christopher (2003): (1) Punnichy Arch; (2) projection of the Precambrian Tabbernor lineament belt; (3) Moosomin–Hudson Bay structural belt (Churchill–Superior Boundary Zone [Li et al., 2005]), (4) axis of Upper Colorado Amaranth Successor Sub-basin, (5) buried subcrop of the Mississippian Lodgepole Formation, (6) Prairie Evaporite salt dissolution front.

seaway to the southwest and west in Montana and Alberta.

3. Hydrocarbon Potential

Prospecting for oil and natural gas in the Upper Colorado sub-Group should focus on the Belle Fourche, the Second White Specks (Favel) and the Boyne Member of the Carlile Formation because of their similar petroleum-friendly lithological and geochemical characters and their stratigraphic proximity to each other. More than thrice as thick as the Second White Specks, the Carlile Formation has that much greater potential for hydrocarbon generation and storage. The organic content of the Upper Colorado formations in the SWP Bredenbury well 11-36-22-1W2 well were analyzed in detail by Bloch *et al.* (1999), and the results, shown in Table 1, serve as a guide for the eastern part of the study area:

The same authors also measured similar values at the US Borax and Chemical 5-22-34-1W3 in the extreme west of the study area. All units are considered potential source beds by virtue of their high TOC; however, the relatively low OIs indicate that their hydrocarbons are sub-mature (Types II and III in Macauley's 1984 classification; Macauley (1984, Figure 57) also contoured the regional values of TOC for Saskatchewan and Manitoba). The region of eastern central Saskatchewan to the outcrop belt in Manitoba, because of its shallow depth, is considered to have the better promise for oil-shale productivity as exemplified by early exploration in the Pasquia Hills for economic deposits of oil shale (Beck, 1974). According to McInnes (1913), retorting of oil shale from the Pasquia Hills indicated a productivity of 7 imp. gal./ton (35 L/t). Recoverable reserves in the region are estimated to be in the range of 413 x 10^6 m^3 (Beck, 1974) to 200 x 10^6 m^3 (Macauley, 1984).

Natural gas prospects are contingent on indigenous generation within the Favel and Carlile formations. Although the transmissible natural gas productive Medicine Hat sandstones of southwestern Saskatchewan do not extend into the study area, ample storage capacity is provided by the Okla and equivalent Belle Fourche sandstones. Moreover, the Milk River Formation is present in full section in the western third of the study area where, at the sub-Lea Park unconformity, it presents an erosional escarpment trending northwest from Township 1, Range 17W2. Natural gas migrating up-dip from source regions in southwestern Saskatchewan would likely encounter permeability barriers in their passage eastward. Both the overlying Pembina and underlying Carlile, the latter containing outlying sandy patches in the western portion of the study area, are likely interceptors of this migration. It appears that a portion of the gas stream that has bypassed stratigraphic traps in these formations escapes into subcrops against the glacial-till cover in northeastern Saskatchewan and southwestern Manitoba, where it has been tapped by incidental drilling. Oil-shale quality increases westward from the outcrop belt (Macauley, 1984), and so may indicate heat sources related to local tectonic action along lineaments associated with the buried Churchill–Superior Boundary Zone at the Second Meridian (long. 102ºW) and, therefore, enhanced potential for biogenic gas generation. Incidental oil and gas shows from Colorado beds in wells drilled in eastern Saskatchewan are delineated in Simpson (1970).

Unit	Total Organic Carbon (TOC)	Oxygen Index (OI)
Keld	07.87%, 8.17%, 08.14%, 1.4%, 0.82% ;	375^0, 373^0, 446^0, 346^0, 255^0
Assiniboine	12.62%, 7.23%, 10.26%, 4.65%, 9.14%	455^0, 423^0, 447^0, 120^0, 177^0
Morden	12.17%, 2.87%, 9.11%, 6.75%, 5.15%	370^0, 320^0, 108^0, 73^0, 134^0
Boyne	7.98%, 0.85%, 5.51%, 7.51%, 10.39%	498^0, 323^0, 405^0, 391^0, 367^0

Table 1 - The organic content of the Upper Colorado formations in the SWP Bredenbury well 11-36-22-1W2 well (data from Bloch et al., 1999).

4. References

Beck, L.S. (1974): Geological Investigation in the Pasquia Hill Area; Sask. Dep. Miner. Resour., Rep. 158, 16p.

Bloch, J., Schröder-Adams, C., Leckie, D.A., McIntyre, D.J., Craig, J., and Staniland, M. (1993): Revised stratigraphy of the Lower Colorado Group (Albian to Turonian), western Canada; Bull. Can. Petrol. Geol., v41, p325-348.

Bloch, J.D., Schröder-Adams, C.J., Leckie, D.A., Craig, J., and McIntyre, D.J. (1999): Sedimentology, Micropaleontology, Geochemistry and Hydrocarbon Potential of Shale from the Cretaceous Lower Colorado Group in western Canada; Geol. Surv. Can. Bull., v531, 185p.

Buckley, L. and Tyson, R.V. (2003): Organic facies of the Cretaceous Lower and basal Upper Colorado Group (Cretaceous), Western Canada Sedimentary Basin – A preliminary report; *in* Summary of Investigations 2003, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2003-4.1, CD-ROM, Paper A-10, 13p.

Caldwell, W.G.E., North, B.R., Stelck, C.R., and Wall, J.H. (1978): A foraminiferal zonal scheme for the Cretaceous System in the Interior Plains of Western Canada; *in* Stelck, C.R. and Chatterton, B.D. (eds.), Western and Arctic Canadian Biostratigraphy; Geol. Assoc. Can. Spec. Pap.18, p495-594.

Christopher, J. E. (2003): Jura-Cretaceous Success Formation and Lower Cretaceous Mannville Group of Saskatchewan; Saskatchewan Industry and Resources, Geological Survey Report 233; CD ROM.

Christopher, J.E. and Yurkowski, M. (2003): The Late Cretaceous (Campanian) sub-Lea Park unconformity in the Weyburn oilfield district, southeastern Saskatchewan; *in* Summary of Investigations 2002, vol. 1, Saskatchewan Geological Survey, Sask. Industry and Resources Misc. Rep. 2003-4-1, CD ROM, Paper A12, 20p.

Christopher, J.E. and Yurkowski, M. (2005): The Upper Cretaceous (Turonian) Second White Specks Formation of eastern Saskatchewan; *in* Summary of Investigations 2005, volume 1, Saskatchewan Geological Survey, Sask. Industry and Resources, Misc. Rep. 2005-4.1, CD ROM, Paper A-18, 12p.

Christopher, J.E., Yurkowski, M., Nicolas, M., and Bamburak, J. (2006): The Upper Cretaceous (Turonian – Santonian) Carlile Formation of eastern southern Saskatchewan and correlative Morden and Boyne members of the Vermilion River Formation of southwestern Manitoba; *in* Summary of Investigations 2006, vol.1, Saskatchewan Geological Survey, Sask. Industry and Resources Misc. Rep. 2006-4.1, CD ROM, Paper A-13, 16p.

Collom, C.J. (2000): High resolution stratigraphy, regional correlation and report of molluscan faunas: Colorado Group (Cenomanian – Coniacian interval), Late Cretaceous, east-central Saskatchewan; *in* Summary of Investigations 2000, volume 1, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2000-4.1, p82-97.

Dawson, S.J. (1859): Report on the exploration of the country between Lake Superior and the Red River settlement and between the latter place and the Assiniboine and Saskatchewan; J.Can. Leg. Assem. v17, Appendix 17, 45p.

Gilboy, C.F. (1989): Upper Cretaceous stratigraphic cross-sections (Fish Scale Sandstone to Milk River Formation) in S.E. Alberta, S.W. Saskatchewan, and N. Montana; *in* Summary of Investigations 1989, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 89-4.

Gilboy, C.F. (1993): The Carlile Shale equivalent (Upper Cretaceous) in southwestern Saskatchewan: A wireline-log study; *in* Summary of Investigations 1993, Saskatchewan Geological Survey, Sask. Energy and Mines, Misc. Rep. 93-4, p197-195.

Gilboy, C.F. (1996): Detailed log-based stratigraphic study of Colorado Group and Milk River Formation (Cretaceous), southwestern Saskatchewan; *in* Summary of Investigations 1996, Saskatchewan Geological Survey, Sask. Energy and Mines Misc. Rep. 96-4, p133-135.

Li, J., Morozov, I.B., and Chubak, G. (2005): Potential-field investigations of the Williston basement; *in* Summary of Investigations 2005, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 20-05-4.1, CD-ROM, Paper A-5, 11p.

Macauley, G. (1984): Cretaceous Oil Shale Potential of the Prairie Provinces, Canada; Geol. Surv. Can. Open File Rep. OF 977, 61p.

McInnes, W. (1913): The Basins of Nelson and Churchill Rivers; Geol. Surv. Can. Mem. v30, 68p.

McNeil, D.H. and Caldwell, W.G.E. (1981): Cretaceous Rocks and Their Foraminifera in the Manitoba Escarpment; Geological Assoc. of Canada Spec. Pap. 21, 439p.

Nielsen, K.S., Schröder-Adams, C.J. and Leckie, D. (2003): A new stratigraphic framework for the Upper Colorado Group (Cretaceous) in southern Alberta and southwestern Saskatchewan, Canada; Bull. Can. Petrol. Geol., v51, p304-346.

North, B. R. and Caldwell, W.G.E. (1975): Foraminiferal faunas in the Cretaceous System of Saskatchewan; *in* Caldwell, W.G.E. (ed.), The Cretaceous System in the Western Interior of North America,; Geological Assoc. of Canada Spec. Pap.13, p303-331.

Pedersen, P. K. (2004): Shallow gas research project in southwestern Saskatchewan: Revised lithostratigraphy of the Colorado Group and reservoir architecture of the Belle Fourche and Second White Specks in the Senate Pool; *in* Summary of Investigations 2004, Volume 1, Saskatchewan Geological Survey, Sask. Industry and Resources, Misc. Rep. 2004-4.1, CD-ROM, paper A-16, 15p.

Ridgley, J.L. and Gilboy, C.F. (2001): Lithofacies architecture of the Upper Cretaceous Belle Fourche Formation, Saskatchewan, Alberta, and Montana – its relationship to sites of shallow biogenic gas production; *in* Summary of Investigations 2001, Volume 1, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2001-4.1, p106-120.

Ridgley, J.L., McNeil, D.H., Gilboy, C.F., Condon, S.M., and Obradovich, J.D. (2001): Structural and stratigraphical controls on sites of shallow biogenic gas accumulations in the Upper Cretaceous Belle Fourche and Second White Specks – Greenhorn formations of southern Alberta, Saskatchewan and northern Montana; *in* Anderson, D.S., Robinson, J.W., Estes-Jackson, J.E., and Coalson, E.B. (eds.), Gas in the Rockies; Rocky Mountain Assoc. Geologists, Denver Colorado, p241-270.

Schröder-Adams, C.J., Cumbaa, S.L., Bloch, J., Leckie, D.A., Craig, J., Seif El Dein, S.A., Simons, D., and Kenig, F. (2001): Late Cretaceous (Cenomanian to Campanian) paleoenvironmental history of the eastern Canadian margin of the Western Interior Seaway: Bonebeds and anoxic events; Palaeogeo. Palaeoclim. Palaeoecol., v170, p261-289.

Simpson, F. (1970): Low depth Saskatchewan Prospect; Oilweek, vol. 58, 30 Mar/70, p14-15.

Simpson, F. (1979): Low-permeability gas reservoirs in marine Cretaceous sandstones of Saskatchewan: 3. Lower Colorado (Middle Albian to Cenomanian) strata of east-central Saskatchewan; *in* Summary of Investigations 1979, Saskatchewan Geological Survey, Sask. Energy Mines; p186-190.

Yurkowski, M., Marsh, A., and Heinemann, K. (2006): The Niobrara and Carlile formations of western Saskatchewan – Preliminary investigations; *in* Summary of Investigations 2006, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2006-4.1, CD-ROM, Paper A-14, 8p.

Wagoner, J.E., Mitchum, R.M., Posamentier, H.W., and Vail, P.R. (1987): Part 2: Key definitions of seismic stratigraphy; *in* Bally, A.W. (ed.), Atlas of Seismic Stratigraphy, Amer. Assoc. Petrol. Geol., Tulsa, OK, p11-14.