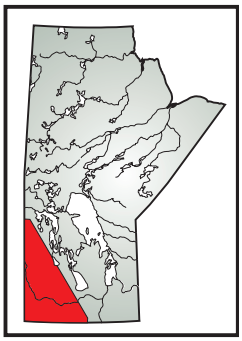
GS-19 Revisions to the Cretaceous stratigraphic nomenclature of southwest Manitoba (parts of NTS 62F, G, H, J, K, N, O, 63C, F)

by J.D. Bamburak and M.P.B. Nicolas



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Summary

The Cretaceous stratigraphic nomenclature of southwest Manitoba has evolved for over a century and continues to change as new information on the geological framework of the province becomes known. Documentation of the historical evolution of the names applied to a stratigraphic unit assists industry and researchers in applying current concepts to areas with unknown hydrocarbon potential or in re-evaluating previously producing localities.

The Cretaceous sedimentary sequence that forms much of the Manitoba Escarpment was deposited during two major cycles of marine sedimentation, near the eastern margin of the Western Canada Sedimentary Basin. The current formational nomenclature of southwest Manitoba's Cretaceous stratigraphic succession, in ascending order, is the Swan River Formation, Ashville Formation, Favel Formation, Carlile Formation, Pierre Shale and Boissevain Formation. Most of these formations are composed of unique members and beds, as well as informal stratigraphic units, which comply with the 2004 revisions to the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005).

Correlation of these Cretaceous formations, members and beds to equivalent units in other provinces and states in North America has resulted in numerous changes to Manitoba's stratigraphic terminology through time. Understanding the evolution of these changes provide exploration opportunities for potential natural gas resources in Manitoba.

Introduction

In 1981, McNeil and Caldwell (1981) completed a comprehensive historical review of the evolution of nomenclature of the Cretaceous stratigraphy of southwest Manitoba. Since then, new interpretations of the stratigraphic succession have resulted in necessary revisions to the framework proposed by McNeil and Caldwell (1981). The most updated, available stratigraphy is used in report generation and presentations by government, the mining industry and the public. The documentation of the successive changes to the stratigraphic framework is critical for the classification of the historical geochemical analyses of Cretaceous shale sequences and the interpretation of their chemostratigraphic signatures, as described by Bamburak (2008). For example, Nicolas and Bamburak (GS-17, this volume) apply modern stratigraphic terminology and formational picks to correlate historical Rock Eval™ data with new sample data in order to create a combined, larger database. Nicolas (2009) discusses the modern stratigraphic framework and its correlations with units and hydrocarbon exploration in eastern Saskatchewan.

This report reviews the historical application of Cretaceous formational nomenclature of southwest Manitoba to 1981, describes revisions from 1982 to 2009, and presents the updated terminology currently in use by the Manitoba Geological Survey. Many of these changes were compiled in detail for each formation of the Phanerozoic by Glass (1997) in the *Lexicon of Canadian Stratigraphy*. Figure GS-19-1 depicts a vertically exaggerated, simplified cross-section of the Paleozoic to Cenozoic formations in southern Manitoba. The cross-section shows that the formations dip towards the southwest, with the Paleozoic beds dipping more steeply than those of the overlying Mesozoic strata. The Cretaceous beds in southwest Manitoba form the uppermost portion of the Mesozoic stratigraphy.

According to McNeil and Caldwell (1981), the 600 m thick Cretaceous sequence that forms the Manitoba Escarpment and adjacent plains was deposited during two major cycles (Greenhorn and Niobrara) of marine sedimentation, near the eastern margin of the Western Canada Sedimentary Basin. The earlier, ca. 4 Ma, Greenhorn marine sedimentary cycle reached its transgressive peak in the early Turonian and was regressive through the late-middle or late Turonian. The younger, ca. 2 Ma, Niobrara cycle reached its transgressive peak in the late Santonian to early Campanian, and was regressive during or after the late Campanian.

The current stratigraphic nomenclature of the Cretaceous outcrop belt of southwest Manitoba is shown in Figure GS-19-2 under column heading 'Nicolas (2009) Southwest Manitoba outcrop belt'. The equivalent nomenclature for the subsurface is shown in Nicolas and Bamburak (Figure GS-17-1, this volume) and for eastern Saskatchewan in Nicolas (2009, Figure 2). In Manitoba, the succession of Cretaceous formations, in ascending order, comprises: the Swan River, Ashville, Favel, Carlile, Pierre Shale and Boissevain formations. The stratigraphic designations, contained within, comply with the 2004 revisions to the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005).

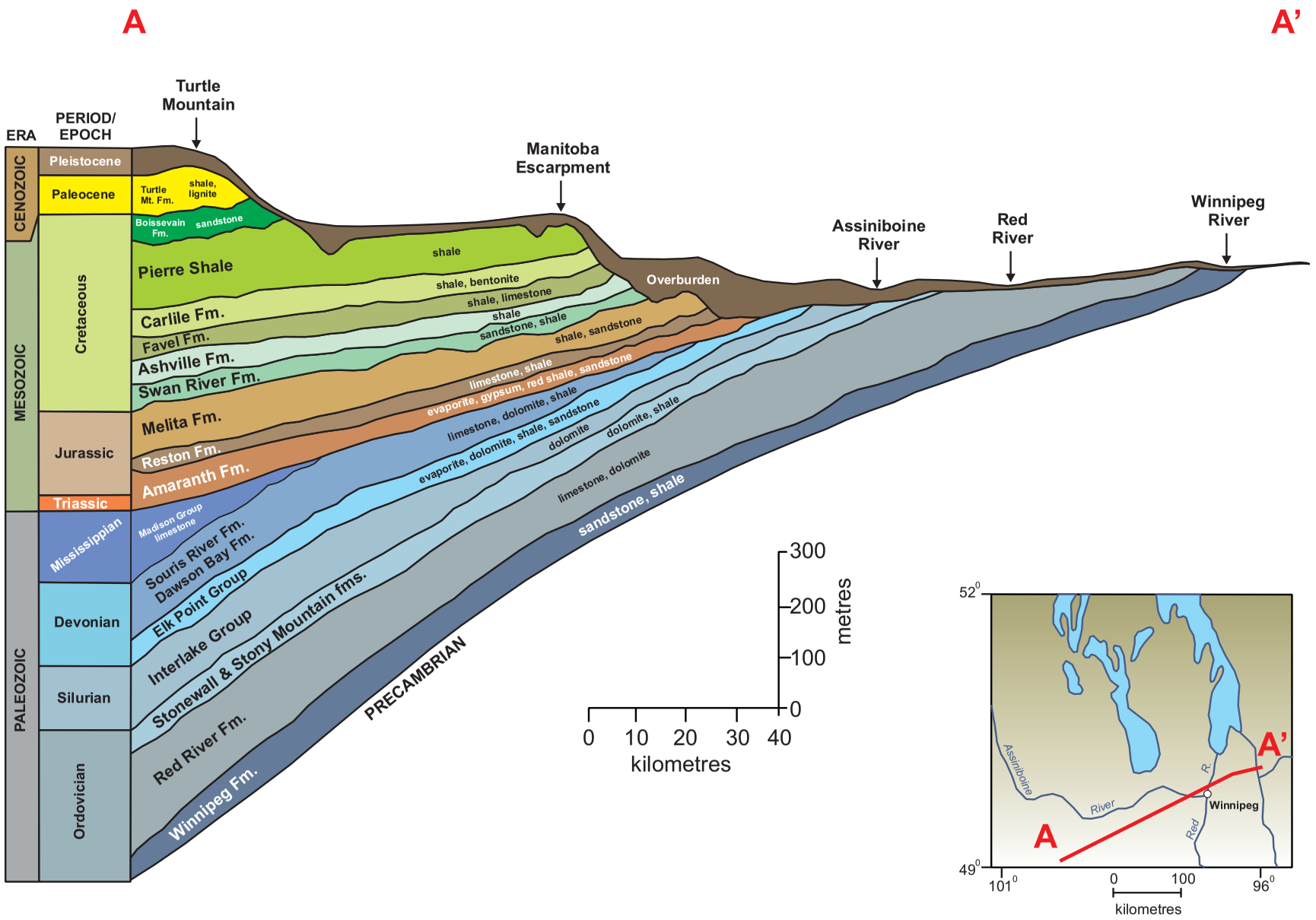

Figure GS-19-1: *Cross-section of Paleozoic to Cenozoic formations in southern Manitoba.*

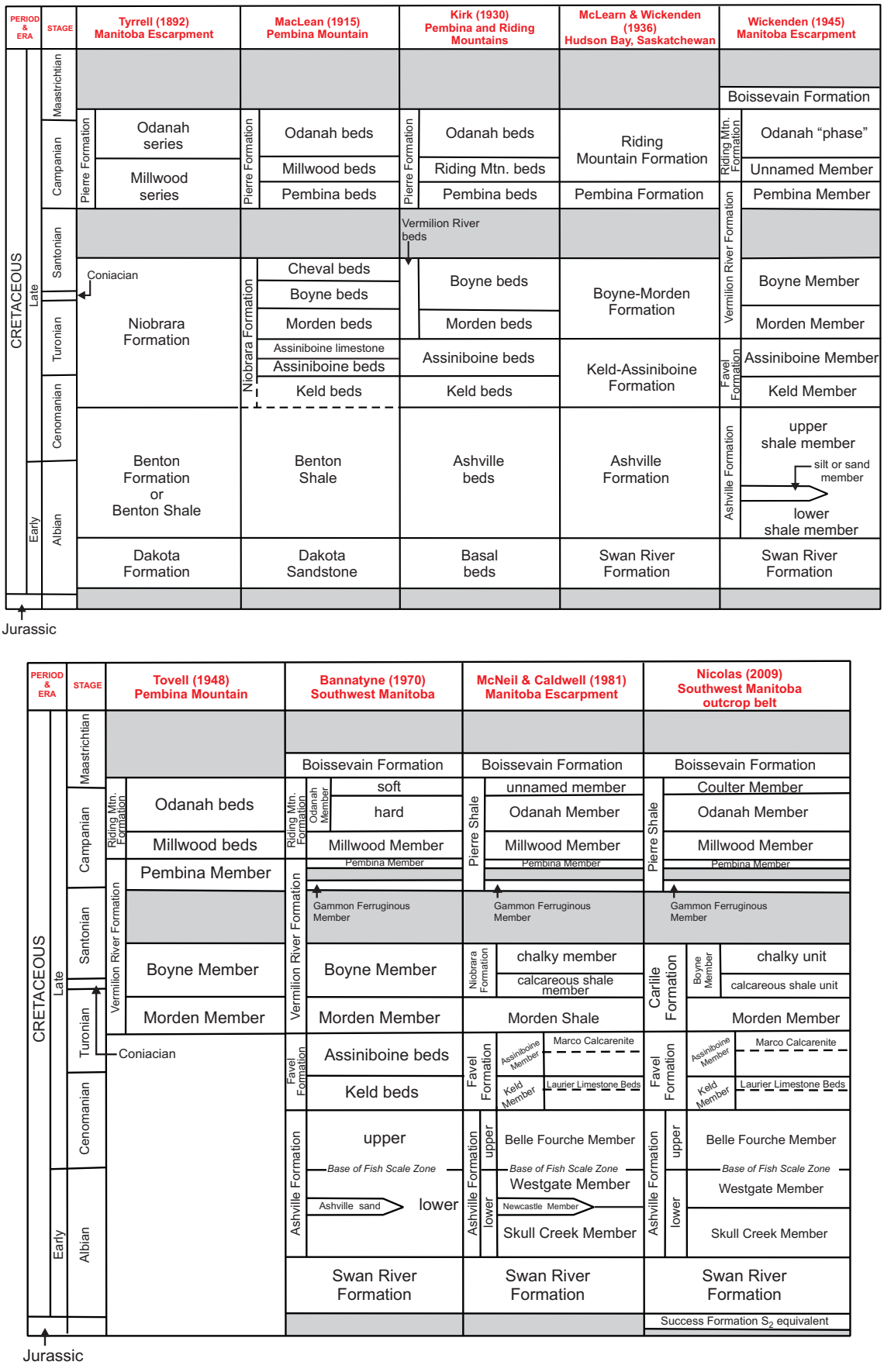

Figure GS-19-2: *Major revisions to the Cretaceous stratigraphic framework of southwestern Manitoba and vicinity.*

Cretaceous stratigraphic nomenclature of southwest Manitoba

Swan River Formation

The Albian Swan River Formation is usually the lowermost Cretaceous formation in southern Manitoba (Figure GS-19-1). Where present, the formation comprises a maximum of 75 m of mainly fine-grained sand or sandstone, with minor silt and light to dark grey, kaolinitic clay, which unconformably oversteps rocks of Jurassic, Devonian, Silurian and Ordovician age. However, Bannatyne (1970, p. 27, Figure 14) and Nicolas (2009, p. 7) noted that the formation is mainly absent in an east-west belt in townships 9 and 10, from the Saskatchewan boundary to the Manitoba Escarpment. According to Nicolas (2009, p. 6–8, Figures 2 and 3) the lower and upper portions of the Swan River Formation are equivalent to the Cantaur Formation and Pense P2 and P3 members of Saskatchewan, respectively, and are underlain in places by the Success S2 Member of Saskatchewan.

Name: Tyrrell (1892, p. 209E) recognized the Dakota Formation on the banks of the Red Deer, Armit and Swan rivers and Kemulch Creek (formerly Kematch River), and at Kettle Hills (south of Swan Lake) in west-central Manitoba. The formation had been named by Meek and Hayden (1862) for Cretaceous sand and shale beds underlying the Benton Shale in northeastern Nebraska. McLearn and Wickenden (1936, p. 4) applied the name Swan River Formation to this lithological unit, as shown in Figure GS-19-2.

Type Locality, Type Section and Geophysical Reference Log: The type locality is found in exposures along the Swan River, east of the town of Swan River, between Sec. 3 and 6, Twp. 37, Rge. 26, W 1st Mer. (McNeil and Caldwell, 1981, p. 40). A composite type section (component-lectostratotype), along the Swan River, was described by McNeil and Caldwell (1981, Outcrop Sections 54–58). Nicolas (2009, Figure 3) depicted the geophysical signatures of the Swan River Formation and its equivalents in a reference log from Tundra's Pierson well in L.S. 6, Sec. 10, Twp. 3, Rge. 28, W 1st Mer. (abbreviated 6-10-3-28-W1).

Ashville Formation

The Albian to Cenomanian Ashville Formation conformably overlies the Swan River Formation or disconformably lies on Jurassic strata (Figure GS-19-1; McNeil and Caldwell, 1981, p. 76; Nicolas, 2009, p. 8). The formation consists of 115 m of grey-black, noncalcareous shale, with subordinate amounts of silt, sand and calcarenite. The Fish Scale Zone, at the base of the upper Ashville Formation (or Belle Fourche Member), marks the division between the Early and Late Cretaceous in Manitoba (Bannatyne, 1970, p. 36). Where possible, the lower Ashville Formation is subdivided, in ascending order, into the Skull Creek, Newcastle (where present) and Westgate members (Nicolas and Bamburak, Figure GS-17-1, this volume).

Name: Tyrrell (1892, p. 209E) recognized the Benton Formation (or Benton Shale) along the Roaring River and Kemulch Creek in west-central Manitoba. The formation had been named by Meek and Hayden (1862) for shale exposed on the Missouri River, near Fort Benton, Montana. Kirk (1930, p. 117B) suggested the name Ashville beds for Benton-equivalent shale beds exposed along the Wilson River, near the village of Ashville. McLearn and Wickenden (1936, p. 4, 5) elevated the unit to the Ashville Formation.

Type Locality, Type Section and Geophysical Reference Log: The type locality is situated on the Wilson River, in Twp. 23, Rge. 20 and 21, W 1st Mer., near Ashville on PTH 10 (Wickenden, 1945, p. 17). A composite type section (component-lectostratotype) on the Wilson River was described by McNeil and Caldwell (1981, Outcrop Sections 65–74). Nicolas (2009, Figure 3) depicted the geophysical signatures of the Ashville Formation and its members in a reference log from Tundra's Pierson well in 6-10-3-28-W1.

Skull Creek Member

Name: Wickenden (1945, p. 17, 22) informally described a lower shale member of dark grey, noncalcareous, noncarbonaceous shale at the base of the Ashville Formation in Manitoba. McNeil and Caldwell (1981, p. 42, 43) officially named the unit the Skull Creek Shale Member (or alternatively Skull Creek Member; Figure GS-19-2), based on correlation with the type section along Skull Creek in Wyoming. Previously, Wickenden (1945, p. 17–23) and Bannatyne (1970, p. 36) included these beds as the basal portion of the lower Ashville Formation; Nicolas (2009, p. 7, 8, Figure 3) indicated that the lower part of the Skull Creek Member (as defined in Manitoba) includes the transgressive glauconitic marine shale of the Pense Formation P4 unit in Saskatchewan.

Manitoba Reference Locality: According to McNeil and Caldwell (1981, Outcrop Section 55) there is only one known outcrop of the lowermost beds of the Skull Creek Member in Manitoba. The outcrop, on the north bank of the Swan River in 1-8-37-26-W1, was not visible during a 2009 visit to the locality, possibly due to slumping.

Newcastle Member

Name: Wickenden (1945, p. 17–22) recognized an informal member of white and light grey, fine- to coarse-grained sand and interbedded dark grey shale above the Skull Creek Member in west-central Manitoba, which he described as the silt or sand member (Figure GS-19-2). Fleming (1957) depicted a sand zone of the Ashville Formation on a structure contour and isopach map

of southwest Manitoba, which was probably the silt or sand member of Wickenden (1945). Davies et al. (1962, p. 143) applied the informal name Ashville sand to the sand zone of Fleming, and described it as occurring in the subsurface in an area northeast of the towns of Virden and Killarney and extending as far north as Clear Lake and the town of Neepawa. Wickenden (1945, p. 17–23) and Bannatyne (1970, Figure 19) included these beds within the basal portion of the lower Ashville Formation. McNeil and Caldwell (1981, p. 43–46) officially termed the unit the Newcastle Sandstone Member (or alternatively Newcastle Member; Figure GS-19-2), based on correlation with its type locality near Newcastle, Wyoming.

Manitoba Reference Locality: According to McNeil and Caldwell (1981, Outcrop Section 36), there is only one known outcrop of the Newcastle Member in Manitoba. The outcrop is on the east bank of the Little Woody River in 9-22-44-29-W1. Due to high water levels in the river in 2009, the outcrop could not be examined.

Westgate Member

Name: McNeil and Caldwell (1981, p. 46) proposed the name Westgate Member (Figure GS-19-2) for dark grey, noncalcareous, noncarbonaceous shale lying above the Newcastle Member and below the Belle Fourche Member. The name was chosen after the community of Westgate on PTH 77, on the north flank of the Porcupine Hills. The shale is essentially identical to shale of the previously described Skull Creek Member. Where the Newcastle Member is thin or absent, the beds are usually placed in the lower Ashville Formation (Wickenden, 1945; Bannatyne, 1970), as shown in Figure GS-19-2.

Type Section: Composite parastratotype and holostratotype sections of the Westgate Member are situated along the Little Woody River, approximately 1.6 to 2.6 km south of National Mills and 5 km east of Westgate, in 9-22-44-29-W1 and 4-23-44-29-W1 (McNeil and Caldwell, 1981, Outcrop Sections 36–39).

Belle Fourche Member

Name: Grey-black to black, noncalcareous, carbonaceous, organic-rich beds that are conformably lying on the Westgate Member or lower Ashville Formation and are unconformably overlain by the calcareous Favel Formation, were named the upper Ashville Formation by Bannatyne (1970, p. 26, 36). As noted earlier, the base of the member is marked by the 6–10 m thick Fish Scale Zone, the bottom of which marks the boundary between the Lower and Upper Cretaceous in the Western Canada Sedimentary Basin. The upper Ashville Formation was renamed the Belle Fourche Member by McNeil and Caldwell (1981, p. 47–53). They also noted that the upper part of the member contains two associated distinctive marker beds – the *Ostrea beloiti* oyster beds and the X bentonite bed.

Manitoba Reference Locality: According to McNeil and Caldwell (1981, p. 47, 48), outcrops of the Belle Fourche Member are numerous along the Manitoba Escarpment between Porcupine Hills and Riding Mountain. Selected reference localities are the Little Woody River on the north flank of the Porcupine Hills (McNeil and Caldwell, 1981, Outcrop Sections 39–42) and the Vermilion River on the north flank of Riding Mountain (McNeil and Caldwell, 1981, Outcrop Sections 81–82).

Favel Formation

The Cenomanian-Turonian Favel Formation comprises olive-black, chalk-speckled, calcareous shale, argillaceous limestone and calcarenite, with a maximum thickness of 40 m, and conformably to nonconformably overlies the Ashville Formation (Figure GS-19-1).

Name: The Favel Formation includes the Keld and Assiniboine members, which were originally named as beds by Kirk (1930, p. 118B–123B), as shown in Figure GS-19-2. McLearn and Wickenden (1936, p. 5, 6) proposed the name Keld-Assiniboine Formation for the strata in the Hudson Bay Junction area of Saskatchewan but Wickenden (1945, p. 23) proposed the name Favel Formation, comprising the Keld and Assiniboine members, because of excellent sections exposed along the East Favel River and West Favel River, on the north flank of Duck Mountain.

Type Locality, Type Section and Geophysical Reference Log: The type locality includes the East and West Favel River valleys in Twp. 35, Rge. 25 and 26, W 1st Mer. However, Wickenden (1945, p. 23) selected the composite type section of the Favel Formation to be on the Vermilion River on the north flank of Riding Mountain in Twp. 23 and 24, Rge. 20, W 1st Mer. A composite type section (component-lectostratotype) on the Wilson River was described by McNeil and Caldwell (1981, Outcrop Sections 60–62). Nicolas (2009, Figure 3) depicted the geophysical signatures of the Favel Formation and its members in a reference log from Tundra's Pierson well in 6-10-3-28-W1.

Keld Member

Name: The calcareous beds immediately overlying the Ashville Formation, which are well exposed on Vermilion River to the east of the village of Keld, were named the Keld beds by Kirk (1930, p. 118B) and Keld Member by Wickenden (1945, p. 23).

Type Section: According to Wickenden (1945, p. 24, 25, 81), Kirk (1930) studied a type section for the Keld Member in 8-2-24-20-W1 on the west bank of the Vermilion River. A holostratotype section of the Keld Member on the west bank of Vermilion River, approximately 12.6 km southwest of Dauphin in west-central 8-2-24-20-W1, was described by McNeil and Caldwell (1981, Outcrop Section 81).

Laurier Limestone Beds

Name: McNeil and Caldwell (1981, p. 53) formally proposed the name Laurier Limestone Beds for the 5 to 15 cm thick beds and lenses of argillaceous limestone beds in the uppermost 5 m of the Keld Member. The beds were named after the village of Laurier, situated about 40 km southwest of the holostratotype of the Keld Member.

Type Section: In the holostratotype section of the Keld Member, situated in 8-2-24-20-W1, the Laurier Limestone Beds consist of early to middle Turonian, medium grey, chalk-speckled, argillaceous, limestone beds, each less than 15 cm in thickness, with interbeds of olive-black, chalk-speckled shale (McNeil and Caldwell, 1981, p. 53–55, Outcrop Section 81).

Assiniboine Member

Name: MacLean (1915, p. 16, 19–23) proposed the name Assiniboine beds for the calcareous shale that outcrops along the Assiniboine River in NE-36-8-11-W1 and Assiniboine limestone for overlying limestone beds (Figure GS-19-2). Both units were eventually combined into the Assiniboine beds by Kirk (1930, p. 120B) and then into the Assiniboine Member by Wickenden (1945, p. 23).

Type Section: According to Wickenden (1945, p. 25, 26, 82), Kirk (1930) measured a type section for the Assiniboine Member in 5-35-23-20-W1. A holostratotype section of the Assiniboine Member on the west bank of Vermilion River, approximately 13.5 km southwest of Dauphin in 5-35-23-20-W1, was described by McNeil and Caldwell (1981, Outcrop Section 80).

Marco Calcarenite

Name: McNeil and Caldwell (1981, p. 55) formally proposed the name Marco Calcarenite for the 1.2 m thick bed of fossiliferous calcarenite (formerly termed the Assiniboine limestone by MacLean [1915]) in the uppermost 3.5 m of the Assiniboine Member. The beds were named after the locality of Marco, situated north of Rossburn.

Type Section: In the holostratotype section of the Assiniboine Member, situated along the Vermilion River in 5-35-23-20-W1, the Marco Calcarenite consists of middle Turonian, medium grey, chalk-speckled, argillaceous limestone beds, each less than 15 cm in thickness, with interbeds of olive-black, chalk-speckled shale. The section (McNeil and Caldwell, 1981, p. 55–58, Outcrop Section 80) is located about 43 km northeast of the Marco locality.

Carlile Formation

The Turonian-Santonian Carlile Formation, which disconformably overlies the Favel Formation (Figure GS-19-1), was only recently recognized in southwest Manitoba by Christopher et al. (2006, p. 3–5, Figure 2). The Carlile Formation consists of the Morden Member, an up to 55 m thick, facies-controlled, basal, noncalcareous, carbonaceous shale, which is overlain by the Boyne Member, an up to 75 m thick calcareous, speckled and chalky shale.

Name: According to McGookey et al. (1972), the terms Carlile Formation or Carlile Shale are used for the middle to upper Turonian marine, noncalcareous shale between the Greenhorn and Niobrara formations found in the Cretaceous Interior Seaway of the western United States. Nielsen et al. (2003, p. 307) correlated the Carlile Formation in the Sweetgrass Hills of Montana with the former Morden Shale of McNeil and Caldwell (1981). Christopher et al. (2006, p. 3–5, Figure 2), however, extended the Carlile Formation into southeast Saskatchewan and southwest Manitoba, and reduced the Morden Shale in rank to member status, and placed it beneath the Boyne Member as subdivisions of the Carlile Formation (Figure GS-19-2).

Geophysical Reference Log: Nicolas (2009, Figure 3) depicted the geophysical signatures of the Carlile Formation and its members in a reference log from Tundra's Pierson well in 6-10-3-28-W1.

Morden Member

Name: MacLean (1915, p. 16, 24–26) proposed the name Morden beds for noncalcareous, carbonaceous shale overlying limestone beds at the top of the Favel Formation of Wickenden (1945; Figure GS-19-2). Once well exposed in NE-36-2-6-W1 along Deadhorse Creek west of Morden, the Morden beds are now mostly flooded by the Lake Minnewasta water reservoir. MacLean (1915) interpreted the Morden beds to be part of the Niobrara Formation; Wickenden (1945, p. 33–35), however, classified the Morden beds as the lower member of his Vermilion River Formation. McNeil and Caldwell (1981, p. 58, 59) elevated the Morden beds to formational status, proposing the name Morden Shale, and at the same time recommended to discontinue the formational name Vermilion River. As stated above, Christopher et al. (2006, p. 3–5, Figure 2) reduced the Morden Shale in rank back to member status and included it as a basal, facies-controlled subdivision of the Carlile Formation.

Type Locality and Section: MacLean (1915, p. 16, 24–26) inferred a potential type locality for the Morden Member along Deadhorse Creek immediately to the west of Morden (in NE-36-2-6-W1). As indicated above, the area is now flooded by Lake Minnewasta. Wickenden (1945) did not describe a type section for the Morden Member, and despite having elevated the Morden beds to formation status, McNeil and Caldwell (1981) did not document a type area or section for their Morden Shale, as they did for the other major formational units described in their report. As a consequence, it is here proposed that the

type locality for the Morden Member should be section road outcrops found along the boundary between Thompson and Stanley rural municipalities, 8 km northwest of Morden, in the vicinity of Shannon Creek (Sec. 3 and 4, Twp.4, Rge. 6, W 1st Mer.).

Boyne Member

Name: MacLean (1915, p. 27–29) introduced the names Boyne and Cheval beds for the underlying lead grey shale and the overlying buff calcareous shale, respectively, situated between the underlying Morden and overlying Pembina beds of noncalcareous shale (Figure GS-19-2). The name of the Boyne beds was probably taken from the south branch of the Boyne River (now known as Roseisle Creek) in southern Manitoba. Kirk (1930, p. 128) raised the upper boundary of MacLean's Boyne beds to incorporate the lithologically similar Cheval beds, but discarded the latter name. Wickenden (1945, p. 35–42) formally recognized the Boyne as the middle member of his Vermilion River Formation. McNeil and Caldwell (1981, p. 37) reapplied the name Niobrara Formation to replace Wickenden's Boyne Member and informally subdivided the Niobrara Formation into an overlying chalky member and an underlying calcareous shale member. As stated above, Christopher et al. (2006, p. 3–5, Figure 2) reintroduced the Boyne Member, but this time as a subdivision of the Carlile Formation. The informal chalky and calcareous shale members of McNeil and Caldwell were, thereby, reduced in rank to informal beds within the Boyne Member. Nicolas (2009, Figure 2) informally replaced the names chalky and calcareous shale beds with chalky and calcareous shale units.

Type Locality and Section: A type locality and section for the Boyne Member have not yet been proposed; Wickenden (1945, p. 35, 36), however, described in detail a 48 m section situated on the north side of the Pembina Valley, near the international border (SW-4-1-6-W1). This section is here proposed as the designated type section for the Boyne Member. Wickenden (1945, p. 36) also stated that the Roseisle Creek (south branch of the Boyne River) area, near St. Lupicin, had outcrops along the valley walls that constituted almost a complete section. One of these outcrops (Zone 14U 541157E, 5480360N [NAD 83]) contains a 2 m thick, shaly siltstone bed within the Boyne Member (Nicolas, 2008). Identification of this bed, informally named the Babcock beds by Nicolas and Bamburak (GS-17, this volume), has implications for the discovery of shallow shale gas reservoirs in the subsurface. For these reasons, it is proposed that this area be designated as the type locality for the Boyne Member.

Pierre Shale

The Campanian-Maastrichtian Pierre Shale unconformably overlies the Carlile Formation (Figure GS-19-1). The 340 m thick, noncalcareous Pierre Shale is subdivided, in ascending order, into the Gammon Ferruginous, Pembina, Millwood, Odanah and Coulter members. The Pierre Shale type section is located near Pierre, South Dakota.

Name: Meek and Hayden (1862) proposed the name Fort Pierre Group for the exposures of dark grey clay lying between the calcareous marl of the Niobrara Formation and the sandstone of the Fox Hills Formation along the Missouri River near Pierre, South Dakota. Tyrrell (1890, p. 230; 1892, p. 209E) recognized the presence of these beds in Manitoba, which he named the Pierre Formation and it comprised the underlying Millwood and overlying Odanah series. MacLean (1915) renamed these subdivisions as beds, and added the Pembina beds as the basal unit of Tyrrell's Pierre Formation (Figure GS-19-2).

Kirk (1930, p. 114B) retained MacLean's beds, but renamed the Millwood beds as the Riding Mountain beds. This set the stage for the next 50 years, where the term Riding Mountain Formation came to be used in Manitoba as the equivalent for the top two beds of Kirk's Pierre Formation, until McNeil and Caldwell (1981, p. 38) discarded the name in favour of the Pierre Shale (Figure GS-19-2). Details on the evolution of stratigraphic names within the Riding Mountain/Pierre formations are described below, as they relate to the individual members.

Manitoba Reference Locality and Geophysical Reference Log: A portion of the Manitoba Escarpment, southwest of Miami, between Twin Sisters to the northwest and Mount Nebo to the southeast (Sec. 13 and 25, Twp. 4, Rge. 7, W 1st Mer.) is, herein, proposed as the reference locality for the Pierre Shale in Manitoba. Within this area, there are numerous exposures of the Pierre Shale. There are two operating aggregate quarries of the Odanah Member and three former calcium bentonite quarries of the Pembina Member, which surrounds remnant buttes of the Millwood Member. Nicolas (2009, Figure 3) depicted the geophysical signatures of the Pierre Shale and its members in a reference log from Tundra's Pierson well in 6-10-3-28-W1.

Gammon Ferruginous Member

Name: Rubey (1930) named uniform, dark grey mudstone or silty shale containing numerous red-weathered ferruginous or sideritic concretions along Gammon Creek, on the northwestern flank of the Black Hills (Twp. 57N, Rge. 67 and 68W, Crook County, Wyoming), the Gammon Ferruginous Member. Bannatyne (1970, p. 26, 52, 53) was the first to recognize in hundreds of oil wells in southwest Manitoba up to 54.9 m of Gammon Ferruginous Member between calcareous speckled shale at the top of the Boyne Member and bentonite beds at the base of the Pembina Member (Figure GS-19-2). According to Christopher and Yurkowski (2007, p. 7, Figure 2) and Nicolas (2009, p. 11, Figure 2), the Gammon Ferruginous

Member is equivalent to part of the Milk River Formation of Saskatchewan.

Manitoba Reference Localities: McNeil and Caldwell (1981, p. 65, Outcrop Section 77) reported that 3.5 m of the Gammon Ferruginous Member is present 17.5 km southwest of Dauphin, on the east bank of the Vermilion River valley, on the north flank of Riding Mountain (7-23-23-20-W1). Bamburak (1996, p. 130) reported that thin (<1 m) ferruginous concretionary beds of the Gammon Ferruginous Member were observed at several sites along the Manitoba Escarpment in the Pembina Hills area.

Pembina Member

Name: MacLean (1915, p. 31–35) gave the name Pembina beds to the lower greyish black, carbonaceous shale with numerous thin bentonite beds and an upper brownish shale at the base of the then Pierre Formation in the Pembina Hills area (Figure GS-19-2). McLearn and Wickenden (1936, p. 7) raised the Pembina beds to formation status as the Pembina Formation, but Wickenden (1945, p. 33) reduced its status to a member of the then new Vermilion River Formation. McNeil and Caldwell (1981, p. 30–32) discarded Wickenden's Vermilion River Formation and placed the Pembina Member above the recently identified Gammon Ferruginous Member of Bannatyne (1970, p. 2).

Type Section: McNeil and Caldwell (1981, Outcrop Section 103) designated a composite type section (component-lectostratotype) in the Pembina River valley of south Manitoba (south-central portion of 4-27-1-8-W1).

Millwood Member

Name: Millwood series was proposed by Tyrrell (1890, p. 230; 1892, p. 209E) for shale beds found near the community of Millwood (14-2-20-29-W1), southwest of the town of Russell. MacLean (1915, p. 35–41) used the name Millwood beds to describe similar beds seen on top of Pembina Hills, but Kirk (1930, p. 114B, 124B–126B) applied the name Riding Mountain beds to this interval (Figure GS-19-2). McLearn and Wickenden (1936) elevated the unit to formation status in the Hudson Bay area of Saskatchewan, and Wickenden (1945) applied the name Riding Mountain Formation to this unit along the entire Manitoba Escarpment. Tovell (1948, p. 2, 5) reinstituted the name Millwood beds as the lower part of the Riding Mountain Formation, but Bannatyne (1970, p. 9, 55, 56) elevated the beds to member rank within the formation. McNeil and Caldwell (1981) placed the member within the Pierre Shale, as shown in Figure GS-19-2.

Type Section: A composite neostratotype section on the east side of the Assiniboine River valley, approximately 8 km south of Millwood in west central 11-11-19-29-W1 and in 15-11-19-W1, was described by McNeil and Caldwell (1981, Outcrop Section 84).

Odanah Member

Name: Odanah series was the name proposed by Tyrrell (1890, p. 230; 1892, p. 209E) for the hard, grey, siliceous shale beds found near the village of Odanah (6-10-15-18-W1) in the Little Saskatchewan River valley, 1 km northwest of the town of Minnedosa (McNeil and Caldwell, 1981, p. 72). MacLean (1915, p. 41, 42) adopted the term Odanah beds for similar beds observed on top of the Pembina Hills (Figure GS-19-2). Bannatyne (1970, p. 26, 56–58) elevated the beds to member rank within the Riding Mountain Formation, but subdivided the member into a lower, hard Odanah and an upper, soft Odanah (the latter, found near the communities of Ninga and Coulter, became the Coulter Member of the Pierre Shale, see below). The hard Odanah was placed into the Pierre Shale by McNeil and Caldwell (1981, p. 38) and became the Odanah Member, excluding the soft Odanah.

Type Section: A lectostratotype section of the Odanah Member was described by McNeil and Caldwell (1981, Outcrop Section 87) in a railroad cut along the Little Saskatchewan River valley, approximately 0.4 km northwest of Minnedosa.

Coulter Member

Name: Bannatyne (1970, p. 58) recognized a light grey to buff, fine-grained, clayey silt, which outcrops between the typical siliceous shale of the Odanah Member and the overlying Boissevain Formation, at the communities of Ninga and Coulter. Bamburak (1978, p. 6) proposed the name Coulter Member for this unit, on the basis of scarce exposures but good continuity in drillholes across the Turtle Mountain area. The proposal was adopted for the Maastrichtian unit in the report by Braman et al. (1999, p. 679).

Principal Reference Section: According to Braman et al. (1999, p. 679–681), core logged by them from the K-T Turtle Mountain drillhole in 13-17-1-23-W1 (drilled under the Canadian Continental Drilling Program) represents the most complete section of the Coulter Member to date.

Boissevain Formation

The middle Maastrichtian Boissevain Formation (Braman et al., 1999, p. 678) forms the uppermost Cretaceous in Manitoba (Figure GS-19-1). The formation was named after the town of Boissevain, situated just north of its type locality. The 33 m thick formation comprises mainly unconsolidated, medium-grained sand with a salt-and-pepper texture due to the 5% dark mineral grains mixed within the quartz grains. In places, induration with calcium carbonate cement formed massive sandstone. Trough-type crossbedding with crosslamination and ripple marks are locally present.

Name: Originally termed the Boissevain Sandstone by Parks (1916, p. 173), Wickenden (1945, p. 50) renamed

the unit as the Boissevain Formation, which has been used since, without further revision (Figure GS-19-2).

Type Locality and Section: Bamburak (1978, p. 8) proposed a type locality for the Boissevain Formation in S½, Twp. 3, Rge. 19 and 20, W 1st Mer. and N½, Twp. 2, Rge. 19, W 1st Mer., where Parks (1916, p. 173–179) had described numerous exposures south of Boissevain. Bamburak (1978, Table 3) also proposed a type section in NE-14-35-2-19-W1; this section, which was within a drainage ditch adjacent to PTH 3, however, has since been filled in and is now poorly exposed. Bamburak (1978, p. 8, 43, 44) also logged and suggested a principal reference section from Manitoba Mines and Natural Resources borehole #1 in 15-32-1-22-W1. In addition, Braman et al. (1999, p. 679, 680) logged and described a reference section for the Boissevain Formation from a Turtle Mountain corehole (13-17-1-23-W1), drilled under the Canadian Continental Drilling Program Cretaceous-Tertiary Boundary Project.

Economic considerations

With new technologies and applications available to study sedimentary basins in more detail than ever before, understanding the currently accepted stratigraphic framework is crucial in the search for new natural gas resources. Understanding the stratigraphic evolution of a unit helps industry and researchers to apply current known concepts to lesser known territories. For example, recognition of the Babcock beds within the Boyne Member of the Carlile Formation by Nicolas and Bamburak (GS-17, this volume) opens up the potential for an extensive gas-bearing reservoir extending from the past-producing natural gas area of Kamsack, Saskatchewan, to the Notre Dame de Lourdes–Manitou area of southern Manitoba. Another example is the recognition by Christopher and Yurkowski (2007, p. 7, 15, Figure 2) that the Gammon Ferruginous Member of the Pierre Shale is correlative with part of the Milk River Formation of Saskatchewan – a voluminous biogenic gas producer over a wide geographical area (>35 000 km^2) in southwestern Saskatchewan and southeastern Alberta. Recognition of these beds in Manitoba as being stratigraphically equivalent to gas-producing reservoir beds in other parts of the Western Canada Sedimentary Basin, suggests that further investigation of these units in Manitoba may prove profitable.

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