GS-16 Stratigraphic correlation of multiple bentonite horizons from the Upper Cretaceous Pierre Shale (Pembina Member) of Manitoba (part of NTS 62G1, 2)

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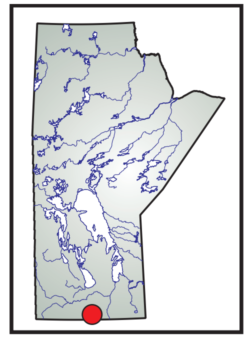

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Summary

The Pembina Member of the Pierre Shale (Campanian, Cretaceous) consists of black carbonaceous shale interspersed with numerous bentonite stringers (or seams), deposited as volcanic ash, within the Western Interior Seaway. The correlation of the bentonite seams is difficult, if not impossible, when it is based solely on visual observations, due to thickness variations and lack of lateral continuity. The purpose of this study, by the Canadian Fossil Discovery Centre in Morden, Manitoba, is to use fossil pollen and spores to correlate the bentonite horizons over long geographic distance within the Pembina Member of the Pierre Shale along the Manitoba Escarpment. This data will be used as a control to study vertebrate fossils within their respective stratigraphic horizons; and could also be used to locate the thickest bentonite seam with the highest economic value within a 5 m thick assemblage of interbedded black shale and bentonite.

Introduction

The Pembina Member of the Pierre Shale (Bamburak and Nicolas, Figure GS-15-1, this volume) consists of black carbonaceous shale interbedded with numerous bentonite stringers (or seams) deposited in the Western Interior Seaway (Nicholls and Isaak, 1987; Cuthbertson et al., 2007; Konishi and Caldwell, 2009). Sedimentary rocks are exposed along the Manitoba Escarpment (Figure GS-16-1) with numerous Pembina Member outcrop sites (adjacent to former quarries) located in the Morden–Miami area of southwestern Manitoba (Figure GS-16-2), and extending to the southeast into North Dakota. Early attempts at regional correlation of the bentonite seams along the Manitoba Escarpment have indicated that the lower Pembina Member seams lie within the *Baculites obtusus* Zone of the early Campanian (Nicholls and Isaak, 1987; Larson et al., 1997); however, no ammonites have been discovered to date from the Pembina Member. Consequently, McNeil and Caldwell (1981) assigned the Pembina Member to the early late Campanian, as shown in Figure GS-16-3, based on foraminifers considered to be diagnostic of the *Trochammina ribstonensis* Zone. To date, this has been the extent of palynological correlation of bentonite seams in the Pembina Member of the Pierre Shale in southwestern Manitoba.

Although previous attempts have been made to correlate the Pembina Member bentonite in Manitoba with the Sharon Springs Formation (formally, the Sharon Springs Member of the Pierre Shale) in South Dakota and Wyoming, and with the Claggett Shale in Montana, researchers have experienced limited success in the correlation of this distinctive unit across the vastness of the Western Interior. Furthermore, Quaternary uplift and glaciation, along with previous bentonite mining activities, have often disturbed the bentonite seams from a position of original horizontality, making it difficult to determine which bentonite horizons can be correlated with fossil vertebrate localities at numerous sites along the Manitoba Escarpment. Based on previous bentonite correlation studies reported by McNeil and Caldwell (1981), a similar method of palynological correlation has been employed by the Canadian Fossil Discovery Centre (CFDC) within the Morden–Miami area of the Manitoba Escarpment.

Pembina Member stratigraphy

MacLean (1915) gave the name Pembina beds to the lower thin, greyish black, noncalcareous carbonaceous marine shale with numerous thin buff (to pinkish, creamy or off-white) bentonite seams that is overlain by an upper brownish shale, which usually forms the base of the Pierre Shale in the Pembina Hills area (Figure GS-16-3). McLearn and Wickenden (1936) raised the Pembina beds to formation status as the Pembina Formation, but Wickenden (1945) reduced its status to a member of his newly proposed Vermilion River Formation. McNeil and Caldwell (1981) discarded Wickenden's (1945) terminology and placed the Pembina Member stratigraphically above the then recently recognized Gammon Ferruginous Member of Bannatyne (1970; Figure GS-16-3). However, McNeil and Caldwell (1981) also indicated that if the Gammon Ferruginous Member is absent, due to nondeposition or to postdepositional erosion during the Cretaceous, then the Pembina Member of the Pierre Shale can be seen to disconformably overlie the Boyne Member of the Carlile Formation. The lower unit of the Pembina Member passes gradationally upwards, with notably less intervening bentonite seams, into an upper unit of

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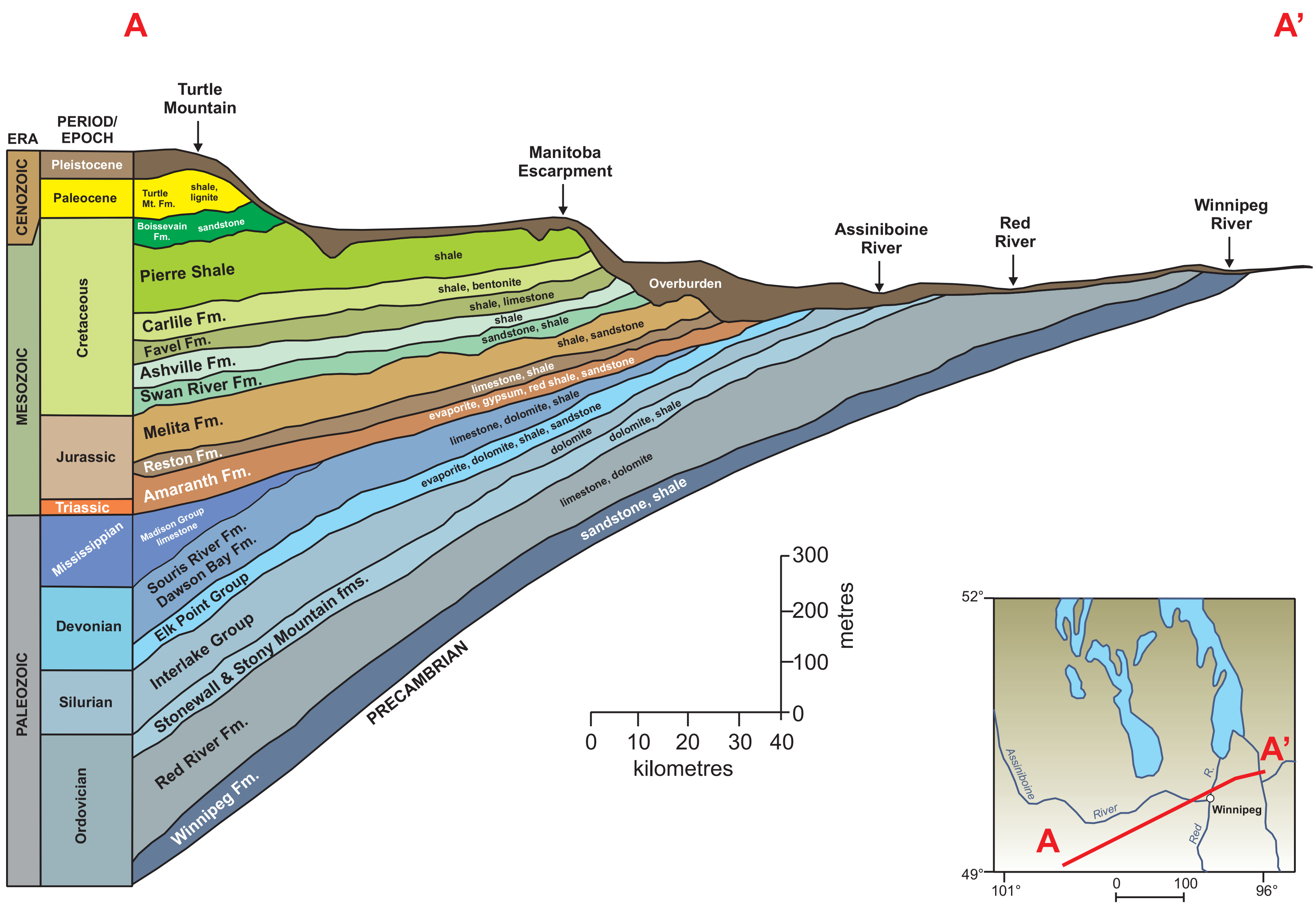

Figure GS-16-1: Cross-section of Paleozoic to Cenozoic formations in southern Manitoba (after Bamburak and Nicolas, 2009b, Figure GS-19-1).

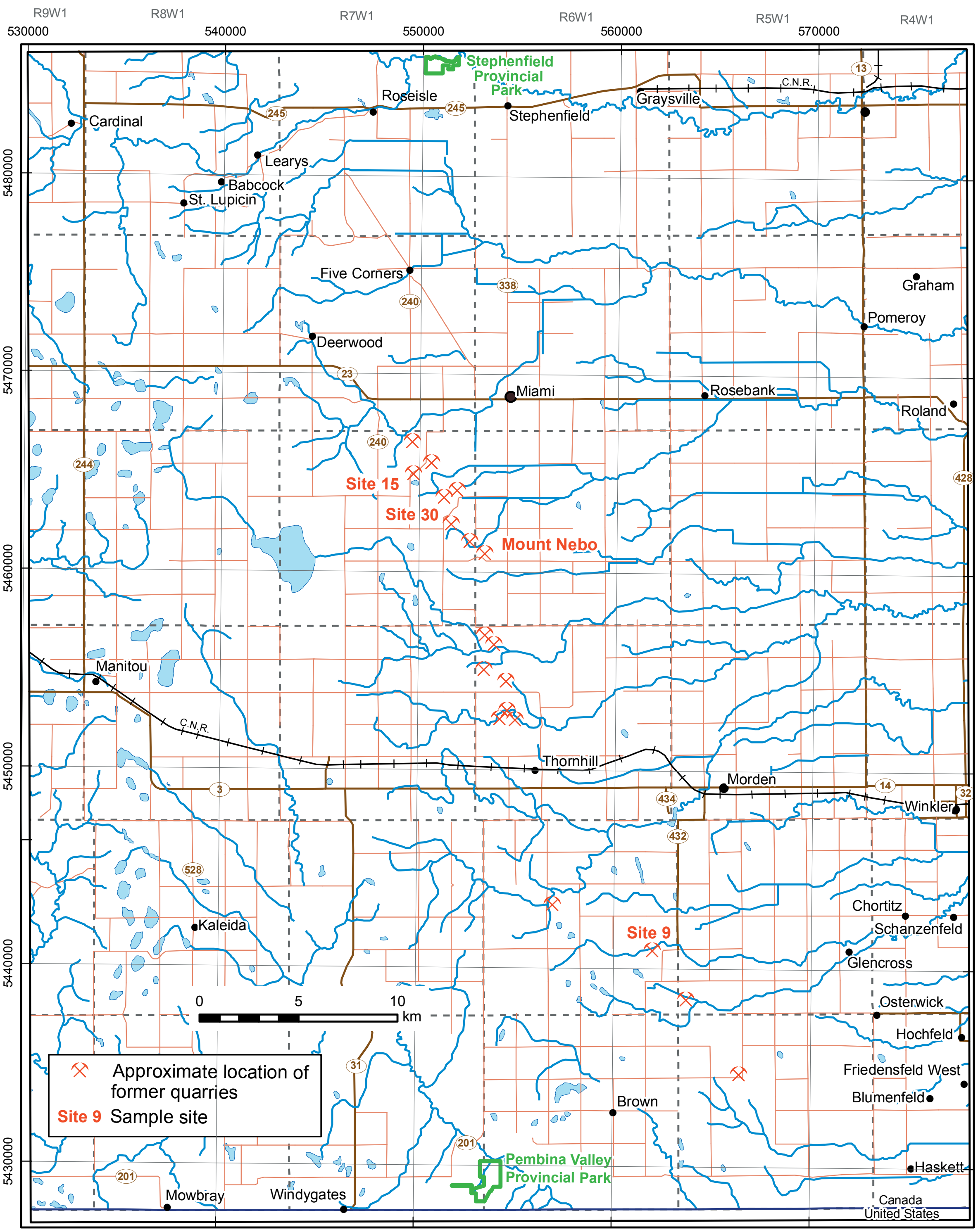

Figure GS-16-2: *Pembina Member outcrop sample and former quarry sites in the Morden–Miami area of southwestern Manitoba. Note: quarry locations are approximate and symbol may cover one or more sites.*

chocolate brown, waxy, less organic shale, and finally into the brownish green, waxy, noncarbonaceous shale of the Millwood Member of the Pierre Shale. According to Bannatyne (1970), the upper part of the Pembina Member in the Miami area exhibits some swelling properties, and is similar to the Millwood Member in its composition and test results.

The lower Pembina Member can usually be seen in roadcuts and in ravines adjacent to almost 20 former mining operations (Figure GS-16-2) along the Manitoba

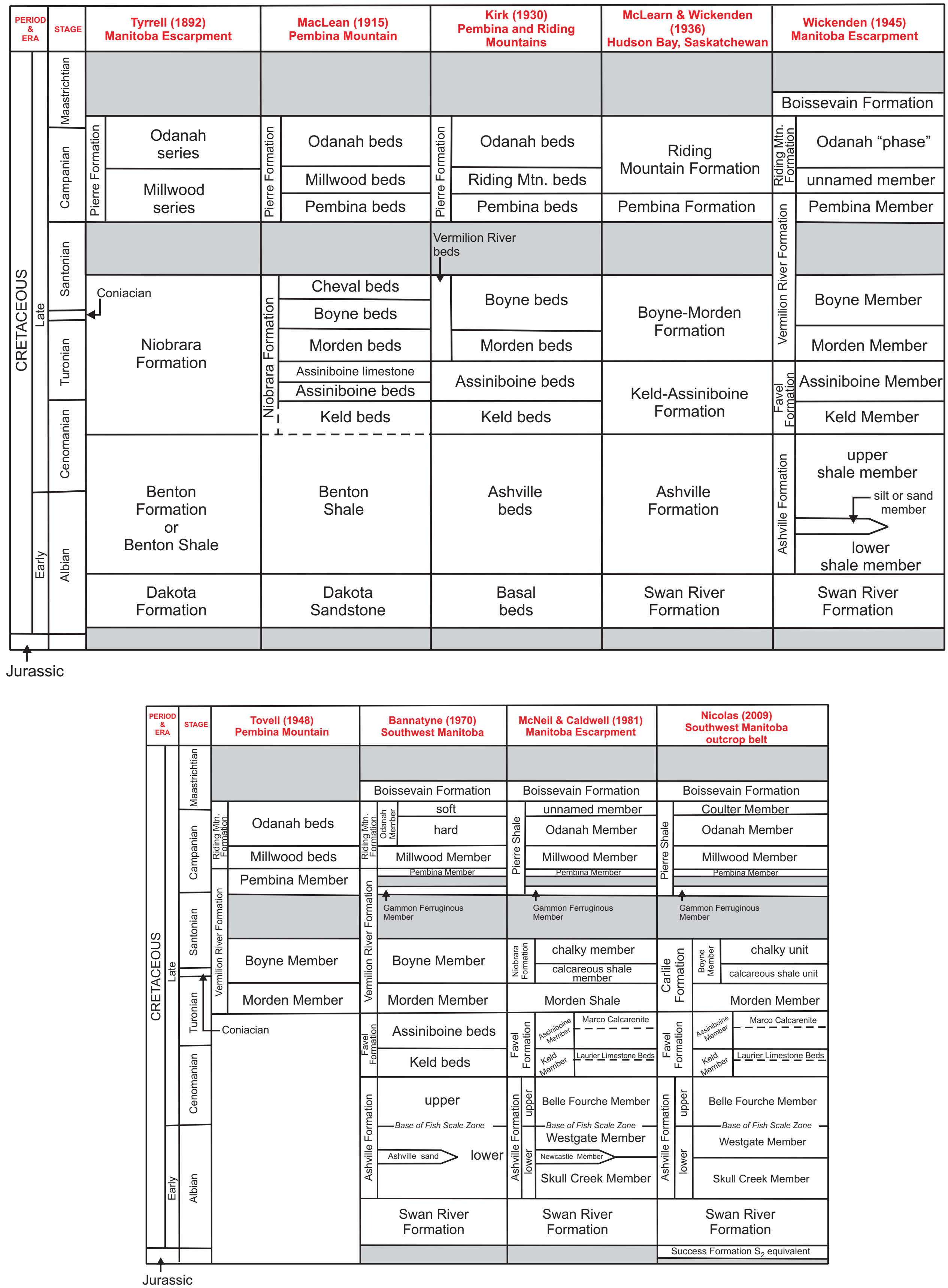

Figure GS-16-3: *Major revisions to the Cretaceous stratigraphic framework of southwestern Manitoba (after Bamburak and Nicolas, 2009b, Figure GS-19-2).*

Escarpment (Bannatyne, 1982, 1984). At many localities, the bentonite seams underlie a terrace at a level approximately 30 m below the top of the escarpment. The terrace can be recognized by numerous 17 m high, rounded knolls (also called buttes), composed of the soft bentonitic shale of the Millwood Member of the Pierre Shale, and the paucity of vegetation. The terrace can best be viewed from west of Miami to northwest of Morden, where it extends for 3 km in length and ranges from 0.4 km to more than 1.6 km in width.

West of the escarpment edge, the Millwood Member is capped by resistant siliceous shale of the overlying Odanah Member of the Pierre Shale, which acted as a cap rock protecting the softer underlying beds from the effects of ice advance during numerous episodes of Pleistocene glaciation.

At least 11 buff bentonite seams, consisting primarily of nonswelling calcium montmorillonite and ranging in thickness from 2.5 to 30 cm were documented in previous investigations by Bannatyne (1963, 1982, 1984). The 30 cm thick seam composed of dense pink bentonite was prized by a former operator, Pembina Mountain Clays Limited, as the most valuable of all the seams. In outcrop, the seams can also be stained a yellowish colour caused by the presence of jarosite (Bannatyne, 1963, 1984; Nicholls, 1988). Guillet (1989) noted significant amounts of magnetite and other dark minerals in 20 bentonite samples taken from a bentonite deposit previously operated in the Morden–Miami area by Pembina Mountain Clays Limited. Seams are separated by variable thicknesses of black carbonaceous, pyritic shale (Bamburak and Nicolas, Figure GS-15-2, this volume). The bentonite seams generally thicken to the west, but the overburden also rapidly increases in thickness (12 to 15 m). Where overburden is greater than 7 m, the unweathered bentonite is usually bluish grey, probably due to reducing conditions (Bannatyne, 1963).

McNeil and Caldwell (1981, outcrop section 103) designated a composite type section (component-lectostratotype) for the Pembina Member in the Pembina River valley of southern Manitoba (south-central portion of L.S. 4, Sec. 27, Twp. 1, Rge. 8, W 1st Mer. [abbreviated 4-27-1-8W1]). According to Gill and Cobban (1965), the volcanic ash, from which the bentonite seams within the Pembina Member were formed, was carried eastward for more than 1100 km by prevailing winds from eruptions in the Elkhorn Mountains of western Montana. However, Bertog et al. (2007) determined three magma sources for the bentonite seams within the lower Pierre Shale. According to Bertog et al. (2007), the Elkhorn Mountains were the source area for the back-arc bentonite seams during deposition of the Pembina Member sediments. In addition, northern British Columbia and northern Washington–southern British Columbia were the likely sources of the fore-arc and volcanic-arc bentonite seams. Bezys et al.(1996) reported on Cretaceous volcanic lapilli from a drillcore taken from southeast of Easterville, Manitoba, within the Churchill–Superior Boundary Zone, with implications for a Cretaceous volcanic vent within the subsurface of the same geographic area. However, if such a volcanic structure exists in the subsurface, it is most likely from the mid-Albian deposits of the Swan River Formation and therefore precedes the Campanian deposition of the Pembina Member bentonite (Playford, 1971; McNeil and Caldwell, 1981, p.42; Bezys et al., 1996).

A K-Ar date from the equivalent Claggett Formation in Chouteau County, Montana, by Russell (1970), gave an age of 87.4 ±2.9 Ma. However, two more recent Ar-Ar determinations returned ages of 80.54 ±0.55 and 80.04 ±0.4 Ma from sanidine of the Ardmore bentonite in the Elk Basin of Wyoming and near Redbird, Wyoming, respectively (Martin et al., 2007). It should be noted that according to Bannatyne (1982, p. 45), McNeil and Caldwell (1981, Table VII) had indicated an age of <82.5 Ma for this interval in Manitoba based upon radiometric age dating of ammonite zones.

Martin et al. (2007) correlated the numerous members of the vast Pierre Shale throughout the Western Interior of the United States by raising previous members to formational status and assigning new members based on their distinctive lithologies and suitability for mapping. As a result, the Pembina Member–equivalent Sharon Springs Member of the Pierre Shale was elevated to formation status within the Pierre Shale Group in North Dakota, Kansas, and around the Black Hills in eastern Wyoming and western South Dakota. However, regional investigators in Manitoba and Saskatchewan have chosen to keep the Pembina at member level status, which is permitted under the North American Stratigraphic Code (Bamburak and Nicolas, 2009a, b).

Materials and methods

A total of 32 bentonite samples was collected from exposed Pembina Member horizons at five field sites, listed in Table GS-16-1 and shown in Figure GS-16-2, by staff from the CFDC. The 30 g samples were assigned an early Campanian age by J. Stein, Ph.D., of National Petrographic Services Inc., Houston, Texas, based on the palynomorphs, spores and dinocyst genera discovered within the samples (DRI2010003[2]). This is consistent with the <82.5 Ma age proposed by McNeil and Caldwell (1981, Table VII).

[2] MGS Data Repository Item DRI2010003, containing the data or other information sources used to compile this report, is available online to download free of charge at http://www2.gov.mb.ca/itm-cat/web/freedownloads.html, or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Innovation, Energy and Mines, 360–1395 Ellice Avenue, Winnipeg, Manitoba R3G 3P2, Canada.

Table GS-16-1: Pembina Member bentonite sample sites.

Sample site	Latitude (°)	Longitude (°)	Location	No. of horizons sampled[1]
Site 9-RW(A)	49.1389	98.23119	SW13-2-6W1	11
Site 9-RW(B)	49.1389	98.23242	SW13-2-6W1	12
Site 15 - West Cox	49.33677	98.30731	NW26-4-7W1	4
Site 30 - Turner	49.32937	98.29627	SW25-4-7W1	4
Mount Nebo	49.29909	98.27083	SW18-4-6W1	1

[1] Detailed palynomorphological study results are listed in MGS Data Repository Item DRI2010003, which is available online to download free of charge at http://www2.gov.mb.ca/itm-cat/web/freedownloads.html, or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Innovation, Energy and Mines, 360–1395 Ellice Avenue, Winnipeg, Manitoba R3G 3P2, Canada.

Sites and horizons

Four of the five sites (Table GS-16-1, Figure GS-16-2) were selected by the CFDC based on their geographic position to establish a correlated control group by which vertebrate fossil specimens discovered in shale horizons between the Pembina Member bentonite layers could be assigned to a specific stratigraphic horizon within the overall Pembina Member depositional sequence. The four control group sites are from south of Thornhill to the Miami area. Sites 9-RW(A) and 9-RW(B) are both located in SW13-2-6W1, site 15-West Cox is located in NW26-4-7W1 (shown in Figure GS-16-4), and site 30-Turner is located in SW25-4-7W1. At sites 9-RW(A) and 9-RW(B), samples were collected from 11 and 12 exposed bentonite horizons, respectively. At site 15-West Cox and site 30-Turner, samples were collected from the four bentonite horizons exposed at each locality. The fifth site, Mount Nebo, is located south of the Miami area (SW18-4-6W1, Table GS-16-1, Figure GS-16-2). It was here that CFDC specimen P.08.01.04, a polycotylid plesiosaur ("Ianto"), was excavated from the base of the Pembina Member, in the first carbonaceous shale horizon immediately beneath a 9 cm thick bentonite seam.

Discussion

Analyses of the palynology data reveal that the marine deposition of the Pembina Member bentonite seams occurred during largely open neritic conditions, as suggested by some of the distinct boreal dynocyst assemblages (presented in DRI2010003). The two northernmost sites tested positive for amorphous kerogen, in horizons 2 and 4 at site 30-Turner and at horizons 1 and 2 at site 15-West Cox (Figure GS-16-4). Kerogen was not encountered at the other three sites. The pollen *Betulaceoipollenites* sp. is present in horizons 1 and 3 at site 9-RW(A) and in horizon 4 at site 9-RW(B). Sites 9-RW(A) and 9-RW(B) are geographically close to each other and horizontal bedding is displayed at both sites. As such, the palynological assemblages closely match up. The spore *Sphagnum affinities* occurs at both 9-RW sites and the dinocyst *Dinogymnium euclaensis* is present in horizon 3 at site 9-RW(A) and in horizon 4 at site 9-RW(B). The Pembina Member bentonite deposition at the two southernmost sites, 9-RW(A) and 9-RW(B), is assigned to the early Campanian based on a rare boreal dinocyst assemblage at site 9-RW(B) and on the absence of the dinocyst *Trithyrodinium suspectum.* The very rare occurrence of the dinocyst *Odontochitina costata* in horizon 8 at site 9-RW(A) is indicative of Tethyan, open neritic conditions to the exclusion of boreal taxa. At site 30-Turner and site 15-West Cox, the two most northerly sites, pollen was absent, while the only spore (*Deltoidospora* sp.) came from horizon 2 at site 15-West Cox. Another polycotylid plesiosaur, CFDC specimen P.04.01.15, was recently collected from the West Cox property (Janzic, 2006), although not at the same outcrop as the bentonite that was sampled for this research. However, the West Cox locality can be assigned to the latter portion of the early Campanian

Figure GS-16-4: *K. Slater-Szirom, of the Canadian Fossil Discovery Centre, examining bentonite seams at site 15-West Cox, southwestern Manitoba, in September 2010.*

based on the presence of the dinocyst *Chatangiella ditissima* along with the absence of *T. suspectum*.

With the establishment of the above control group of data, a closer examination of the bentonite data from the site of CFDC's plesiosaur specimen P.08.01.04 reveals that the plesiosaur enjoyed open neritic conditions as is suggested by the rarity of associated pollen along with a distinct boreal dinocyst assemblage. As with horizons 1 and 3 at site 9-RW(A) and horizon 4 at site 9-RW(B), the pollen *Betulaceoipollenites* sp. was also discovered in the bentonite layer (Spl 1) overlying the fossil plesiosaur skeleton, and the presence of the dinocysts *D. euclaensis* and *T. suspectum* help to assign an early Campanian age to CFDC plesiosaur specimen P.08.01.04.

Conclusion

The nonswelling calcium bentonite horizons in the Pembina Member of the Pierre Shale contain fossil palynomorphs, such as terrestrially derived pollens, spores and dinocysts, which can be traced across geographic and stratigraphic distances to correlate exposed units in sites exhibiting a varied topography. Furthermore, the subsequent data can have tremendous implications as it relates to larger vertebrate fossil specimens and placing them within the proper stratigraphic context. Other researchers have studied plesiosaur extinction cycles to map out different geological points within the Cretaceous period (Bakker, 1993). Two polycotylid plesiosaur specimens were selected from the CFDC collection based on the geographic and stratigraphic proximity of the nearest sampled bentonite outcrop used for palynological analysis in this study. Four field sites were selected along the Manitoba Escarpment and 31 bentonite samples were collected for palynological analysis and the establishment of a control group. Then, a 32nd sample, discovered directly overlying CFDC's polycotylid plesiosaur specimen P.08.01.04, was analyzed against the control group. The resulting data (shown in DRI2010003) indicates that CFDC plesiosaur specimen P.08.01.04 was deposited during open neritic conditions with a distinct boreal dinocyst assemblage, and the specimen can be assigned to the early Campanian based on the presence of the dinocysts *D. euclaensis* and *T. suspectum*. Additionally, it can be hypothesized that another CFDC polycotylid plesiosaur specimen P.04.01.15, excavated from the West Cox locality, can be assigned to the latter portion of the early Campanian based on the presence of the dinocyst *C. ditissima* and on the absence of *T. suspectum*. Thus, from this data it is possible to place two recently excavated polycotylid plesiosaurs within their specific stratigraphic horizons. Although the two specimens were geographically located only 5 km apart, they are stratigraphically separated into the early and the latter portions of the early Campanian. As with horizons 1 and 3 at 9-RW(A) and horizon 4 at 9-RW(B), the pollen *Betulaceoipollenites* sp. was also discovered in the bentonite layer (Spl 1) overlying the fossil plesiosaur skeleton, and the presence of the dinocysts *D. euclaensis* and *T. suspectum* help to assign an early Campanian age to CFDC plesiosaur specimen P.08.01.04. Therefore, the Pembina Member shale exposed at Mount Nebo can now be correlated with the earliest Pembina Member bentonite deposition from horizons 1 and 3 at site 9-RW(A), over 18 km to the south.

Economic considerations

While the focus of this study by the CFDC has been the correlation of vertebrate fossils within bentonite seam stratigraphy, using unique fossil pollen and spores, previous quarry operators in the Pembina Hills area were looking for the thickest bentonite seam, which usually ranged from 20 to 25 cm in thickness. This seam would be found within a 4.5 m thick interval of interbedded nonswelling calcium bentonite and black shale of varying thicknesses, usually 5 to 10 cm, within the Pembina Member of the Pierre Shale. Development of a system of correlating individual seams would be a bonus for any mining company attempting to rejuvenate the bentonite industry in Manitoba, because it would allow for a simpler method of resource estimation and mining. If seams higher and lower than the target seam could be easily identified, the company would know whether to dig deeper, or possibly remove more of the overlying material.

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