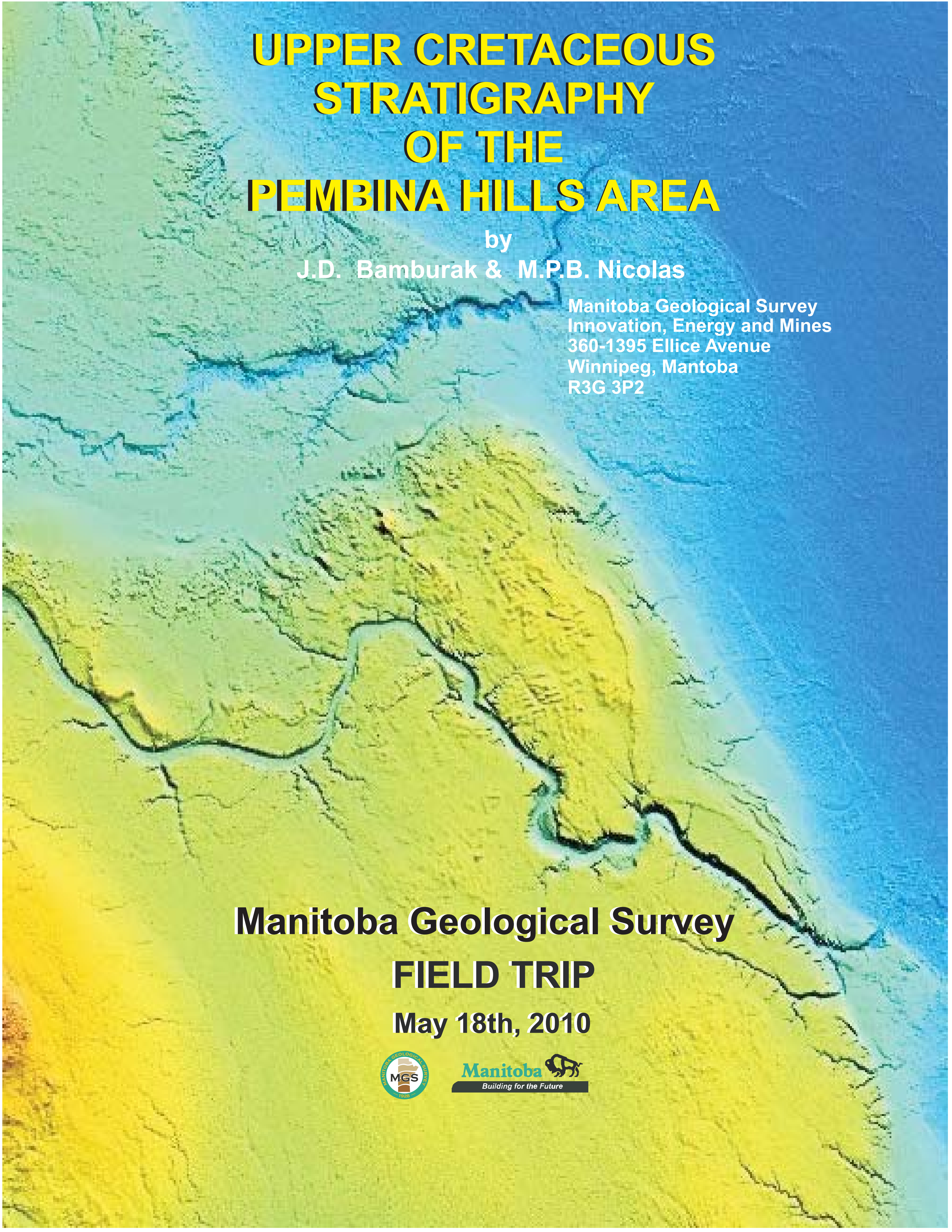

# UPPER CRETACEOUS STRATIGRAPHY OF THE PEMBINA HILLS AREA

by

J.D. Bamburak & M.P.B. Nicolas

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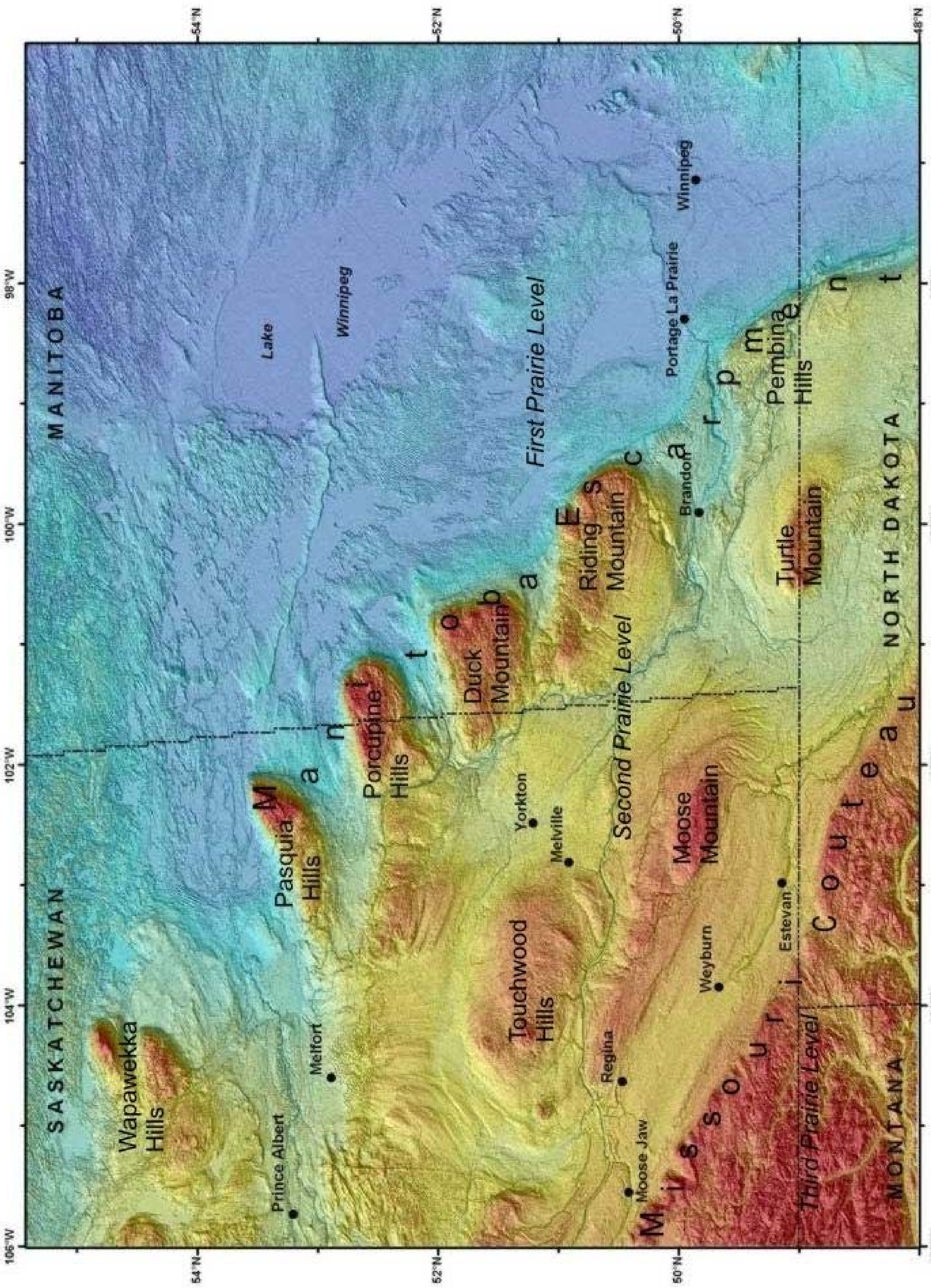

SASKATCHEWAN
MANITOBA
NORTH DAKOTA
MONTANA
Lake
Winnipeg
First Prairie Level
Second Prairie Level
Third Prairie Level
Manitoba Escarpment
Missouri Coteau
Wapawekka Hills
Pasquia Hills
Porcupine Hills
Duck Mountain
Riding Mountain
Touchwood Hills
Moose Mountain
Turtle Mountain
Pembina Hills
Prince Albert
Melfort
Yorkton
Melville
Regina
Moose Jaw
Weyburn
Estevan
Brandon
Portage La Prairie
Winnipeg
106°W
104°W
102°W
100°W
98°W
54°N
52°N
50°N
48°N

## PART I: STRATIGRAPHIC SETTING

### *INTRODUCTION*

McNeil and Caldwell (1981) defined the Manitoba Escarpment (Figure 1) as being composed mainly of Cretaceous rocks (Figure 2) that form part of the eastern erosional edge of the Western Canada Sedimentary Basin - a composite feature which includes both the Elk Point Basin, centered in south-central Saskatchewan (which controlled Devonian deposition), and the Williston Basin, centered in northwestern North Dakota (which controlled the depositional patterns throughout the remainder of post-Cambrian time). The escarpment extends for 675 km from the Pasquia Hills in Saskatchewan, across southwest Manitoba, to the Pembina Hills (note: also, referred to as Pembina Mountain) area of North Dakota. The escarpment ranges in relief from a height from 442 m in the Pasquia Hills to 90 m in the Pembina Hills in North Dakota. The escarpment forms the irregular riser between the First Prairie Level on the Manitoba Lowlands and the second step, which forms Second Prairie Level to the west.

***Figure 1:*** *Topography of southwest Manitoba, southeast Saskatchewan, and northern North Dakota and Montana (Frontispiece).*

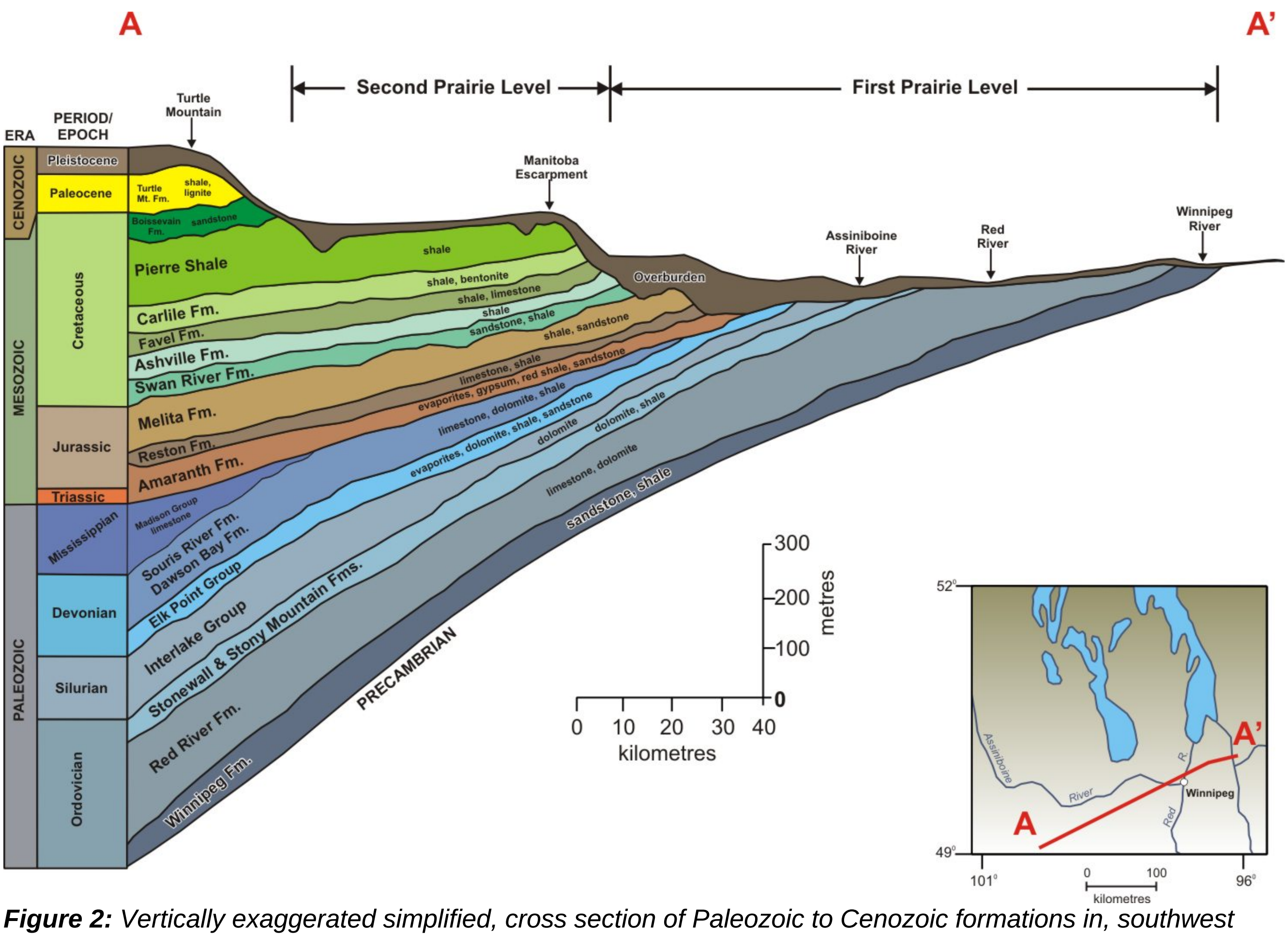



***Figure 2:*** *Vertically exaggerated simplified, cross section of Paleozoic to Cenozoic formations in, southwest Manitoba (Bamburak and Nicolas, 2009).*

It should be noted that the Cretaceous stratigraphy that forms the face of the Manitoba Escarpment changes from north to south. In the Pasquia, Porcupine and Duck components, the edge of the escarpment normally comprises the Favel Formation down to the Ashville Formation (Figure 3). In contrast, in the Riding and Pembina components, the escarpment edge is the Pierre Shale down to the Carlile Formation. Therefore, the Cretaceous beds that form most of the Manitoba Escarpment range in age from 75 to 125 Ma.

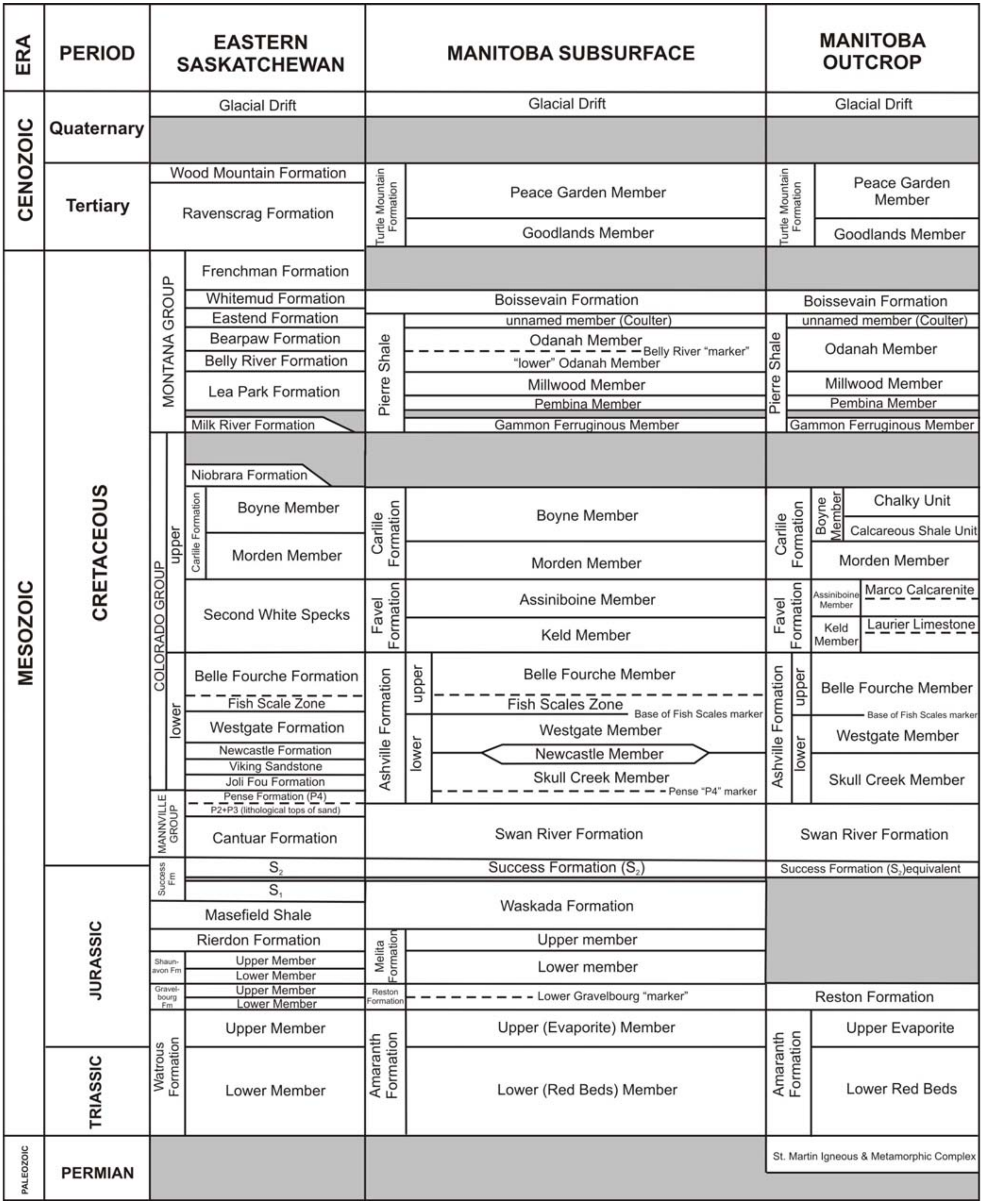



***Figure 3:*** *Mesozoic and Cenozoic stratigraphy of eastern Saskatchewan and of the subsurface and outcrop belt of southwest Manitoba (Nicolas, 2009, Figure 2).*

The escarpment is also comprised of glacial material that was deposited as moraines during multiple glaciations and by a succession of beach deposits formed at the margins of Glacial Lake Agassiz. The Manitoba Escarpment originated as an erosional feature that developed as a consequence of the Laramide Orogeny, which occurred 84 to 50 Ma. During the orogeny, the Rocky Mountains were built to the west and the Severn Arch, on the Precambrian Shield to the east, was uplifted. The Manitoba Escarpment is thus at least 50 Ma; however, it probably extended much further to the east than its present position.

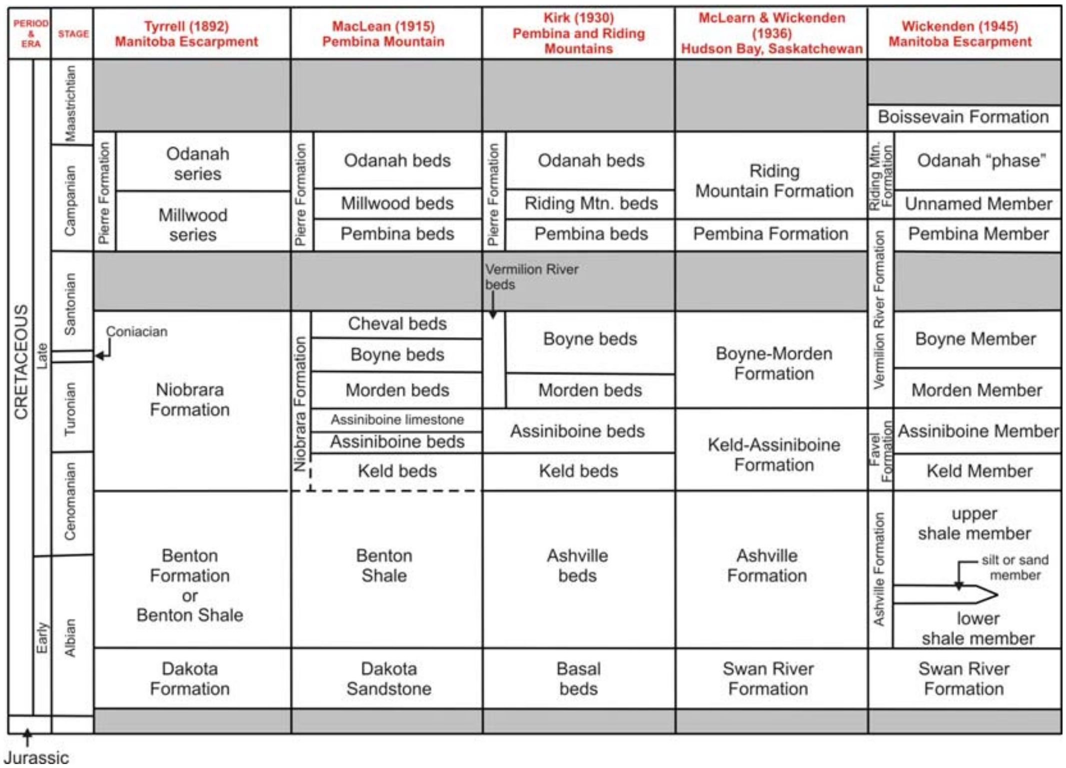
From north to south, the Manitoba Escarpment is breached by four major rivers – the Red Deer, Swan, Valley and Assiniboine. The resulting upland sections (part of the Second Prairie Level) are named the Pasquia and Porcupine hills, the Duck and Riding mountains and the Pembina Hills. West of the escarpment, the Second Prairie Level is underlain by Cretaceous shale and sand units, dipping southwest at 1.5 to 1.9 m/km and by a thickness of the glacial drift cover ranges from zero to a reported 259 m maximum in the central part of Duck Mountain. An exceptional feature on the Second Prairie Level is Turtle Mountain, underlain by rock of Upper Cretaceous and Tertiary age, and up to a hundred metres of glacial drift. Turtle Mountain is an erosional remnant of the Third Prairie Level, the main part of which extends westward from the Missouri Coteau (Figure 1).

The Manitoba Escarpment is underlain by a foundation comprised of Devonian carbonate rock (Figure 2), dipping southwest at approximately 2.8 m/km; and in the south due to the angular unconformity, by an intervening sequence of shale, sandstone and anhydrite and/or gypsum of Jurassic and Triassic age. Cretaceous sediment was draped over this foundation. The combined thickness of Triassic, Jurassic and Cretaceous beds at the Manitoba-Saskatchewan boundary with North Dakota attain a maximum thickness of about 1070 m. Dissolution of salt in evaporite beds (such as the Prairie, Hubbard, Davidson and Amaranth evaporates) within the underlying Devonian and Triassic-Jurassic sedimentary rocks disrupted the normal sedimentation process of the overlying Cretaceous beds. The detailed stratigraphy of the Manitoba Escarpment is briefly described below.

## *CRETACEOUS STRATIGRAPHY*

The evolution of Manitoba's Cretaceous stratigraphic nomenclature over the past century has recently been documented by Bamburak and Nicolas (2009). Both locally derived names and names from Saskatchewan (Figure 3) and from the northern United States have repeatedly been applied to and removed from the Cretaceous stratigraphic succession in Manitoba, as shown in Figure 4a and 4b. It is important to be aware of these revisions, when consulting historical references, such as McNeil and Caldwell's (1981) publication, which has been regarded by many geologists, as the definitive guide to the stratigraphy of the Manitoba Escarpment.

a)




b)

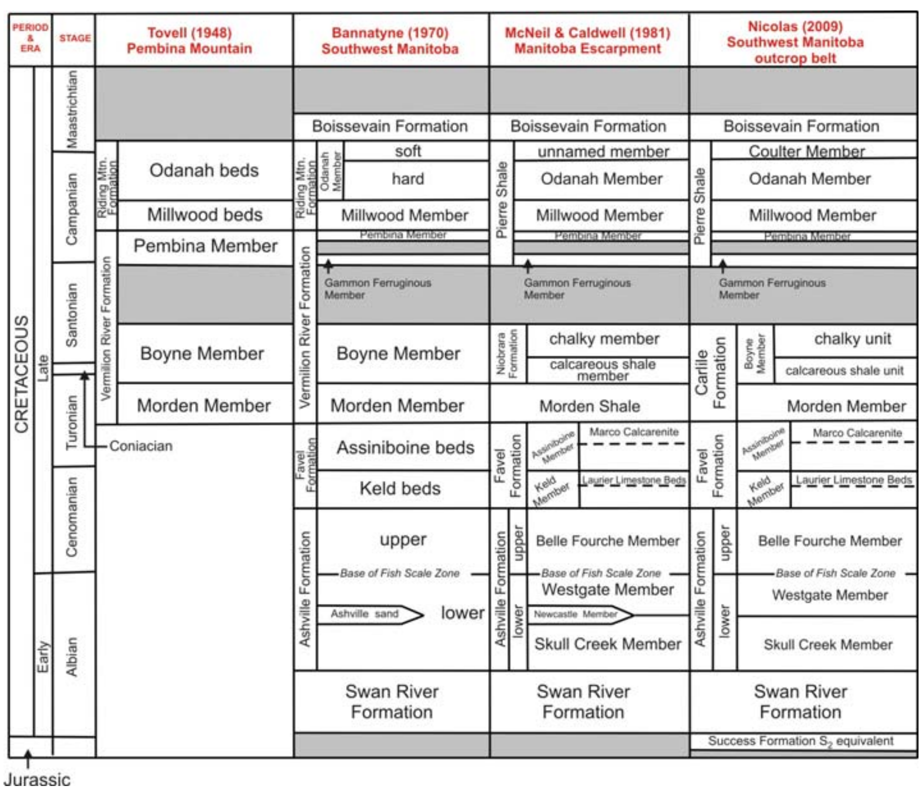



***Figure 4a and b:*** *Major revisions to the Cretaceous stratigraphic framework of southwest Manitoba (Bamburak and Nicolas, 2009).*

Triassic and Jurassic strata (Figures 2 and 3) are overlain with marked unconformity by Lower Cretaceous strata of the Swan River and Ashville formations, which are comprised of soft, recessive-weathering sand and shale (Table 1); and outcrop only rarely along the foot of the escarpment. These strata are in turn overlain by the Favel, Carlile and Pierre formations, which dip gently to the southwest at 0.8 to 1.5 m/km, and which consist primarily of more resistant siliceous and calcareous shales. These resistant strata form the cap rock for the east-facing Manitoba Escarpment (Figures 1 and 2), and outcrops are common along the escarpment as well as in the southwestern upland area. For the most part, the Upper Cretaceous marine shale and thin limestone beds were removed by erosion east of the Manitoba Escarpment.

**Table 1: Cretaceous Formations in the vicinity of the Manitoba Escarpment**

| **Formation/Member** | | **Maximum Thickness** m | **Lithology** |
|---|---|---|---|
| Boissevain Formation | | 0 | Sandstone, sand and silt, quartzose |
| Pierre Shale | | | |
| | Coulter Member | 0 | Bentonitic silt |
| | Odanah Member | 150 | Hard grey siliceous shale |
| | Millwood Member | 60 | Soft bentonitic clay |
| | Pembina Member | 7 | Non-calcareous black shale with numerous bentonite interbeds near base |
| | Gammon Ferruginous Member | 30 | Ferruginous black shale |
| Carlile Formation | | | |
| | Boyne Member | 30 | Chalky buff and grey speckled calcareous shale |
| | Morden Member | 30 | Non-calcareous black shale with abundant jarosite |
| Favel Formation | | | |
| | Assiniboine Member | 17 | Olive-black speckled calcareous shale with Marco Calcarenite beds near top |
| | Keld Member | 17 | Olive-black shale speckled shale with Laurier Limestone Beds near top |
| Ashville Formation | | 80 | Non-calcareous black to dark grey shale, silty; Newcastle sand zone, in places |
| Swan River Formation | | 150 | Sandstone, sand and silt, quartzose, pyritic shale, non-calcareous |

Following deposition of the Jurassic Waskada Formation (Figure 3), an emergent interval occurred. Erosion resulted in extensive truncation of Jurassic strata, and the development of a deeply incised drainage pattern. Fragments of lignified wood near the base of the Lower Cretaceous Swan River Formation indicate that those beds were deposited in a terrestrial environment, but the presence of glauconite interbeds in the upper part of the Swan River suggests a change to predominantly marine conditions by late Swan River time during the Albian stage (Figure 4a and b).

The deposition of the Cretaceous deposits occurred within the “east-median hinge” and “eastern platform” zones of the major Cretaceous epicontinental sea that flooded the Western Interior of the North American craton. The seas encroached from both the Arctic Ocean in the north and from the Gulf of Mexico in the south until they merged about late Albian time, and the seaway was in existence until early Maestrichtian time (Figure 4a and b). It was bordered on the west by land involved in episodic Mesozoic orogenic pulses.

McNeil and Caldwell (1981, p. 295) interpreted the Cretaceous rocks exposed in the Manitoba Escarpment and adjacent plains as the depositional products of two major cycles of marine sedimentation – the Greenhorn and Niobrara cycles:

- Greenhorn cycle
  - The transgressive phase of the Greenhorn cycle is represented by marginal-marine and marine sands of the Middle to Late Albian Swan River Formation, the non-calcareous shales of the Late Albian and Cenomanian Ashville Formation, and the chalk-speckled shales with shelly limestone stringers of the Early Turonian lower Keld Member of the Favel Formation (Figure 4a and b).
  - The regressive phase of the Greenhorn cycle is represented by the chalk-speckled shales with limestones of the early Middle Turonian upper Keld and Assiniboine Members of the Favel Formation; and possibly by, the non-calcareous shale of the late Middle Turonian Morden Member of the Carlile Formation (Figure 4a and b). An alternative interpretation is that the uppermost beds of the Morden Member actually record the earliest stage of the transgressive Niobrara sea, the start of Niobrara cycle. These two differing interpretations have led to many of the nomenclature debates, in Manitoba, between the Niobrara Formation vs. Boyne Member of the Vermillion River/Carlile Formation.
- Niobrara cycle
  - In Manitoba, the transgressive phase of the Niobrara cycle is largely or wholly lost in unconformity, as it is in the mid-basin of the United States. But, the long period of expansion of the Niobrara sea is recorded in the chalk-speckled shales, chalky shales, and marlstones of the late Turonian to eary Middle Santorian Niobrara Formation of McNeil and Caldwell (1981) (or Boyne Member of the Carlile Formation of Nicolas (2009), as shown in Figure 4b).

- The largely non-calcareous Pierre Shale and the unconsolidated sand and carbonate-cemented sandstone of the Boissevain Formation (Figure 4a and b) form the sedimentary record of regression of the Niobrara sea.

McNeill and Caldwell (1981, p. 295) stated that although the Greenhorn sea well may have reached its transgressive peak in Manitoba in Early Turonian time, as it did in the mid-basin of the United States; the Niobrara sea may not have reached its transgressive peak (with Pierre Shale deposition) in Manitoba until Early Campanian time, much later than in the United States. They also suggested that other cycles, defined in other parts of the Western Interior basin, if recognized in Manitoba, “should be viewed as secondary transgressive-regressive pulses during primary Greenhorn transgression and primary Niobrara regression”.

## SWAN RIVER FORMATION/MANNVILLE GROUP

The Lower Cretaceous Swan River Formation (Figure 3, Table 1) is mainly a fine-grained unconsolidated impure silica sand, with silt and light to dark grey clays. These sediments were deposited in a deltaic environment at the margin of a transgressing sea, which continued into Saskatchewan and Alberta. The names Mannville (Figure 3) and Dakota groups have been applied to equivalent strata in Saskatchewan/Alberta and North Dakota, respectively.

Swan River strata lie unconformably on a weathered surface of Jurassic and Devonian rocks, and are conformably overlain by shales of the Ashville Formation (Figure 3). In the southern part of Manitoba, the Swan River strata are probably of Lower Cretaceous age, but in the northern part of the area, some non-marine Jurassic strata may be included (Wickenden, 1945, p. 12). The Swan River Formation occurs beneath younger bedrock in two areas separated by a broad belt extending eastward from the Saskatchewan boundary through the Virden area to beyond Brandon (Figure 1), in which no Swan River deposits are known to occur. Both the Swan River and Jurassic Waskada formations (Figure 3) are difficult to distinguish on mechanical logs; and are therefore usually combined in most isopach maps. Similarly the Swan River Formation, north of township 19, may include sand of the underlying Jurassic Melita Formation (Figure 3).

Locally, the sand was cemented by calcium carbonate to form sandstone. Large ovoid sandstone concretions are exposed at surface south of Swan Lake in west-central Manitoba, where they are referred to as kettle stones. A Manitoba Provincial Park has been proclaimed over the site. Outcrops of the formation are also known along Pine, Swan, and Roaring rivers, and south of Mafeking, where the formation is composed of fine- to coarse-grained quartzose sandstone, commonly unconsolidated, glauconitic, argillaceous, and lignitic; numerous interbeds of shale and silty shale are present.

Cretaceous Swan River Formation subcrops beneath glacial sediments to the southwest of Rosebank, as shown in Figure 5.

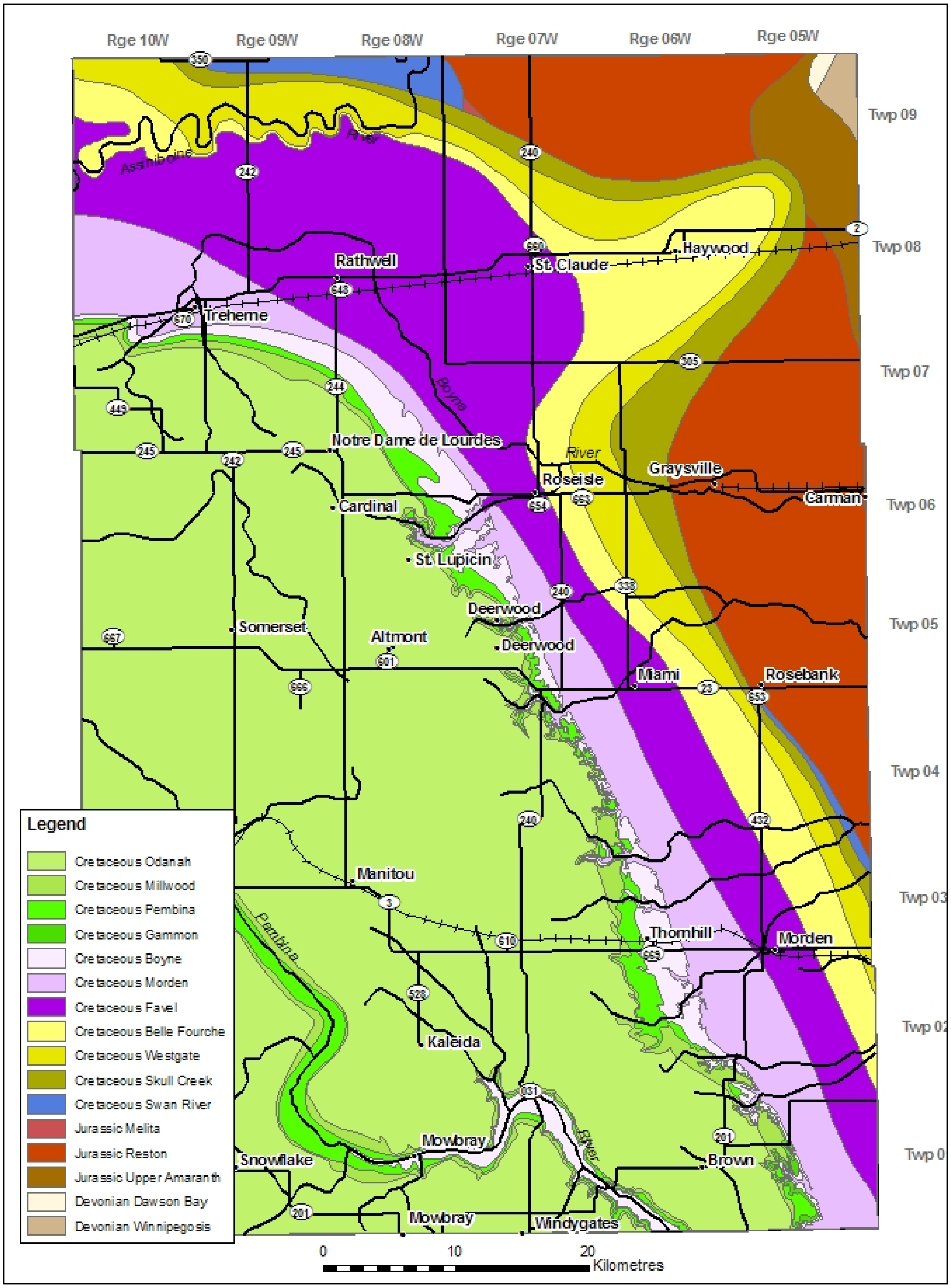



***Figure 5: Bedrock geology of the Pembina Hills area.***

## ASHVILLE FORMATION

The Lower to Upper Cretaceous Ashville Formation (Figure 3, Table 1) overlies the Swan River Formation and disconformably underlies the Favel Formation. It is a non calcareous, carbonaceous grey-black shale with small quantities of silt, sand and calcarenite. The formation has been informally divided into lower and upper members (Figure 3). Wickenden (1945) noted that the upper part of the formation is a greasy black rock that weathers brownish and breaks into numerous flat chips. The lower shale is dark grey, has a more clayey texture, and breaks into chunky fragments. The formation also contains minor calcareous bands, as well as numerous thin layers of bentonite.

The lower Ashville comprises the interval from the base of the Fish Scale Zone to the base of the overlying Belle Fourche Member. If the Newcastle Sand Member is present within this interval, the lower Ashville is usually subdivided into the Skull Creek, Newcastle and Westgate members (McNeil and Caldwell, 1981). The lower Ashville is conformably overlain by the upper Ashville. The base of the “Fish Scale” marker zone is picked as the contact between the Lower Ashville (Lower Cretaceous age) and Upper Ashville (Upper Cretaceous age).

Outcrops of the formation occur along the northeast and north slopes of Riding Mountain, along the Wilson River eastward from Ashville, and on the lower slopes of Duck and Porcupine mountains. The Skull Creek, Westgate and Belle Fourche members subcrop in the Porcupine Hills area, as shown in Figure 5.

## FAVEL FORMATION

The Upper Cretaceous Favel Formation (Figure 3, Table 1) overlies the Ashville Formation and underlies the Morden Shale. The Upper Cretaceous Favel Formation is a calcareous olive-black shale, usually containing visible white specks. It is also referred to as the “Second White Speckled Shale”. Kirk (1930) subdivided the Favel into the lower Keld beds and upper Assiniboine beds (Figure 4a). These beds were elevated to member status, as shown in Figure 4b, by McNeil and Calwell (1981), who also noted the presence of the Laurier Limestone beds, near the top of the Keld Member; and the Marco Calcarenite beds, near the top of the Assinboine Member (Photo 1). A few thin bentonite beds are present within the Favel Formation. The upper contact with the noncalcareous Morden Shale is sharp and conformable.

The formation is best exposed in west-central Manitoba, especially along the east and west branches of the Favel River, and along the Vermilion River. The middle part of the formation is exposed along the banks of the Assiniboine River north of Holland.

The formation, consisting mainly of grey shale with specks of white calcareous material, contains many limestone beds, as well as beds of impure limestone, and some thin bentonite layers. The formation ranges in thickness from 21 to 24 m in the northern part of the area, from 27 to 34 m in the Riding Mountain area, and from 30 to 40 m in the Pembina Hills area.

The Favel Formation reaches its maximum thickness in Manitoba, within the Brandon area. Over 40 m of Favel beds are present along a north-south trend following Rge. 10W, south of the Assiniboine River. Its thickness decreases to less than 34 m to the east and west. The upper surface of the Favel rises from +91 m at Turtle Mountain to over +274 m east of the Escarpment (Bannatyne, 1970).

Very limited exposures of the Marco Calcarenite beds and overlying and underlying speckled calcareous shales of the Favel Formation (Table 1) are located in the Assiniboine River valley, east of P.T.H. 34. Another exposure (within the subcrop area shown in Figure 5), 8 km east of Mount Nebo in SW1-14-4-6W was drilled (M-10-77) by the Department in 1977.

The conformable contact of the Favel with the overlying Morden Shale, marked by a ferruginous zone at the top of the former, can be seen in the south bank of Assiniboine River in NW9-27-8-11W.

## CARLILE FORMATION

### Morden Member

The Upper Cretaceous Morden Member (Figure 3, Table 1) is a thick sequence of dark grey to black carbonaceous noncalcareous shale (Bannatyne, 1970). The Morden Member is sharply and unconformably overlain by the Boyne Member of the Carlile Formation.

The Morden Shale, will be examined at **STOP 2**. The Morden Member shows little variation in lithology throughout its extent, either vertically or regionally. A few thin bentonite beds and partings occur within the Morden, but these are much less common than in the other Upper Cretaceous strata.

The shale beds contain calcareous concretions, some septarian or turtle-back, and some as large as 1.8 m in diameter. Iron sulphide is present as concretions, in irregular masses, or as layers of fine crystals between the shale layers. The iron sulphide is probably responsible for the strong sulphur odor when the outcrop is wet. A considerable amount of selenite (gypsum) as flakes and crystals is associated with the iron sulphide. A coating of yellow material, possibly jarosite KFe3(S04)2(0H)6, is present in most exposures of the shale, and in places occurs as laminae between the thin layers of shale (14-33-3-6W, south of Miami, former Red River Brick and Tile shale pit, **STOP 2 WEST**). This site lies within the subcrop/outcrop area of the Morden Member shown in Figure 5.

Isopachs of the Morden Shale, from northwest to southeast across the Brandon area, show an increase in thickness from less than 50 m to more than 65 m (Bannatyne, 1970). According to Bannatyne and Watson (1982, p.9), across southwestern Manitoba "The Morden shows a fairly uniform thickness from the northwest to southeast. This pattern, the result of syndepositional subsidence, differs markedly from that of older Cretaceous units, which generally show an increase in thickness to the southwest." Its upper surface rises from +152 m at Turtle Mountain to at least +349 m in drillhole M-10-77 at the edge of the Escarpment.

## Boyne Member

The Upper Cretaceous Boyne Member of the Carlile Formation (Figure 3, Table 1) is a medium grey and buff calcareous or chalky shale, limestone, chalk or marlstone that overlies the Morden Member. Numerous thin bands and partings of bentonite occur throughout the section. The Boyne (recently called the Niobrara Formation by McNeil and Caldwell (1981)) is also known as the “First White Speckled Shale”. McNeil and Caldwell (1981) divided the Boyne Member into lower calcareous beds and upper chalky beds. The Boyne Member is unconformably overlain by the Gammon Ferruginous Member, or where it is absent, by the Pembina Member of the Pierre Shale.

The disconformable contact of the Boyne with the Pembina Member will be examined at **STOP 3**. The top of the Boyne rises from 385 m in the Pembina Valley in 18-1-6W to 391 m at Deadhorse Creek in 21-2-6W (Tovell, 1948), and to 396 m in drillhole M-8-77. Excellent exposures of the Boyne can be seen in road cuts along Roseisle Creek (Snow Valley) **(STOP 8)**. The highly calcareous shale (37% Ca0, 1.5% Mg0) from this unit was used as late as 1924 in the production of natural cement. The Niobrara/Morden contact can be roughly approximated between two outcrops along the south side of P.T.H. 23, 5 km west of Miami.

The Boyne, shown in Figure 5, is 43 to 46 m thick in the Pembina Hills area. The upper part consists of buff and grey speckled calcareous shale, and corresponds to the "chalky member" of McNeil and Caldwell (1981). The lower part consists of dark grey carbonaceous and calcareous shale, containing abundant small white specks that are small fossils, mainly foraminifera, rhabdoliths and coccoliths. This corresponds to the "calcareous shale" (op. cit.). Most of the Boyne shales are low grade oil shales (Bannatyne and Watson, 1982, p. 9-11).

In the area along the east side of Riding Mountain, the upper highly calcareous shale of the Boyne Member of the Carlile Formation is not present, either through erosion prior to deposition of the Pembina Member, or possibly because of a facies change. Instead, the member consists of a dark grey to black carbonaceous shale, in places showing some white specks. (Bannatyne and Watson, 1982, p. 9-11).

## PIERRE SHALE

The Upper Cretaceous Pierre Shale forms the bedrock for most of the Second Prairie Level in Manitoba, west of the Escarpment (Figures 1 and 2). In most places it is covered by glacial and recent deposits, ranging from a metre to over 260 m in thickness; in the Turtle Mountain area it is overlain by younger rocks of the Upper Cretaceous Boissevain and Paleocene Turtle Mountain Formation.

The Upper Cretaceous Pierre Shale (Figure 3) comprises in upward ascending order, the Gammon Ferruginous, Pembina, Millwood, Odanah and Coulter members (McNeil and Caldwell, 1981). The Gammon Ferruginous and Pembina members were formerly included within the Vermilion River Formation; and the Millwood, Odanah and an unnamed unit were included as members within the Riding Mountain Formation, as shown in Figure 4b (Bannatyne, 1970). The uppermost member of the Pierre Shale in southwestern Manitoba was named the Coulter Member by Bamburak (1978).

## Gammon Ferruginous Member

The Gammon Ferruginous Member of the Pierre Shale (Table 1) is a uniform dark grey mudstone or silty shale, containing numerous red weathering ferruginous or sideritic concretions, which usually forms the base of the Pierre Shale. Before 1967, the Gammon had not been recognized in Manitoba. However, Bannatyne (1970) recognized the presence of the Gammon on mechanical logs from hundreds of oil wells drilled in southwestern Manitoba. The Gammon thins from a thickness of 55 m at the southwest corner of the Province to only a few centimetres or less along the Manitoba Escarpment (Figure 5). The only exception to this is along the Vermilion River, south of Dauphin, where the Gammon is 3.5 m thick. The Pembina Member of the Pierre Shale unconformably overlies the Gammon, if it is present.

A suggestion that some of the upper part of the section along Vermilion River in SW ¼ Sec. 23, Twp. 23, Rge. 20 WPM, described by Sternberg (in Wickenden, 1945, p. 39) and assigned to the Boyne Member, may be correlated with the Gammon Ferruginuous Member was confirmed by McNeil and Caldwell (1981). In most of the outcrop belt, the Pembina Member lies disconformably on the Niobrara Formation. The Gammon Ferruginuous Member is very thin or absent in the Pembina Hills area of Manitoba.

Gill and Cobban (1965) mention that the lower 50 cm or so of the Pembina Member exposed in the Pembina Valley, North Dakota in SW 1/4 sec. 30, tp.163N., rge. 57W, 10 km south of the International Boundary, may represent the thin eastern edge of the Gammon Ferruginuous Member, which reaches a thickness of 260 to 330 m in extreme western North Dakota."

## Pembina Member

The Pembina Member of the Pierre Shale (Figure 3, Table 1) overlies the Gammon Ferruginuous and/or Boyne Member of the Carlile Formation. The Pembina Member is a distinctive interlayered sequence of thin buff bentonite seams and thin greyish black noncalcareous marine shale beds. The Pembina Member was formerly placed within the former Vermilion River Formation.

A disconformable Pembina/Boyne contact will be seen at **STOP 3*.*** The contact can also be seen in gullies at the west end of an old quarry in SE11-6-2-5W and in a deep ravine in NW13-34-4-7W. It can be approximated in a road cut in 14-16-5-7W. The outcrop area of the Pembina Member can be seen in Figure 5. According to Bannatyne (1963, p. 7), towards the top of the Pembina Member the black shales pass graditionally upward into chocolate brown, more waxy, less organic shale and finally into the brownish green, waxy, non-carbonaceous shales of the Millwood beds.

The Pembina type shales thin markedly to the north, from 24 m in the Pembina River Valley to 8 m in Deadhorse Creek Valley (Tovell, 1948. p.5) to 5.7 m in drillhole M-8-77. "The upper part of the Pembina Member in the Miami area exhibits some swelling properties, and is close to the Millwood beds in its composition and test results" (Bannatyne 1963, p. 7). The upper surface of the Pembina Member rises northeastward across the map area from +213 m at Turtle Mountain (Bannatyne, 1970) to +402 m in drillhole M-8-77.

The Pembina Member usually can be seen in road cuts and in ravines adjacent to former mining operations along the Escarpment. Former bentonite quarries will be examined at **STOPS 3, 4, and 6**. At least 11 buff bentonite seams, ranging in thickness from 1 cm to 30 cm have been documented in previous investigations (Bannatyne, 1963, 1984; and Bannatyne and Watson, 1982). The seams are separated by similar thicknesses of black carbonaceous, pyritic shale. The bentonite seams thicken to the west, but the overburden rapidly increases in thickness to 12 to 15 m.

McNeil and Caldwell (1981, Table VII) indicated an age of <82.5 Ma for this interval in Manitoba (Bannatyne and Watson, 1982, p. 45), based upon radiometric age dating of ammonite zones.

## Millwood Member

The Millwood Member of the Pierre Shale (Table 1) is a popcorn or cauliflower-weathering olive-grey silty clay with abundant clay-ironstone concretions. The Millwood (formerly, a member of the Riding Mountain Formation) consists of bentonitic shale that is composed mostly of partly-swelling montmorillonite (Bannatyne, 1970), and it is the eastern expression of coarser grained deltaic sediments of the Judith River Formation (McNeil and Caldwell, 1981). The Millwood grades upward into the overlying Odanah Member.

The Millwood outcrops in places along the Manitoba Escarpment (Figure 5) and along the Souris, Pembina and Assiniboine River valleys, usually under a cover of hard Odanah shale. Rounded buttes of Millwood shale are common in the outcrop belt; an example will be examined at **STOP 4**. Outcrops show a distinctive “popcorn” or “cauliflower” weathered surface with little or no vegetation. Brown and reddish-brown ironstone and yellowish calcite concretions occur in layers within the Millwood Member. Although the lower Millwood/Pembina contact is not exposed because the soft "flowing" nature of the Millwood, an estimate of its position can be made at the break in slope at the base of the buttes.

1977 drilling in the Miami area indicated a thickness of 18.9 m for the Millwood Member. Across the southern Manitoba, the thickness of the Millwood increases from east to west. The Millwood Member increases in thickness from 26 m in the Pembina Hills area to over 150 m in the St. Lazare-Roblin area and is accompanied by an increase in quartz silt content (Bannatyne, 1970, p. 56). This thickening to the northwest contrasts markedly with the depositional pattern shown by all other Cretaceous formations." (Bannatyne and Watson, 1982, p. 14, 15.). In Saskatchewan, these beds are included in the upper part of the Lea Park Foramtion (Figure 3).

The uppper surface of the Millwood Member rises from about +259 m at Turtle Mountain (Bannatyne, 1970) to 421 m along the Escarpment (drillhole M-8-77).

Southward from the Pembina River area, the lower part of the Millwood Member increases in calcareous content (Bannatyne and Watson, 1982, p. 13). In North Dakota the upper Millwood beds are named the De Grey Member and the lower beds are called the Gregory Member.

## Odanah Member

The predominant lithology of the Odanah Member of the Pierre Shale (Table 1) is light, hard siliceous shale which will be examined in a quarry exposures at **STOPS 5 and 12**. The shale is steel grey or slightly greenish-grey when dry and dark greenish-grey when moist. The content of amorphous silica averages approximately 80 per cent. The shale occurs both as thin fissile beds, and as thick massive beds that are brittle and break with a subconchoidal fracture. The joints and bedding planes within the shale are usually stained brown or reddish to purplish brown from iron and manganese weathering products. Ironstone nodules of concretionary or septarian structure occur throughout the whole of the Odanah, but are more common in the upper part; Kirk (1930) reported that compact, ellipsoidal, grey limestone concretions are found in some exposures. Thin interbeds of bentonite and bentonitic shale are present, most commonly within the lower 33 m of the member.

The Odanah (formerly, a member of the Riding Mountain Formation, Figure 4) caps the Manitoba Escarpment and is exposed in numerous road and river cuts, ravines and quarries along the eastern side of Riding Mountain and the Pembina Hills. The contact is not exposed because undercutting of the softer Millwood causes collapse of the "heavier" overlying blocks of Odanah. However, the Millwood-Odanah contact can be seen at NE13-30-1-5W.

Studies of outcrops in the Pembina Hills (Figure 5) showed that the contact between the Odanah and Millwood shales is a definite stratigraphic marker horizon. It is associated with a 17 to 25 cm bed of green to olive waxy bentonite that has been traced for a distance of 300 km in surface outcrops. The contact has also been correlated with both an electric log marker and a change in gamma ray-neutron response shown on mechanical logs; these responses are correlatable across all of southwestern Manitoba. On this basis, the Pierre Shale was divided into the Odanah Member and the Millwood Member. (Tyrrell (1890) divided the former Riding Mountain Formation into a lower Millwood Series and an upper Odanah Series, based on outcrop occurrences, Figure 4a). These names were proposed for Manitoba only, although Gill and Cobban (1963) extended the Odanah into North Dakota. The reason for restricting the geographic extent of these members is the occurrence of facies variations whereby the Odanah Member loses its distinctive hard siliceous lithology to the west near the Saskatchewan boundary, and the calcareous content in the lower part of the Millwood Member increases southward from the Pembina River area.

In the extreme southwest portion of Manitoba, the thickness of the Odanah, below the Boissevain Formation, is approximately 230 m and its surface elevation is about +518 m. In Saskatchewan, near the Manitoba boundary, the Odanah "loses its distinctive hard siliceous lithology (Bannatyne and Watson, 1982, p. 13) and the beds are correlated with the Belly River Formation (Figure 3).

### Coulter Member

A bentonitic soft silty clay overlies the Odanah in southwest Manitoba, but not in the Pembina Hills area. These beds were informally named the Coulter Member of the Riding Mountain Formation, now the Pierre Shale (Table 1), by Bamburak (1978, p. 6); and are transitional upwards into the overlying sands of the Boissevain Formation. The Coulter Member was formally recognized as a stratigraphic name by Braman et al. (1999).

A former exposure of the Coulter in NW15-35-2-19W1, at the base of a Boissevain Formation section, is no longer visible due to slumping of surrounding sediments. The thickness of Coulter Member ranges from 37.2 m to 43.6 m and its upper surface rises from 481.6 m to over 506.0 m in three holes in the Turtle Mountain area (Bamburak, 1978).

## BOISSEVAIN FORMATION

Greenish-grey sand with ovoid sandstone concretions of the Upper Cretaceous Boissevain Formation (Table 1) overlies the Pierre Shale, west of the Pembina Hills area, near Turtle Mountain. The crossbedded sands were deposited in a fluvial environment (Bamburak, 1978, p. 23, 24). The sands become kaolinitic upwards indicating an erosional unconformity. The Boissevain Formation is equivalent to the Eastend and Whitemud formations of Saskatchewan (Figure 3).

An excellent exposure of the Boissevain can be seen in a gully south of P.T.H. 3, about 16 km west of Killarney, in NW15-35-2-19W1. The Boissevain Formation maintains a thickness of about 30 m across Turtle Mountain. Its upper surface rises from west to east from less than +499.9 to more than +530.4 m (Bamburak, 1978).

# PART II: GENERAL ROADLOG AND OUTCROP DESCRIPTIONS

***Leave Winnipeg (from junction of Perimeter Highway and PTH 3) and drive southwest on PTH 3 through Carmen. At junction of PTH 3 and 23, drive West on PTH 23 to junction with P.R. 432 and turn left (South). Continue South for 8 km. Junction with section road (Road 20N), turn right (West) for about 3.4 km and stop on section road beside large tree.***

## STOP 1: FAVEL PAVEMENT OUTCROP

**Cretaceous Favel Formation (Assiniboine Member with Marco Calcarenite, Table 2).** 1-14-4-6W1, NTS 62G8SE, NAD 83, Zone 14U, 560803E, 5460668N. The Marco Calcarenite outcrop is located on the First Prairie Level (Figure 1), 7 km east of the Pembina Hills component of the Manitoba Escarpment. The exposure, **STOP 1**, shown in Table 2 and Figures 6 and 7, is at the base of a shallow ditch on the north side of the road; and also appears within the ditch to the south, and as broken slabs in a small borrow pit in the farm field south of the ditch.

The outcrop consists of a 30 m long pavement of buff calcarenite, about 20 cm thick, overlying beige oxidized clay. Fish scales, Inoceramus and oyster shells, and shark vertebrae impressions have been found. Rock Eval™ 6 $T_{max}$ and total organic carbon (TOC) values for samples collected at this site are 432°C and 0.62 wt.% (Nicolas and Bamburak, 2009).

Drillhole M-12-77 was put down in the ditch on the north side of the section road.

**Corehole M-12-77**
**Miami SE**
**1-14-4-6WPM**
**5460500N**
**560900E**
**Elevation: 297.2 m**
**Total Depth: 45.1 m**
**Map sheet: 62G/8**
**Logged by H. R. McCabe**

| **METRES** | **DESCRIPTION** |
|---|---|
| **0.0-45.1** | **MESOZOIC**<br>**CRETACEOUS**<br>**FAVEL FORMATION:**<br>Limestone, calcareous speckled shale, oil shale. |

**End of Hole**

References: Corehole M-12-77, Bannatyne (1970).

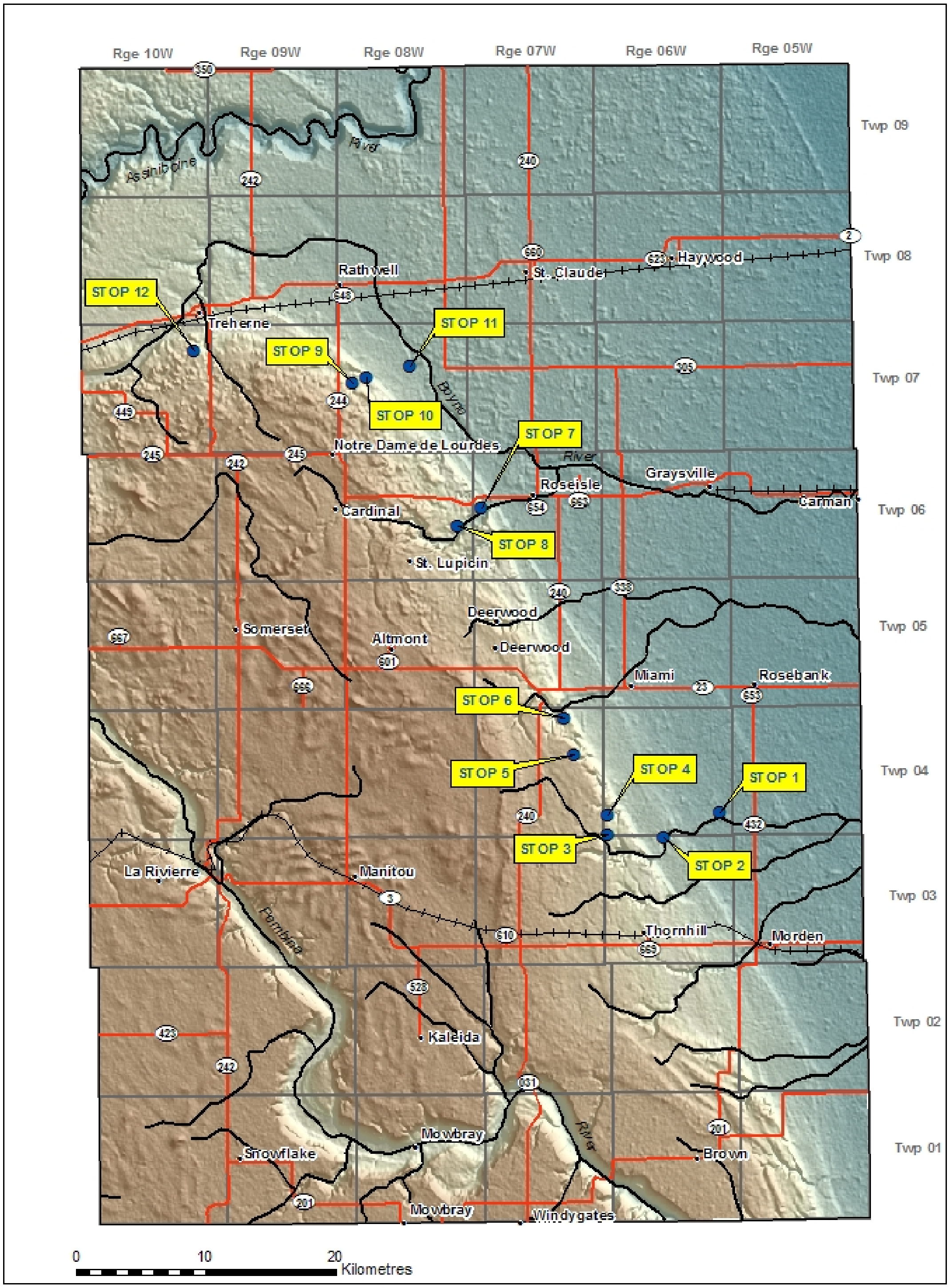



*__Figure 6:__ Topographic map of the Pembina Hills area, with field trip stops.*

## Table 2: Mesozoic and Cenozoic formations and field trip stops

| ERA | PERIOD | Manitoba subsurface | Manitoba outcrop | Field Trip Stops (Stops as shown in Figure 1) |
|---|---|---|---|---|
| CENOZOIC | Quaternary | glacial drift | glacial drift | |
| CENOZOIC | Quaternary | | | |
| CENOZOIC | Tertiary | Turtle Mountain Formation: Peace Garden Member | Turtle Mountain Formation: Peace Garden Member | |
| CENOZOIC | Tertiary | Turtle Mountain Formation: Goodlands Member | Turtle Mountain Formation: Goodlands Member | |
| MESOZOIC | CRETACEOUS | | | |
| MESOZOIC | CRETACEOUS | Boissevain Formation | Boissevain Formation | |
| MESOZOIC | CRETACEOUS | Pierre Shale: Coulter Member | Pierre Shale: Coulter Member | |
| MESOZOIC | CRETACEOUS | Pierre Shale: Odanah Member; Belly River "marker"; "lower" Odanah Member | Pierre Shale: Odanah Member | Stops 5 and 12 |
| MESOZOIC | CRETACEOUS | Pierre Shale: Millwood Member | Pierre Shale: Millwood Member | |
| MESOZOIC | CRETACEOUS | Pierre Shale: Pembina Member | Pierre Shale: Pembina Member | Stops 4 and 6 |
| MESOZOIC | CRETACEOUS | Pierre Shale: Gammon Ferruginous Member | Pierre Shale: Gammon Ferruginous Member | |
| MESOZOIC | CRETACEOUS | | | |
| MESOZOIC | CRETACEOUS | Carlile Formation: Boyne Member | Carlile Formation: Boyne Member: chalky unit | Stop 3 |
| MESOZOIC | CRETACEOUS | | Carlile Formation: Boyne Member: calcareous shale unit | Stops 8 to 10 |
| MESOZOIC | CRETACEOUS | Carlile Formation: Morden Member | Carlile Formation: Morden Member | Stops 2 and 7 |
| MESOZOIC | CRETACEOUS | Favel Formation: Assiniboine Member | Favel Formation: Assiniboine Member: Marco Calcarenite | Stops 1 and 11 |
| MESOZOIC | CRETACEOUS | Favel Formation: Keld Member | Favel Formation: Keld Member: Laurier Limestone | |
| MESOZOIC | CRETACEOUS | Ashville Formation, upper: Belle Fourche Member; Fish Scales Zone; base of Fish Scale marker | Ashville Formation, upper: Belle Fourche Member; base of Fish Scale marker | |
| MESOZOIC | CRETACEOUS | Ashville Formation, lower: Westgate Member | Ashville Formation, lower: Westgate Member | |
| MESOZOIC | CRETACEOUS | Ashville Formation, lower: Newcastle Member | | |
| MESOZOIC | CRETACEOUS | Ashville Formation, lower: Skull Creek Member; Pense "P4" marker | Ashville Formation, lower: Skull Creek Member | |
| MESOZOIC | CRETACEOUS | Swan River Formation | Swan River Formation | |
| MESOZOIC | CRETACEOUS / JURASSIC | Success Formation ($S_2$) | Success Formation ($S_2$) equivalent | |
| MESOZOIC | JURASSIC | Waskada Formation | | |
| MESOZOIC | JURASSIC | Melita Formation: Upper Member | | |
| MESOZOIC | JURASSIC | Melita Formation: Lower Member | | |
| MESOZOIC | JURASSIC | Reston Formation; Lower Gravelbourg "marker" | Reston Formation | |
| MESOZOIC | JURASSIC | Amaranth Formation: Upper (Evaporite) Member | Amaranth Formation: Upper Evaporite | |
| MESOZOIC | TRIASSIC | Amaranth Formation: Lower (Red Beds) Member | Amaranth Formation: Lower Red Beds | |
| PALEOZOIC | PERMIAN | | St. Martin Igneous & Metamorphic Complex | |

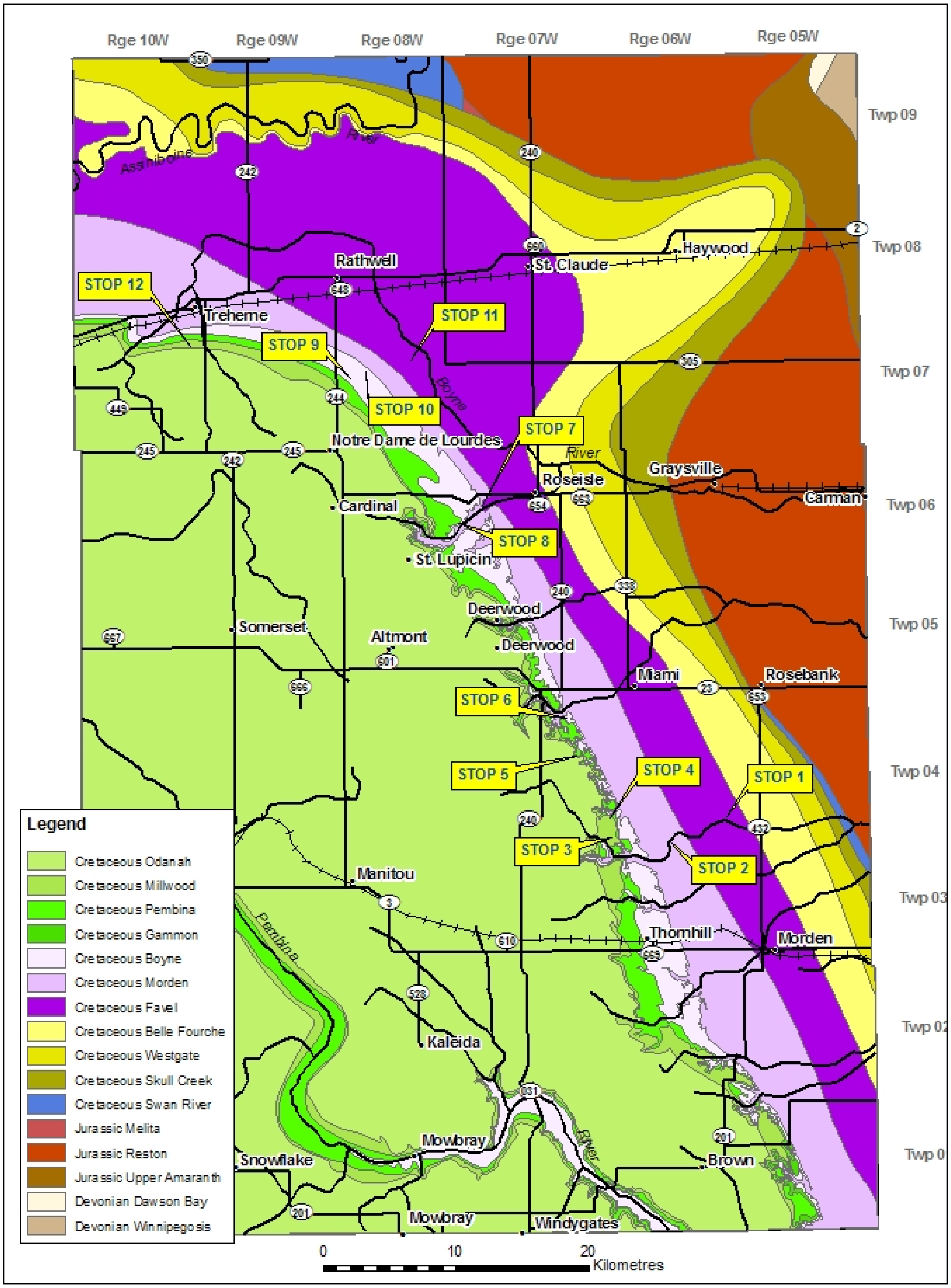



***Figure 7:*** *Bedrock geological map of the Pembina Hills area, with field trip stops.*

***Proceed West to next section corner and turn left (South) for 3.2 km. Then turn right (West) at the section corner and drive for 1.3 km up the Escarpment. Park on shoulder of road and "watch for traffic", as this is a busy route.***

## STOP 2: MORDEN MEMBER OUTCROP AND REHABILITATED BRICK SHALE QUARRY

**Cretaceous Carlile Formation (Morden Member).** 16-33-3-6W1, NTS 62G8SE, NAD 83, Zone 14U, 557628E, 5457278N. The outcrop (**STOP 2**, shown on Table 2 and Figures 6 and 7) is situated about 1.6 km east of the Pembina Hills component of the Manitoba Escarpment, and about 11 km south-southeast of Miami, Manitoba. About 800 m to the west, a similiar shale was quarried for brick shale.

**Outcrop**

Shale of the Morden Member is exposed on both sides of a road cut, over a 300 m length. Abundant small selenite crystals and broken septarian concretions, similar to those at are present on the surface of the weathered shale. Rock Eval$^{TM}$ 6 $T_{max}$ and TOC values for samples collected at this site are 428°C and 2.27 wt.% (Nicolas and Bamburak, 2009).

***Continue 800 m towards the West, across bridge and briefly stop. A former brick shale quarry site can be seen in the field to the South. Waste bricks (backhauled from the plant at Lockport) can be seen that form the road base of the access road into the former quarry.***

**Quarry**

The quarry was operated by Red River Brick and Tile (a subsidiary of I-XL Industries Ltd.) from 1971 to 1992, to mine the Morden Member for use in making face brick. The shale was transported over 160 km to Lockport, Manitoba (29 km north of Winnipeg), where it was mixed with other clays (such as from **STOP 5 WEST**) to produce a variety of colours. The quarry was rehabilitated with the shut down of the Lockport plant.

References: Bannatyne (1970), Shayna (1975).

***Continue West for about 3.2 km. Stop on shoulder of road, park and carefully cross to south side of road.***

## STOP 3: SPENCER'S DITCH AND O'DAY FORMER BENTONITE ADIT

**Cretaceous Pierre Shale (Millwood Member/Pembina Member) overlying Carlile Formation (Boyne Member).** 15-31-3-6W1, NTS 62G8SW, NAD 83, Zone 14U, 553821E, 5457330N. The elevation of the top of the outcrop (**STOP 6**, shown on Table 2 and Figures 6 and 7) is 392 m above sea level. The former adit was situated on the north side of Shannon Creek, a deep east-west trending valley that has cut deep into the Cretaceous stratigraphy of the Pembina Hills. The O'Day stop is about 11 km south of Miami, Manitoba.

In the vicinity of the former adit opened by J.O'Day (Bannatyne, 1963, p. 13), a southerly-trending ravine, "Spencer's Ditch", has been incised into the soft Cretaceous beds. Run-off from a large holding pond to the north of Dunston Road, through a culvert and into Shannon Creek, has caused substantial downcutting of the bedrock. This exposure is located on private land.

On the east wall of Spencer's Ditch, 2 m of glacially disturbed bentonite beds of the Pembina Member of the Pierre Shale can be seen overlying about 10 m of buff Boyne Member, with numerous thin bentonite seams. Plastic flow of the Boyne Member into Shannon Creek is evident at the south end of the exposure. The Gammon Ferruginous Member is believed to be present as a 0.5 m thick bed between the underlying Boyne Member and overlying Pembina Member. The Millwood Member is present on the west wall on the ravine, forming a low relief Millwood butte, above the Pembina Member. Rock Eval™ 6 $T_{max}$ and TOC values for the Boyne and Pembina member samples collected at this site average 426°C and 2.30 wt.%, and 424°C  and 4.61 wt.%, respectively (Nicolas and Bamburak, 2009).

<u>References</u>: Bannatyne (1963, 1970).

***Return to vehicles and drive 1 km West to next section corner, turn right (North) for 0.8 km then turn left (West) for 1.6 km. At the next section corner turn right (North) for 2.4 km. At section corner, turn right (East) and proceed 1.8 km down the Escarpment. Mount Nebo is on the left, (if dry) turn into driveway and park.***

## STOP 4: MOUNT NEBO FORMER BENTONITE QUARRY

**Cretaceous Pierre Shale (Millwood Member overlying Pembina Member).** 4-18-4-6W1, NTS 62G8SW, NAD 83, Zone 14U, 552995E, 5460834N. The former quarry (**STOP 4**, shown in Table 2 and Figures 6 and 7) was opened at the base of Mount Nebo, one of the typical Millwood buttes, found at the edge of Pembina Hills. Mount Nebo is located about 8 km south of Miami, Manitoba.

Bentonite beds of the Pembina Member of the Pierre Shale were quarried by Pembina Mountain Clays Limited to the north and south of the section road at the base of Mount Nebo. However, several thin beds of bentonite can still be seen adjacent to the road allowance.

The quarry to the north has not been rehabilitated and is used by locals for dirt bike riding, as are most of the flanks of Mount Nebo. The distinctive sparsely vegetated popcorn or cauliflower surface of the greenish-grey bentonitic shale of the Millwood Member can readily be seen, but the contact with the underlying Pembina

Member is not exposed. Brown to purple manganiferous ironstone concretions are common. Shark's teeth and bone fragments have been found. Fragments of the hard grey siliceous shale of the Odanah Member have been reported to have been found at the top of the butte.

Rock Eval™ 6 $T_{max}$ and TOC values for Pembina Member samples collected at this site are 440°C and 3.32 wt.% (Nicolas and Bamburak, 2009).

Bannatyne (1963) and Bannatyne and Watson (1982) gave a detailed description of the most northwesterly of the Twin Sisters buttes in SW25-4-7W1, 3.3 km northwest of Mount Nebo. The description of a measured section of the butte, in a fresh cut in 1962, is reproduced below:

| Section of Twin Sister Butte | | Thickness (m) |
|---|---|---|
| **8** | Top of butte; overburden; fragments of Odanah shale | 0.92 |
| **Pierre Shale** | | |
| **Millwood Member** | | |
| **7** | Bentonitic shale, greenish-grey; 3 bands of green waxy bentonite, 1", 1" and ½" thick; 1" purple-stained hard ironstone band 6'6" from top | 3.02 |
| **6** | Bentonite, olive-green, waxy, pure | 0.18 |
| **5** | Bentonite shale, greenish-grey, some minor iron staining; ½" ironstone band at base | 2.74 |
| **4** | Bentonitic shale, grey, darker weathering than above sections; more iron stained and several bands of ironstone each ¾" to 1" thick | 3.48 |
| **3** | Bentonitic shale, grey, contains brown ironstone concretions, some stained purple | 3.79 |
| **2** | Bentonitic shale, grey, selenite crystals in upper part; scattered brown and purple ironstone concretions | 3.94 |
| **1** | Millwood beds, basal section; covered by slumped material | 3.05 |
| | Total Section | **21.12** |

References: Bannatyne (1963, 1970).

***Return to section road and turn right (West) up the Escarpment for about 1.8 km. Intersection, turn right (North) for 2.2 km. R.M. of Thompson Shale Aggregate Quarry is on right (East). Turn into quarry and park.***

## STOP 5: R.M. OF THOMPSON SHALE AGGREGATE QUARRY

**Cretaceous Pierre Shale (Odanah Member).** (McCabe and Bannatyne, 1970, Stop 21 and Bannatyne and Watson, 1982, Stop 3) in SW5-24-4-7W1, NTS 62G8SW, NAD 83, Zone 14U, 551426E, 5462654N. The quarry (**STOP 5**, shown in Table 2 and Figures 6 and 7) is located on the northeast flank of the Pembina Hills, 3 km southwest of Miami, Manitoba.

A 6 m section of hard grey siliceous shale that is typical of the Odanah Member is exposed in the Rural Municipality of Thompson quarry. Odanah shale contains 79 to 82% $SiO_2$, mainly amorphous silica mixed with illite with a montmorillonite component. The shale is well bedded and cut by joints that are stained with iron and manganese oxides. The municipality uses the shale as a crushed aggregate for surfacing roads. Note on the east wall of the quarry the contact with overlying fragmental and distorted shale-rich till, formed by cryoturbation (E. Nielsen, pers. comm.).

Rock Eval™ 6 $T_{max}$ and TOC values for Odanah Member samples collected at this site are 416°C and 0.33 wt.% (Nicolas and Bamburak, 2009).

Another quarry (**STOP 5 WEST**) is located, across the section road to the west, in SE9-23-4-7W1. This quarry was operated from 1971 to 1992 by Red River Brick and Tile (a subsidiary of I-XL Industries Ltd.) to mine the Odanah to make face brick. The shale was transported over 160 km to Lockport, Manitoba (29 km north of Winnipeg) where it was mixed with other clays from **STOP 2** and other localities to produce a variety of colours. With the shutdown of the Lockport plant, the quarry is now used by RM of Thompson for aggregate.

**Corehole M-08-77**

**Pembina Hills, Miami**

**5-24-4-7WPM**

**5462450N**

**551300E**

**Elevation: 434.3 m**

**Total Depth: 74.4 m**

**Map sheet: 62G/8**

**Logged by H. R. McCabe**

| METRES | DESCRIPTION |
|---|---|
| **0.0-13.7** | **MESOZOIC** |
| | **CRETACEOUS** |
| | **PIERRE SHALE** |
| | **Odanah Member:** |
| | Shale- siliceous. |
| **13.7-32.6** | Shale- bentonitic. |
| **32.6-38.4** | **PIERRE SHALE** |
| | **Millwood Member:** |
| | Shale- bentonite. |
| **38.4-74.4** | **CARLILE FORMATION** |
| | **Boyne Member:** |
| | Calcareous and non-calcareous shale. |

**End of Hole**

References: Corehole M-8-77, McCabe and Bannatyne (1970), Bannatyne (1970), Bannatyne and Watson (1982), Shayna (1975).

***Return to section road and turn left (South) for 0.6 km. Intersection, turn right (West) for 1.6 km until junction with north-south section road. Turn right (North) for about 3.5 km, proceeding partway down Escarpment towards the northwest. Park and assemble at side of road.***

## STOP 6: ROBERT'S FARM FORMER BENTONITE QUARRY

**Cretaceous Pierre Shale (Pembina Member).** (McNeil and Caldwell, 1981, Outcrop Section 99) in the south-central portion of 3-35-4-7W1, NTS 62G8SW, NAD 83, Zone 14U, 550270E, 54622419N. The rehabilitated quarry (**STOP 6**, shown in Table 2 and Figures 6 and 7) is situated at the eastern edge of the Pembina Hills, 5.6 km southwest of Miami, Manitoba on the Robert's Farm.

Outcrop Section 99 of McNeil and Caldwell (1981) is no longer exposed and described the interval below the main bentonite seams. It is not reproduced; however, a typical section that was quarried by Pembina Mountain Clays Limited from Bannatyne and Watson (1982) is shown below. They also noted that the bentonite beds vary from pit to pit, and even show variations in thickness in a single pit. On average, six bentonite beds recovered have a combined thickness of 75 cm, and the five interlayers of black shale have a combined thickness of 25 cm.

| **Pierre Shale** | | **Thickness (cm)** |
|---|---|---|
| **Pembina Member** | | |
| **12** | Shale, black, with organic remains, e.g. fish scales, teeth | 80 |
| **11** | Bentonite, creamy yellow, dries to grey or pale buff | 13 |
| **10** | Shale | 5 |
| **9** | Bentonite | 25 |
| **8** | Shale | 5 |
| **7** | Bentonite | 9 |
| **6** | Shale | 5 |
| **5** | Bentonite | 10 |
| **4** | Shale, in places with thin bentonite layer | 8 |
| **3** | Bentonite | 10 |
| **2** | Shale | 6 |
| **1** | Bentonite | 9 |
| | Total Section | **185** |

References: McNeil and Caldwell (1981), Bannatyne (1963, 1970), Bannatyne and Watson (1982).

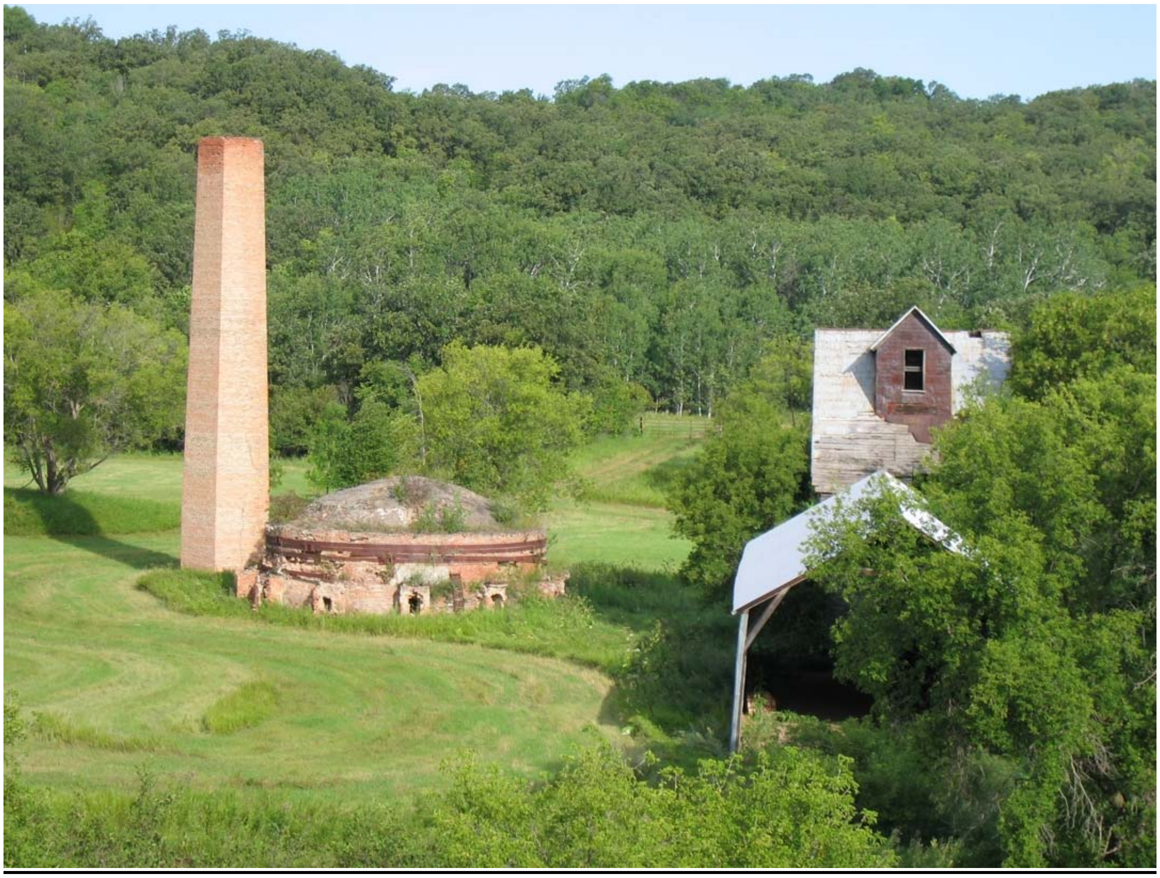
***Continue down Escarpment to the north and east for about 4 km until junction with PTH 23. Turn right (East) for 12.8 km until junction with P.R. 432. Turn right (South) for about 12 km until the town of Morden. Turn left (East) at the first crosswalk (Gilmour St.). Proceed East on Gilmour until you see the CFDC on the left. Park and go inside.***

***Lunch and tour of Canadian Fossil Discovery Centre in Morden, 12 Noon, http://www.discoverfossils.com/, (204) 822-3406.***

***Return West on Gilmour St. to junction with PR 432. Turn right (North) for about 20 km until junction with PTH 23. Turn left (West) for 14.4 km until junction with P.R. 240. Turn right (North) on P.R. 240. Continue North on section road for 6.4 km to Five Corners Junction. Follow diagonal road to northwest. Note: we are driving on a natural road base, a beach ridge of Glacial Lake Agassiz. Follow this road for about 5 km to another five corner junction, and then continue 1.6 km to the North. Turn left (West) on Roseisle Creek (Snow) valley road and proceed westward towards the Escarpment. Continue West on road for about 5 km and park on side of road. Leary's brick plant (abandoned) to the left. Park and walk towards the property gate but do not enter.***

## STOP 7: FORMER LEARY'S BRICK PLANT AND SHALE OUTCROP

**Cretaceous Carlile Formation (Morden Member).** (McCabe and Bannatyne, 1970, Stop 18) in 6-13-6-8W1, NTS 62G8NW, NAD 83, Zone 14U, 541656E, 5480664N. The former brick plant (**STOP 7**, shown in Table 2 and Figures 6 and 7) is located a few hundred metres north of Roseisle Creek and the shale outcrop is on the south bank of the creek. Both are situated near the eastern edge of the Pembina Hills, about 6 km southwest of Roseisle, Manitoba.



**Brick Plant**

The plant was in operation from 1900 to 1907, and again from 1947 to 1952. An unsuccessful attempt was made in 1962 to resume production. The quarried shale was passed through a crusher, and carried by bucket elevators to screens, with the coarse material being returned to the crusher. Bricks, formed by the dry press method, were fired in patches of 80 000 in the bee-hive kiln. Burning of one load required 2 to 3 weeks, in order to produce a good red colour.

**Morden Shale**

A 9 m high bank of black carbonaceous Morden Member is present on the south slope of Snow Valley, 60 m south of the brick plant. Note the well-developed large septarian concretions on the sides of the creek valley; these were discarded during the stripping operations. Rock Eval™ 6 $T_{max}$ and TOC values for Morden Member samples collected at this site are 423°C and 2.35 wt.% (Nicolas and Bamburak, 2009).

References: McCabe and Bannatyne (1970), Bannatyne (1970).

***Continue westward for about 2 km along Roseisle Creek (Snow) valley road and park adjacent to outcrop on right. Watch for traffic while getting out of vehicles on the left; and for a slight drop off if getting out on the right.***

## STOP 8: ROSEISLE OUTCROP (WITH BABCOCK BEDS)

**Cretaceous Carlile Formation (Boyne Member with Chalky and Calcareous Units).** (McCabe and Bannatyne, 1970, Stop 17) in 13 to 16-10-6-8W1, NTS 62G8NW, NAD 83, Zone 14U, 541157E, 5480360N. One of a string of generally east-west trending outcrops, which line the north side of Roseile Creek or Snow Valley, within the Pembina Hills. **STOP 8** (shown in Table 2 and Figures 6 and 7) is the easternmost of the outcrops and has the Babcock Beds, in its mid-section. The valley is located about 1.8 km northeast of St. Lupicin, Manitoba.

The westernmost outcrop, before the road to St. Lupicin crosses the bridge, consists of 50 m of grey and buff calcareous Boyne Member of the Carlile Formation that is capped by 16 m of glacial drift. However, directly below the drift and above the Boyne, a 58 cm thick bed of Gammon Ferruginous Member and a 1.4 m interval of Pembina Member have been found near the top of a climbing trail. According to McCabe and Bannatyne (1970), an outcrop of Morden Member has been reported below the road level, but now is covered.

Rock Eval™ 6 $T_{max}$ values for Boyne Member samples collected at this site average 421°C, and have TOC values up to 10.55 wt.% (Nicolas and Bamburak, 2009).

Calcareous shale from the Boyne Member has been used in the production of natural cement. The shale was recovered by room and pillar mining methods from 1907 to 1924 by way of an adit into the south slope of the valley, near the former Babcock railroad station (about 0.5 km to the east of **STOP 8**).

References: McCabe and Bannatyne (1970), Bannatyne (1970), Nicolas (2008), Nicolas and Bamburak (2009).

***Continue westward along Roseisle Creek (Snow) valley road until junction with section road (to St. Lupicin) on right. Turn right (North) and proceed up valley wall and across Second Prairie Level for3.2 km. Turn left (West) on PR 245 for about 6 km until junction with PR 244. Turn right (North) for about 10 km until section road. Turn right (East) for 0.8 km and stop at gate on the right. Park and go through fence gate and proceed to quarry on the South.***

## STOP 9: BOSC FARM WEST AGGREGATE QUARRY

**Cretaceous Carlile Formation (Boyne Member).** 15-19-7-8W1, NTS 62G10SE, NAD83, Zone 14U, 533408E, 5493092N. The quarry (**STOP 9**, shown in Table 2 and Figures 6 and 7) is situated on the north flank of the Pembina Hills, 6 km north-northeast of Notre Dame de Lourdes, on the farm of Normand and Guy Bosc.

Rock Eval™ 6 $T_{max}$ and TOC values for Boyne Member samples collected at this site average 410°C and 4.19 wt.% (Nicolas and Bamburak, 2009).

***Continue East on section road for 0.8 km. Intersection with section road, turn left (North) and then left again into farm.***

## STOP 10: BOSC FARM GAS WELL

**Cretaceous Carlile Formation (Boyne Member) overlying Morden Shale and Favel Formation.** 1-30-7-8W1, NTS 62G10SE, NAD 83, Zone 14U, 533936E, 5493491N. The gas well (**STOP 10**, shown in Table 2 and Figures 6 and 7) is situated on the north flank of the Pembina Hills, 6 km north-northeast of Notre Dame de Lourdes, on the farm of Norman and Guy Bosc.

The well was drilled to a depth of about 52 m, about 1930. The bottom of the well is probably into the Favel Formation (Second White Specks), which is known to contain oil shale. Boyne Member of the Carlile Formation bedrock is exposed at two locations, a short distance to the southeast and to the southwest. The exposures are at about the same elevation as the top of the well.

The well produces natural gas, with a weak petroleum smell, that burns when ignited. The well recharges with 32 lbs. gas pressure every 12 hours when the valve is closed. The pressure drops to 3 lbs. after being opened for 0.5 hour. Poor quality drinking water has been encountered in all wells drilled in the entire Section. Free-gas samples from this site contained over 80% methane, with a dry gas index of 0.997. Stable isotope analyses returned $\delta^{13}C$ and $\delta D$ values within the biogenic gas range (Nicolas and Grasby, 2009)

Wallace (1925) reported that natural gas was being used for domestic lighting purposes in southwestern Manitoba. One location was in the “Waskada-Sourisford district”. The other was near Treherne on a farm of a Mr. Rannard. The later, might be the well described by Wallace.

References: Wallace (1925), Bannatyne (1970).

***Return to vehicles and turn left (North) onto section road. Continue North for about 1 km until next section corner and turn right (East) for about 4 km. Turn into gravel pit on right and park.***

## STOP 11: LAKEVIEW QUARRY – GRAVEL WITH MARCO CALCARENITE BOULDERS

**Pleistocene clay-rich gravel overlying possible Favel Formation.** 15-22-7-8W1, NTS 62G9SW, NAD 83, Zone 14U, 538383E, 5493261N. Water-filled Pleistocene gravel pit (**STOP 11**, shown in Table 2 and Figures 6 and 7) with possible Favel Formation at base. Owner reported black oily rocks. Abundant large Marco Calcarenite boulders found in rubble

***Turn left (West) onto section road and continue West and for 5.6 km until junction with P.R. 244. Turn right (North)) for 4.8 km until junction with PTH 2 .Turn left (West) for about 11 km until junction with section road. Turn left (South) for about 2 km and stop on top of small knoll.***

## STOP 12: TREHERNE SHALE AGGREGATE QUARRY

**Cretaceous Pierre Shale (Odanah Member).** 12-25-7-10W1, NTS 62G10SE, NAD 83, Zone 14U, 520969E, 54955817N. The quarry (**STOP 12**, shown in Table 2 and Figures 6 and 7) is located on a knoll, on the north flank of the Pembina Hills, about 2 km south of Treherne, Manitoba.

A 5.5 m section of well-bedded manganese-stained Odanah Member of the Pierre Shale is exposed on the east wall of a quarry south of Treherne. A 21 cm thick green swelling bentonite seam is found 1.5 m above the base of the quarry. The shale beds are thin bedded at the top and bottom of the section but appear to be more thickly bedded in the middle of the section. About 1.5 m of overburden is on top of the outcrop. A major thrust plane indicates glacial disturbance; and channel fill at the top of the knoll suggests that glacial meltwater once flowed on the top of the outcrop.

References: Bannatyne (1970).

***End of formal field trip. Supper in Treherne, or return to Petro-Canada Winnipeg by PTH 2.***

## *ECONOMIC GEOLOGY*

The Pembina Hills area has produced a wide variety of industrial minerals during the past hundred years and has the potential for further development of commodities for construction, energy and miscellaneous uses. Following is an alphabetic listing of past, present and future commodities.

## AGGREGATE SHALE

Numerous quarries for shale for use as aggregate road metal and for fill have been opened in southwest Manitoba. Most of the quarries are situated within the Odanah Member of the Pierre Shale, but at least three are within the Boyne Member of the Carlile Formation (Figures 2, 3 and 7). According to the Canadian Minerals Yearbooks for 2003 and 2006, the average annual aggregate shale production in Manitoba from 2000 to 2006 was 176 000 t valued at approximately $0.60/t (based upon 2000 prices). Most of this production is believed to have originated from the Odanah Member. Potential resources of aggregate shale in southwest Manitoba are infinite, except for land use concerns.

### Odanah Member of the Pierre Shale

The Odanah Member of the Pierre Shale is referred to as being siliceous and contains 81% $SiO_2$. It has also been called a porcelanite by Young and Moore (1994). The Odanah shale is currently extracted for aggregate from over 50 pits and quarries, located mostly in the south half of the Brandon area. The shale is found "in place", "glacially disturbed", as a shale-rich till, or as a combination of all three. Because the shale exfoliates so readily, blasting is not usually required. Only a short period of time is required for a new talus pile to develop at the base of an excavation.

One of the largest Odanah shale quarry to operate in the province is the Brown quarry in 15-1-1-6W1**.** The Brown quarry is situated just over 1 km north of the USA border, where the Pembina Hills enters North Dakota. The Odanah shale in the Brown quarry is unique in that there are two major units – an oxidized upper layer and an unoxidized lower layer. Another Odanah quarry, the Treherne quarry, in 12-25-7-10W1, is part of this field trip (**STOP 12**, shown in Table 2 and Figures 6 and 7).

### Boyne Member of the Pierre Shale

Calcareous shale from the Boyne Member of the Carlile Formation, obtained from the Bosc West quarry (**STOP 9**, shown in Table 2 and Figures 6 and 7) in NW15-19-7-8W, has also been used as a fill in road construction.

## BENTONITE

### Non-swelling calcium bentonite
### *Pembina Mountain Clays Limited*

From 1939 to December 1990, Pembina Mountain Clays Limited produced the only non-swelling natural and activated calcium montmorillonite clays in Canada. The bentonite was quarried from the Pembina Member of the Pierre Shale (Figures 2, 3 and 7), on a seasonal basis from May to October, by a contractor from at least 21 sites located 30 km west of Morden **STOPS 3, 4 and 6** are former quarry sites of Pembina Mountain Clays. The main processing plant (21,300 sq. ft.) was in Winnipeg; and the drying and crushing plant (10,000 sq. ft.) was in Morden (128 km southwest of Winnipeg). In 1990, twenty-three employees, with an annual payroll of $800,000, worked at the two plant sites. Goods and services purchased in the area totaled nearly $2.3 million; and more than $43,000 was paid in local taxes (Englehard Corporation, Fact Sheet, 1989).

The mining technique used by Pembina Mountain Clays remained similar throughout the life of the operation. The typical mining season was from May to October. During the winter, the normal frost depth is two to three metres and separation of the bentonite from the black shale is impossible. And, poor ground conditions in the early spring and the late fall restrict the weight that can be transported on haul roads.

The overburden and black shale were removed from the bentonite layers with small-scale scrapers and the bentonite carefully removed to minimize contamination by extraneous material. However, contamination was always a problem especially during inclement weather when the black clay would cake to the scrapers and the trucks hauling the bentonite. A front end loader was used to load the clay onto trucks at the quarry site for transport to a stockpile at the Morden plant. After preliminary drying and crushing, some was sold as is and the remainder was transported by truck to Winnipeg for further processing.

In the Winnipeg plant, the raw clay was chemically treated with 93% virgin sulphuric acid and water. The mixture was heated until the reaction was completed. The resulting slurry was washed, dried and screened. The activated finished product was the sold to producers of edible and inedible vegetable oils, in either bulk or bags, as a bleaching agent. The product was used as an adsorbant to decolourize or to remove impurities from: tallow, animal fats, waxes, waste lube oils, petroleum feed stock, linseed oil, canola oil, soybean oil, palm oil, sunflower oil, coconut oil and peanut oil. Major consumers of the clay in Canada were: Proctor and Gamble, Canada Packers, Monarch Fine Foods and C.S.P. Foods. Some bentonite was also used to produce kitty litter.

### *Bird River Mines Inc.*

Bird River Mines extracted a small stockpile of high-purity, non-swelling calcium bentonite near Deerwood, 8 km northwest of Miami, Manitoba in 2001 The quarry, in 10&11-16-5-7W1 is also situated within the Cretaceous Pembina Member of the Pierre Shale (Figure 2). Over the years, the company has attempted to find markets for the bentonite, but no further work has been done on the site since 2001.

## Partly Swelling Bentonite

Partly swelling bentonite occurs in the upper part of the Pembina Member and is the major constituent of the Millwood Member of the Pierre Shale (Figure 2, 3 and 7). The best quality material is in the Pembina Hills area **(STOP 4)** where the Millwood averages 19.8 m in thickness. Along the Assiniboine Valley, in the Millwood-Binscarth area, an increase in Millwood thickness to over 91 m, is accompanied by an increase in silt content.

No production has occurred. However, tests conducted over the years have indicated some success in pelletizing iron ores, as a fire retardant in fighting forest fires and as raw material for lightweight aggregate. The addition of sodium carbonate, 2% of the dry weight of the bentonite, was found to greatly increase its gel-forming properties. However, this product had much lower viscosity than a true swelling bentonite.

## Swelling Bentonite

A 17.5 to 35 cm bed of green swelling bentonite occurs near the contact between the Millwood and Odanah members of the Pierre Shale (Figures 2, 3 and 7). It has been observed in numerous outcrops along eastern flank of the Pembina Hills **(STOP 12)**, and also outside the map area in the Assiniboine Valley in the Oak Lake, Miniota, Beulah and Binscarth areas. Northwest of Beulah, it is locally up to 67.5 cm thick.

No production has occurred. Bannatyne (1963, p. 43) stated that this bed was uneconomic because of: 1) its thinness; 2) added cost of sodium carbonate to improve its swelling properties; and 3) availability of other swelling bentonites in western Canada and the northern United States. However, more exploration work was recommended to locate larger size bentonite deposits with better swelling properties. In the Millwood-Harrowby area, a higher quartz silt content results in beds having in a lower swelling potential than those in the Pembina Hills area (Bannatyne, 1970, p. 56)

## BRICK CLAY/SHALE

Brick clays are mechanical mixtures of kaolinite, illite, quartz, carbonate, iron oxide and chlorite that form a hard, non-porous, non-glossy mass upon heating to fusion (Gunter, 1989). Over 40 brick plants have operated in the Province since 1871 utilizing Cretaceous, Pleistocene and Holocene clays. Shayna (1975) has documented a brief history of brick making.

## Learys Brick Plant and Quarry

The Morden Member of the Carlile Formation (Figures 2, 3 and 7) was quarried as a brick shale beginning in 1900 southwest of Roseisle **(STOP 7)**, in SW13-6-8W1, by the Boyne Valley Brick Company. The shale was quarried from a 10 m high bank situated along Roseisle Creek, south of the plant. In 1914, the operations were taken over by C.E. Leary and the adjacent plant was operated until 1917. In 1947 the operations were restarted by W.A. Leary, and up to 1952, annual production comprised 30 000 to 97 000 dry-press face brick and from 3 800 to 94 000 common brick. In 1962, Tallclay Products Limited attempted to bring the plant, into production, but only one kiln-load of brick was fired (Bannatyne, 1970, p. 47).

## Red River Brick and Tile

The most recent brick plant to be operated in the Province was I-XL Industries Ltd.'s Red River Brick and Tile plant at Lockport. From 1971 to 1992, over 16 million bricks were manufactured, in three different sizes as well as two sizes of paving brick (Gunter, 1989). Five quarries produced 8 types of clays and shales from which it was possible to make face brick in colours from red to near white, including variegations and browns, blacks, buff, tans, etc. (Shayna, 1975).

Red River quarried Cretaceous Swan River Formation and Jurassic clays near Ste. Rose du Lac, 200 km from the plant. Medicine Hat Brick and Tile Company Limited, a predecessor to I-XL, opened the Ste. Rose quarry in 1970. A second pit, 1.6 km to the south, was opened up in 1972-73. Small quantities of Morden Member of the Carlile Formation and Odanah Member of the Pierre Shale, quarried west of Miami (160 km from the plant), were also added to the Ste. Rose clay to alter its properties. The Morden Member quarry, now rehabilitated, is situated in E14-33-3-6W1, a short distance to the west of **STOP 2**.

The Odanah Member quarry is situated across the section road from the Rural Municipality of Thompson Odanah quarry **(STOP 5)** in SW05-24-7W1.


In addition, some Pleistocene lacustrine clay was quarried at Ladywood, north of Beausejour and fine-grained sand (uncontaminated by limestone) was quarried about 45 km from the plant, near the Brokenhead River (Shayna, 1975).

### Swan River Clay Products Limited Plant and Quarry

Swan River Clay Products Limited quarried kaolinitic shale at the top of the Cretaceous Swan River Formation (Figures 2, 3 and 7) northeast of Swan River in SW10-37-26W1 for the production of dry press face brick from 1953 to 1955. Almost 220 000 bricks were produced at the company's plant located in Swan River. Additional bricks were produced in 1959, but production ceased shortly after (Bannatyne, 1970).

The Swan River Formation, possibly containing brick clay/shale, subcrops to the northeast of Pembina Mountain (Figure 7). There is also some potential for occurrences of kaolin and silica sand within the formation that could be used in stoneware, ceramic and other applications.

## BUILDING STONE

Stone quarried south of Boissevain at (9-7-3-19W1, for use in several buildings constructed in the vicinity of the town of Boissevain in the late 1800s and early 1900s (Parks, 1916). The irregular blocks of sandstone from the Cretaceous Boissevain Formation (Figure 2) were set in mortar to fill in the rough surfaces between the blocks. The sandstone concretions are generally widely distributed near the top of the formation and because the stone is subject to the effects of weathering; future quarrying of this building stone is unlikely.

## COAL

In 2008, Goldsource Mines Inc. announced that an average of 32.8 m sub-bituminous to bituminous coal and partings had been discovered in two drillholes, 1.6 km apart, on their Border property near the Manitoba-Saskatchewan boundary. The coal zone, beneath 79 m of overburden, was interpreted by the company to extend into west-central Manitoba.

### Pine River area

In 1937, Manitoba Coal Mines Syndicate investigated a lignite occurrence in the vicinity of the Pine River lignite occurrence within the Cretaceous Swan River Formation (Figures 3 and 7). Surface and underground work was carried out by the Syndicate and by Silco Limited without much success. As a result of this work, a large pile of weathered lignite is present on the south side of the Pine River in 7-7-34-20W1.

In addition, a 9 m thick lignite seam is believed to be present at a depth of 85 m near Pine River school, 22 km southwest of the Pine River occurrence. However, drilling by the MGS in 1978 was unable to confirm its presence (Bannatyne, 1978). Future drilling in the general area of the initial report could possibly prove up the lignite occurrence . Goldsource Mines Inc.has a quarry exploration permits in the Pine River area, and two exploratory drill holes on their property has turned up 1 to 3 m of coal.

### Porcupine Mountain, north flank

Westcore Energy Ltd. completed a 5-hole core drilling program on its 19 440 ha Black Diamond property in west-central Manitoba, immediately east of Goldsource Mines Inc.'s Border property in Saskatchewan, in April 2009. Three of the holes intersected a coal zone comprising black to brown carbonaceous material, within the Cretaceous-age Mannville-equivalent Swan River Formation (Figure 3), beneath 22.2 to 25.9 m of overburden. The carbonaceous zone includes coal, silty/sandy coal (high-ash units) and partings of poor to moderately consolidated sedimentary units of sand, sandstone or siltstone (which contain variable amounts of coal fragments and stringers that range from minor to abundant). The coal samples ranged from Lignite A to Sub-bituminous C in rank. The company believed that the drill results and subsequent analyses confirmed the continuation of Goldsource Mines' Durango coal seam into Manitoba.

## GYPSUM

Gypsum has been quarried near Harcus (in Sec. 22 and 27 of Twp. 20, Rge. 10W1) by CertainTeed Gypsum Canada Inc. (formerly, Westroc Industries Limited or BPB Canada Inc.) since 1978. Exploratory drilling revealed 3 to 9 m of high-grade gypsum (90 to 92%), within the Jurassic Upper (Evaporite) Member of the Amaranth Formation (Figure 3), beneath 3 to 8 m of glacial drift. In 1991, annual production from the Harcus Quarry was 100 000 tonnes (Bannatyne, 1984). Westroc has its wallboard plant in Winnipeg, and two haulage trucks make several trips daily from the quarry to the plant. Additional deposits of gypsum have been outlined by drilling and leased in the vicinity of the present quarries by Lehigh Cement Ltd.

The Evaporite Member of the Amaranth Formation also subcrops beneath glacial sediments a short distance to the northeast of the Pembina Hills, at a relatively shallow depth, as shown in Figure 7. In the past, several underground gypsum mines operated near Amaranth, south of Harcus, and to the east under the Red River, south of Winnipeg, near Silver Plains.

## HIGH CALCIUM LIMESTONE

Canadian Infrastructure Corp. (a subsidiary of Infrastructure Materials Corp. of the U.S.A.**)** has obtained over 35 quarry leases for high-calcium limestone, 10 km southwest of Dauphin. The leases trend northwestward as a discontinuous 3 km wide band for almost 13 km northwestward across Twp. 24 from Rge. 19 W1 to Rge. 21 W1. The intervening gaps in the band probably reflecting privately held mineral rights. The high-calcium limestone is situated within relatively near-surface beds of the Marco Calcarenite of the Assiniboine Member of the Cretaceous Favel Formation (Figure 3), as shown in the Vermilion River valley (11-35-23-20W1).

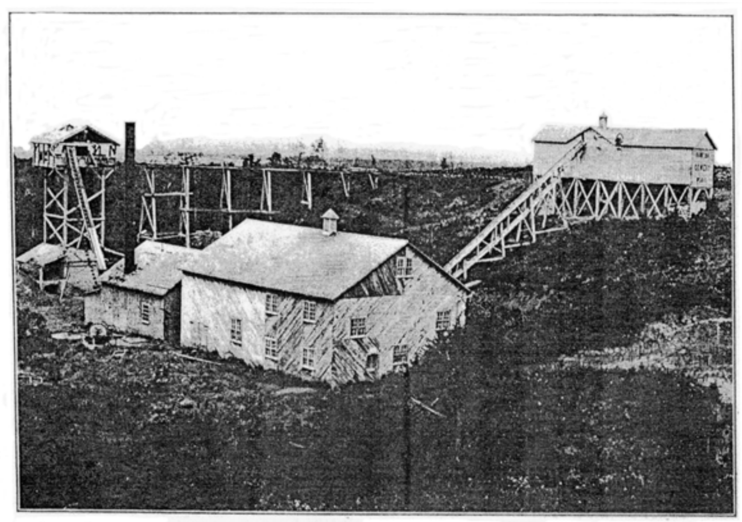
Marco Calcarenite outcrops, on the First Prairie Level, to the east of the Porcupine Hills and north of Morden (**STOP 1**, Table 2 and Figures 6 and 7)**;** and likely is present to the north of **STOP 11** (Table 2 and Figures 6 and 7) as indicated by large boulders on site.

## NATURAL CEMENT ROCK

A few exposures of the natural cement rock occur in the southern part of the Province along the Manitoba Escarpment. Natural cement has been produced in Manitoba from the highly calcareous (37% CaO, 1.5% MgO) shale beds of the Boyne Member of the Carlilie Formation at Arnold and Babcock in the Pembina Hills area (Bannatyne, 1970, p. 52). However, the characteristics of the natural cement material were too variable to compete with Portland cement (Gunter, 1989).

### Arnold Cement Plant and Quarry

Cement production began with natural cement mined from the “Babcock” beds of the Cretaceous Boyne Member of the Carlile Formation at Arnold**,** east of Deerwood) on the east slope of Pembina Mountain from 1898? to 1904.



View of Arnold Cement Works, Pembina Hills, showing Vertical Clinker Kiln, Clinker Grinding House and Storage Shed on the Canadian Northern Railway.

### Babcock Cement Plant and Quarry

A second plant and an adit followed at Babcock situated in Roseisle Creek (or Snow) Valley (NAD 83, Zone 14U, 539683E, 5479792N) west of Miami), which operated from 1907 to 1924. The Babcock deposits, some of which can be seen at **STOP 8** (Table 2 and Figures 6 and 7), were leased by Lafarge Canada Inc. in 1992, but were cancelled by the company in 2004.

## OIL

Oil has been produced from over 1000 wells from the Triassic Lower (Red Beds) Member of the Amaranth Formation (beginning in 1955); and from three wells in the Jurassic Melita Formation (starting in 1993). All of the oil production from the Lower Amaranth occurs in the Coulter, Waskada, Whitewater, and Pierson fields, and from three small pools outside of field boundaries. Lower Amaranth oil production from the Pierson Field is comingled with the Mississippian Mission Canyon Formation, MC-3b Member, and with the Mississippian Lodgepole Formation in a small pool near Oak Lake. In the vicinity of St. Lazare, production of oil was from three wells within the Melita A and B pools intermittently since 1993.

## OIL SHALE

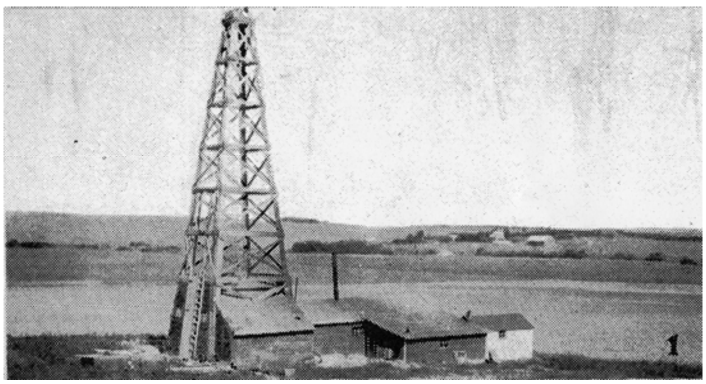
The Favel Formation was investigated along the Manitoba Escarpment by three oil companies in 1965 and 1966 as a possible source of oil shale. An earlier report by Ells (1921) had indicated oil contents of up to 37.5 litres per tonne in the Favel shale in the Riding Mountain and Porcupine Mountain areas. The recent work in the Pembina Hills area reported a maximum content of 60.0 litres per tonne in the Favel Formation at a depth of 105 m in a corehole located in 16-11-8-11W1. However, the average content of the tested section was only 18.0 litres per tonne over a 48-metre interval. Samples from the Boyne and Morden members of the Carlile Formation and the Ashville Formation were included in the analyses; the results showed maximum contents of 65.0, 24.0, and 59.5 litres per tonne, respectively (Bannatyne, 1970).

## SHALE GAS

Shallow unconventional biogenic shale gas is present in the Cretaceous shale sequences from the Belle Fourche Member of the Ashville Formation up to the Pembina Member of the Pierre Shale (Figure 2) in southwest Manitoba (Nicolas and Grasby, 2009; Nicolas and Bamburak, 2009; Fedikow et al. 2009).

### Notre Dame de Lourdes-Treherne area

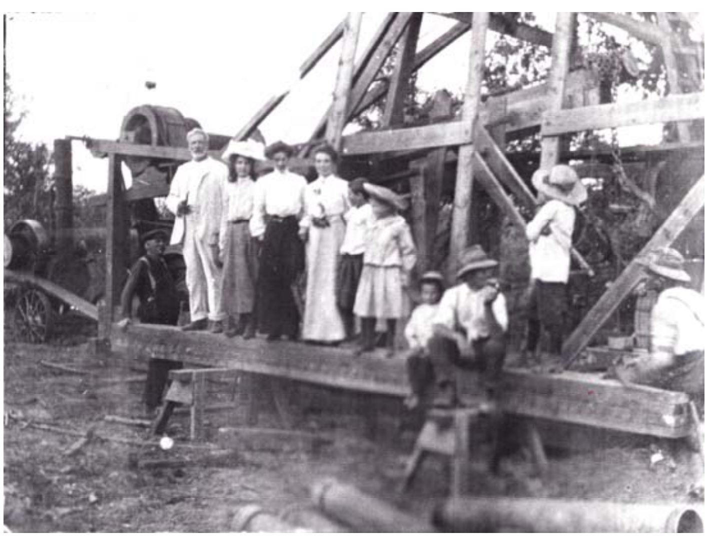
The shallow gas shows near Notre Dame de Lourdes are derived from the “Babcock” beds of the Boyne Member of the Carlile Formation. A water well produces gas on the farm of Normand and Guy Bosc in 1-30-7-8W1. Another well drilled in 1911, to the northwest near Treherne on the farm of E.C. Haskell in NE28-7-10W1. The gas, produced for over 15 years, was sufficient for household lighting, and occasionally for a small heater.




The “Babcock” beds in the Notre Dame des Lourdes-Treherne area correlate with the gas-producing reservoir unit in the town of Kamsack, Saskatchewan. From 1941 to 1953, 4.7 million $m^3$ of shale gas was produced at Kamsack from 8 wells drilled into the Boyne sand to a depth of 60 m.

### Manitou area

Capped gas wells in the Pembina Valley southwest of Manitou are producing from the Assiniboine Member of the Favel Formation in S23-2-9W1. Drilling of the well shown was done in 1907.



## REHABILITATION

At many potential quarry sites, the bentonite clay underlies prime agricultural land. At these sites, the topsoil excavated from above the bentonite layers must be stockpiled and later returned to the exhausted pit to rehabilitate the land back to its original condition. The satisfactory reclamation of farm lands is critical to the continued mining of these lands. During their most recent years of operation, Pembina Mountain Clay Ltd. had a good record for rehabilitation.

Although mineral rights are controlled by the mining company, the permission to disturb the land surface is in the hands of the farmer and must be negotiated to receive permission to mine. Poor reclamation will either increase the cost per hectare or cause cessation of mining operations until the Mining Board arbitrates the disagreement. Not all mineral rights in the area are vested in the crown. Access to bentonite reserves in areas of private mineral rights will have to be negotiated with the rights holders.

## FOSSILS

Mososaur fossils found during these early operations were taken to Ottawa and placed in the Geological Museum. Numerous fossils have been uncovered in the quarry operations including fish scales and shark teeth, but most importantly, plesiosaurs. A spectacular find was made in 1972 of the plesiosaur Dolichornychops in a quarry 0.6 km west and 8.2 km north of Thornhill (Figures 5-7). The fossil was recovered and placed on display in the Canadian Fossil Discovery Centre in Morden. Since then many other fossils have been found and can be seen at the Morden Museum. Plesiosaur fossils are also in the Museum of Man and Nature in Winnipeg.


## ACKNOWLEDGEMENTS

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