The Upper Cretaceous (Turonian-Santonian) Carlile Formation of Eastern Southern Saskatchewan, and the Correlative Morden and Boyne Members of Southwestern Manitoba

J.E. Christopher [1], M. Yurkowski, M. Nicolas [2], and J. Bamburak [2]

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

Abstract

The Upper Cretaceous (Turonian to Santonian) Carlile Formation of eastern southern Saskatchewan and southwestern Manitoba consists of the Morden Member, made up of black shale, and the Boyne Member, comprising repetitive sequences of dark grey and black noncalcareous and calcareous shale transitional upward into calcareous, coccolithic marlstone and capping calcarenitic and calciruditic limestone. In this study, the Boyne Member, though established as "Niobrara" in the classic literature, is integrated with the Carlile Formation by west to east facies change. The black shale of the Morden Member is transitional westward into the calcareous facies of the Boyne Member, and the facies of both members in the extreme west of the study area yield, in general, to the dark grey, noncalcareous shale lithosome of the Carlile Formation in southwestern Saskatchewan. In this interpretation, the Morden-Boyne pair is a stratigraphic and sedimentological re-iteration of the underlying Belle Fourche and Second White Specks (Favel) parasequence sets. In a west-to-east traverse across the study area, the Carlile Formation successively underlies the (Santonian) Niobrara Formation, and the erosional unconformities at the base of the succeeding Milk River–Gammon (Santonian to Campanian) and Pembina (Campanian) formations.

Keywords: *Upper Colorado, Turonian, Santonian, Niobrara Formation, Carlile Formation, Morden Shale, Boyne limestone, black shale, calcarenite, sequence sets, structural lineaments, Punnichy Arch, Amaranth successor basin.*

1. Introduction

Mapping of the Phanerozoic formations in the eastern half of southern Saskatchewan and southwestern Manitoba was initiated in 2004 as part of a larger project known as the Williston Basin Architecture and Hydrocarbon Potential Targeted Geoscience Initiative (TGI II) Project. This trans-provincial mapping project was undertaken in conjunction with Saskatchewan Industry and Resources, Manitoba Industry, Economic Development and Mines, and the Geological Survey of Canada in order to provide correlatable continuity for all the major Phanerozoic stratigraphic units present in the region. This paper addresses the distribution and lithological characterization of the Upper Colorado Carlile Formation of southern Saskatchewan and its counterparts (Morden and Boyne) in the outcrop belt of southwestern Manitoba. The overall context is oil and natural gas exploration in the Cretaceous of the study area.

Though intensive studies have been carried out in the outcrops of the Pasquia Hills in eastern Saskatchewan and the escarpment of the Cretaceous rocks in southwestern Manitoba, as well as in certain potash cores from the interprovincial boundary region of eastern Saskatchewan and from other sites in the line of potash mines across east-central Saskatchewan in or about Tp 35 (Wickenden, 1945; Beck, 1974; North and Caldwell, 1975; McNeil and Caldwell, 1981; Bloch *et al.*, 1999; Cumbaa and Tokaryk, 1999; Schröeder-Adams *et al.*, 1999; Collum, 2000; Cumbaa and Bryant, 2001), no similar studies done in the region to the south have been published. With respect to the largely dark grey, argillaceous Carlile Formation of southwestern Saskatchewan, extrapolation to the black shale of the Morden Formation of southwestern Manitoba across the 'terra incognita' of southern Saskatchewan has been based largely on similarity of their sparse faunas. Correlation of the coccolithic uppermost unit of the Niobrara, the 'First White Specks' Member, with the calcareous Boyne Member of Manitoba has been extrapolated from the western and southeastern margins of the Western Interior Basin from Kansas to Alberta on the basis of comparative fauna and the presence of coccolithic limestone and marlstone. 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

1 Geological Consultant, 252 Coldwell Road, Regina, SK S4R 4L2.
[2] 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.

detailed in McNeil and Caldwell (1981) and, therefore, is not pursued further in this paper. These strata were laid down in the eastern portion of the Western Interior Seaway. The counterpart Colorado Group strata of southwestern Saskatchewan are deposits in the western flank of the seaway, a region that was more tectonically active, resulting in thicker accumulations of sediment sourced from the Rocky Mountain orogenic belt. The major papers (Bloch *et al.*, 1999; Schröder-Adams *et al.*, 2001) dealing with correlation of the Manitoba outcrops with 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 papers are authoritative faunal, floral, sedimentological, and geochemical studies of the Upper Colorado Subgroup using essentially the same core and outcrop sources located on the northern and eastern peripheries of the present study area. The study area (Figure 1) lies between Rge 4W3 in Saskatchewan and the outcrop belt of southwestern Manitoba, and between the Canada-U.S.A. international boundary and the edge of the Precambrian Shield which is, in Saskatchewan, north of Tp 52.

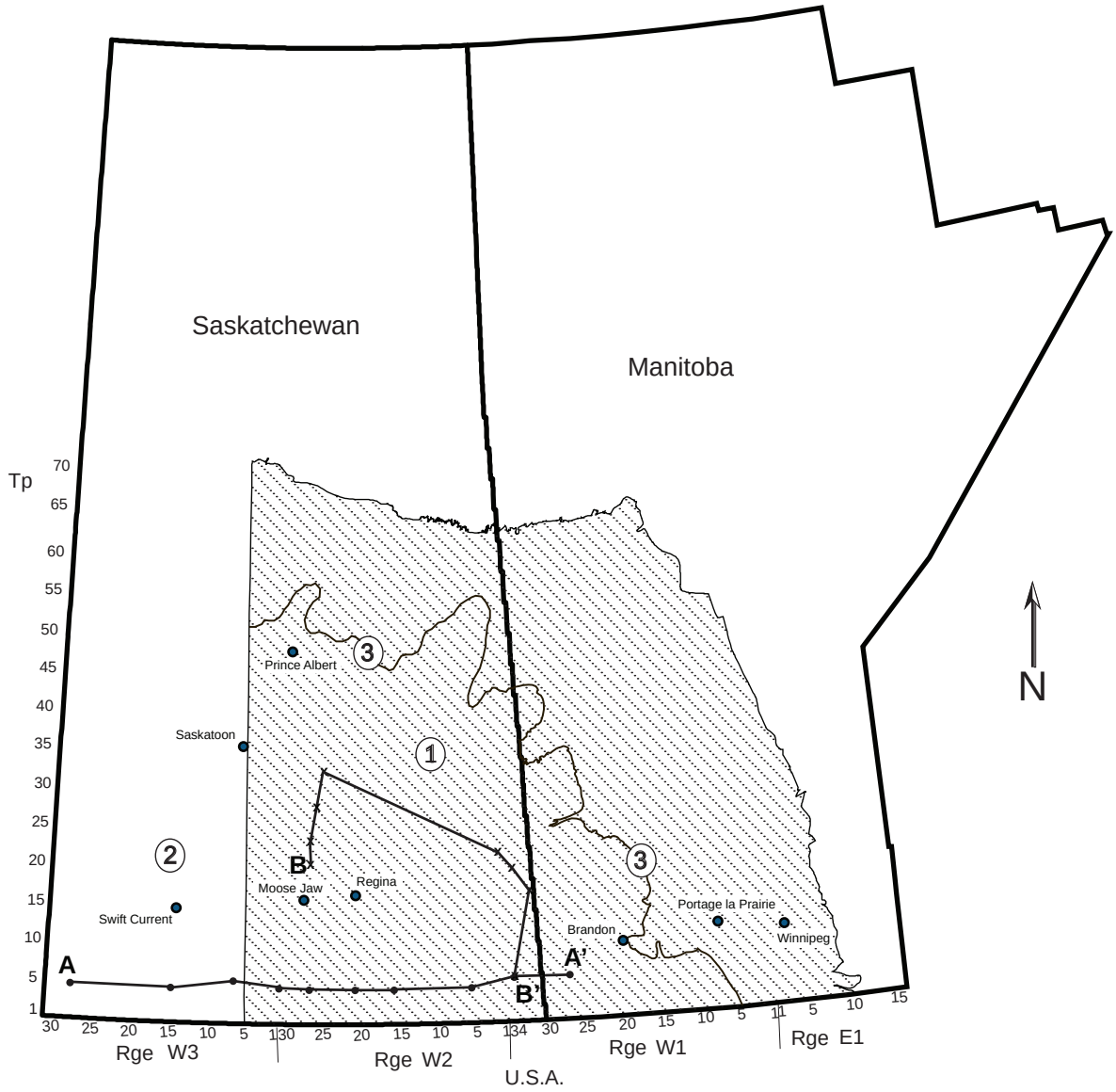


Figure 1 - Map showing (1) the study area; (2) the adjacent western area of Saskatchewan to the Alberta boundary; (3) approximate northern and eastern erosional limit of the Upper Colorado Subgroup in the study area; and (4) the locations of west-to-east stratigraphic cross-section A-A', and stratigraphic cross-section B-B' of cored wells discussed in text.

2. Two Formations by the Name "Niobrara" – Southwestern Saskatchewan *vs.* Manitoba

The Turonian to Santonian Niobrara Formation (Gilboy, 1993, 1996; Nielsen, 2003; Nielsen *et al.*, 2003) of southwestern Saskatchewan and southeastern Alberta is the uppermost unit of the Colorado Group. It consists of three members (oldest to youngest): the Govenlock or Verger (black, bituminous shale and calcareous shale and marlstone with or without calcareous white coccoliths), the Medicine Hat (grey black shale, and silty to sandy mudstone), and the First White Specks (medium to light grey calcareous mudstone and shale, generally coccolithic as the name implies). This Niobrara Formation overlies the Carlile Formation and is overlain by the Milk River Formation. Recent mapping (see Yurkowski *et al.*, this volume), as confirmed by the present authors through geophysical-log stratigraphic cross sections from the reference line of section along Rge 27W3 (Gilboy, 1996) to Manitoba, indicates the presence of a sub-Milk River unconformity (predicted by Gilboy, 1996), under which the Niobrara is progressively truncated northeastward until terminated along a north-northwesterly front that is mostly located west of the Third Meridian (Longitude 106^{o}). Thus, as shown in Figures 2 and 4, the Niobrara is not present in the study area, except for possible vestigial outliers of the basal Verger unit of Nielsen *et al*., 2003) underlying the Milk River Formation.

In southwestern Manitoba, the uppermost Colorado Group nomenclature comprises an eastern 'Niobrara' (the name applied to the medial Boyne Member of the discarded Vermillion River Formation by McNeil and Caldwell, 1981), and the underlying Morden Member of the Vermillion River Formation. The overlying Campanian Pembina Member was assigned by McNeil and Caldwell to the Pierre Shale. The eastern Niobrara is faunally dated as "largely Santonian", but with a potential range from Late Turonian to Early Campanian (McNeil and Caldwell, 1981, p59) and is equated with the Santonian western Niobrara First White Specks Member on the basis of faunal similarity, the first appearance downward of coccolithic shale, and the deductions that: 1) the First White Specks Member undergoes an eastward convergence with the eastern Niobrara (Boyne) by truncation of underlying members across the study area (North and Caldwell, 1975), and 2) the underlying Morden Shale is a full stratigraphic equivalent of the Carlile Formation. Like the Carlile Formation, the Morden overlies the Second White Specks (*i.e.*, the Favel Formation). The present study, as developed below, indicates different relationships: 1) the Morden Member is a basal facies-controlled subdivision of the Carlile; 2) the Boyne Member is an equivalent of the upper units of the western Carlile Formation; 3) the western Niobrara, as aforementioned, does not have a significant presence in the study area by virtue of the sub-Milk River unconformity (revision of Christopher and Yurkowski, 2005, Figure 3); and 4) the Milk River Formation is extensively distributed across eastern Saskatchewan and extreme southwestern Manitoba, though truncated asymptotically across its distal beds by the succeeding Campanian sub-Lea Park (Pierre) unconformity (Williams and Baadsgaard, 1975; Christopher and Yurkowski, 2003). These relationships are depicted in the geophysical log stratigraphic cross section across southern Saskatchewan (Figure 2), and on the isopach maps of Figures 5, 6, and 7. Finally, the simple procedure of differentiating formations by the presence or absence of coccoliths is poorly utilitarian, in that these algal remains occur in varying amounts in all the formations of the Upper Colorado Subgroup and, as shown by this study, in the distal beds of the Milk River Formation. Thus the "first white specks" encountered in drilling may occur in different stratigraphic units at different localities, and do not necessarily attest to the presence of the uppermost member of the Niobrara Formation of southwestern Saskatchewan. An inspection of the regional stratigraphic cross section of the Carlile-Niobrara relationship, to the south of the study area (across North Dakota, South Dakota, Nebraska, and the type region of Colorado by Shurr and Sieverding, 1980), is illuminating with respect to the variable facies relationships between the three formations. Apparently, the Boyne joins the Morden as shale in the greatly thickened Carlile Williston Basin facies of North Dakota. However, the uppermost bed of the Boyne Member retains its limestone integrity, and is traceable into their Niobrara "C" chalk tongue, *i.e.*, the lowest of three basin-ward–attenuating chalk tongues of their regional Niobrara Formation. On the other hand, their Niobrara Formation is considered to be a chalk lithotope of the Gammon Formation, *i.e.*, Milk River Formation in Saskatchewan.

3. Relationship of the Carlile Formation of Southwestern Saskatchewan to the Morden and Boyne (Niobrara) Members of Southwestern Manitoba

a) General

The Carlile Formation 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). As black shale, the Morden is distinctive and correlatable. However, westward across southeastern Saskatchewan, the black shale thins (Figure 2) and in general,

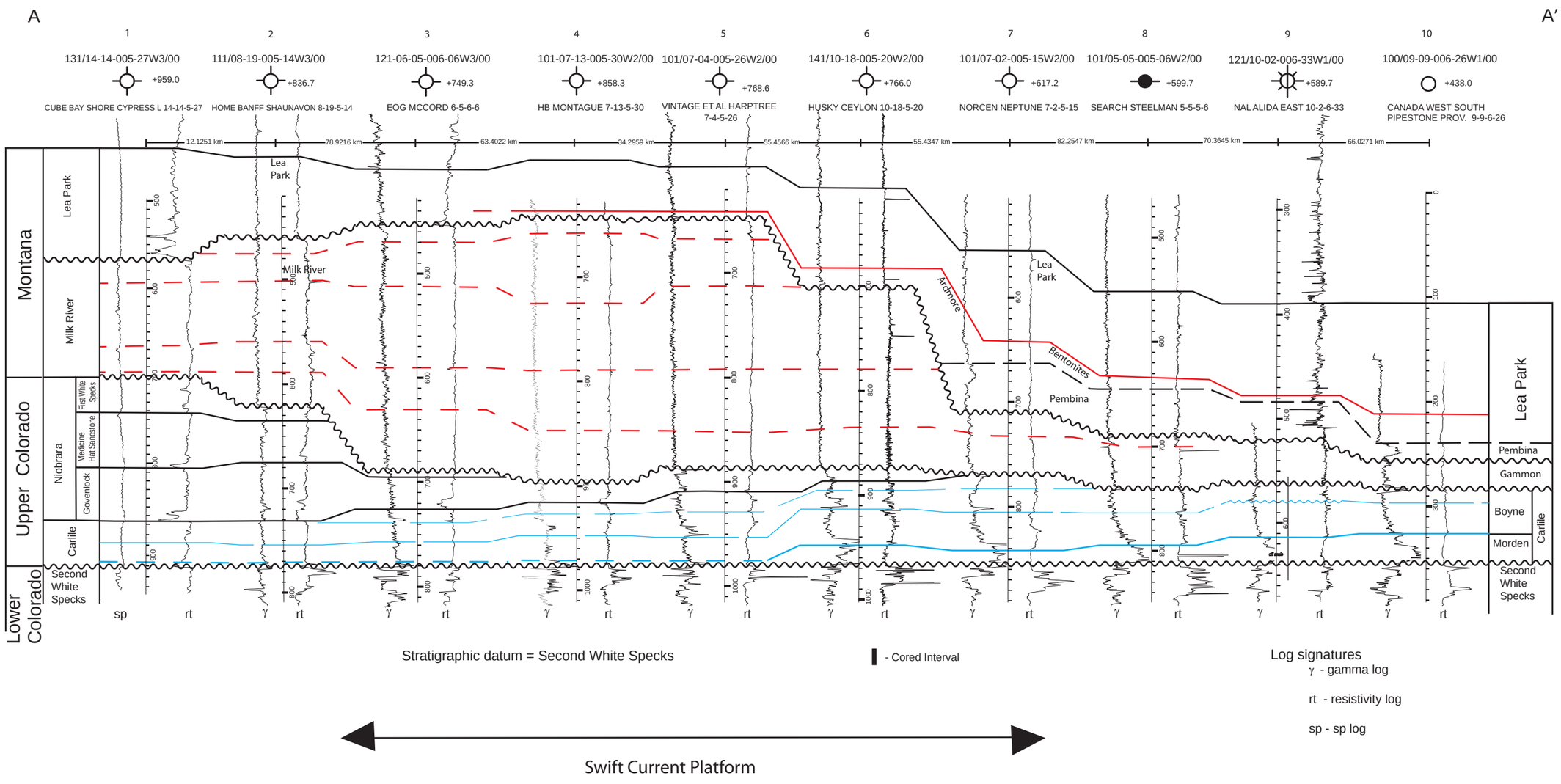


Figure 2 - Geophysical-log stratigraphic cross-section A-A', west to east along Tp 5, southern Saskatchewan and Manitoba, showing relationships of the Upper Colorado Subgroup, and the Milk River and Pierre (Lea Park) formations.

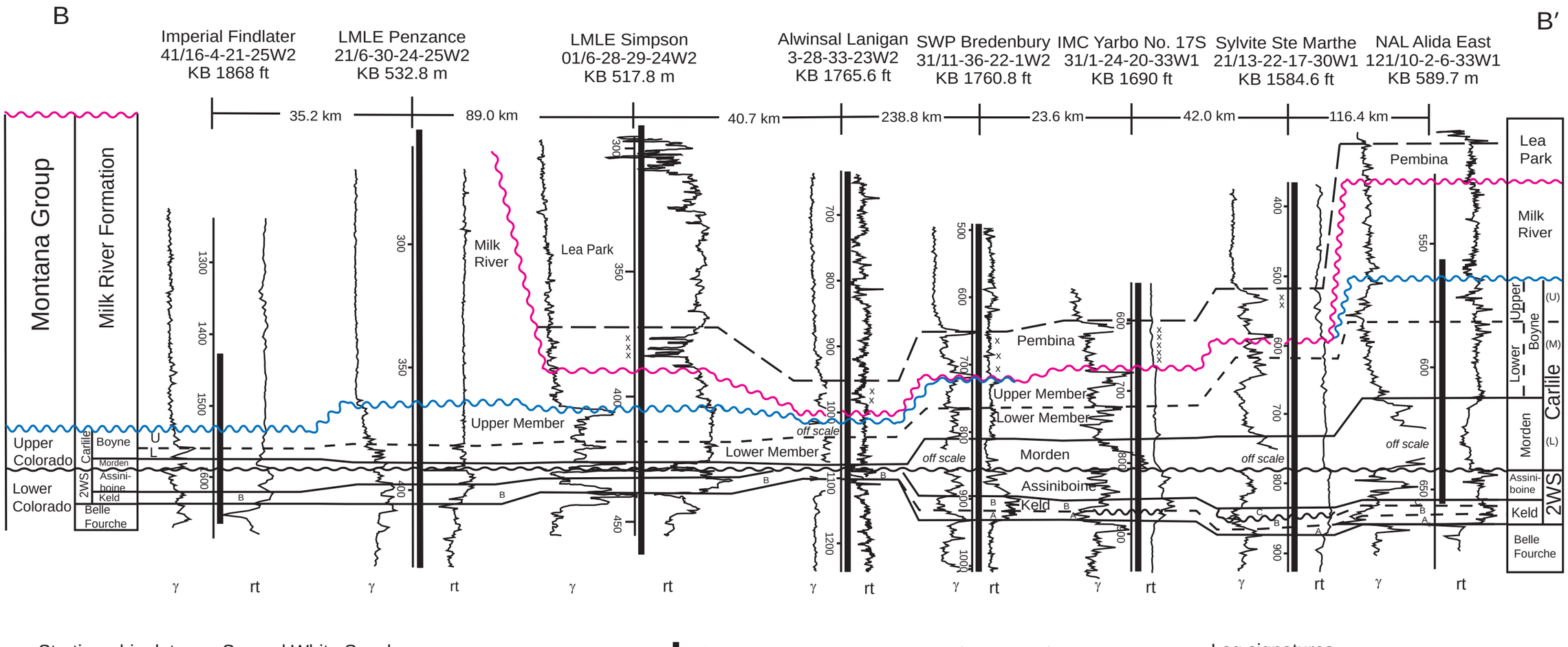
attenuates as basal tongues into the Carlile Formation, and phases into noncalcareous grey mudstone and coccolithic marlstone of the Middle Carlile west of Rge 15W2. However, northward onto the Punnichy Arch of Saskatchewan, the Morden is erosionally overlapped by the Boyne marlstone and limestone. Thus, the Morden is a black shale lithosome 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. On the other hand, the Boyne 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.

The Boyne is traced westward on capping cemented limestone pavements that, where seen in core, 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 else 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, because of the westward attenuation of the black shale, the Boyne calcareous content increases, becoming dominant westward across the study area. Likewise, 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 region of Saskatchewan, and are described and called such by North and Caldwell (1975, p318). A formal lithological description of a Carlile reference section in southwestern Saskatchewan does not exist, however, so no attempt was made in this study to characterize eastward 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 by Pedersen (2004, Figure 3) and, in this study, the stratigraphic cross section of Figure 2. 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 Manitoba (Schröder-Adams *et al*., 2001) and with the base of the Carlile in southeastern Alberta. The Carlile is in unconformity with respect to the Milk River Formation, as indicated by the absence of the western Niobrara, and by the calcite-cemented, joint-inlaid calcarenite that caps the Boyne Member throughout the study area. For want of evidence to the contrary, the Carlile is presumed to be in conformity with the Niobrara of western Saskatchewan.

b) Detailed Stratigraphy

A 4 to 5 m thick section of the Morden Member crops out in the Cretaceous escarpment of southwestern Manitoba. It consists of soft, flaky, greyish black shale to black shale with abundant fish scales and bone debris, and intercalated bentonite seams toward the base (McNeil and Caldwell, 1981, p354). Contacts are apparently obscured by surface debris creep. Their Niobrara Formation (Boyne Member) on the 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, and three intercalated bentonites; and an upper “Calcareous Member”, 12.19 m thick, of dark olive-grey, calcareous shale with fine- to medium-sized chalk specks, bioturbated in the upper 1.83 m, with two bentonite seams. As observed in the cored wells, the upper Boyne is transgressive with respect to the lower. In all the wells, it features basal upward-deepening beds that are in sharp contact with underlying beds, or show an erosive conglomeratic contact, or a basal sand veneer on an erosive contact. Like the sub-Morden unconformity, the regional significance of the sub-upper Boyne disconformity remains undetermined, leaving 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 and Schröder-Adams (1999). The correlation pursued in this study is that the upper Boyne correlates with the upper member of the tripartite Carlile Formation recognized by Nielsen and Schröder-Adams (1999).

The foregoing stratigraphic trichotomy of the Carlile is exhibited in core from wells in southeastern Saskatchewan (Figure 3). At NAL Alida East 121/10-02-006-33W1, the Morden Member is 28.19 m thick. From its base at 642.19 m (2106.9 ft), the Morden grades upward through a basal 0.2 m thick, inoceramid-rich, coccolithic, light grey, cryptocrystalline limestone in erosional contact with the Second White Specks Formation, a 21.49 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, laminated with black shale, and intercalated with abundant inoceramid bioclasts. At 614.0 m (2014.4 ft), the transition into the limestone and shale of the Middle Member of the Carlile (lower Boyne) continues through: (a) 24.05 m of dark grey, variably calcareous, shaly mudstone, into bioturbated marlstone with scattered inoceramid fragments; (b) four layers of medium grey, current-bedded and burrowed, argillaceous limestone, 1.01, 1.32, 2.30, and 5.32 m thick, respectively; and (c) a capping, 0.5 m thick, grey-white, cryptocrystalline limestone, solution-pitted and calcite-filled to a depth of 0.3 m. The Upper Member, at 579.5 m (1901.3 ft), displays similar mini-transitions, but of marlstone to bioturbated, inoceramid-rich, argillaceous limestone, and a solution-pitted limestone 2.55 m below the top, in the superjacent 9.15 m thick stratum ending at 570.35 m (1871.2 ft). 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,



Stratigraphic datum = Second White Specks

▌ - Cored Interval

X = Ardmore Bentonites

Log signatures

γ - gamma log

rt - resistivity log

Figure 3 - Stratigraphic cross section of selected cored wells in the Carlile Formation of the study area. Stratigraphic datum: Second White Specks (2WS).

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 has thinned to 14.6 m (236.8 to 222.2 m (776.9 to 729.0 ft) depth), but features 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 193.1 m (729.0 to 633.53 ft) depth) of the lower unit of the Boyne Member, dated Middle Turonian by North and Caldwell (1975, p318), feature two divisions. In the lower, 23.3 m thick division, dark grey and greyish black, calcareous mudstone with thin *Inoceramus* larger than the 10 cm (4 in) diameter of the core, grade upward 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, 5.8 m thick division displays dark grey, calcareous mudstone, which grades upward into coccolith-speckled, calcite-cemented, laminated, quartzose siltstone and marlstone; it also terminates at a sharp contact. The upper unit of the Boyne features a basal 2.6 m thick layer made up of couplets of dark grey and medium grey calcareous mudstone and marlstone with intercalated bentonite and, at 190.5 m (625.0 ft), an overlying 10.1 m of interbedded coccolithic marlstone and calcareous mudstone with intercalated biotitic bentonite. The Carlile is terminated under the Pembina at 180.4 m (591.8 ft) by the sub-Lea Park (sub-Pierre) unconformity; the Boyne Member here is dated as Late Turonian to Early Santonian (North and Caldwell, 1975).

The 13.11 m thick Morden Member at IMC International Yarbo No 17S (1-24-20-33W1) retains its black shale character as displayed at depths 245.67 to 232.53 m (806.0 to 762.9 ft) (McNeil and Caldwell, 1981). In this study, the strata between the Morden and the sub-Lea Park unconformity at 202.8 m (665.3 ft), *i.e.*, the Niobrara Formation of McNeil and Caldwell, are re-designated the Boyne Member of the Carlile Formation. The 15.56 m thick lower unit of the Boyne Member consists of four upward-shallowing sequences as follows: 1) dark grey and greyish black mudstone grading 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 to (upward) greyish black shale with abundant fish teeth and millimetre-scale fish remains, grading 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). The upper Boyne, from a sharp contact at 217.0 m (711.9 ft), rises through a 9.92 m thick, medium grey, calcareous and noncalcareous mudstone with a basal, thin, calcareous, very fine-grained quartzose sandstone, 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 (663.0 ft) depth by the sub-Lea Park unconformity and is overlain by the Pembina Formation.

At SWP Bredenbury 11-36-22-1W2, attenuation, lenticular bedding, and erosional contacts are abundantly present in the studied section. The basal contact of the Morden on the Second White Specks at 259.7 m (852.0 ft) depth is sharp, irregular, and marked by pyritic nodules, and its 14.9 m-thick, black shale is carbonaceous, noncalcareous, fissile, and sulphurous. The 12.2 m-thick lower unit of the Boyne at 244.8 m (803.2 ft) comprises: 1) sharp-based and sharp-topped, dark grey, slightly argillaceous, 0.4 m thick, cryptocrystalline limestone veined by coarsely crystalline calcite; 2) noncalcareous, greyish black mudstone, 6.0 m thick, with basal inoceramid shell debris on a sharp, irregular contact; 3) coccolithic and calcarenitic, argillaceous, greyish brown, shaly limestone, 2.4 m thick; and 4) a 3.4 m thick, dark brownish grey, noncalcareous, but calcite-veined mudstone on bentonite, grading upward into medium grey, coccolithic and fish-scale–strewn limestone interbedded with calcareous mudstone. The 14.27 m thick upper unit at 232.6 m (763.1 ft) displays a basal erosional contact under a 0.1 m-thick layer of porous, coarse- and medium-grained, quartzose sandstone, with abundant green lithic fragments, black chert, biotite, and fish teeth, This sandstone is successively overlain by a bed of bentonite and 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 10.25 m of noncalcareous, medium brownish grey mudstone that grades, by intercalation, into coccolithic marlstone capped by coccolithic limestone. A sharp, irregular, cemented, coccolithic, calcarenite pavement, 0.02 m thick, terminates the Carlile succession. Between the Carlile at 218.33 m (716.3 ft) and the Campanian Pembina Formation at 217.2 m (712.6 ft) lies a 1.13 m thick, dark grey marlstone with about 15% white specks. It grades upward into dark grey, noncalcareous mudstone that is probably a distal bed of the Milk River Formation.

At Alwinsal Lanigan 3-28-33-23W2 in the western part of the study area, the Carlile is attenuated to 23.10 m. The 2.1 m thick Morden, at a depth of 331.6 to 329.5 m (1087.93 to 1081.0 ft), is composed of greyish black mudstone intercalated with two layers of coarse-grained, white-speckled, coccolithic, argillaceous calcarenite, 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 Morden contact on the Second White Specks is erosional. The overlying Middle Member of the Carlile succession consists of two upward-shallowing marlstone to coccolithic calcarenite transitions, 7.9 m and 4.8 m thick. In the Upper Member, an 8.3 m thick coccolithic calcarenite features centimetre-thick coquinas of *Ostrea*, three bentonite laminae, and a basal, fish-bone-rich, calcarenitic marlstone bed resting on a sharp and

irregular contact marked by black mudstone fragments. Between the Carlile Formation at 308.5 m (1012.1 ft) and the Pembina Formation at 305.1 m (1000.98 ft) lies a dark grey calcareous mudstone with scattered bands of coccoliths. Although possibly a vestigial Verger (Govenlock) Member of the western Niobrara, it is here taken to represent a distal facies of the Milk River Formation. This lithological remnant under the sub-Lea Park unconformity is also present in contact with the Carlile pavement at the SWS Bredenbury 11-36-22-1W2 well.

To the south, at LMLE Simpson 6-28-29-24W2, the Carlile at 403.12 m (1322.6 ft) depth, thickens slightly to 24.31 m. The 2.43 m thick Morden Member comprises black and greyish black mudstone intercalated with seven beds of light grey bentonite, 0.01 to 0.17 m thick, and a basal pisolitic conglomerate on an eroded Second White Specks Formation. The Boyne Member shallows upward overall, through three upward-shallowing sequences constituting the 7.76 m thick lower unit or Middle Member of the Carlile, and an overlying upper unit calcarenite bed, 14.12 m thick, representing the Upper Member of the Carlile. Sequence 1 is a 2.9 m thick, dark grey, faintly bedded marlstone with scattered fish scales and an upward increase in fine-grained, quartzose sand to about 15% over the upper 0.3 m. Sequence 2 is 1.5 m thick repeat of sequence 1, but includes three white bentonite laminae. Sequence 3 is a 3.36 m thick marlstone with an upward increase of quartzose silt and *Ostrea*, and a medial 0.07 m thick layer of fish-bone hash and contiguous bentonite. The calcarenite bed of the Upper Member is fine grained, brown speckled with white, current and wavy bedded, and well indurated by lime mud; it includes coccolithic laminae, scattered layers of *Ostrea* and five layers of bentonite, rests on a sharp contact, and is terminated by the sub-Lea Park unconformity.

At LMLE Penzance 21/6-30-24-25W2, the Carlile is 23.33 m thick. The Morden contracts to a 0.16 m thick, unconformity-bounded conglomerate made up of rounded pebbles of black bituminous shale, green argillaceous, very fine-grained quartzose sandstone and buff sideritic mudstone, which, along with abundant mudstone flakes, fish scales and bone fragments, are set within a matrix of coarse-grained quartzose sand bound in mud. The 9.64 m-thick lower unit of the Boyne consists of three upward-shallowing sequences, 4.39, 2.45, and 2.8 m thick, respectively. These sequences comprise: 1) greyish black, platy, noncalcareous mudstone with scattered white specks, gradational to dark greenish grey, calcareous mudstone with about 10% coarse-grained, white volcanic fragments, and greyish black, laminated and current-bedded marlstone and argillaceous limestone with muscovitic partings; 2) noncalcareous, dark grey mudstone transitional to marlstone with intercalated mudstone and bentonite; and 3) dark grey, noncalcareous mudstone with intercalated bentonite and calcareous, dark brownish grey, mudstone with about 20% coarse-grained, white feldspar and abundant biotite. The lower unit also includes six bentonite laminae, mostly biotitic. The 13.53 m thick upper unit features an upward-deepening lower bed, 4.05 m thick, of dark greenish grey marlstone with locally developed small-scale current-bedding and channelling. It grades into dark grey, patchily calcareous to noncalcareous mudstone with abundant white pelecypod fragments that is overlain by a 9.48 m-thick, upward-shallowing, current-bedded and thinly cross-bedded argillaceous calcarenite with about 15% fine-grained white specks, scattered laminae of pelecypod clasts, and a seventh layer of bentonite. It is terminated by a sharp contact with the Milk River Formation at 368.67 m (1209.5 ft) depth.

4. Basin Setting

The consistent lithological format of the members of the Carlile Formation across the study area shows the Morden-Boyne stratigraphic couple echoes that of the subjacent Second White Specks (Favel)–Belle Fourche (Christopher and Yurkowski, 2005). It also indicates that no drastic tectonic change in basin geometry occurred in this region over the time represented by both formation sets. The stratigraphic relationship of the formations making up the Upper Colorado Subgroup and the Montana Group (along the line of Figure 2) between the reference region of southwestern Saskatchewan and the outcrop belt in Manitoba is depicted in Figure 4A, using the low-relief sub-Carlile unconformity on the Second White Specks Formation as datum. This unconformity gently truncates the latter from east to west, thereby indicating mild post-Second White Specks, pre-Carlile uplift in the west. The diagram also depicts truncation of the Niobrara Formation on to the Carlile Formation by erosional 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, mostly as a high-relief cut antecedent to the northwesterly front of the Cenozoic Missouri Coteau at Rge 14W2 (Christopher and Yurkowski, 2003). To the east, the unconformity surface is essentially low relief, and supported by a veneer of Milk River silty shale, named the Gammon Shale in Manitoba (McNeil and Caldwell, 1981), on the Carlile (Boyne Member). Both the Niobrara and Milk River formations are westerly sourced foreland basin deposits laid in active depocentres (in a similar way to Carlile deposition in southwestern Alberta where the formation thickens from 40 to 160 m, Nielsen *et al.*, 2003). Thus, the pattern appears to be a progression of eastward-advancing downwarps creating accommodation space for the Upper Cretaceous stratigraphic bodies. A more realistic portrayal of these events is presented in Figure 4B, wherein the cross section of Figure 4A is reformatted to a datum on the sub-Milk River unconformity. This diagram portrays the formations of the Upper Colorado Subgroup as downwarped in the west under a progradational Milk River body and preserved there, though truncated across a nearly flat eastern shelf. Accordingly, the Boyne represents shelf facies (Niobrara type) of coccolithic and bioclastic carbonates built up on the broad, episodically emergent, marine platform of eastern Saskatchewan and southwestern Manitoba, in counterpoint to the differentially subsiding

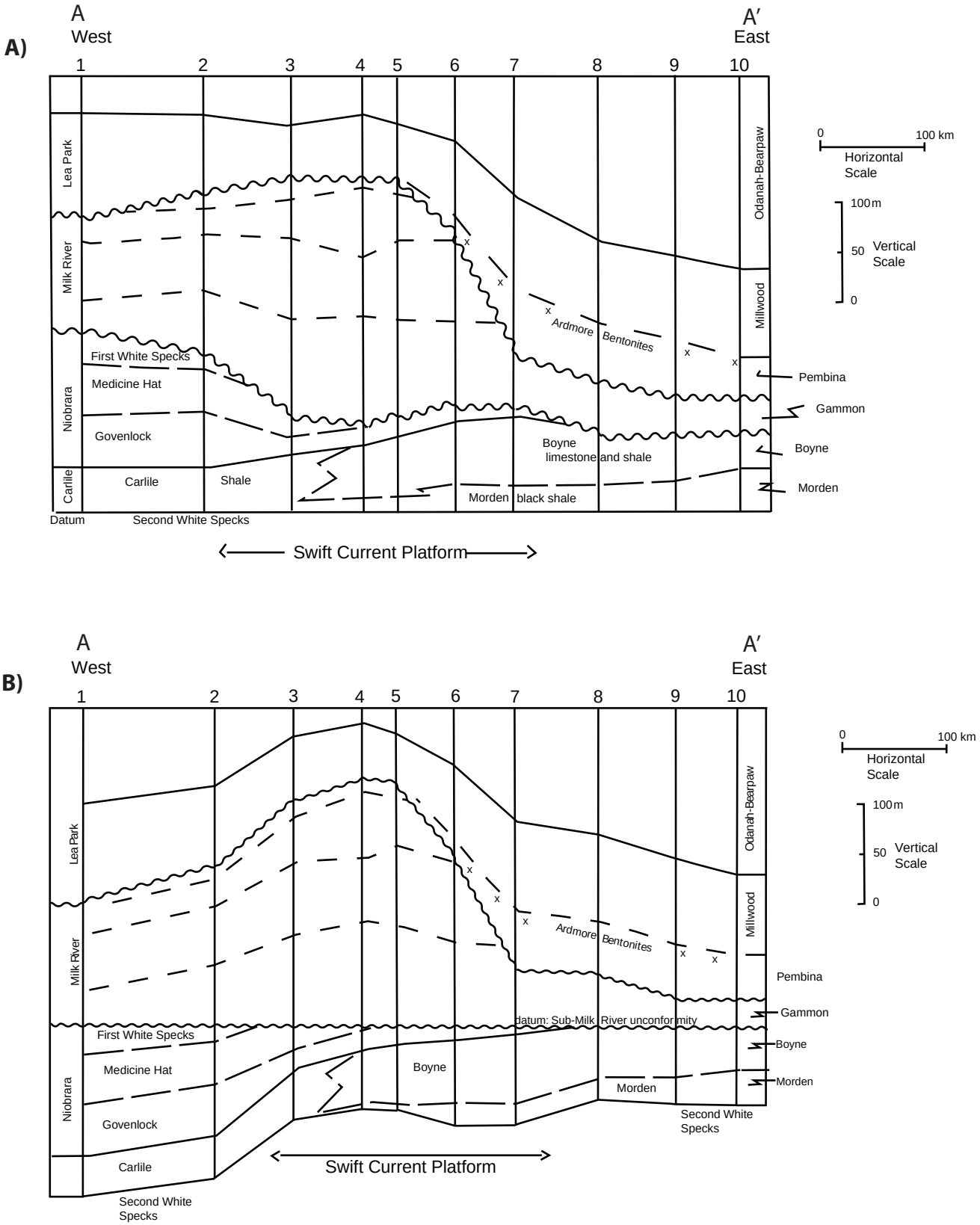


Figure 4 - A) West-to-east stratigraphic diagram of the formations of the Upper Colorado Subgroup and Montana Group along Tps 5 and 6, southwestern Saskatchewan and southwestern Manitoba; wells are as numbered in Figure 2, but scaled spatially: datum on the Second White Specks–Favel Formation; B) As in 4A, but with datum on the sub-Milk River unconformity.

tectonic depocentre of the Carlile in southeastern Alberta. By the same argument, the Morden black shale depocentre in the southeast of the study area represents an early Carlile repeat in the eastern part of the Williston Basin of Belle Fourche subsidence in the western part of the basin.

The isopach map of the Morden Formation (Figure 5) is that of the black shale facies and equivalent grey, calcareous shale in the lower part of the Carlile. The isopach map of the Boyne Member represents overlying Middle and Upper Carlile strata (Figure 6). Accordingly, the Carlile Formation (Figure 7) is that of the combined members. The three maps by virtue of the relative thinness of the units portrayed and the lithological contrast of limestone and shale, reveal in their isopach patterns much about the architecture of the depositional basin. Some of the elements of this architecture had persisted through Early Mesozoic and Lower Cretaceous depositional episodes, energized by basement reactivation effects and by differential compaction on topographic forms of the Paleozoic erosion surface. These elements are plotted on the isopach maps.

The **Morden Member** is thickest in the successor basin to the Jura-Triassic Amaranth sub-basin in southwestern Manitoba. From 60 m in the south (Figure 5), the Morden – within a north-northwesterly–trending trough (4) – thins to 20 m at Tp 30 near the interprovincial boundary. Cenozoic erosion has stripped the Morden strata back to the outcrops of the Manitoba escarpment. In Saskatchewan, the black shale body thins northeastward on and over the Punnichy Arch (1) to a veneer less than 5 m thick, but thickens toward the south between Rges 20W2 and 5W2, from 15 m to 36 m at the international border. The broad regional depositional control of the Morden successor to the Amaranth basin (4) is reflected in the isopach map by the southeasterly thickening and dominant northeasterly isopachous strike over most of the study area. Multiples of the axial thickening associated with the Morden successor trough are present in southeastern Saskatchewan, as suggested by the northwesterly projecting embayment of thickening from the international border, between Rges 26W1 and 32W1, wherein the Morden thins from 43 m to less than 20 m in Saskatchewan at Rge 6W2, Tp 19. A comparable trend also occurs at Rge 22W2, whereby the Morden, 45 m thick at the international border, thins to the northeast along a steep front trending northwesterly from the Hummingbird Trough at Rge 18W2. This front is believed to be a multiple of a set of linears back-stepped from the eastern front of the Swift Current Platform. Salt-dissolution sinks emanating from the Middle Devonian Prairie Evaporite are apparently present in the eastern site of thickening (Tps 23 to 32, Rges 5W2 to 7W2). These coincide with sites of Jura-Cretaceous and Early Cretaceous collapse linked to the Tabbernor Lineament Zone (2) fronting the Moosomin-Hudson Bay structural trend (3) (Christopher, 2003) and, in the south, to tectonic down-hinging on a subsiding Morden successor basin to the Amaranth. In general, the prevailing black shale of the Morden reflects strongly reduced bottom conditions arising from an oxygen-depleted water-seafloor interface. Northwestward attenuation of the Morden on the Punnichy Arch reflects similar conditions, but on a rising seafloor, with greater oxygenation and less accommodation for introduced sediments, as suggested by the presence of coccolithic laminae.

The **Boyne** isopach map (Figure 6) displays patterns similar to those of the Morden but with offsets, and reflects exposure to more open-marine conditions associated with carbonate build-ups on bottom sites of higher elevations. Thus the axis of Boyne thickening (4) in the Amaranth successor basin of southwestern Manitoba lies west of that in the Morden. The shift reflects not only the effects of Cenozoic erosion, but also Boyne carbonate build-up on buried highs associated with the sub-Mesozoic erosional edge of the Mississippian Lodgepole Formation (5). Thus a thickness of 50 to 70 m on the approach to the Williston Basin in the south persists northward on the draped Lodgepole cuesta (5) to where the trend coincides with the Moosomin–Hudson Bay structural front (3) along Rge 30W1 in eastern Saskatchewan. Likewise, to the south along this front, thicknesses of 40 to 50 m prevail to the east on the draped sub-Cantuar Moosomin Paleo-upland (Christopher, 2003). South of Tp 10, between Rges 5W2 and 26W2 in Saskatchewan, the Boyne exceeds 30 m in thickness, and increases toward the Williston Basin depocentre, reaching more than 84 m at the international border, Rge 18W2. This region is coincident with a sub-Cantuar paleo-upland on the Jura-Cretaceous Success Formation, and presumably represents a Boyne carbonate build-up on the medium-level terrace presented by the buried Willowbunch Paleo-upland (Christopher, 2003). A broad expanse of 55 to 34 m thickness in the western part of the study area, north from the international border to the northwest-aligned salt-dissolution edge of the Middle Devonian Prairie Evaporite, coincides with the region of absent salt beds from the Prairie Evaporite, a coincidence which might be linked to sapping of the salt beds at depth. However, the multiple progradational Boyne sequences indicate episodic subsidence of the underlying basement-controlled Swift Current Platform, similar to that which had previously occurred during the Albian Pense depositional episodes (Christopher, 1974, p108). Other trends are post-Boyne erosional effects such as the southeasterly trending zone of thinning to 21 m, between Tps 27 and 18 between Rge 3W2 and the Manitoba boundary, which reflects incision associated with the sub-Lea Park (sub-Pierre) erosion surface. In Saskatchewan, unlike Manitoba, Boyne strata thin by about 10 m where they drape over the buried peaks of the Mississippian Lodgepole escarpment (5). Penecontemporaneous erosion associated with mild uplift of the Punnichy Arch (1) is indicated. On the upper expanse of the arch, Boyne thicknesses of 20 to 30 m are widespread. Localities with thickness of up to 40 m are attributable to infill of contemporaneous subsidence over sites of Prairie Evaporite salt dissolution.

South of Tp 10, the **Carlile Formation** (Figure 7) thickens rapidly from a full regional spread on an east-west hinge about the 60 m isopach to more than 110 m at the international border. The isopachous slope reflects deepening of

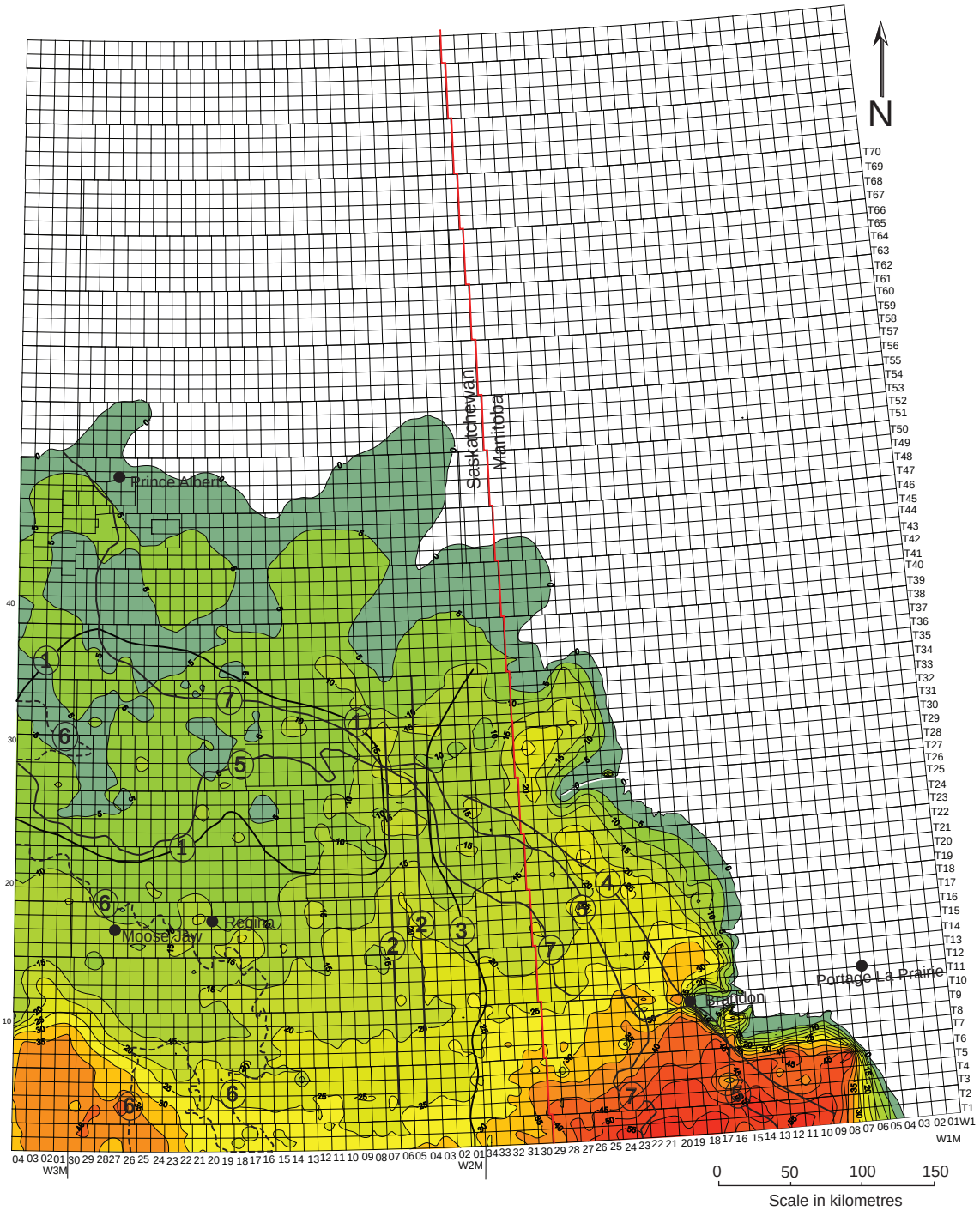


Figure 5 - Isopach map of the Morden Member of the Carlile Formation, southeastern Saskatchewan and southwestern Manitoba. Contour interval is 5 m; depicted from Christopher (2003): 1) Punnichy Arch; 2) projection of the Precambrian Tabbernor Lineament Zone; 3) Moosomin–Hudson Bay structural belt (Churchill-Superior Boundary Zone (Li* et al., *2005)); 4) axis of Upper Colorado successor basin to the Jura-Triassic Amaranth; 5) buried subcrop of the Mississippian Lodgepole Formation; 6) Prairie Evaporite salt-dissolution front; and 7) erosional edge of the Milk River Formation.

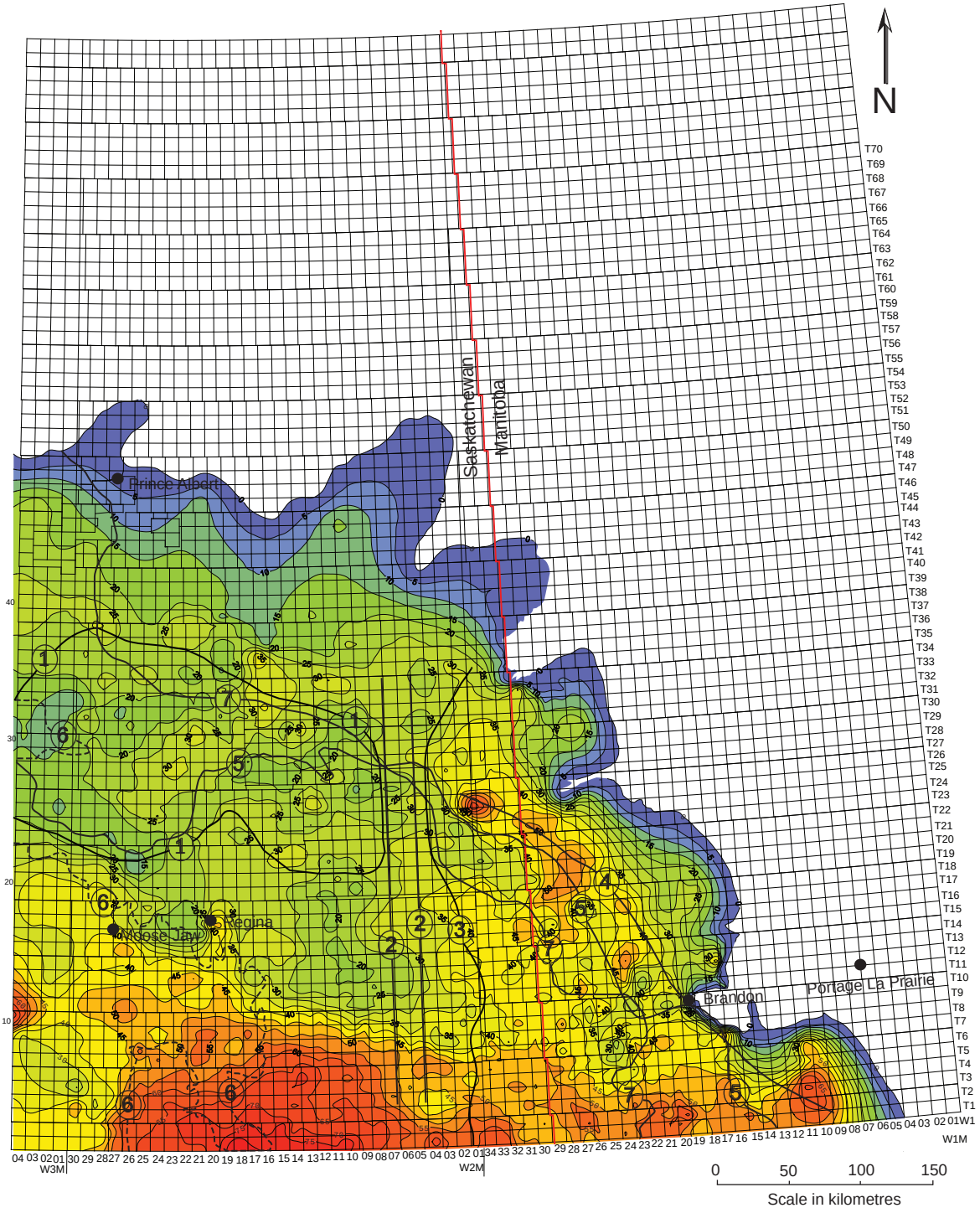


Figure 6 - Isopach map of the Boyne Member of the Carlile Formation, southeastern Saskatchewan and southwestern Manitoba. Notations are as in Figure 5.

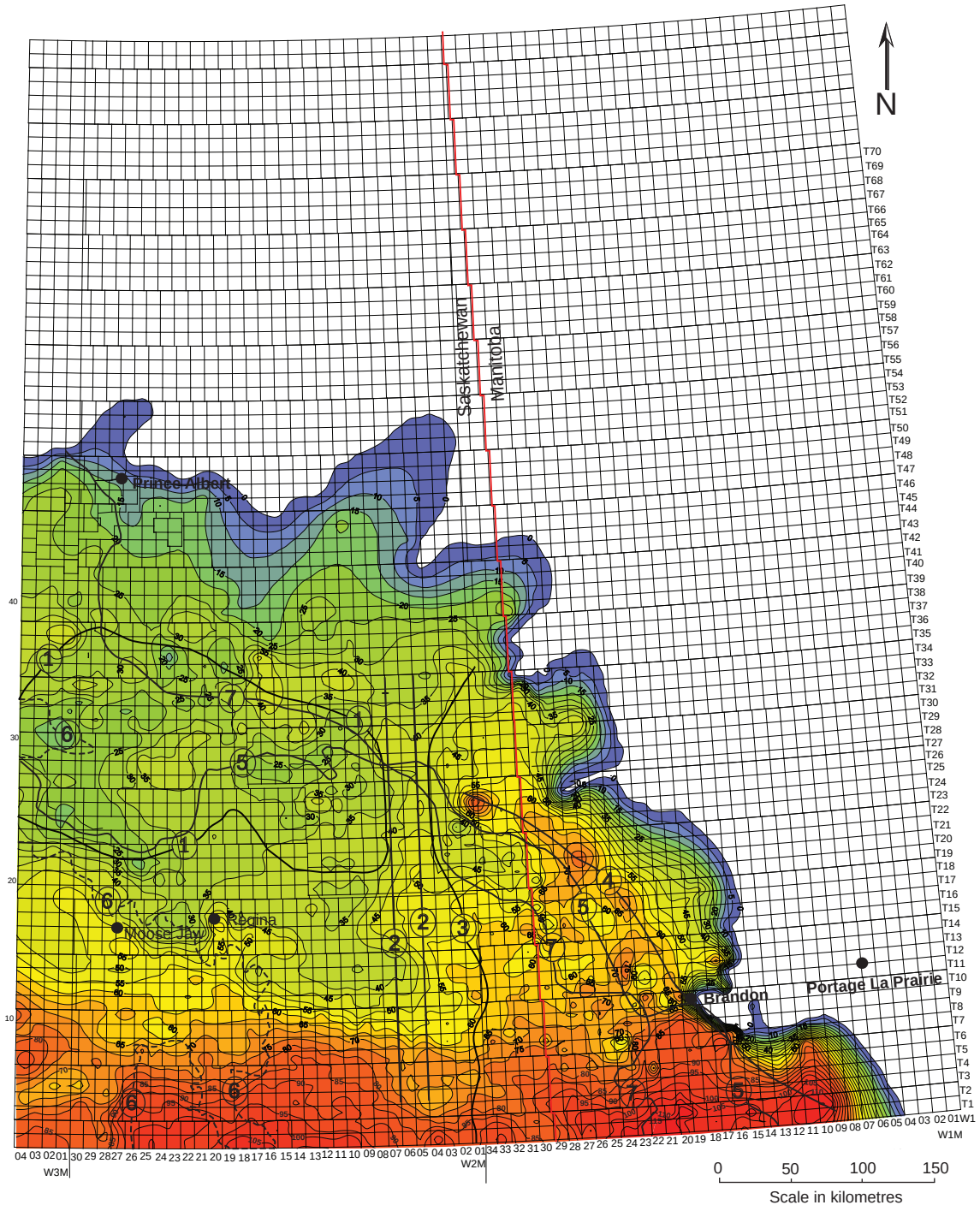


Figure 7 - Isopach map of the Carlile Formation, southeastern Saskatchewan and southwestern Manitoba. Notations are as in Figure 5.

the Williston Basin which had expanded northward in response to downwarp of the structural blocks controlling the Amaranth successor basin and the Swift Current Platform. The successor basin to the Amaranth in Manitoba is elongated north-northwest, its axis (4) parallel to, but generally outside, the buried edge of the Mississippian Lodgepole Formation (5). Its eastern flank has been stripped back to the Cretaceous escarpment by Tertiary erosion, and its western flank is apparently bounded by the Tabbernor Lineament Zone (2) along Rges 5W2 and 6W2 in Saskatchewan. Sedimentary thickness ranges from 120 m at the international border to about 50 m in the interprovincial region at Tp 30, where the trough of the Carlile successor basin apparently terminates along the Moosomin–Hudson Bay structural trend (3) at Rge 3W2 in Saskatchewan. South of Tp 10 in the sub-basin, the Carlile thickens rapidly toward its depocentre in the Williston Basin. The bifurcation of the successor basin deposits in the northwest, by a southeasterly projected zone of thinning to about 40 m ending at about Tp 18 and the interprovincial boundary, reflects truncation along the edge of the Milk River Formation (7) by pre-Lea Park erosional agents. West of Rge 6W2, the 45 m contour trends northwest along the edge of the Swift Current Platform as projected along the dissolution edge of the Middle Devonian Prairie Evaporite (6), From here, the Carlile steps down into the Williston Basin across an eight township-wide, 45 to 65 m thick terrace, south of which the formation thickens to 120 m. The region to the north of the Swift Current Platform is one of broad flats supported by the Punnichy Arch (1); here, the Carlile is mostly represented by condensed limestone and marlstone between 45 and 25 m thick. Isopachous thins, in the range of 17 to 25 m, are associated with the buried subcrop of Mississippian strata (5), reflecting drape of buried hills on the sub-Mesozoic topography. Northeast and east of the edge of the Milk River Formation (7), the Carlile underlies the Campanian Pembina Formation at the sub-Lea Park (sub-Pierre) erosion surface.

The depositional format of the Carlile Formation is a more elaborate repeat of Belle Fourche–Second White Specks depositional cycles. It begins with black shale controlled by downwarp and restriction in the Amaranth successor basin of Manitoba, succeeded by cyclic build-ups of black and grey shale to marlstone and calcarenitic limestone on the low-relief platform region of eastern southern Saskatchewan and extreme southwestern Manitoba. The basal contact of the Carlile is erosional everywhere in the study area, but other than a mild westward erosion of the Second White Specks Formation, the indicated hiatus appears not to reflect profound tectonic changes in the shelf setting of the study area. The upper contact is marked by widespread calcite-cemented pavements, which have 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 built up by weak incursions of sediment derived from distant sources and by growth of indigenous bioclastic banks. Multiple emergences of the seafloor occurred on the basin's higher eminences such as the Punnichy Arch, the eastern front of the Precambrian Superior Province represented by the Moosomin–Hudson Bay structural front and associated lineaments such as the Tabbernor, and the compactional highs of the buried Mississippian escarpment. The northern Williston Basin flank with its re-entrants represented by the Amaranth successor basin and embayed Swift Current Platform lay outboard to the foreland-basin depocentre of the Western Interior Basin of southwestern Alberta and north-central Montana. In the southwest of the study area, thickening is attributable to tectonic subsidence, hinging not only on the Williston Basin but also on an active western foreland basin. Both Morden and Boyne maps are congruent across the study area, indicating thereby absence of a regional hiatus between the units. The Morden, by virtue of its black shale lithotope, indicates early subsidence in an eastern restricted basin, and the Boyne, by the trapping of argillaceous sediments in the trough of southwestern Saskatchewan–southeastern Alberta, made for better circulation in the study area and correspondingly greater life support that led to biogenic limestone deposition.

5. Hydrocarbon Potential

Any prospecting for oil and natural gas in the Second White Specks (Favel) of the study area automatically involves the Boyne Member of the Carlile Formation because of their similar lithological and geochemical characteristics and stratigraphic proximity. Moreover, the Carlile Formation is more than twice as thick as the Second White Specks and, therefore, has greater potential with respect to hydrocarbon generation and storage. As regards to organic content, the Upper Colorado formations in the SWP Bredenbury well 11-36-22-1W2 well were analyzed in detail by Bloch *et al.* (1999); the results serve as a standard for the eastern part of the study area:

	Total Organic Carbon (TOC in %)	Oxygen Index (OI):
Keld	7.87, 8.17, 8.14, 1.4, 0.82	375º, 373º, 446º, 346º, 255º
Assiniboine	12.62, 7.23, 10.26, 4.65, 9.14	455º, 423º, 447º, 120º, 177º
Morden	12.17, 2.87, 9.11, 6.75, 5.15	370º, 320º, 108º, 73º, 134º
Boyne	7.98, 0.85, 5.51, 7.51, 10.39	498º, 323º, 405º, 391º, 367º

Bloch *et al.* (1999) 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 their hydrocarbons to be sub-mature: Types II and III in the classification of Macauley (1984), who also contoured the regional values of TOC for Saskatchewan and Manitoba (Macauley, 1984, Figure 57). The region of eastern central Saskatchewan to the outcrop belt in Manitoba is considered to have the better promise of productivity, as exemplified by earlier exploration in the Pasquia Hills for economic deposits of oil shale (Beck, 1974). According to McInnes (1913), retorting of oil shales from the Pasquia Hills indicates a productivity of 7 gallons (Imp.)/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 from the Favel and Carlile formations, in that the transmissive natural gas productive Medicine Hat sandstones of southwestern Saskatchewan do not extend into the study area. However, the Milk River Formation is present *en masse* in the western third of the study area, where it is severely truncated by the sub-Lea Park erosional front trending northwest from Tp 1, Rge 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 the underlying Carlile, the latter containing outlying sand patches in the western portion of the study area, are likely interceptors of this migration. That portion of the gas stream bypassing stratigraphic traps in these formations occasionally appears to be trapped against the glacial till cover in northeastern Saskatchewan and southwestern Manitoba, where it has from time-to-time been tapped by incidental drilling. The fact that oil-shale quality increases eastward (Macauley, 1984) may indicate heat sources related to local tectonic action along lineaments associated with the buried Churchill–Superior Boundary Zone at the Second Meridian (Longitude 102ºW) and, therefore, enhanced potential for biogenic gas generation.

6. References

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

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. 531, 185p.

Christopher, J.E. (1974): The Upper Jurassic Vanguard and Lower Cretaceous Mannville Groups of Southwestern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 151, 349p.

_____ (2003): Jura-Cretaceous Success Formation and Lower Cretaceous Mannville Group of Saskatchewan; Sask. Industry Resources, Rep. 233, CD-ROM.

Christopher, J.E. and Yurkowski, M. (2003): The major Late Cretaceous (Campanian) unconformity, southeastern Saskatchewan; *in* Summary of Investigations 2003, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2003-4.1, CD-ROM, Paper A-12, 20p.

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

Collum, 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.

Cumbaa, S.L. and Bryant, H.N. (2001): Stratigraphic position of a Late Cretaceous (Cenomanian) bonebed, east-central Saskatchewan; *in* Summary of Investigations 2001, Volume 1, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2001-4.1, p121-124.

Cumbaa, S.L. and Tokaryk, T.T. (1999): Recent discoveries of Cretaceous marine vertebrates in the eastern margins of the Western Interior Seaway; *in* Summary of Investigations 1999, Volume 1, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 99-4.1, p57-63.

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. (1993): The Carlile Shale equivalent (Upper Cretaceous) in southwestern Saskatchewan: A wireline-log study; *in* Summary of Investigations 1993, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 93-4, p133-135.

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

Li, J., Morozov, I., 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. 2005-4.1, 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): Basins of Nelson and Churchill Rivers; Geol. Surv. Can., Mem. 30, 146p.

McNeil, D.H. and Caldwell, W.G.E. (1981): Cretaceous Rocks and their Foraminifera; Geol. Assoc. Can., Spec. Pap. No. 21, 439p.

Nielsen, K.S. (2003): Lithostratigraphy, sequence stratigraphy and paleoenvironments of the Upper Colorado Group in southern Alberta and southwestern Saskatchewan: Definition of the Carlile and Niobrara formations (Upper Turonian to Santonian); unpubl. Ph.D. thesis, Carleton Univ., Ottawa, 515p.

Nielsen, K.S. and Schröder-Adams, C.J. (1999): Upper Colorado lithology and wire-line log correlations in southwestern Saskatchewan; *in* Summary of Investigation 1999, Volume 1, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 99-4.1, p79-84.

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, Geol. Assoc. Can., Spec. Paper No. 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 Resources, Misc. Rep. 2004-4.1, CD-ROM, Paper A-16, 15p.

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; Palaeogeog. Palaeoclim. Palaeoecol., v170, p261-289.

Schröder-Adams, C.J., Leckie, D.A., Craig, J., and Bloch, J. (1999): Upper Cretaceous Colorado Group in Pasquia Hills, northeastern Saskatchewan: A multidisciplinary study in progress; *in* Summary of Investigations 1999, Volume 1, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 99-4.1, p52-56.

Shurr, G.W. and Sieverding, J.L. (1980): Preliminary Synthesis of Subsurface Stratigraphy of the Niobrara Formation (Upper Cretaceous) in the Northern Great Plains; U.S. Geol. Surv., Open File Rep. 80-1266, 19p.

Wickenden, R.T.D. (1945): Mesozoic Stratigraphy of the Eastern Plains, Manitoba and Saskatchewan; Geol. Surv. Can., Mem. 239, 37p.

Williams, G.D. and Baadsgaard, H. (1975): Potassium-Argon dates and Upper Cretaceous biostratigraphy in eastern Saskatchewan; *in* Caldwell, W.G.E. (ed.), Cretaceous System in the Western Interior of North America, Geol. Assoc. Can., Spec. Paper No. 13, p417-426.