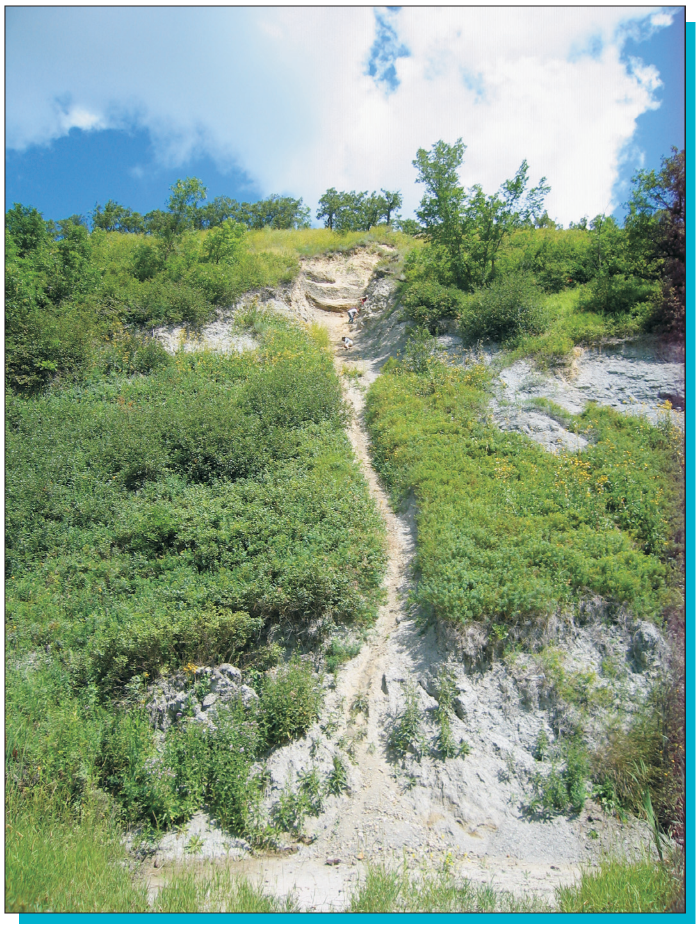
GAC-MAC WINNIPEG 2013

AT THE CENTRE OF THE CONTINENT

AU CENTRE DU CONTINENT



FIELD TRIP GUIDEBOOK

Field Trip Guidebook FT-A4 / Open File OF2013-9

Upper Cretaceous-Paleocene stratigraphy and mineral resources of southwestern Manitoba (parts of NTS 62F, G)

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

Held in conjunction with
GAC®-MAC • AGC®-AMC
Joint Annual Meeting • Congrès annuel conjoint
May 22–24, 2013

Open File OF2013-9

Field Trip Guidebook FT-A4

Upper Cretaceous-Paleocene stratigraphy and mineral resources of southwestern Manitoba (parts of NTS 62F, G)

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

Geological Association of Canada–Mineralogical Association of Canada Joint Annual Meeting, Winnipeg
May, 2013

When using information from this publication in other publications or presentations, due acknowledgment should be given to the Manitoba Geological Survey. The following reference format is recommended:

Bamburak, J.D. and Nicolas, M.P.B. 2013: Upper Cretaceous-Paleocene stratigraphy and mineral resources of southwestern Manitoba (parts of NTS 62F, G); Geological Association of Canada–Mineralogical Association of Canada Joint Annual Meeting, Field Trip Guidebook FT-A4; Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Open File OF2013-9, 42 p.

NTS grid: parts of 62F, G

Keywords: Manitoba, Upper Cretaceous, Paleocene, stratigraphy, mineral resources, shale gas, industrial minerals, calcium bentonite, Fieldtrip Guidebook.

Published by:

Manitoba Innovation, Energy and Mines
Manitoba Geological Survey
360–1395 Ellice Avenue
Winnipeg, Manitoba
R3G 3P2 Canada
Telephone: (800) 223-5215 (General Enquiry)
(204) 945-4154 (Publication Sales)
Fax: (204) 945-8427
E-mail: minesinfo@gov.mb.ca
Website: manitoba.ca/minerals

This publication is available to download free of charge at manitoba.ca/minerals

Cover illustration: Roseisle Creek Bridge outcrop at STOP 22A.

SAFETY INFORMATION

General Information

The Geological Association of Canada (GAC) recognizes that its field trips may involve hazards to the leaders and participants. It is the policy of the GAC to provide for the safety of participants during field trips, and to take every precaution, reasonable in the circumstances, to ensure that field trips are run with due regard for the safety of leaders and participants. Field trip safety is a shared responsibility. The GAC has a responsibility to take all reasonable care to provide for the safety of the participants on its field trips. Participants have a responsibility to give careful attention to safety-related matters and to conduct themselves with due regard to the safety of themselves and others while on the field trips.

Field trip participants should be aware that any geological fieldwork, including field trips, can present significant safety hazards. Foreseeable hazards of a general nature include inclement weather, slips and falls on uneven terrain, falling or rolling rock, insect bites or stings, animal encounters and flying rock from hammering. **The provision and use of appropriate personal protective equipment (e.g., rain gear, sunscreen, insect repellent, safety glasses, work gloves and sturdy boots) is the responsibility of each participant.** Each field trip vehicle will be equipped with a moderate sized first-aid kit, and the lead vehicle will carry a larger, more comprehensive kit of the type used by the Manitoba Geological Survey for remote field parties.

Participants should be prepared for the possibility of inclement weather. In Manitoba, the weather in May is highly unpredictable. The average daily temperature in Winnipeg is 12°C, with record extremes of 37°C and -11°C. North-central Manitoba (Thompson) has an average daily temperature of 7°C, with record extremes of 33°C and -18°C (*Source:* Environment Canada). Consequently, participants should be prepared for a wide range of temperature and weather conditions, and should plan to dress in layers. A full rain suit and warm sweater are essential. Gloves and a warm hat could prove invaluable if it is cold and wet, and a sunhat and sunscreen might be just as essential in the heat and sun.

Above all, field trip participants are responsible for acting in a manner that is safe for themselves and their co-participants. This responsibility includes using personal protective equipment (PPE) when necessary or when recommended by the field trip leader, or upon personal identification of a hazard requiring PPE use. It also includes informing the field trip leaders of any matters of which they have knowledge that may affect their health and safety or that of co-participants. Field Trip participants should pay close attention to instructions from the trip leaders and GAC representatives at all field trip stops. Specific dangers and precautions will be reiterated at individual localities.

Specific Hazards

Some of the stops on this field trip may require short hikes, in some cases over rough, rocky, uneven or wet terrain. Participants should be in good physical condition and accustomed to exercise. Sturdy footwear that provides ankle support is strongly recommended. Some participants may find a hiking stick a useful aid in walking safely. Steep outcrop surfaces require special care, especially after rain. Access to bush outcrops may require traverses across muddy or boggy areas; in some cases it may be necessary to cross small streams or ditches. Field trip leaders are responsible for identifying such stops and making participants aware well in advance if waterproof footwear is required. Field trip leaders will also ensure that participants do not go into areas for which their footwear is inadequate for safety. In all cases, field trip participants must stay with the group.

Other field trip stops are located adjacent to roads, some of which may be prone to fast-moving traffic. At these stops, participants should pay careful attention to oncoming traffic, which may be distracted by the field trip group. Participants should exit vehicles on the shoulder-side of the road, stay off roads when examining or photographing outcrops, and exercise extreme caution in crossing roads.

Road cuts or rock quarries also present specific hazards, and participants MUST behave appropriately for the safety of all. Participants must be aware of the danger from falling debris and should stay well back from overhanging cliffs or steep faces. Participants must stay clear of abrupt drop-offs at all times, stay with the field trip group, and follow instructions from leaders.

Participants are asked to refrain from hammering rock. It represents a significant hazard to the individual and other participants, and is in most cases unnecessary. Many stops on this field trip include outcrop with unusual features that should be preserved for future visitors. If a genuine reason exists for collecting a sample, please inform the field trip leader, and then make sure it is done safely and with concern for others, ideally after the main group has departed the outcrop.

Subsequent sections of this guidebook contain the stop descriptions and outcrop information for the field trip. In addition to the general precautions and hazards noted above, the introductions for specific localities make note of any specific safety concerns. Field trip participants must read these cautions carefully and take appropriate precautions for their own safety and the safety of others.

TABLE OF CONTENTS

TABLES

FIGURES

Introduction

The Upper Cretaceous-Paleocene field trip of southwestern Manitoba traverses the First and Second Prairie levels, as shown in Figures 1 and 2. The First Prairie Level, or the Manitoba Lowland, ranges in elevation from 185 to 275 m. It includes the Red River Valley and lakes: Winnipeg, Winnipegosis and Manitoba, which during the late Pleistocene formed the basin of Glacial Lake Agassiz. Lacustrine and deltaic sediments deposited in the ancient lake bottom infilled erosional lows on the pre-glacial surface resulting in the nearly flat topography seen while travelling across the First Prairie Level.

The First and Second Prairie levels, shown in Figure 1, are the lowest, and eastern-most, of at least four upward rising steps (Figure 2) across the Phanerozoic Western Canada Sedimentary Basin (WCSB). The basin is 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) (McNeil and Caldwell, 1981). The steps record the periods of uplift of the rising Rocky Mountains during the Laramide Orogeny, which occurred from 84 to 50 Ma.

The First Prairie Level (Figure 1) is bordered on its northeast and north margins by the Precambrian Canadian Shield, which forms much of the basement (Figure 2) of the continent beneath the WCSB. The Shield lies generally northeast and north of Lake Winnipeg as shown in Figure 1. Bedrock within the First Prairie Level is generally comprised of Paleozoic and lower Mesozoic sedimentary rock, which generally become younger moving from east to west across the southern portion of the Province.

The First Prairie Level is bounded to the southwest by the Manitoba escarpment, shown in Figure 1. The escarpment extends for 675 km from the Pasquia Hills in Saskatchewan, across southwestern Manitoba, to the Pembina Hills (note: also, referred to as Pembina Mountain) area of North Dakota (Figure 1). The escarpment ranges in relief from 442 m in the Pasquia Hills to 90 m in the Pembina Hills in North Dakota.

From north to south, at the Manitoba escarpment, the Second Prairie Level is breached by four major rivers – the Red Deer, Swan, Valley and Assiniboine. The resulting upland sections are named the Pasquia and Porcupine hills, the Duck and Riding mountains and the Pembina Hills (Figure 1). The Second Prairie Level is underlain by Cretaceous shale and sand units (Figure 3), which range in age from 75 to 125 Ma. The Cretaceous beds dip southwest from 0.8 to 1.9 m/km and are covered by glacial drift that ranges in thickness from zero to a reported 259 m in the central part of Duck Mountain. An

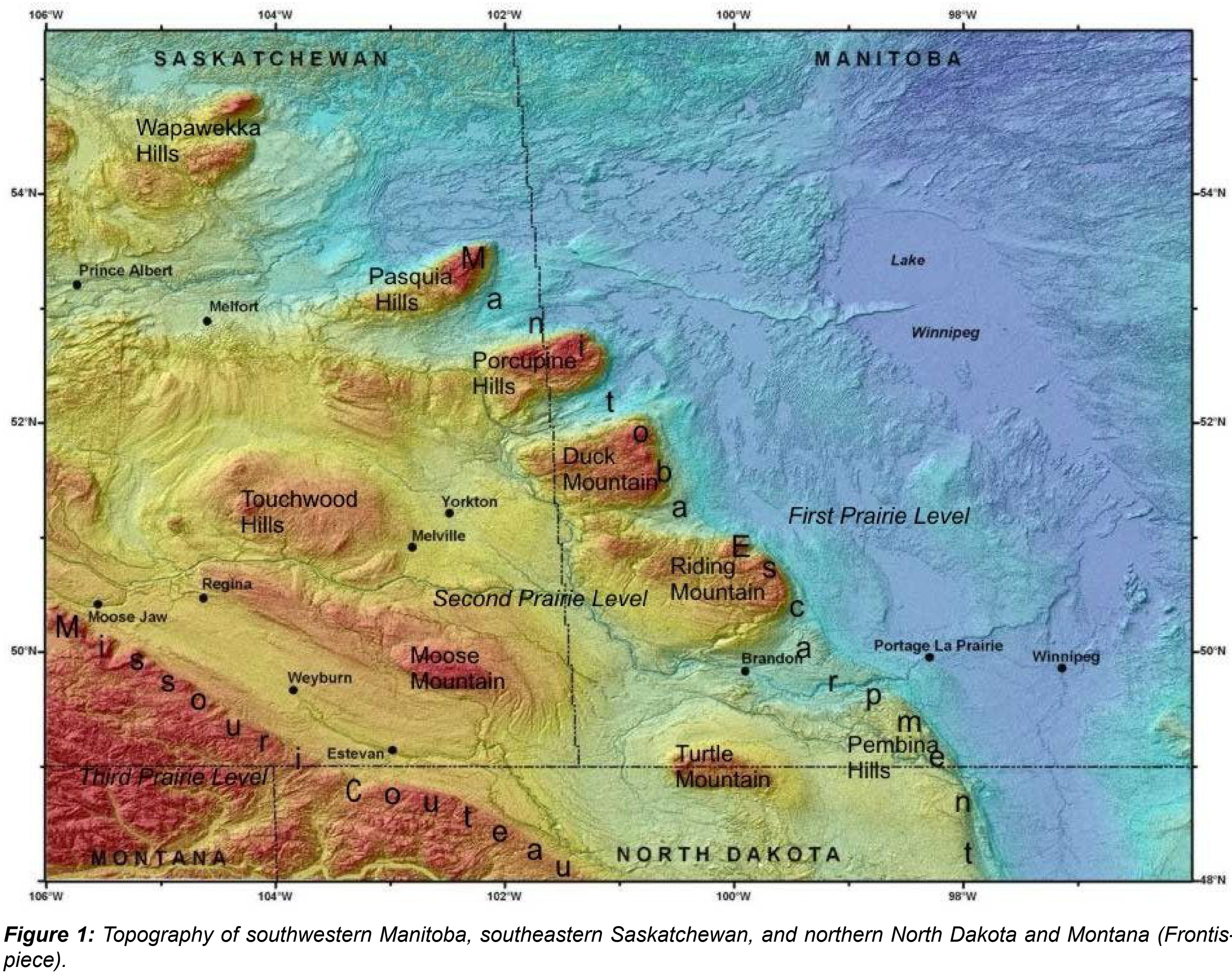


Figure 1: Topography of southwestern Manitoba, southeastern Saskatchewan, and northern North Dakota and Montana (Frontispiece).

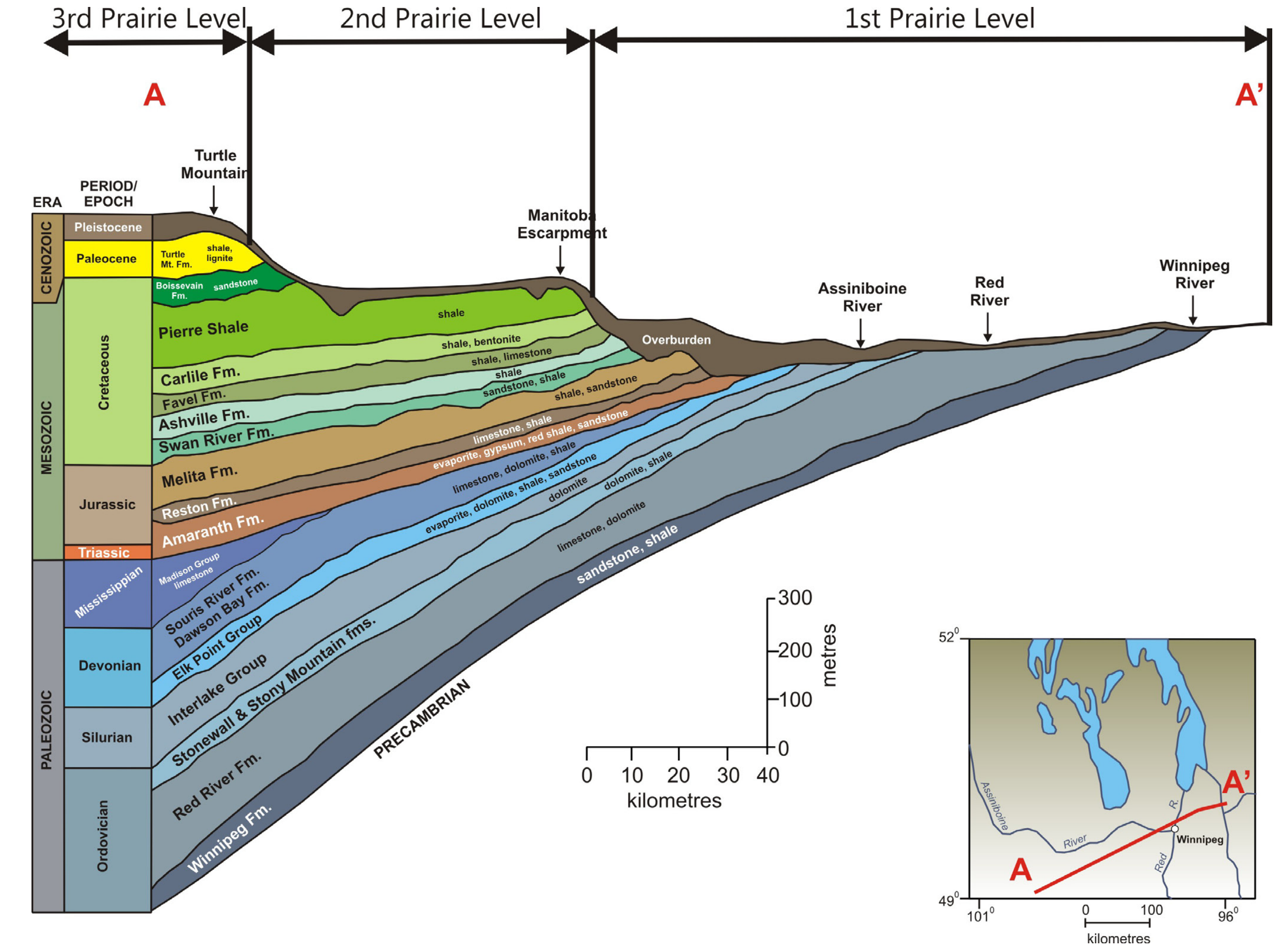


Figure 2: *Vertically exaggerated simplified, cross section of Paleozoic to Cenozoic formations in, southwestern Manitoba (Bamburak and Nicolas, 2009).*

exceptional feature on the Second Prairie Level is Turtle Mountain (Figure 1), which is underlain by rock of Upper Cretaceous and Tertiary age, and covered by almost a hundred metres of dead-ice moraine. Turtle Mountain is an erosional remnant of the Third Prairie Level, the main part of which extends to the southwest of the Missouri Couteau, shown in Figure 1.

The combined thickness of Triassic, Jurassic and Cretaceous beds at the Manitoba-Saskatchewan boundary with North Dakota (Figure 3) attain a maximum thickness of about 1070 m. It should be noted that 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 Upper Cretaceous and Paleocene stratigraphy of the First to Third Prairie levels in southwestern Manitoba will be seen at 23 field trip stops (Figure 4), on the three day field trip that extends from townships 1 to 8 and between ranges 4 to 24W1. Please see below.

Cretaceous and Paleocene stratigraphy

The evolution of Manitoba's Cretaceous stratigraphic nomenclature over the past century has recently been documented by Bamburak and Nicolas (2009). Locally derived names, names from Saskatchewan (Figure 3) and names from the northern United States have repeatedly been applied to and removed from the Cretaceous stratigraphic succession in Manitoba, as shown in Figure 5a and 5b. 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 First and Second Prairie Level as seen at the Manitoba escarpment.

Triassic and Jurassic strata (Figures 2 and 3) are unconformably overlain by Lower Cretaceous strata of the Swan River and lower Ashville formations. These formations 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 of the Second Prairie Level. For the most part, the Upper Cretaceous marine shale and thin

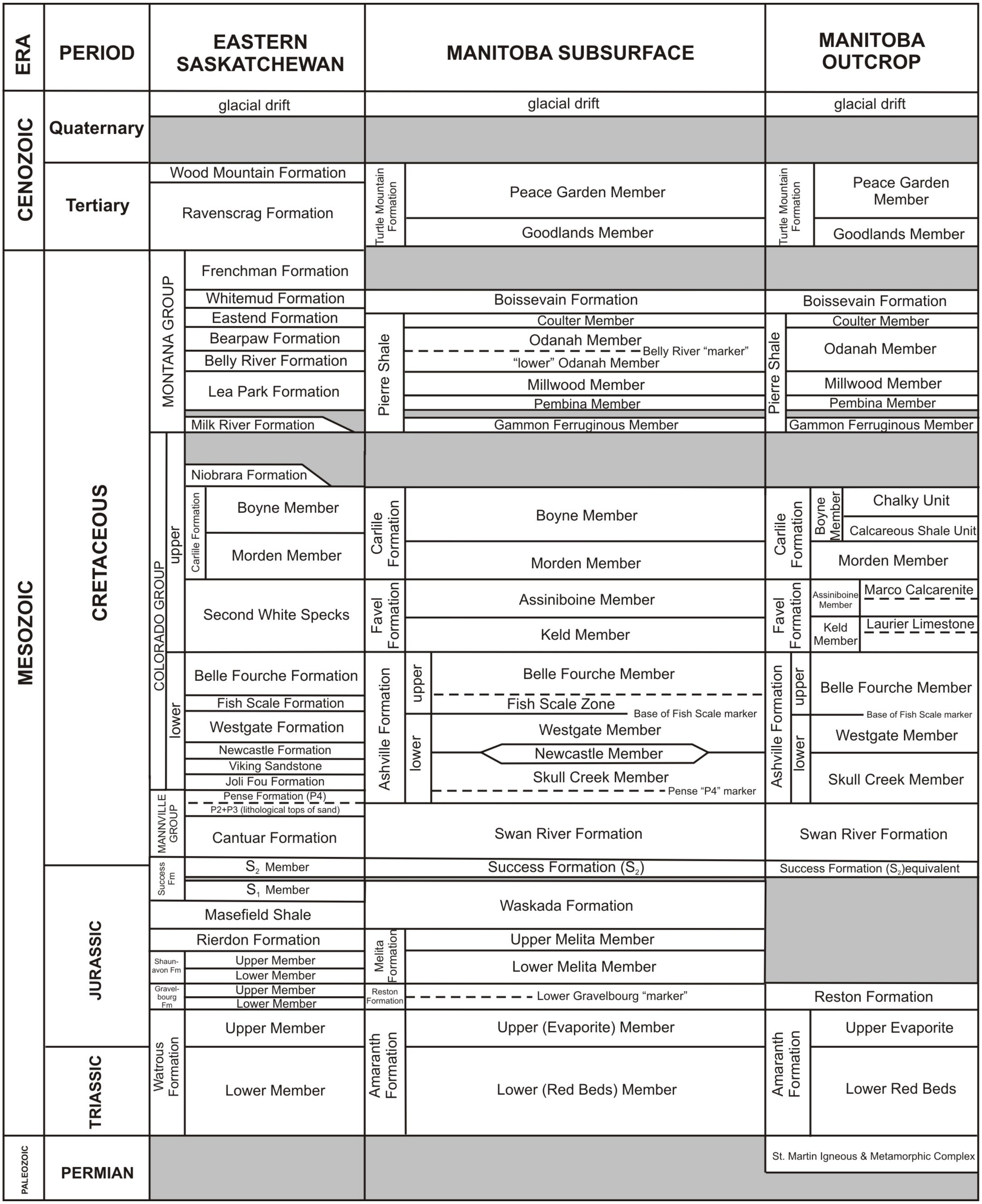


***Figure 3**: Mesozoic and Cenozoic stratigraphy of eastern Saskatchewan and of the subsurface and outcrop belt of southwestern Manitoba (Nicolas, 2009, Figure 2).*

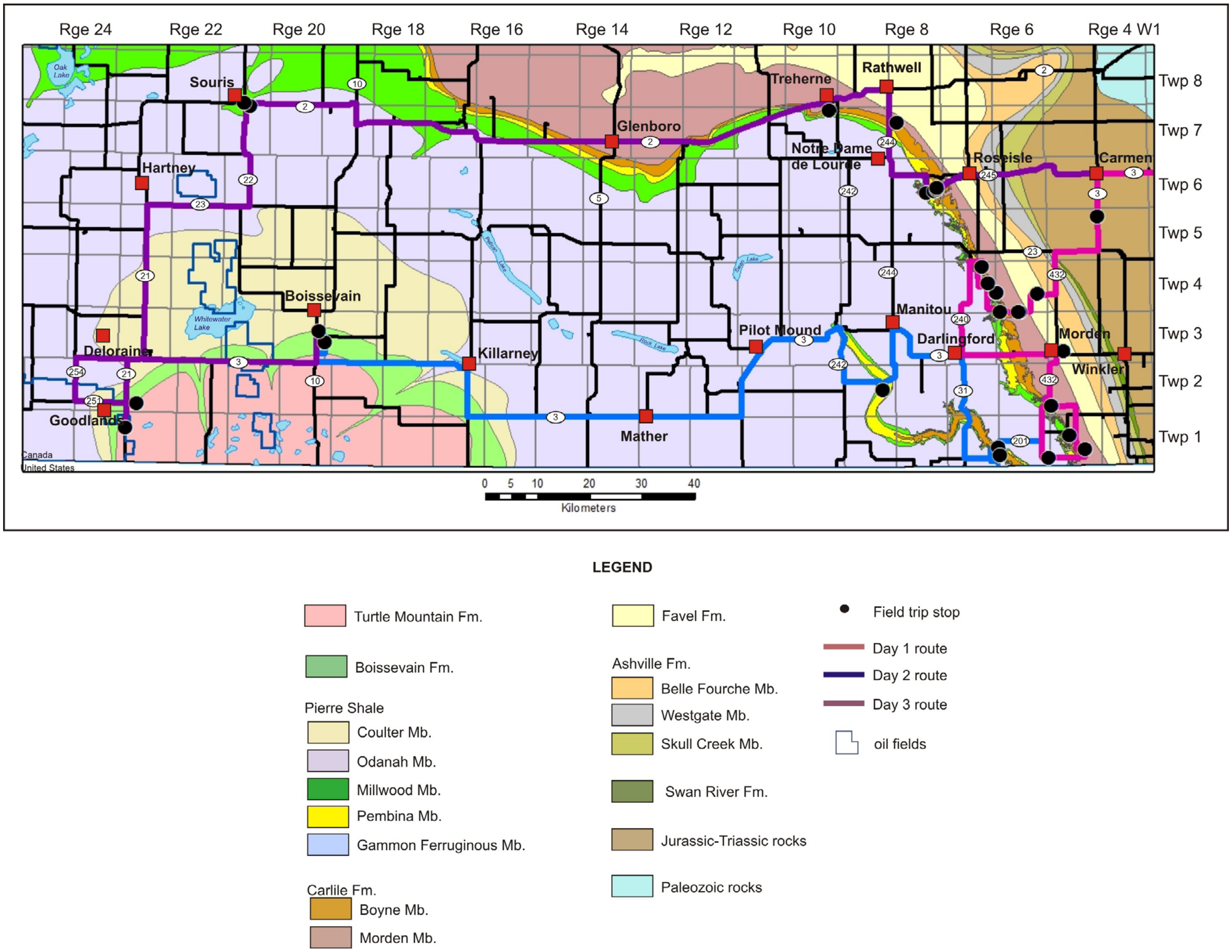


***Figure 4:** Bedrock geology and field trip stops in the Pembina Hills – Turtle Mountain area. Detailed legend shown in Figure 3.*

limestone beds were removed by erosion east of the Manitoba escarpment.

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 5a 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 (McNeil and Caldwell, 1981, p.7-10). 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 Western Interior Seaway was in existence until early Maestrichtian time (Figure 5a 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 noncalcareous shale of the Late Albian and Cenomanian Ashville Formation, and the chalk-speckled shale with shelly limestone stringers of the Early Turonian lower Keld Member of the Favel Formation (Figure 5a and b).
    - The regressive phase of the Greenhorn cycle is represented by beds of chalk-speckled shale and limestone of the early Middle Turonian upper Keld and Assiniboine Members of the Favel Formation; and possibly by, the noncalcareous shale of the late Middle Turonian Morden Member of the Carlile Formation (Figure 5a and b). An alternative interpretation is that the uppermost beds of the Morden Member actually record

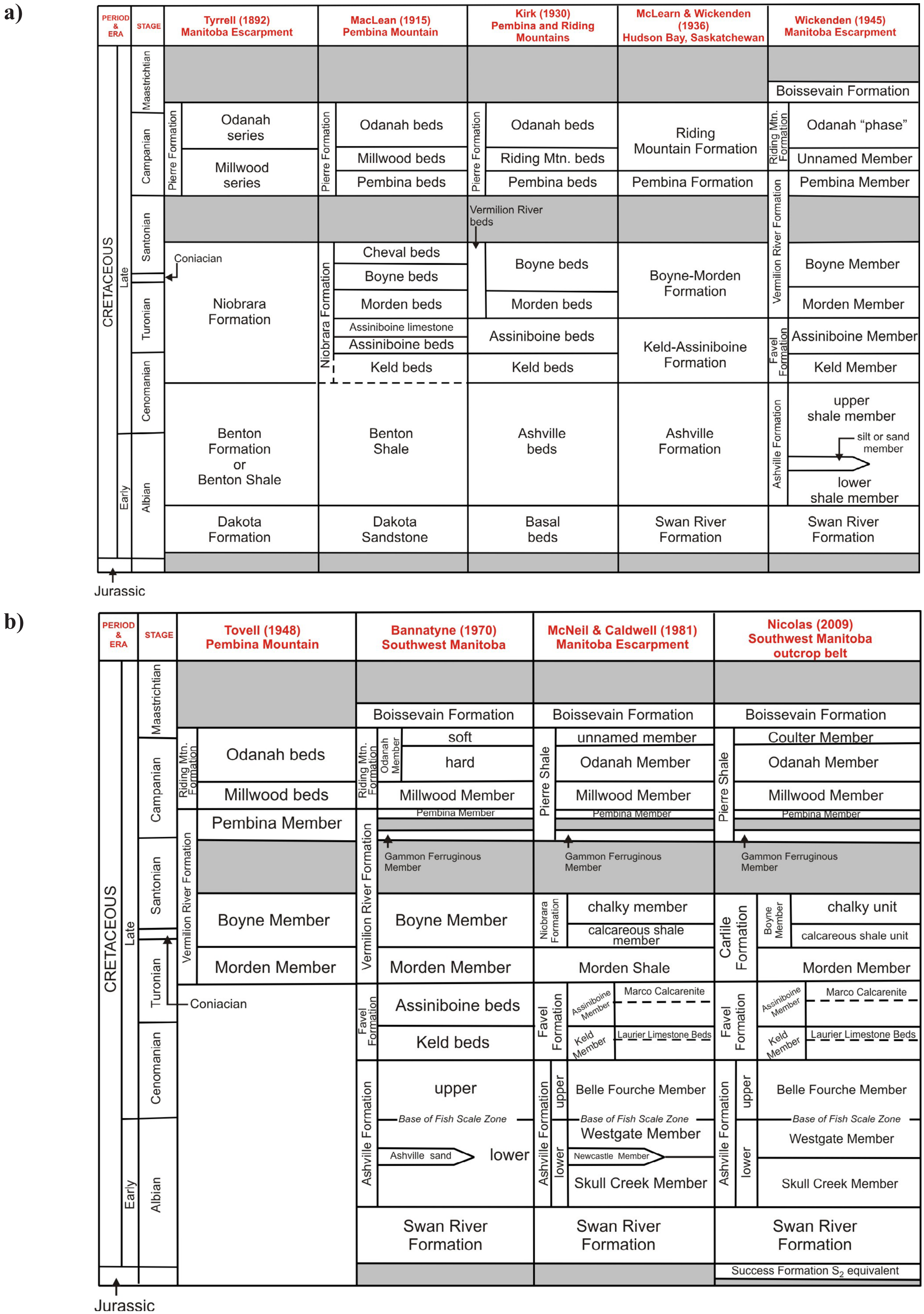


Figure 5a and b: *Major revisions to the Cretaceous stratigraphic framework of southwestern Manitoba (Bamburak and Nicolas, 2009).*

Table 1: Cretaceous and Paleocene formations southwest of the Manitoba Escarpment.

Formation/Member	Maximum Thickness m	Lithology
Turtle Mountain Formation		
Peace Garden Member	125	Yellow-weathering, silty clay with minor thin very fine-grained sand beds
Goodlands Member	33	Grey, bentonitic carbonaceous sands, silts and clays, with minor lignite.
Boissevain Formation	30	Sandstone, sand and silt, quartzose
Pierre Shale		
Coulter Member	44	Bentonitic silt
Odanah Member	150	Hard grey siliceous shale
Millwood Member	60	Soft bentonitic clay
Pembina Member	7	Noncalcareous 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	Noncalcareous 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	Noncalcareous black to dark grey shale, silty; Newcastle sand zone, in places
Swan River Formation	150	Sandstone, sand and silt, quartzose, pyritic shale, noncalcareous, minor glauconite and lignite

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 shale, chalky shale, and marlstone of the late Turonian to early Middle Santorian Niobrara Formation of McNeil and Caldwell (1981) (or Boyne Member of the Carlile Formation of Nicolas (2009), as shown in Figure 5b).
  - The largely noncalcareous Pierre Shale and the unconsolidated sand and carbonate-cemented sandstone of the Boissevain Formation (Figure 5a 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 NTS 62F & G, 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 (Twp.) 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 designated over this 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. North of the Porcupine Hills in west-central Manitoba, the Swan River Formation also contains extremely thick occurrences of subbituminous coal.

The Cretaceous Swan River Formation subcrops beneath glacial sediments, on the First Prairie Level, to the east of Morden, as shown in Figures 4 and 6.

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 noncalcareous, 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 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 (Figure 3) is picked as the contact between the lower Ashville (Early Cretaceous age) and upper Ashville (Late Cretaceous age).

The Skull Creek, Westgate and Belle Fourche members of the Ashville Formation subcrop, on the First Prairie Level, to the east of Morden, as shown in Figures 4 and 6.

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. In other parts of the basin it is referred to as the "Second White Speckled Shale". Kirk (1930) subdivided the Favel into the lower Keld beds and upper Assiniboine beds (Figure 5a). These beds were elevated to member status, as shown in Figure 5b, 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 Assiniboine Member. 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. It 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. 10W1, 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 shale of the Favel Formation (Table 1) are located in the Assiniboine River valley, east of PTH 34, in SW36-8-11W1 (Wells, 1905a, p. 63). Another exposure (**STOP 2**) within the subcrop area shown in Figures 4 and 6), 8 km east of Mount Nebo in SW1-14-4-6W1, 45 m of Favel Formation was drilled (M-12-77) by the Manitoba Geological Survey (MGS; then the Manitoba Mines Branch) 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 NW9-27-8-11W1.

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; Bannatyne and Watson, 1982). The Morden Member is sharply and unconformably overlain by the Boyne Member of the Carlile Formation.

The Morden Member, will be examined at **STOP 3A**. The 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 some septarian or turtle-back calcareous concretions with diameters as large as 1.8 m. 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 odour 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 $KFe_3(S0_4)_2(0H)_6$, is present in most exposures of the shale, and in places occurs as laminae between the thin layers of shale (14-33-3-6W1, south of Miami, former Red River Brick and Tile shale pit, **STOP 3B**). This site lies within the subcrop/outcrop area of the Morden Member shown in Figures 4 and 6.

Isopachs of the Morden Member, 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). This pattern, the result of syndepositional subsidence, differs markedly from that of older Cretaceous units, which generally show

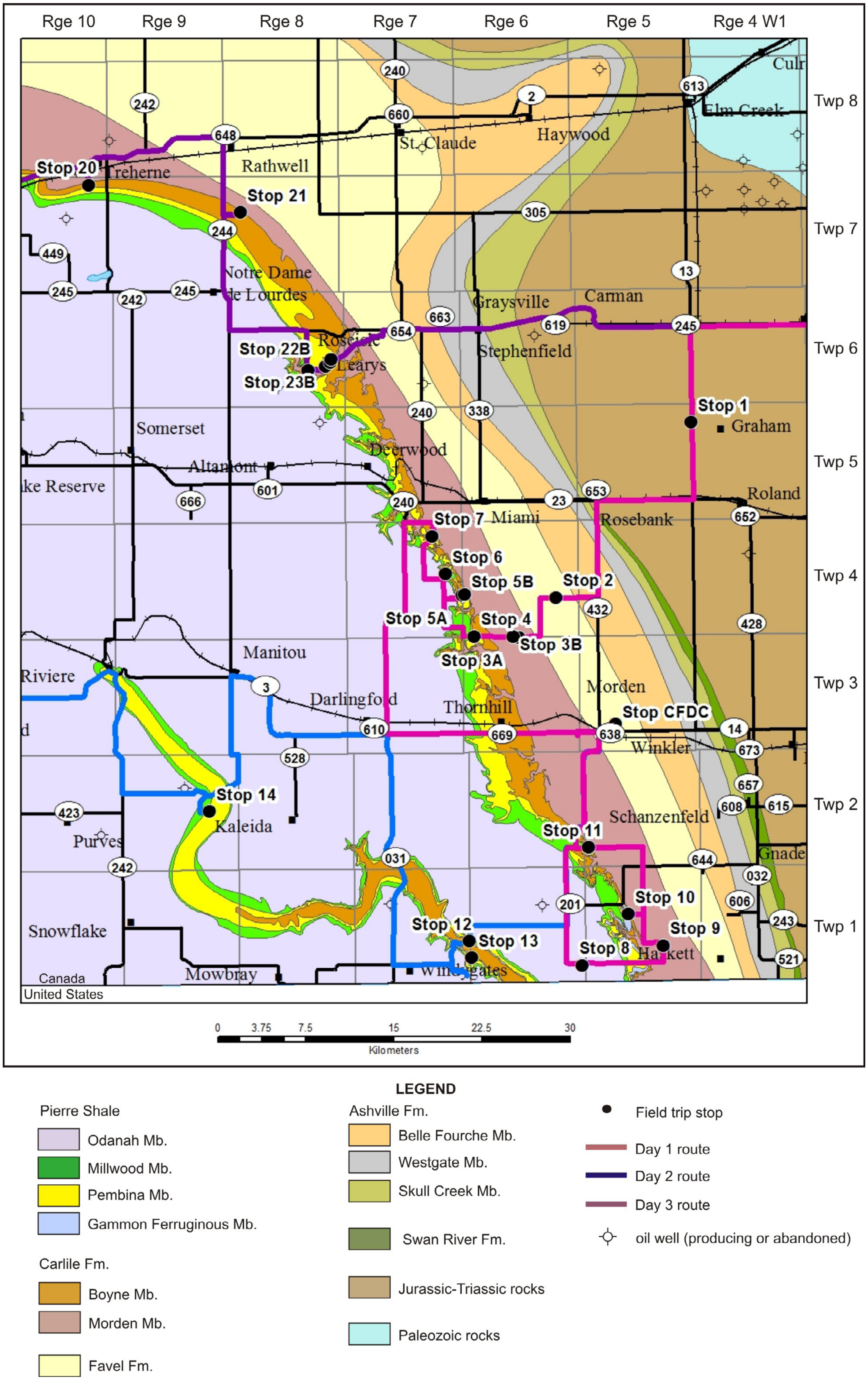


Figure 6: *Bedrock geology and field trip stops in the Pembina Hills area. Detailed legend shown in Figure 3.*

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" in other parts of the basin. McNeil and Caldwell (1981) divided the Boyne Member into lower calcareous beds and upper chalky beds (Figure 5b). 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 top of the Boyne rises from 385 m in the Pembina Valley in 18-1-6W1 to 391 m at Deadhorse Creek in 21-2-6W1 (Tovell, 1948), and to 396 m in MGS drillhole M-8-77. Excellent exposures of the Boyne can be seen in road cuts along Roseisle Creek (Snow Valley) **(STOP 22A and B)**. The highly calcareous shale (37% Ca0, 1.5% Mg0) from this unit was used as late as 1924 in the production of natural cement (Wallace, 1925a, b).

The Boyne, shown in Figures 4 and 6, is 43 to 46 m thick in the Pembina Hills area. The upper part of the member comprises buff and grey speckled calcareous shale that corresponds to the "chalky member" of McNeil and Caldwell (1981). The lower part is dark grey carbonaceous and calcareous shale with abundant small white specks, which are small fossils (mainly foraminifera, rhabdoliths and coccoliths). This corresponds to the "calcareous shale member" of McNeil and Caldwell (1981). Most of the Boyne shale units 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 formations.

The Upper Cretaceous Pierre Shale (Figure 3, Table 1) 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 5b (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 (Figure 3, 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 Ferruginous had not been recognized in Manitoba. However, Bannatyne (1970) recognized the presence of the Gammon Ferruginous on mechanical logs from hundreds of oil wells drilled in southwestern Manitoba. The Gammon Ferruginous 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 2). The only exception to this is along the Vermilion River, south of Dauphin, where it 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 W1, described by Sternberg (in Wickenden, 1945, p. 39) and assigned to the Boyne Member, may be correlated with the Gammon Ferruginous Member was confirmed by McNeil and Caldwell (1981). In most of the outcrop belt, the Pembina Member lies disconformably on the Boyne Member of the Carlile Formation. The Gammon Ferruginous Member is very thin or absent in the Pembina Hills area of Manitoba (Figure 6).

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, Twp.163N., Rge. 57W, 10 km south of the international border, may represent the thin eastern edge of the Gammon Ferruginous 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 Ferruginous and/or Boyne Member of the Carlile Formation. The lower portion of the Pembina Member consists of 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 (Bannatyne and Watson, 1985).

A disconformable Pembina/Boyne contact can be seen in gullies at the west end of an old quarry in SE11-6-2-5W1 and in a deep ravine in NW13-34-4-7W1. It can be approximated in a road cut in 14-16-5-7W1. The outcrop area of the Pembina Member can be seen in Figures 4 and 6. According to Bannatyne (1963, p. 7), towards the top of the Pembina Member the black shale passes gradationally upward into chocolate brown, more waxy, less organic shale and finally into the brownish green, waxy, non-carbonaceous shale of the Millwood beds.

The Pembina-type shale thins 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 4, 5, and 7**. At least 11 buff bentonite seams, ranging in thickness from 1 to 30 cm have been documented in previous investigations (Bannatyne, 1963, 1984; and Bannatyne and Watson, 1982). The seams are separated by similar beds of black carbonaceous, pyritic shale. Figure 7 shows a recent detailed interpretation of the relative thicknesses and characteristics of the interlayered bentonite seams and intervening black shale in the lower portion of the Pembina Member (Bamburak et al., 2012b). The bentonite seams thicken to the west, but the overburden rapidly increases in thickness from 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 (Figure 3, 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; Bannatyne and Watson (1985, p. 13)) 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 of west central Saskatchewan and Montana (McNeil and Caldwell, 1981, p. 125). The Millwood grades upward into the overlying Odanah Member.

Millwood outcrops can be found along the Manitoba Escarpment (Figure 2) and within the Souris, Pembina and Assiniboine river valleys, normally under a cover of hard Odanah shale (Bannatyne and Watson, p. 15). Rounded buttes of Millwood shale are common in the outcrop belt; an example will be examined at **STOP 5A**. Layers of brown and reddish-brown ironstone and yellowish calcite concretions are present 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.

The drilling of hole M-8-77 in 1977 at **STOP 6** indicated a thickness of 18.9 m for the Millwood Member at that location. Across 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 (Figure 6) to over 150 m in the St. Lazare-Roblin area (west of Riding Mountain in Figure 1) 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 Formation (Figure 3).

The upper 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

Light, hard siliceous shale is the predominant lithology of the Odanah Member of the Pierre Shale (Figure 3, Table 1). Its content of amorphous silica averages approximately 80%. The shale, which will be examined at **STOPS 6 and 8**, may occur as thin fissile beds; or as thick massive beds that are brittle and break with a subconchoidal fracture. The shale is dark greenish-grey when moist; and steel grey or slightly greenish-grey when dry. Joints and bedding planes weather brown or reddish to purplish brown, due to the presence of iron and manganese. Athough more common in the upper part of the member, ironstone nodules of concretionary or septarian structure do occur throughout the Odanah Member.Compact, ellipsoidal, grey limestone concretions are found in some exposures (Kirk, 1930). Thin interbeds of bentonitic shale and bentonite and are present within the lower 33 m of the member, but also can occur higher in the section as well (Bannatyne and Watson, 1985, p. 15).

The Odanah (formerly, a member of the Riding Mountain Formation, Figures 4 and 6) caps the Manitoba Escarpment (Figure 2) and is exposed in numerous road and river cuts, ravines and quarries along the eastern side of Riding Mountain and the Pembina Hills (Figure 1). 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 NE13-30-1-5W1.

Studies of outcrops in the Pembina Hills (Figure 6) show that the contact between the Odanah and Millwood shale is a definite stratigraphic marker horizon (Bannatyne and Watson, 1985, p.13). It is associated with a 17 to 25 cm thick seam of green to olive waxy bentonite, which has been traced in surface outcrops for 300 km. The contact has also been correlated, across all of southwestern Manitoba, with both an electric log marker and a change in gamma ray-neutron response shown on mechanical logs. On this basis, Bannatyne and Watson (1985, p. 13) divided the Pierre Shale within Manitoba into the Odanah Member and the Millwood Member. For interest, it should be stated that Tyrrell (1890) had previously divided the former Riding Mountain Formation into a lower Millwood Series and an upper Odanah Series as shown in Figure 5a, based on outcrop occurrences. According to Bannatyne and Watson, the reason to restrict the geographic extent of both members was due facies variations whereby the calcareous content in the lower part of the Millwood Member increases southward from the Pembina River area, and the Odanah Member loses its distinctive hard siliceous lithology to the west near the Saskatchewan

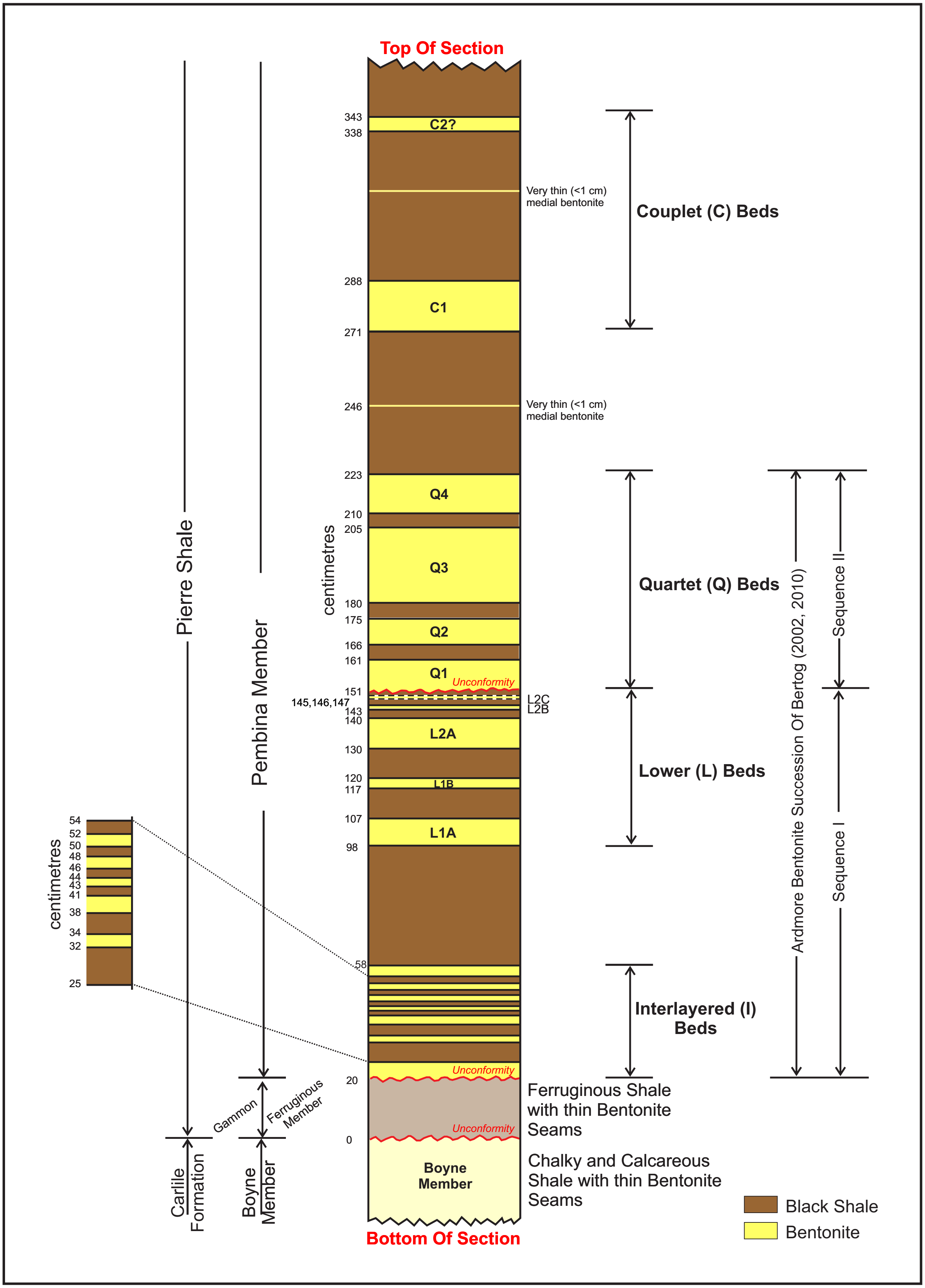


Figure 7: *Schematic representation of the lowermost bentonite seams in the Pembina Member and underlying units in the Pembina Hills area, MB and ND (Bamburak et al., 2012b).*

boundary. However, they also noted that Gill and Cobban (1963) had recognized its distinctive lithology in North Dakota.

In the extreme southwestern 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).

In 1977, 32.6 m of the Odanah Member was drilled at **STOP 6** in 5-24-4-7W1 by the MGS in hole M-8-77.

Coulter Member

A bentonitic soft silty clay overlies the Odanah in southwestern Manitoba (Figures 4 and 8), but is not present in the Pembina Hills area. These beds were named the Coulter Member of the Riding Mountain Formation, now the Pierre Shale (Figure 3, 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). The subcrop extent of the Coulter Member beneath glacial and recent sediments, as shown in Figures 4 and 8, has been greatly extended from that depicted by Bamburak (1978, Figure 10) on the basis of recent 3-D modelling carried out by Matile et al. (2011).

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 (Figure 3, Table 1) overlies the Pierre Shale, west of the Pembina Hills area, near Turtle Mountain (Figures 4 and 8). Outcrops can be found to the south and southeast of Boissevain. The crossbedded "salt and pepper" sands were deposited in a fluvial environment (Bamburak, 1978, p. 23, 24). The sand becomes kaolinitic upwards indicating a long period of weathering at the end of Boissevain time and an erosional unconformity at the top of the formation. The Boissevain Formation is equivalent to the Eastend and Whitemud formations of Saskatchewan (Figure 3).

In 1971, 18.9 m of the Boissevain Formation was drilled in the road allowance south of PTH 3, in 13-33-2-21W1, by the MGS in hole M-1-71 (Bamburak, 1978, p. 45, 46). The Boissevain Formation generally 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, Figure 11). However, its upper surface is incised by at least three major pre-glacial stream valleys as interpreted by Bamburak (1978, Figure 11).

Turtle Mountain Formation

The Turtle Mountain Formation unconformably overlies the Boissevain Formation (Figure 3, Table 1). The formation is only present in Manitoba in the Turtle Mountain area (Figures 4 and 8) and is comprised of the lower Goodlands Member and the upper Peace Garden Member. The maximum known thickness of this formation is 158 m. The upper surface of the formation is deeply incised by at least three major pre-glacial stream valleys as interpreted by Bamburak (1978, Figure14). This surface of unconformity is overlain by up to 120 m of glacial drift and recent sediments (McCabe, 1963).

Goodlands Member

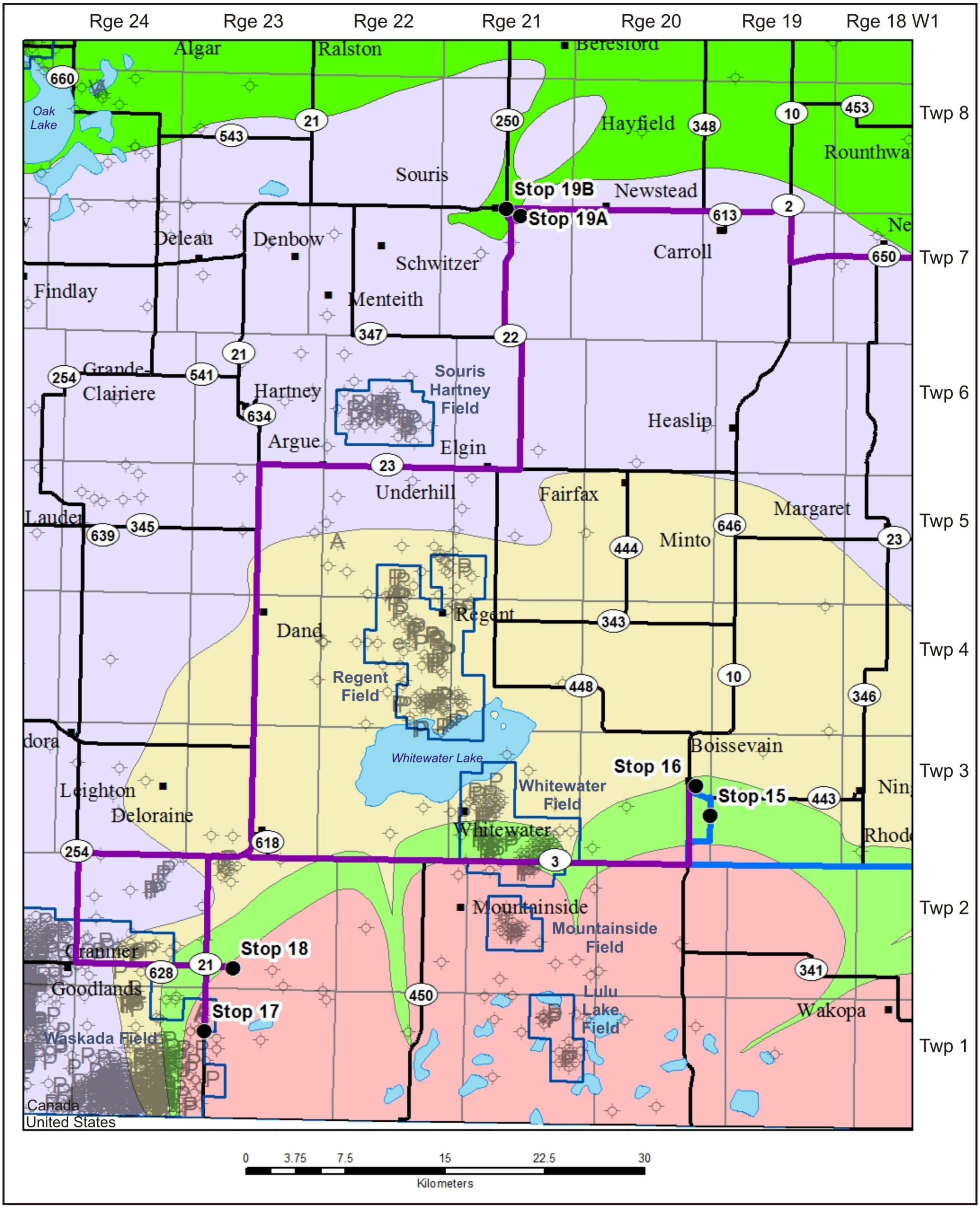
The Goodlands Member of the Tertiary Paleocene Turtle Mountain Formation (Table 1) is an assemblage of non-marine bentonitic carbonaceous sand, silt, and clay that unconformably overlies the Upper Cretaceous Boissevain Formation (Figures 2 and 3). The change from the massive, bentonitic, carbonaceous, grey silty clay of the Goodlands Member to the overlying marine well-bedded, flat-lying, nonbentonitic, noncarbonaceous, yellow-weathering, grey silt marks the position of the contact with the unconformably overlying Peace Garden Member of the Turtle Mountain Formation. Both members are present only within the Turtle Mountain area of Manitoba (Figures 4 and 8). Lignite seams ranging in thickness from 0.15 to 1.83 m occur throughout the Goodlands Member. The sediments between the lignite seams are for the most part bentonitic carbonaceous grey silty clay with a few crossbedded grey sand units. Light grey to brown underclay is usually present directly beneath the lignite seams (Bamburak, 1978, p. 14, 15).

In 1971, a thickness of 22.5 m of the Goodlands Member was drilled at **STOP 18** in 15-5-2-23W1 by the MGS in hole M-2-71 (Bamburak, 1978, p. 46, 47).

Peace Garden Member

The Peace Garden Member of the Tertiary Paleocene Turtle Mountain Formation (Table 1) is a marine thin-bedded, flat-lying, nonbentonitic, noncarbonaceous, yellow-weathering, grey silt that unconformably overlies the nonmarine massive, bentonitic, carbonaceous, grey silty clay of the Goodlands Member of the Turtle Mountain Formation (Figures 2 and 3). The Peace Garden Member, which may also contain minor greenish sand and silt, is sometimes capped by calcium carbonate cemented siltstone containing leaf imprint fossils and tiny lignite specks. The member is present only within the Turtle Mountain area of Manitoba (Figures 4 and 8). The Peace Garden Member is unconformably overlain by Pleistocene glacial drift and recent sediments (Bamburak, 1978, p. 16).

In 1971, 12 m of the Peace Garden Member was drilled at **STOP 18** in 15-5-2-23W1 by the MGS in hole M-2-71 (Bamburak, 1978, p. 46, 47).



LEGEND

Figure 8: *Bedrock geology and field trip stops in the Turtle Mountain area.*

General roadlog and outcrop descriptions

The field trip stops during Days 1 to 3 are shown in Figures 4, 6, 8 and 9. Figure 4 shows the area to be covered during this field trip generally extends from Twp. 1 to Twp. 8 and from Rge. 4W1 to Rge. 24W1. Figure 6 shows the locations of the numbered field trip stops in the Pembina Hills portion of the field trip; and Figure 8 shows the numbered stops in the Turtle Mountain portion. Figure 9 depicts the stratigraphic position of the field trip stops on a composite gamma ray log from two petroleum wells. In Figure 9 the gamma ray signature of the Gammon Ferruginous and Pembina members of the Pierre Shale is not fully representative of these units in outcrop because the Gammon Ferruginous is much thinner in outcrop and the Pembina is much thicker in outcrop. For the Pembina this is due to its apparent subsurface thinning in the vicinity of the selected wells, and the lack of gamma ray logs in the outcrop belt of the Pembina Member where it attains its maximum thickness, while the opposite is true for the Gammon Ferruginous where it thickens in the subsurface and thins dramatically in outcrop.

Day 1: Upper Cretaceous stratigraphy of the Pembina Hills area – non-swelling calcium bentonite, cement rock, shale aggregate and brick shale

Day 1 will focus on the Upper Cretaceous stratigraphy of the Pembina Hills component of the Manitoba Escarpment (Figure 6). We will start the field trip on the First Prairie Level south of Carman, Manitoba and will generally proceed to the southwest, rising up the Escarpment to the Second Prairie Level, before proceeding southward towards the U.S.A border. We will finish the day examining the remains of Upper Cretaceous marine reptiles, and other contemporaries, at the Canadian Fossil Discovery Centre in Morden.

Formations and members to be examined in the morning of the field trip comprise of the Upper Cretaceous stratigraphic section in southwestern Manitoba. From the top of the Favel Formation, through the Morden and Boyne members of the Carlile Formation, and then into the overlying Gammon Ferruginous, Pembina, Millwood and Odanah members of the Pierre Shale. During the afternoon we will re-examine a number of aspects of these beds that demonstrate a lateral continuity over a length of 50 kilometres.

Leave Winnipeg (from junction of Perimeter Highway and PTH 3) and drive 72 km south and southwest on PTH 3, through Carmen (Pink line on Figure 6). STOP 1 is approximately 12 km South of Carman, stop where safe on the West shoulder of PTH 3.

STOP 1: PTH 3 view of the Manitoba Escarpment – Pembina Hills (Optional)

Upper Cretaceous formations and members (Morden to Odanah), Table 1. 8-13-5-5W1, NTS 62G8SE, NAD 83, Zone 14U, 572417E, 5471388N. **STOP 1**, shown in Figures 4 and 6, is situated on the west side of PTH 3, 1 km South of Tobacco Creek, near the junction of section road 26N, approximately 18 km east of the Pembina Hills component of the Manitoba Escarpment. On the horizon to the southwest, on a clear day, it is possible to discern a low range of hills, as a dark shadowy image. This is the first view of the Manitoba Escarpment that can be seen immediately to the south of Carmen, Manitoba. Early explorers into the region had hopes that these were foothills leading to a mountain range at the margin of the Pacific Ocean, thus the name "Pembina Mountain" was derived; and which has been used in the past to describe the rise from the First to the Second prairie levels. The Pembina Hills are actually a composite feature that comprises a thicker lower sequence of Upper Cretaceous beds ranging upwards from the Morden Member of the Carlile Formation (at the base) to the Odanah Member of the Pierre Shale (at the top) that is usually covered by a thinner upper sequence of younger Quaternary (Pleistocene) glacial sediments and Recent alluvium. The Manitoba Escarpment is definitely an erosional feature on the Manitoba Prairies, however, there is a suggestion that bedrock faulting may be partially responsible for its northwest-southeast orientation. This orientation parallels a pervasive joint direction (the Rocky Mountain front) that is seen in outcrop and the horizontal stress trajectories projected across the Western Canada Sedimentary Basin (Bell et al., 1994).

Continue driving South on PTH 3 to the junction with PTH 23. Turn right (West) on PTH 23 to the junction with PR 432 and turn left (South). Continue South for 8 km to junction with section road 20N. Turn right (West) for about 3.4 km and stop on north side of section road 20N, beside large tree.

STOP 2: Favel (Marco Calcarenite) pavement outcrop (20N)

Upper Cretaceous Favel Formation (Assiniboine Member with Marco Calcarenite), Table 1. 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 Favel Formation forms the foundation of the Manitoba Escarpment in the Pembina Hills area.

The exposure, **STOP 2**, shown in Figures 4 and 6, is at the base of a shallow ditch on the north side of section road 20N. It also appears within the same ditch to the south (Figure 10), 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*, 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 indicate a maximum temperature of 432°C was reached and this rock contains 0.62 wt.% TOC (Nicolas and Bamburak, 2009).

Corehole M-12-77 (Table 2) was put down in the ditch on the north side of section road 20N.

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

Proceed West to the next section corner and turn left (South) on section road 32W for 3.2 km. Then turn right (West) at the section corner with section road 18N and drive for 1.3 km "up the Escarpment". Park on north shoulder of road and "watch for traffic", as this is a busy route.

Composite gamma ray log and stratigraphic position of field trip stops

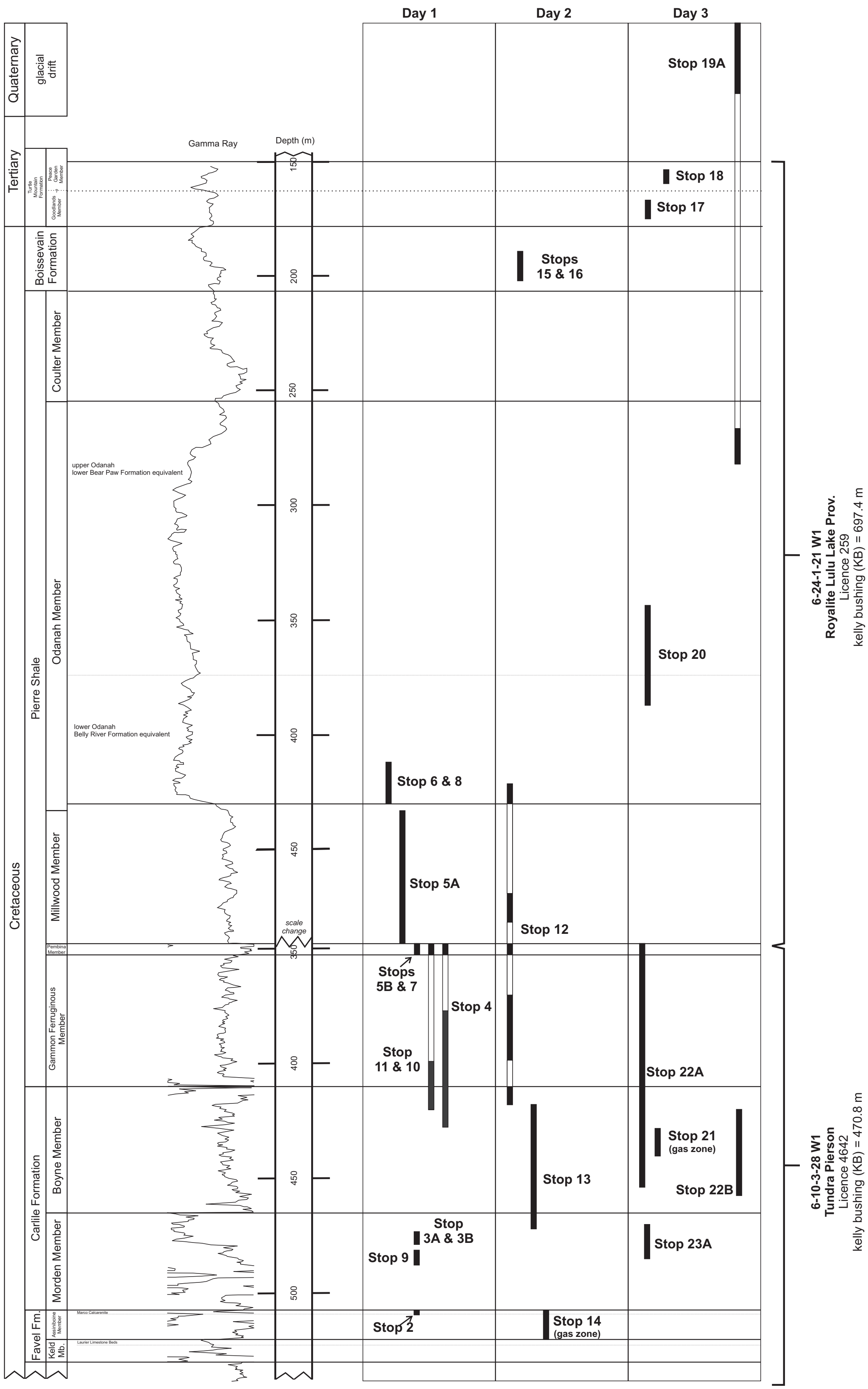


Figure 9: *Composite gamma ray log and stratigraphic position of the field trip stops.*

***Figure 10:** Marco Calcarenite pavement outcrop (**STOP 2**) on south side of section road 20N, M. Nicolas for scale (2008-08-25).*

***Figure 11:** Weathered Morden Member of the Carlile Formation at **STOP 3A** (2008-08-25).*

Table 2: Log of MGS Corehole M-12-77.

Location	Twp. & Rge.	Northing	Easting	Elevation	Total Depth
Miami SE, NTS 62G08	1-14-4-6W1	5460500N	560900E	297.2 m	45.1 m

METRES	DESCRIPTION
0.0-45.1	MESOZOIC-CRETACEOUS-FAVEL FORMATION
	Limestone, calcareous speckled shale, oil shale.

Logged by H. R. McCabe

STOP 3A: Morden Member (18N) roadside outcrop

Upper Cretaceous Carlile Formation (Morden Member), Table 1. 16-33-3-6W1, NTS 62G8SE, NAD 83, Zone 14U, 557628E, 5457278N. The outcrop (**STOP 3A**, shown in Figures 6 and 9) is situated along section road 18N, west of 35W, about 11 km south-southeast of Miami, Manitoba.

Shale of the Morden Member is exposed on both sides of the section road (18N), over a 300 m length (Figure 11). The black shale weathers into thin paper-like wafers, as it dries in the sun, completely covering the outcrop surface. Abundant small selenite crystals, broken septarian concretions and jarosite fragments are present on the surface of the weathered shale. The Morden Member is at the base of the Manitoba Escarpment, but because of the recessive nature of the soft carbonaceous beds, the rising relief is quite subdued. The main rise (with closely-spaced contour lines) appears to occur 1.6 km further to the west, at the base of the more resistant calcareous overlying Boyne Member of the Carlile Formation.

Rock Eval™ 6 T_{max} and TOC values for samples collected at this site are 428°C and 2.27 wt.% (Nicolas and Bamburak, 2009). About 800 m to the west, a similar shale was quarried **(STOP 3B)** for brick shale.

Continue 800 m towards the West on section road 18N, across Shannon Creek bridge and briefly stop. A former brick shale quarry site can be seen in the field to the South. Please view the site only from section road 18N. Waste bricks (backhauled from the Red River Brick and Tile plant at Lockport) can be seen in the road base of the access road into the former quarry.

STOP 3B: Rehabilitated brick shale (18N) quarry

Upper Cretaceous Carlile Formation (Morden Member), Table 1. 14-33-3-6W1, NTS 62G8SE, NAD 83, Zone 14U, 557150E, 5457306N. The former quarry (**STOP 3B**), shown on Figures 6, 9 and 12 is situated, south of section road 18N, about 1 km east of the Pembina Hills component of the Manitoba Escarpment, and about 11 km south-southeast of Miami, Manitoba.

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 6 (West)**) to produce a variety of colours. The quarry was rehabilitated with the shutdown of the Lockport plant.

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

Continue West on section road 18N, up the Manitoba Escarpment, for about 3.2 km. Stop in grassed area of farm field on north side of road (before dip to the west), park and carefully cross the road walking to the southwest. Note: This site, which is on private land, is included for information only and it should not be visited. However, it can be viewed from section road 18N.

STOP 4: Spencer's Ditch and O'Day former bentonite adit (18N)

Upper Cretaceous Pierre Shale (Millwood/Pembina/Gammon Ferruginous members) overlying Carlile Formation (Boyne Member), Table 1. 15-31-3-6W1, NTS 62G8SW, NAD 83, Zone 14U, 553821E, 5457330N. Spencer's Ditch outcrop (**STOP 4)**, shown in Figures 6 and 9 is located on private land, about 11 km south of Miami, Manitoba. The elevation of outcrop top, approximately half way up the Escarpment, is 392 m above sea level.

Spencer's Ditch, a southerly-trending ravine into Shannon Creek, has been incised into the relatively soft Upper Cretaceous beds due to repetitive spring meltwater run-off from a large holding pond, situated to the north of Dunston Road (section road 18N). Annually, an ice plug in the culvert beneath the road holding back the water in the pond, gives way with sudden force, which results in substantial downcutting of the bedrock.

On the east wall of Spencer's Ditch, 2 m of glacially disturbed white bentonite seams within black shale of the Pembina Member of the Pierre Shale can be seen overlying about 10 m of buff Boyne Member, with numerous thin orange-coloured bentonite seams (Figure 13). Plastic flow of the Boyne Member

***Figure 12:** Former quarry of Red River Brick and Tile, **STOP 3B**. Note: discarded and backhauled waste bricks in access road to quarry (c1992).*

Figure 13: *East wall of Spencer's Ditch (**STOP 4**) showing glacially-disturbed white bentonite beds of the Pembina Member of the Pierre Shale overlying generally flat-lying buff calcareous beds of the Boyne Member of the Carlile Formation (2004-09-09).*

into Shannon Creek, to the south, is evident at the southern end of the exposure where the orange bentonite seams "flow downward" into the valley. 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 of 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 at 2.30 wt.%, and 424°C at 4.61 wt.%, respectively (Nicolas and Bamburak, 2009).

The nearby former O'Day adit, opened by J.O'Day, in the early 1930s, (Bannatyne, 1963, p. 13), is not visible due to collapse of the overlying beds.

References: Bannatyne (1963, 1970).

Return to vehicles and drive 1 km West to next section corner with section road 36W, turn right (North) for 0.8 km then turn left (West) for 1.6 km. At the next section corner with section road 37W, turn right (North) for 2.4 km. At section corner with section road 20N, 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 5A: Millwood butte – Mount Nebo (20N)

Upper Cretaceous Pierre Shale (Millwood Member), Table 1. 1-24-4-7W1, NTS 62G8SW, NAD 83, Zone 14U, 552853E, 5460845N. Mount Nebo (**STOP 5A)**, shown in Figures 6 and 9, is one of the typical Millwood buttes in the Pembina Hills area (Figure 14), it is located about 8 km south of Miami, Manitoba.

The distinctive sparsely vegetated popcorn or cauliflower surface of the greenish-grey bentonitic shale of the Millwood Member can readily be seen at Mount Nebo, 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 hard grey siliceous shale of the Odanah Member have reportedly been found at the top of the butte.

Figure 14: *Mount Nebo (**STOP 5A**), a typical Millwood butte. Pierre Shale, Millwood Member, view towards northwest (2007-09-29).*

The stratigraphy of Mount Nebo has not been described in detail, however, 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 this butte, in a fresh cut in 1962, is reproduced in Table 3.

Bentonite beds of the Pembina Member of the Pierre Shale were quarried by Pembina Mountain Clays Limited to the north (**STOP 5B**) and south of section road 20N at the base of Mount Nebo. The quarries have not been rehabilitated and are being used by locals for dirt bike riding, as most are on the flanks of Mount Nebo.

References: Bannatyne (1963, 1970).

Walk 250 m downslope of Mount Nebo to the East and into former bentonite quarry of Pembina Mountain Clays.

STOP 5B: Mount Nebo former (20N) bentonite quarry

Upper Cretaceous Pierre Shale (Millwood Member overlying Pembina Member), Table 1. 4-18-4-6W1, NTS 62G8SW, NAD 83, Zone 14U, 553043E, 5460936N. The former quarry (**STOP 5B)**, shown in Figures 6 and 9 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.

White-weathering bentonite seams within the carbonaceous black shale of the Pembina Member can be seen near the road allowance of section road 20N, south of the butte and to the east. Remaining seams can be found within the road buffer that was provided under the quarrying regulations and which may have been deemed uneconomic by Pembina Mountain Clays. 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).

References: Bannatyne (1963, 1970).

Proceed back upslope to STOP 5A. Return to section road 20N and turn right (West) up the Escarpment for about 1.8 km. Intersection with section road 37W, turn right (North) for 2.2 km. The Rural Municipality (R.M.) of Thompson Shale aggregate quarry is on the right (East). Turn into quarry and park. If quarry is active, please contact operator before proceeding to examine quarry. Hart hat recommended for safety.

STOP 6: R.M. of Thompson shale (37W) aggregate quarry

Upper Cretaceous Pierre Shale (Odanah Member), Table 1. (McCabe and Bannatyne, 1970, Stop 21 and Bannatyne and Watson, 1982, Stop 3) in 5-24-4-7W1, NTS 62G8SW, NAD 83, Zone 14U, 551426E, 5462654N. The quarry (**STOP 6)** shown in Figures 6, 9 and 15) 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 quarry. Odanah shale contains 79 to 82% SiO_2, mainly as 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 this shale as a crushed aggregate for surfacing roads. Note on the east wall of the quarry, if exposed, is the contact with overlying fragmental and distorted shale-rich till, formed by cryoturbation (Bannatyne and Watson, 1982, p. 18).

Corehole M-8-77 (Table 4) was drilled near the quarry in 1977. 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 6 (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 for face brick. The shale was transported over 160 km to Lockport, Manitoba (29 km north of Winnipeg) where it was mixed with clays from **STOP 3** and other localities to produce a variety of colours. With the shutdown of the Lockport plant, the quarry became used by Rural Municipality of Thompson for aggregate.

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

Figure 15: *R.M. of Thompson shale aggregate quarry at* ***STOP 6*** *(2008-08-25).*

Table 3: Description of outcrop section at Twin Sister Butte (Bannatyne, 1963; Bannatyne and Watson, 1982).

Formation/Member	Lithology	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

Table 4: Log of MGS Corehole M-08-77.

Location	Twp. & Rge.	Northing	Easting	Elevation	Total Depth
Miami SE, NTS 62G08	5-24-4-7W1	5462450N	551300E	434.3 m	74.4 m
METRES	**DESCRIPTION**				
	MESOZOIC-CRETACEOUS				
	PIERRE SHALE-ODANAH MEMBER				
0.0-13.7	Shale- siliceous				
13.7-32.6	Shale- bentonitic				
	PIERRE SHALE-ODANAH MEMBER				
32.6-38.4	Shale- bentonite				
	CARLILE FORMATION-BOYNE MEMBER				
38.4-74.4	Calcareous and noncalcareous shale.				
Logged by H. R. McCabe					

Table 5: Description of outcrop section at Robert’s farm (modified from Bannatyne and Watson, 1982).

Bed	Lithology	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 (Q4)	13
10	Shale	5
9	Bentonite (Q3)	25
8	Shale	5
7	Bentonite (Q2)	9
6	Shale	5
5	Bentonite (Q1)	10
4	Shale, in places with thin bentonite layer (L2B)	8
3	Bentonite (L2A)	10
2	Shale	6
1	Bentonite (L1A)	9
	Total Section	**185**

Return to section road 37W and turn left (South) for 0.6 km. Intersection with section road 21N, turn right (West) for 1.6 km until junction with section road 38W. Turn right (North) for about 3.5 km, proceeding part-way down Escarpment towards the northwest. Park and assemble at side of road.

STOP 7: Robert's farm former (37.5W) bentonite quarry

Upper Cretaceous Pierre Shale (Pembina Member), Table 1. (McNeil and Caldwell, 1981, Outcrop Section 99) in the south-central portion of 3-35-4-7W1, NTS 62G8SW, NAD 83, Zone 14U, 550239E, 5465884N. The rehabilitated quarry (**STOP 7**, shown in Figures 6 and 9) 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, there they described the interval below the main bentonite seams. This interval has not been reproduced, but a typical section that was quarried by Pembina Mountain Clays Limited (from Bannatyne and Watson, 1982, p. 16) is shown in Table 5. Bannatyne and Watson noted that the bentonite beds vary from pit to pit, and even show variations in thickness within a single pit. On average the 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. The bentonite seams identified by Bannatyne and Watson (1982) have been annotated with the Q and L bed designations according to the format, as shown in Figure 7 (proposed by Bamburak et al., 2012b).

References: McNeil and Caldwell (1981), Bannatyne (1963, 1970), Bannatyne and Watson (1982), Bamburak et al. (2012b).

Continue down Escarpment to the north and east for about 4 km until junction with PTH 23. Turn left (West) for 3.2 km until junction with PR 240. Turn left (South) for about 19 km until junction with PTH 3. Turn left (East) for about 14 km until reaching the city of Morden. Proceed eastward on PTH 3 until junction with 2nd Street, and turn into Subway, on left across from Esso Station.

After lunch, turn right (West) onto PTH 3 and continue West until junction with PR 432. (After a brief stop at Tim Horton's, if necessary), turn left (South) for 25 km on PR 432 and section road 31W (Pink line on Figure6). Turn left (East) at junction with PR 243 (section road 1N).

STOP 8: Brown shale (1N) aggregate quarry (Optional)

Upper Cretaceous Pierre Shale (Odanah Member), Table 1. (McCabe and Bannatyne, 1970, Stop 21 and Bannatyne and Watson, 1982, Stop 3) in 13-3-1-5W1, NTS 62G1SE, NAD 83, Zone 14U, 563047E, 5429282N. The quarry (**STOP 8**, shown in Figures 6, 9 and 16) is located 1.6 km north of the USA border, along the Little North Pembina River, a tributary to the Pembina River. Figure 16, shows the sharp contrast between the overlying oxidized Odanah beds and the underlying unoxidized beds.

Continue eastwards on PR 243 (section road 1N) for 7 km to junction with section road 26W and turn right (South) for a few hundred metres.

STOP 9: Morden Member (26W) roadside outcrop

Upper Cretaceous Carlile Formation (Morden Member), Table 1. 16-3-1-5W1, NTS 62G1SE, NAD 83, Zone 14U, 569940E, 5430982N. The outcrop on the west side of section road 26W, south of 1N, is situated about 1.4 km north of the USA border. The outcrop (**STOP 9**, shown in Figures 6, 9 and 17) is located, east of the Pembina Hills component of the Manitoba Escarpment on the First Prairie Level, about 18 km south-southeast of Morden, Manitoba. The black shale weathers into thin paper-like wafers as it dries in the sun (See **STOP 3A**). Minor lenticular limestone concretions are present along the bedding planes, as shown in Figure 17.

As of June 2013, this outcrop was rehabilitated and the Morden Member beds are no longer exposed. A similar, but less exposed outcrop, can be seen 1.6 km to the north in 16-10-1-5W1.

Turn around, and head north on section road 26W to junction with section road 3N, turn left (West) for 1.6 km to junction with section road 27W. Turn right (North) for 0.8 km to junction with mid-section road (3.5N), turn left (West) for 1.4 km. Hopefully, the road is dry!

Figure 16: *Odanah Member of the Pierre Shale, south wall of Brown aggregate shale quarry (**STOP 8**), 15-1-1-6W1. Distinct break between oxidized beds at the top and the unoxidized beds below can be seen several metres above individual in the quarry (2004-09-10).*

*Figure 17: Thin bedded (paper-weathering) black shale, with minor thin lens-like limestone concretions, of the Morden Member at **STOP 9** (2008-08-26).*

STOP 10: Stonehenge roadside (3.5N) outcrop

Upper Cretaceous Boyne Member of the Carlile Formation/Gammon and Pembina members of the Pierre Shale, Table 1. 12-21-1-5W1, NTS 62G1SE, NAD 83, Zone 14U, 566979E, 5433657N. The outcrop (**STOP 10**, shown in Figures 6, 9 and 18) is located on the northeast flank of the Pembina Hills, 16 km south of Morden, Manitoba.

Figure 18 shows the interpreted beds of the Pembina Member overlying the Gammon Ferruginous Member of the Pierre Shale, which overlies the Boyne Member of the Carlile Formation.

Turn around, and head east on mid-second road 3.5N to junction with second road 27W. Turn left (North) and travel 5.6 km to junction with section road 7N and turn left (West) for 4.5 km. Again, hopefully, the road is dry!

STOP 11: Friesen roadside (7N) outcrop (Optional)

Upper Cretaceous Pierre Shale (Pembina and Gammon Ferruginous members) overlying Carlile Formation (Boyne Member), Table 1. 4-7-1-5W1, NTS 62G1SE, NAD 83, Zone 14U, 563579E, 5439339N. The outcrop (**STOP 11**, shown in Figures 6, 9 and 19) is weathered but shows many features of the previous stop (**STOP 10**). It is located on the northeast flank of the Pembina Hills, 8 km southwest of Morden, Manitoba.

Continue up the Escarpment on section road 7N to junction of PR 432, turn right (North) and travel 16 km north and west, by way of PTH 3, to the Morden Super 8, 1.6 km west of Morden. Check-in at Super 8 and then travel 3.2 km east on PTH 3 to 2nd Street and Thornhill Street. Turn left (North) on 2ns Street and travel 0.8 km north to Canadian Fossil Discovery Centre (CFDC), for supper and tour of the museum. After supper and tour, return to the Morden Super 8.

Day 2: Upper Cretaceous stratigraphy of the Pembina River Valley – biogenic gas wells near Manitou and the uppermost Cretaceous beds of sand and sandstone south of Boissevain.

Day 2 will focus on the incised Pembina River Valley (into the Second Prairie Level); and then upwards through the Upper

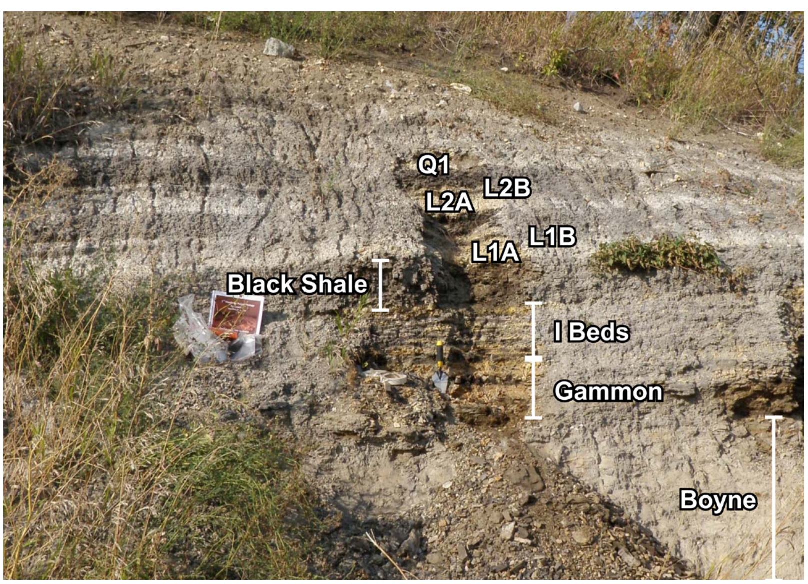


*Figure 18: Stonehenge road cut (**STOP 10**). Interlayered black shale and non-swelling bentonite beds (as per Figure 7) of the Pembina Member overlying the Gammon Ferruginous Member of the Pierre Shale and the Boyne Member of the Carlile Formation (2011-09-11).*

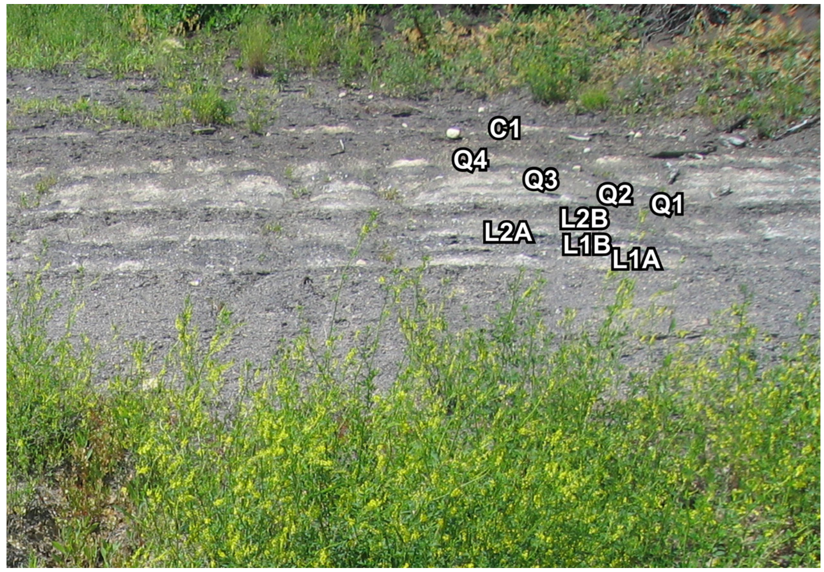


Figure 19: *Friesen outcrop (**STOP 11**). Interlayered black shale and non-swelling bentonite beds (as per Figure 7) of the Pembina Member overlying the Gammon Ferruginous Member of the Pierre Shale and the Boyne Member of the Carlile Formation (2008-07-09).*

Cretaceous stratigraphy of Manitoba to its highest known beds in the Turtle Mountain area (Figure 7).

Formations and members to be examined, during the day, comprise the Upper Cretaceous stratigraphic section of southwestern Manitoba from the Morden Member of the Carlile Formation to the top of the Upper Cretaceous in Manitoba – the Boissevain Formation. A "highlight" of the afternoon will be the lighting of a Manitoba natural gas well, south of Manitou.

From the Super 8, head east on PTH 3 towards Morden to junction with PR 432, turn right, South, to junction with PR 201 (Blue line on Figure 6). Turn right (West) and follow PR 201 west and then south into the Pembina River Valley (32 km), but stopping first at an Odanah shale quarry on the left (East), at the top of the valley. The bus will then descend into valley; and then will finally stop before the Holo Crossing bridge over the Pembina River and await our return.

STOP 12: Holo Crossing (36W) outcrops

Upper Cretaceous Pierre Shale (Odanah/Millwood/Pembina/Gammon Ferruginous members) overlying Carlile Formation (Boyne Member), Table 1. 1-13-1-7W1, NTS 62G1SW, NAD 83, Zone 14U, 553407E, 5431337N. This stop (Figures 6, 9 and 20) involves visits to multiple Upper Cretaceous outcrops descending into the Pembina River Valley (which requires a small amount of exertion, by walking along a gravel road (PR 201).

Proceed west and south on PR 201 crossing the Pembina River and then climb the south wall of the valley (on 37W). At junction with 1N (and westward continuation of PR 201), follow 37 W to the south and then east to the entrance of Pembina Valley Provincial Park and then into the parking lot with the picnic shelter and washrooms (5 km). Note: Provincial park permit required for each vehicle as of May 1, 2013. Gather at the trailhead sign to the east of the parking lot.

STOP 13: Pembina Valley Provincial Park hiking trail outcrops

Upper Cretaceous Pierre Shale Odanah Member; and Carlile Formation (Morden Member underlying Boyne Member), Table 1. 5-7-1-6W1, NTS 62G1SW. The hiking

Figure 20: *Chalky beds of the Boyne Member of the Carlile Formation at the base of the Holo Crossing outcrops at **STOP 12** (2008-08-26).*

trails (Pembina Rim, Boulder Creek and Porcupine Ridges) to be followed during the field trip that roughly parallels an unnamed tributary of the Pembina River within the Pembina Valley Provincial Park (**STOP 13**) are shown in Figure 21. The park is situated on land that was formerly owned by the Wozniak family that was donated to Nature Conservancy Canada. For this reason, the name "Wozniak Creek" will unofficially be used for the tributary during this field trip.

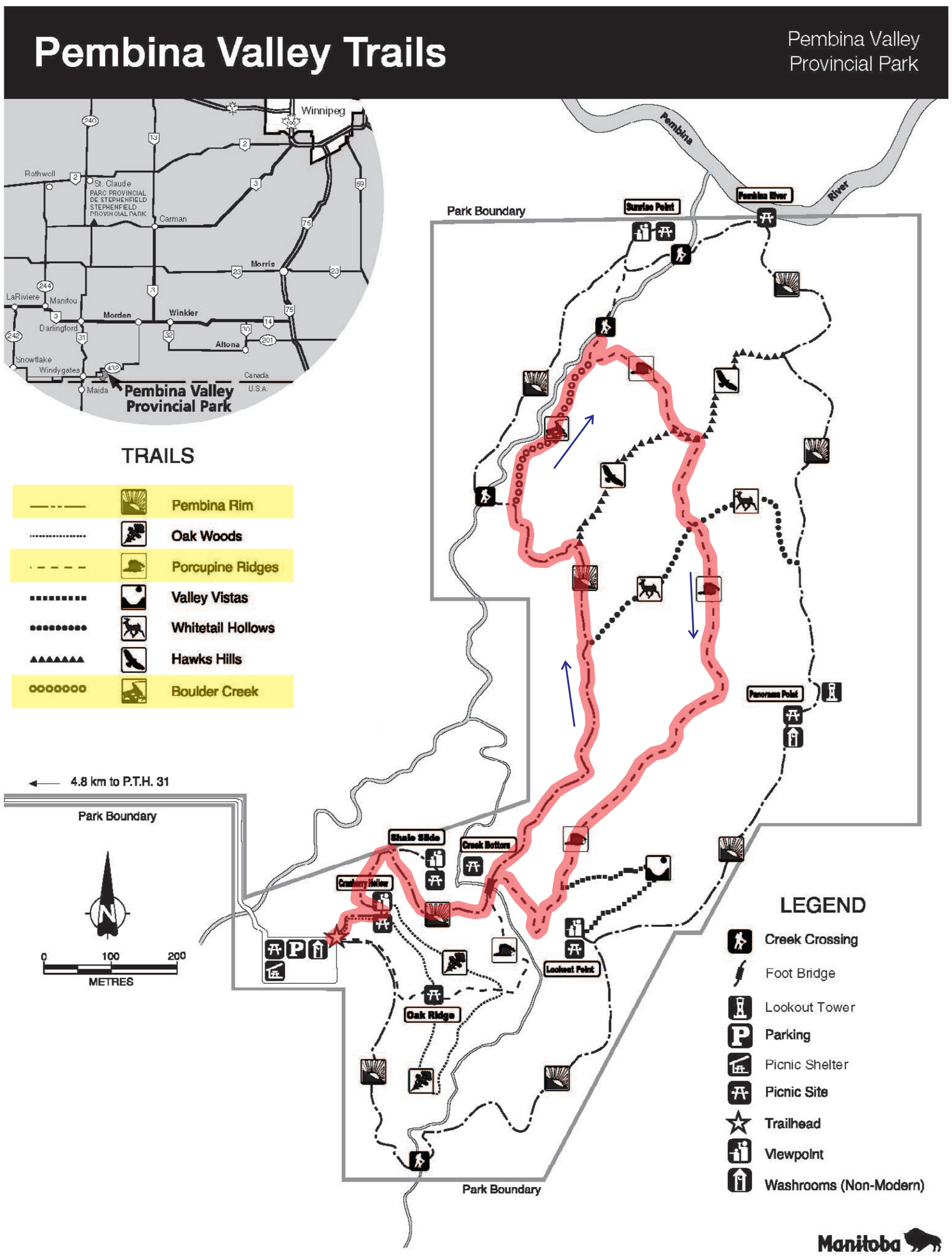
The hike will involve walking 4.5 km on moderately difficult terrain (possibly wet and slippery in places) and will take approximately 2.5 hours to complete. Layered clothing, a snack and water is recommended for the hike. The bus will remain in the parking lot for those not wishing to traverse.

The objective of the traverse along the Pembina Valley Provincial Park hiking trails, shown in Figure 21, is to apply the knowledge gained from Stops 2 to 12 to interpret the Upper Cretaceous stratigraphy at a series of outcrops beginning within the Odanah Member of the Pierre Shale at the top of the section and ending near the top of Morden Member of the Carlile Formation at the bottom.

Starting from trailhead (east of parking lot) proceed about 300 m northwards along the Pembina Rim trail (Figure 21) to the "Shale Slide" site (at the end of a small trail that branches off to east from the main trail).

STOP 13A: Shale Slide (Pembina Rim Trail)

Upper Cretaceous Pierre Shale Odanah Member, Table 1. NAD 83, Zone 14U, 553043E, 5460936N. The noncalcareous siliceous olive green Odanah Member outcrop is situated



(Map modified from http://www.gov.mb.ca/conservation/parks/pdf/maps/2012_trail_maps/pembina_valley_trails.pdf)

Figure 21: *Pembina Valley Provincial Park (**STOP 13**) hiking trails with traverse, shown in orange.*

on the side of a valley wall of a smaller tributary into "Wozniak Creek"; and is covered by abundant weathered sub-concoidal shale fragments. Minor manganese coats some of the fracture surfaces. The shale was last seen at **STOPS 6, 8 and 12**.

Return to the Pembina Rim trail and head eastward and downward for about 300 m to "Creek Bottom" bridge. Continue northwards aong the Pembina Rim trail for 1.1 km (mainly downhill) until reaching the Boulder Creek trail (Figure 21) that parallels the southeast side of "Wozniak Creek". Follow the Boulder Creek trail for about 100m, and then drop down to the stream bed of the creek if the water levels are low. Carefully follow (over slippery rocks) the winding stream bed until reaching STOP 13B.

STOP 13B: Boyne Outcrop (Boulder Creek Trail)

Upper Cretaceous Carlile Formation Boyne Member, Table 1. NAD 83, Zone 14U, 553530E, 5429721N. The buff chalky beds overlie the grey calcareous beds of the Boyne Member on the north side of the valley wall of "Wozniak Creek". The contact of the buff and grey beds is covered by talus; however, the contact will be visible at **STOP 13C**. At the top of the outcrop section, beneath the glacial till, numerous thin seams of orange bentonite can be seen. These bentonite seams can be visually correlated with the seams seen at **STOP 4**.

Return to the stream bed and carefully follow "Wozniak Creek" for about 400 m to the northeast until reaching STOP 13C, which is just before the sign marking the junction of the Boulder Creek trail with the Porcupine Ridges trail, on the south bank of the creek.

STOP 13C: Boyne/Morden Outcrop (Boulder Creek Trail)

Upper Cretaceous Carlile Formation Boyne and Morden members), Table 1. The buff chalky beds overlie the grey calcareous beds of the Boyne Member and overlie the black shale of the Morden Member on the north side of the valley wall of "Wozniak Creek". Near the centre of the outcrop (NAD 83, Zone 14U, 553649E, 5429902N), the silt-rich Babcock beds of Nicolas and Bamburak (2009) can be seen at the contact of the buff and grey Carlile beds. This unit will also be seen at **STOP 22B**. At the northeasten end of the outcrop (NAD 83, Zone 14U, 553663E, 5429909N), thin grey calcareous beds of the Boyne Member are interlayered with thin black noncalcareous beds of the Morden Member. The contact is transitional over several metres.

Walk for 2.3 km back to the trailhead (mainly uphill) using the Porcupine Ridges trail, as shown in Figure 21. Upon reaching the parking lot, have lunch, and board the bus about 12:30 p.m. Drive to section road 37W, turn right (North) until 1N (PR 201) and turn left (West). Drive West for 4.8 km to PTH 31 (Figure 21) and turn right (North) and drive for about 20 km, crossing the Pembina River Valley, until reaching PTH 3. Turn left (West) and drive West and then North for about 15 km, crossing the Darlingford Moraine, until reaching the west side of Manitou and section road 48W(PR 244, on right). Turn left (South) and drive about 7 km South to intersection with PR 423; and then follow PR 423 South for 3.8 km, and West (10N), crossing the Pembina River Valley, to section road 50W. Turn left (South) for 1.6 km to junction with section road 9N. Turn left (East) and follow the winding section road (9N) to the fenced-off gas well.

STOP 14: Manitou gas wells (9N)

NOTE: This site can only be visited with permission from the land owner.

Cretaceous Favel Formation (Assiniboine Member), Table 1. 3-23-2-9W1, NTS 62G2NE, NAD 83, Zone 14U, 531268E, 5442380N. The gas well, **STOP 14**, shown in Figures 6, 9 and 22, probably receives all or part of its natural gas from the Assiniboine Member (Nicolas and Grasby, 2009, p. 179). The 1932 well, on the west side of the Pembina River Valley in Twp. 2, Rge. 9W1, is situated at the northwest end of a pronounced deflection towards the southwest of the incised river valley. The abrupt change in stream direction corresponds to a low and broad anticlinal nose plunging to the southwest. This

***Figure 22:** 1932 gas well with propane tank and natural gas bar-be-cue on west side of Pembina Valley (**STOP 14**) (late P. Lea tending the bar-be-que on October 9, 2008).*

was interpreted by Tovell (1951, p. 6) from the structure contours on the top of the Boyne Member of the Carlile Formation.

A second gas well, drilled in 1906/07 is situated in the bottom of the stream valley, a short distance to the northeast of the 1932 well. The earlier well was originally drilled for oil, but gas was unexpectedly encountered at a depth of 180 m, and subsequently ignited, producing a "gas jet" visible in Manitou, 12 km to the north.

Leaving the gas well, return back (West) on the winding section road (9N) to junction with section road 50W and turn right (North) for 1.6 km to junction with PR 423 (section road 10N). Turn left (West) and travel about 7 km to junction with PR 242. Approximately 2.5 km West of the previous turn, the top of the valve stem of the New Midland petroleum test hole can almost be decerned in the farm field to the North. At the junction with PR 242, turn right (North) and travel 11 km North to La Riviere and the junction with PTH 3. Turn left (West) and follow PTH 3 for about 120 km to junction with section road 114N (Blue line on Figure 8). Turn right (North) for 3.5 km and stop on side of road opposite quarry on north side of rise.

STOP 15: Boissevain North (114W) aggregate quarry

Upper Cretaceous Boissevain Formation, Table 1. 91-713-3-20W1, NTS 62F1NE, NAD 83, Zone 14U, 424458E, 5451389N. Unconsolidated sand and lithified sandstone, with "salt and pepper texture", is present in the Boissevain North aggregate quarry (**STOP 15**, shown in Figures 8, 9 and 23). The quarry is situated southeast of Boissevain, Manitoba on the west side of section road 114W and north of the Boissevain Reservoir, which supplies the town's drinking water.

Another excellent exposure of the Boissevain Formation can be seen from the road in a gully south of PTH 3, about 16 km west of Killarney, in NW15-35-2-19W1.

Continue northwards on section road 114W until junction with PR 443 (Mountain Street, section road 15N). Turn left (West) and drive to intersection with Johnson Street. Turn right (North) and continue to South Railway Street. Boissevain Methodist Church is on southeast corner of the intersection.

STOP 16: Boissevain Methodist Church

Upper Cretaceous Boissevain Formation, Table 1). 11-24-3-20W1, NTS 62F1SE, NAD 83, Zone 14U, 423359E, 5453628N. The former Boissevain Methodist Church (now, St. Paul's United Church of Canada) (**STOP 16)** is situated at the corner of Johnson and South Railway, in the town of Boissevain, Manitoba.

The exterior frontage of the church, built in 1893, is shown in Figure 24. Approximately 90% of its exterior walls are slabs of cemented Upper Cretaceous Boissevain Formation with some Tyndall Stone (from Garson, Manitoba) used around the windows and doorways. The slabs of sandstone are enclosed in mortar, most of which appear to be original, and some that appears to have been added more recently. A few of the sandstone slabs show distinct cross-bedding, which is enhanced through oxidation of ferruginous minerals deposited along the bedding planes. Stone for the church was probably obtained from several former quarries south of the town (near its present water reservoir and **STOP 15**), where the Cretaceous Boissevain Formation is exposed at surface. Additional information on the church can be found at: http://www.mhs.mb.ca/docs/mb_history/20/boissevain.shtml.

Continue westwards for several blocks on South Railway Street to junction with Mill Road (PTH 10). Turn left (South) and arrive at Red Coat Inn, on left, and check in.

Day 3: Paleocene stratigraphy of the Turtle Mountain area – Souris gravel derived partially from Tertiary beds in Saskatchewan and Alberta; biogenic gas wells near Notre Dame de Lourdes; shallow gas, cement rock and brick shale in Manitoba's "Grand Canyon", west of Roseisle

Day 3 will focus on the return downward through the stratigraphic section of southwestern Manitoba from Pleistocene

***Figure 23:** Calcareous cemented sandstone concretionary layer overlying compacted, but unlithified crossbedded "salt and pepper" sand (oxidized in places) of the Upper Cretaceous Boissevain Formation in the Boissevain North aggregate quarry, **STOP 15**. M. Nicolas making notes (2011-07-18).*

Figure 24: *North facing frontage of the St. Paul's United Church on South Railway Street in Boissevain, Manitoba at* ***STOP 16*** *(2010-06-01).*

reworked Tertiary gravel through Paleocene beds of the Turtle Mountain Formation and back to the lower beds of the Upper Cretaceous, seen in Day 1.

Also on Day 3, a brief side trip will be taken into Manitoba's oil patch where oil development has increased significantly during the past few years, due to advances in horizontal drilling and multi-stage hydraulic fracturing techniques.

Drive south on Mill Road (PTH 10) from the Red Coat Inn in Boissevain to the junction with PTH 3 (Purple line on Figure 8). Turn right (West) onto PTH 3, driving through the southern portion of the Whitewater oil field and then past Deloraine, to junction with PTH 21. Follow PTH 21, first West and then South to STOP 17 (where the road allowance for section road 4N, meets PTH 21 on the right side of the highway.)

STOP 17: Coal mining plaque (PTH 21)

Paleocene Turtle Mountain Formation (Goodlands Member, Table 1). 1-25-1-24W1, NTS 62F2SE, NAD 83, Zone 14U, 386332E, 5435123N. The plaque (Figure 25), commemorating the intermittent lignite mining in the Turtle Mountain area from 1883 to 1943, is located at **STOP 17** (Figures 8 and 9). The stop is located on the west flank of Turtle Mountain and is surrounded by at least 15 former lignite mine workings – now collapsed and overgrown. The underground mines and open pits were developed near the base of the Goodlands Member of the Paleocene Turtle Mountain Formation lying beneath thick overburden, usually along streams draining the highlands, to the east. The discontinuous lignite seams, ranging in thickness from 0.15 to 1.83 m, were water-saturated and erratically distributed due to primary deposition, ice-thrusting and slumping. About 30 000 tonnes of lignite was mined from 1883 to

Figure 25: *Plaque (****STOP 17****) showing location of former coal mines on the north and west flanks of Turtle Mountain (2010-04-18).*

1908 and from 1931 to 1943, despite poor roof conditions and water problems. Possible reserves of lignite would only be a few million tonnes if strip mining was ever assumed to be economical (Bannatyne, 1978).

Turn around and return northwards on PTH 21 to junction with section road 7N. Turn right (East) and proceed up the northwest flank of Turtle Mountain for 2 km and stop at bedrock aggregate quarry, on south side of road allowance.

STOP 18: Peace Garden (7N) aggregate quarry

Paleocene Turtle Mountain Formation (Peace Garden Member, Table 1). 14-5-2-23W1, NTS 62F2SE, NAD 83, Zone 14U, 388501E, 5439878N. **STOP 18** is shown in Figures 8, 9 and 26. Hole M-2-71 was drilled by the MGS in 1971 in NE13-5-2-23W1 into a lignite seam within the Goodlands Member, at a depth of 34 m near **STOP 18** (Bamburak, 1978, p. 46, 47).

Return (20 km) back down section road 7N, crossing PTH 21 and continuing westward on PR 251 to junction with PR 452. This area is the northern portion of the Waskada oil field (Figure 8). Turn right (North) and drive 19.2 km to junction with section road 12N. Turn right (East) for 17.6 km until reaching intersection with PTH 21. Continue East and then North on PTH 21 for about 30 km until the intersection with PTH 23 and turn right (East). Continue East on PTH 23, south of the Souris Hartney oil field, for approximately 20 km, until the intersection with PTH 22. Turn left (North) and continue for about 20 km until reaching a private road, about 0.5 km north of section road 41N (south of Souris, Figure 8). Note: access to pit is only allowed after a vehicle permit is purchased at Souris Rock Shop (STOP 19B). Turn right (East) on private road for about 0.5 km until reaching gravel pit on left. Proceed down ramp and stop away from excavating equipment and trucks, as this is an active pit.

STOP 19A: Souris gravel pit

Pleistocene gravel overlying Upper Cretaceous Odanah Member of the Pierre Shale, Table 1. 9-34-7-21W1, NTS 62F9SE, NAD 83, Zone 14U, 410159E, 5496597N. In the Souris gravel pit, (**STOP 19A)**, Pleistocene gravel containing clasts derived from Tertiary beds (65-60 Ma) in Alberta and Saskatchewan (possibly from the Wood Mountain Formation, Figure 3) can be found overlying the Upper Cretaceous Odanah Member of the Pierre Shale, as seen in Figure 27 below. The Tertiary clasts were derived from the Rocky Mountains, which were elevated at the western edge of the Western Canada Sedimentary Basin during the Laramide Orogeny. The gravel was reworked during the Pleistocene and Precambrian cobbles and boulders were introduced into the mix.

Return West along private road to PTH 22 and turn right (North) at the intersection. Follow PTH 22 generally northwards until PTH 2. The Souris Rock Shop is on the southwest corner of the junction.

STOP 19B: Souris Rock Shop

Pleistocene gravel (Table 1). 16-33-7-21W1, NTS 62F9SW, NAD 83, Zone 14U, 409112E, 5497202N. The Souris Rock Shop (**STOP 19B**) is located at the junction of PTH 2 and 22 in Souris, Manitoba, as seen in Figure 28. Specimens unique to this area of the province are on display in the store. They were collected mainly in the Shop's operating gravel pit located along the Souris River, southeast of town. At the Shop, it is possible to purchase a one-day vehicle pass to the pit (**STOP 19A**) to collect well-rounded clasts of petrified wood, jasper, flint, agate, epidote and other rocks. Please visit: http://www.souris-rockshop.com/ on line for more information, including hours of operation of the pit.

Continue East on PTH 3 for 125 km to section road 55W, just before Treherne (Purple line on Figure 6). Turn right (South) for 1.6 km, and arrive at quarry on small knoll.

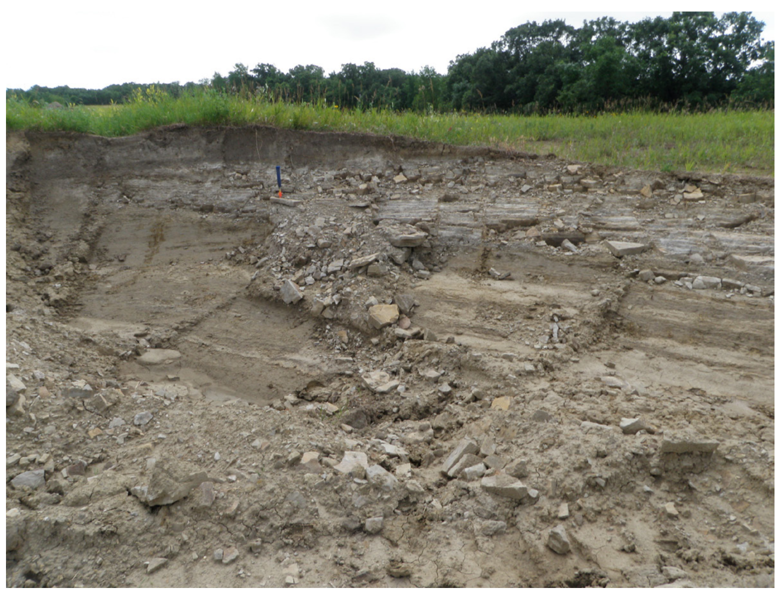


***Figure 26**: Paleocene Peace Garden Member in an aggregate quarry (**STOP 18**) in 14-5-2-23W1 (2011-07-19).*

Figure 27: *Pleistocene gravel overlying Upper Cretaceous Odanah Member of the Pierre Shale in Souris gravel pit (**STOP 19A**). Bottom of hammer head roughly marks position of unconformity (2005-08-17).*

Figure 28: *H. Groom (left) and J. Bamburak (right) “prospecting” outside Souris Rock Shop (**STOP 19B**) in Souris, Manitoba (2005-08-17).*

STOP 20: Treherne shale aggregate quarry (55W)

Cretaceous Pierre Shale (Odanah Member). 12-25-7-10W1, NTS 62G10SE, NAD 83, Zone 14U, 520969E, 54955817N. The quarry (**STOP 20**, shown in Figures 6, 9 and 29) is located on a knoll, on the east side of section road 55W, 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).

Return back to PTH 3 on section road 55W. Turn right (East) and travel for about 12 km to Rathwell and the junction with PR 244. Turn right (South) for 6.4 km to section road 40N. Turn left (East) for 1.6 km to intersection with 47W. Turn left (North) and turn onto farm road on left.

STOP 21: Bosc Farm gas well

NOTE: This site can only be visited with permission from the land owner.

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 21**, shown in Figures 6, 9 and 30) is situated on the north flank of the Pembina Hills, 6 km north-northeast of Notre Dame de Lourdes, on the farm of N. and G. Bosc.

The well was dug by hand to a depth of about 10.18 m in 1936. The bottom of the well is probably into the Boyne

Figure 29: *Well-bedded manganese-stained Odanah Member of the Pierre Shale with distinctive greenish swelling bentonite bed about 1 m above the top of the talus slope in Treherne shale aggregate quarry at* ***STOP 20*** *(2004-09-09).*

Figure 30: *Lighting the Bosc farm gas well at* ***STOP 21*** *(2003-10-03).*

Member of the Carlile Formation, which is known to contain oil shale. Boyne Member is exposed at two locations, a short distance to the south and to the southwest (See: Aggregate – Boyne Member of the Carlile Formation). The exposures are at about the same elevation as the top of the well.

This water well is fitted with a one inch gas-collection tube that collects gas from the bedrock at the bottom of the well. Gas can be seen escaping from the water at the bottom 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 dD values within the biogenic gas range (Nicolas and Grasby, 2009).

Wallace (1925b, p.35, 1927, p. 38, 39) reported that natural gas was being used for domestic lighting purposes in southwestern Manitoba. One location was in the "Waskada-Sourisford district" (west of Goodlands in Figure 8). Other locations where gas was used for lighting were on farms situated near Treherne and Rathwell-Notre Dame De Lourdes (See: Economic geology – Shale Gas).

References: Wallace (1925b, 1927), Bannatyne (1970).

Return back to PR 244 on section roads 47W and 40N. Turn left (South) and travel for about 12 km to Rathwell and the junction with PR 244. Turn right (South) for almost 10 km (through Notre Dame de Lourdes) to PR 245. Turn left (East) for 6.4 km to intersection with 44W. Turn right (South) and travel about 3 km and descend into the valley of Roseisle Creek. Watch for sharp turn onto section road 32N, approaching on the left (East). When safe make slow turn to left onto section road 32 N; and stop (when safe) on right shoulder of road, opposite high cliff face to left (North).

STOP 22A: Roseisle Creek Bridge outcrop

Upper Cretaceous Pierre Shale (Pembina Member overlying Gammon Ferruginous Member) overlying Car-

lile Formation (Boyne Member with Chalky and Calcareous Units). (McCabe and Bannatyne, 1970, Stop 17) in 13-11-6-8W1, NTS 62G8NW, NAD 83, Zone 14U, 539656E, 5480024N. **STOP 22A** (shown in Figures 6, 9, 31 and 32) is the westernmost of a string of generally east-west trending outcrops (east of section road 44W), which line the north side of Roseisle Creek (Snow Valley) within the Pembina Hills. The valley, herein termed "Manitoba's Grand Canyon", is located about 1.8 km northeast of St. Lupicin, Manitoba.

The Roseisle Creek Bridge outcrop consists of 50 m of grey and buff calcareous Boyne Member of the Carlile Formation that is capped by 16 m of glacial drift (Figure 31). Directly below the drift and above the Boyne, a 58 cm thick bed of the Gammon Ferruginous Member (Figure 32, below) and a 1.4 m interval of the Pembina Member (I Beds, Black Shale and L Beds) have been found near the top of a climbing trail. According to McCabe and Bannatyne (1970), an outcrop of the Morden Member has also been reported below the road level, but this is now covered.

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

Continue to East on section road 32 N for about 1.5 km; and stop (when safe) on right shoulder of road, opposite small cliff face to left (North).

STOP 22B: Roseisle outcrop (with Babcock beds)

Cretaceous Carlile Formation (Boyne Member with Chalky and Calcareous Units). (McCabe and Bannatyne, 1970, Stop 17) in 1-14-6-8W1, NTS 62G8NW, NAD 83, Zone 14U, 541157E, 5480360N. This outcrop is at the eastern end 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 22B** (shown in Figures 6, 9 and 33) has the Babcock beds, in its mid-section (shown several metres above the bottom of M. Nicolas' traverse vest in Figure 33) and is located in a valley about 1.8 km northeast of St. Lupicin, Manitoba.

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 Babcock beds within the Boyne Member has been used in the production of natural cement (Wallace, 1925a, p. 31; 1925b, p. 16; 1927, p. 16). 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

Figure 31: *Roseisle Creek Bridge outcrop at* ***STOP 22A*** *(2008-08-27).*

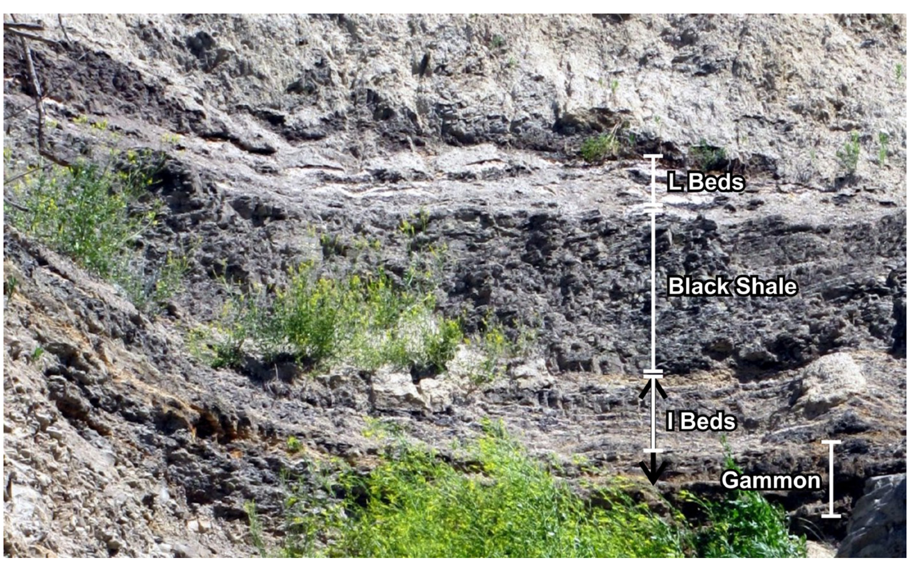


Figure 32: *58 cm thick bed of Gammon Ferruginous Member underlying a 1.4 m interval of Pembina Member (I Beds, Black Shale and L Beds, as per Figure 7) at top of section seen at* ***STOP 22A*** *(2012-06-28).*

***Figure 33:** Babcock beds at **STOP 22B**, just above the bottom of M. Nicolas' traverse vest (2008-08-27).*

the former Babcock railroad station (about 0.5 km to the southeast of **STOP 8**). (See: Economic Geolology – Natural cement rock - Babcock cement works).

References: Wallace (1925a, b; 1927), McCabe and Bannatyne (1970), Bannatyne (1970), Nicolas (2008), Nicolas and Bamburak (2009).

Continue to East on Roseisle Creek road for about 0.25 km; and stop (when safe) on right shoulder of road, opposite former brick plant on right (South). Do not attempt to access the workings, which are on private land.

STOP 23A: Former Leary's brick plant and shale outcrop (Optional)

Cretaceous Carlile Formation (Morden Member). (McCabe and Bannatyne, 1970, Stop 18) in 6-13-6-8W1, NTS 62G8NW, NAD 83, Zone 14U, 541559E, 5480700N. The former brick plant (**STOP 23A**, shown in Figures 6, 9, 23A and 34) is located on private land, 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 (Figure 34). Burning of one load required 2 to 3 weeks, in order to produce a good red colour (See: Economic Geology - Learys Brick plant and quarry).

Morden Shale bank

A 9 m high bank of black carbonaceous Morden Member is present on the south side of Roseisle Creek, 60 m south of the brick plant. Well-developed large septarian concretions can be found on the sides of the creek valley; these were discarded

***Figure 34:** Leary's brick plant on the north side of Roseisle Creek at **STOP 23A**. View from the south, in the vicinity of the shale bank on the south side of Roseisle Creek (2009-10-13).*

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). (See: Economic Geology - Learys Brick plant and quarry).

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

Continue to East on Roseisle Creek road for about 0.25 km; and stop (when safe) on right shoulder of road, opposite the Leary house. to left. This the last stop of the field trip.

STOP 23B: Leary's home (Optional)

Cretaceous Carlile Formation (Morden Member). (McCabe and Bannatyne, 1970, Stop 18) in 6-13-6-8W1, NTS 62G8NW, NAD 83, Zone 14U, 541626E, 5480980N. The former brick plant (**STOP 23B**, shown in Figures 6 and 9) is located a few hundred metres north of Roseisle Creek and the shale outcrop 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.

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

Continue to East on Roseisle Creek road, for about 4 km, to junction with section road 40W, just before Roseisle. Turn left (North) for 200 m and turn right (East) back onto PR 245. Return to Winnipeg along PR 245 (through Carmen); and then PTH 3.

Economic geology

A wide variety of economic minerals have been extracted from southwestern Manitoba during the past hundred years. Further development potential exists in the extraction of commodities for construction, energy and other uses. Mineable commodities can be found throughout the stratigraphic column of southwestern Manitoba with many being found in the Upper Cretaceous and Paleocene beds. The following is a description of the identified past, present and future commodities in alphabetical order.

Aggregate

Numerous shale (and to as lesser extent silt) quarries have been opened in southwestern Manitoba, to supply the demand for aggregate road metal and for fill. Most of these quarries are situated within the Odanah Member of the Pierre Shale, but at least three have been opened within the Boyne Member of the Carlile Formation, two are in the Boissevain Formation and one is in the Turtle Mountain Formation. According to the Canadian Minerals Yearbook (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 southwestern Manitoba are vast, but development could be hindered by land use concerns.

Boyne Member of the Carlile Formation

Chalky calcareous shale from the Boyne Member of the Carlile Formation, can be found at the Bosc southwest quarry (Figure 35), 1 km southwest of **STOP 21**. The Boyne member quarried in NW15-19-7-8W1 lying 100 m south of section road 40N has been used as fill in road construction. A second smaller quarry in the Boyne Member also has been opened near the junction of section roads 40N and 47W.

Odanah Member of the Pierre Shale

The Odanah Member of the Pierre Shale is siliceous, containing 81% SiO_2 and has been referred to as 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. This shale can be found in place, with various amounts of glacially disturbance, or as a shale-rich till. When mined blasting is not usually required as this shale exfoliates readily, and only a short period of time is required for a new talus pile to develop at the base of an excavation.

Figure 35: *Bosc southwest Boyne Member shale aggregate quarry in NW15-19-7-8W1. Note chalk on bedding planes on fresher surface (2008-08-29).*

One of the largest Odanah shale quarries to operate in the province is the Brown quarry in 15-1-1-6W1**.** The Brown quarry (**STOP 8**, shown in Figures 6, 9 and 16) is situated just over 1 km north of the USA border, where the Pembina Hills enter 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.

Other Odanah aggregate shale quarries, which are part of this field trip, can be seen at **STOP 6** – the R.M. of Thompson Odanah quarry in SW05-24-7W1 (shown in Figures 6, 9 and 15); and at **STOP 20** –the Treherne quarry, in 12-25-7-10W1 (shown in Figures 6, 9 and 29).

Boissevain Formation

One of two adjacent Upper Cretaceous Boissevain Formation aggregate quarries can be seen at **STOP 15**, (Figures 8 and 9) immediately north of the Boissevain Reservoir and to the west of section road 114W. The North (Figure 23) and South quarries are about 100 m apart and consist mainly of greenish-grey crossbedded "salt and pepper" sand, with random ovoid calcareous-cemented sandstone concretions. The material from the quarries is probably used only as fill. However, in the past the concretions found in the general vicinity were split for use as a building stone (See: below).

Peace Garden Member of the Turtle Mountain Formation

A recently opened Peace Garden Member aggregate quarry can be seen at **STOP 18** (Figures 8 and 9), on the south side of section road 7N, in 14-5-2-23W1 (Figure 26). Several smaller openings can also be seen about 300 m to the south. The greenish-grey, yellow-weathering, silt-rich and minor sand beds capped with thin siltstone slabs (found in the quarry below till and overburden) are probably used only as fill.

Bentonite

Non-swelling calcium bentonite

Pembina Mountain Clays Limited

From 1939 to December 1990, Pembina Mountain Clays Limited produced the only non-swelling, dried, natural and acid-treated activated calcium montmorillonite clays in Canada. In 1982 B.B. Bannatyne estimated that annual production of this product ranged from 9 000 to 18 000 tonnes (Bannatyne and Watson, 1982, p. 44). By 1990, twenty-three employees, with an annual payroll of $800,000, worked at two plant sites, in Winnipeg and Morden. In 1994, production of this product had a significant effect on the local economy as goods and services purchased in the area totalled nearly $2.3 million and more than $43,000 was paid in local taxes (Shetty, 1994).

This bentonite was quarried from the Pembina Member of the Upper Cretaceous Pierre Shale (Figures 2, 3 and 7), from at least 21 sites located 30 km west of Morden. This member was mined on a seasonal basis from May to October, as during the winter separation of the bentonite from the black shale was very difficult. In addition, poor ground conditions in the early spring and the late fall restricted the weight that could be transported on haul roads.

Figure 36 shows one of these former quarry sites (with annotated bentonite seams as per Figure 7); and other former quarries will be visited at **STOPS 4, 5 and 7**.

To mine this material, small scale scrapers were employed to carefully remove the black shale overburden from the bentonite layers. A front end loader was used to load the clay onto trucks at the quarry site for transport to a stockpile at the drying and crushing plant (929 m^2) in Morden. After preliminary drying and crushing, some was sold as is and the remainder was transported by truck, 128 km to the northeast, to the main processing plant in Winnipeg for further processing.

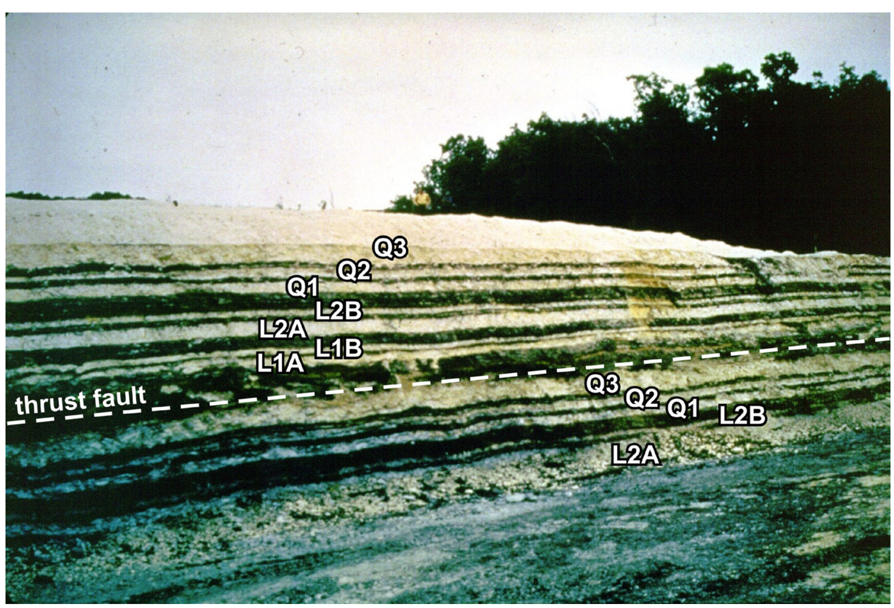


Figure 36: *Former Friesen quarry, possibly located in 7-2-5W1. The bentonite beds are labelled as per Figure 7. Note the presence of a thust fault (Miami Museum Incorporated, 1974, p. 7), which effectively doubled the number of mineable beds at this site (c1970).*

In the 1979 m² Winnipeg plant, the raw clay was chemically treated with 93% virgin sulphuric acid, water and heat. The resulting slurry was washed, dried and screened. Then the activated finished product was either sold to producers of edible and inedible vegetable oils, as a bleaching agent or was used as an adsorbent to decolourize and 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 Resources Inc.

Bird River Resources (formerly, 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 (shown in Figure 37) 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 5A)** 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 (Bannatyne, 1970, p.55, 56).

Partly swelling bentonite has not been produced in Manitoba. 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 (Bannatyne, 1963, p. 37-42).

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 20)**, and also, outside the field trip 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.

Swelling bentonite has not been produced in Manitoba. Bannatyne (1963, p. 43) stated that it was uneconomic because of: 1) its thinness; 2) added cost of sodium carbonate to improve its swelling properties; and 3) availability of other swelling bentonite deposits in western Canada and the northern United States. However, more exploration work was recommended to locate larger size bentonite deposits in Manitoba with better swelling properties.

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) documented a brief history of brick making in the province.

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 by the Boyne Valley Brick Company, southwest of Roseisle **(STOP 23A)** in SW13-6-8W1. The remnants of the quarry are located, south of the plant (Figure 34), along a 9 m high shale bank along Roseisle Creek (Wells, 1905b, p. 21, 22, 24, 25, 32); Bannatyne, 1970, p. 47, Plate 2B).

Figure 37: *Property of Bird River Resources in 10&11-16-5-7W1, under development in 2001. The quarry is situated within the Cretaceous Pembina Member of the Pierre Shale (2001-10-12).*

In 1914, the operations were taken over by C.E. Leary and bricks were made at the site until 1917. In 1947 the operations were restarted by W.A. Leary and continued until 1952. During this period, the annual production comprised 30 000 to 97 000 dry-press face bricks and from 3 800 to 94 000 common bricks. In 1962, Tallclay Products Limited attempted to bring the plant, into production, but only one kiln-load of brick was fired.

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 located at Lockport. From 1971 to 1992, over 16 million bricks were manufactured – three sizes of wall bricks and two sizes of paving brick (Gunter, 1989). Five quarries produced 8 types of clay and shale 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):

1. Cretaceous Swan River Formation and Jurassic clays were quarried near Ste. Rose du Lac, 200 km from the Lockport plant by the Medicine Hat Brick and Tile Company Limited, a predecessor to I-XL who opened the Ste. Rose quarry in 1970.
2. A second pit near Ste. Rose du Lac, 1.6 km to the south of the above quarry, was opened up in 1972-73.
3. The Morden Member quarry, situated in E14-33-3-6W1. Small quantities of Morden Member of the Carlile Formation (**STOP 3B**, Figure 12), were quarried west of Miami (160 km from the plant). This was added to the Ste. Rose clay to alter its properties. This quarry is now rehabilitated.
4. The Odanah Member of the Pierre Shale Formation, quarried west of Miami (160 km from the plant), was also added to the Ste. Rose clay to alter its properties.
5. The Odanah Member quarry (Figure 38) is situated across the section road 37W from the R.M. of Thompson Odanah quarry **(STOP 6)** in SW05-24-7W1.

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

There is potential for future brick production in Manitoba, 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 was quarried from ravines and coulees located south of the town of Boissevain in the vicinity of **STOP 15**. This stone was used in several buildings (See: **STOP 16**) constructed in Boissevain and in the surrounding area in the late 1800s and early 1900s (Parks, 1916, p. 173-180; Bamburak, 1978, p. 30). The irregular sandstone concretions from the Upper 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

Turtle Mountain area

As mentioned earlier, under **STOP 17**, coal mining was carried out in the Turtle Mountain area from 1883 to 1908 and from 1931 to 1943 (Figure 25), producing only about 30 000 tonnes of lignite coal from the Goodlands Member of the Turtle Mountain Formation (Figure 3). The coal produced required substantial time to dry out before it could be burnt; and when it was used, it produced substantial smoke and ash. The thick overburden, lack of sufficient lignite thickness (seams ranging from 0.15 to 1.83 m), and water problems ruled out any further underground development; and even strip mining (similar to that presently being carried out near Estevan, Saskatchewan), would be hampered by these uneconomic conditions (Bannatyne, 1978).

Figure 38: *Former property of Red River Brick and Tile (west of **STOP 6**), c1980.*

Porcupine Hills, north flank

Well to the north of the field trip area but also within the Swan River Formation (Figure 3) of the Lower Cretaceous stratigraphic section in Manitoba and Saskatchewan, there have been recent significant coal discoveries along the Manitoba Escarpment, north and west of the Porcupine Hills. This coal is characterized by low sulphur values, low ash content and moderate to high calorific values. Westcore Energy Ltd. (2012a, b) announced that a total of 54.9 million tonnes of measured; 13.7 million tonnes of indicated; and 19.7 million tonnes of inferred subbituminous C coal resources had been measured on their adjacent Panther and Black Diamond properties (outlined as of October 24, 2012 and November 21, 2012, respectively) located roughly halfway between The Pas and Swan River. Additional resources are also being proven up by Saturn Minerals Inc. in the general vicinity of the Westcore properties. And just over the provincial boundary in Saskatchewan, Goldsource Mines Inc. reported on March 19, 2012 that their Border Coal Project comprises 117.0 million tonnes of indicated and 33.0 million tonnes of inferred coal resources.

High calcium limestone

Marco Calcarenite of the Assiniboine Member of the Favel Formation

Morden north area

Marco Calcarenite, near the top of the Favel Formation, outcrops on the First Prairie Level north of Morden (**STOP 2**, Figures 6 and 9) and probably underlies the farm fields to the north and south of section road 20N, for several kilometres to the east and west of the stop. The thickness and quality of the calcarenite in this area is unknown. However, as shown in Figures 4 and 6, the unit is present north of Treherne, where Wells (1905a, p. 63) reported a 1.2 m limestone thick bed outcropping in the Assiniboine River valley in SW36-8-11W1. Two samples of the Marco Calcarenite collected by Wells showed slightly less than 95% $CaCO_3$ – the minimum value necessary to qualify as high-calcium limestone, according to Bannatyne (1975, p. 10).

Dauphin southwest area

Situated to the north of the field trip area, but also within the Favel Formation Canadian Infrastructure Corp. in 2008 and 2009 (a subsidiary of Infrastructure Materials Corp. of the USA**)** obtained over 35 quarry leases and gained access to privately held mineral rights. These rights were obtained for "high-calcium limestone" contained within the relatively near-surface beds of the Marco Calcarenite of the Assiniboine Member of the Cretaceous Favel Formation, 10 km southwest of Dauphin. However, many of the quarry leases were cancelled in 2011. No work was reported.

Natural cement rock

A few exposures of natural cement rock occur in the southern part of the Province along the Manitoba Escarpment. Natural cement was produced in Manitoba from the highly calcareous (37% CaO, 1.5% MgO) shale beds of the Boyne Member of the Carlile Formation in the previously existing communities of 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 works

Cement production in Manitoba began with natural cement rock mined by Manitoba Union Mining Company along the former Canadian Northern railway line, in 9-16-5-7W1, near the former community of Arnold**,** east of Deerwood, on the east slope of Pembina Mountain from 1898(?) to 1904 (Wells, 1905b, p. 35, 36, 52, 53, and Plate 2; Wallace, 1925b, p. 16; 1927, p. 18). Figure 39 shows tram cars, vertical clinker kiln, grinding house and product conveyer at the plant site. The raw material for the plant was the "Babcock" beds within the Boyne Member (Nicolas and Bamburak, 2009).

Babcock cement works

An adit and a second cement rock plant followed at Babcock situated in Roseisle Creek (or Snow) Valley, west of Miami. The Commercial Cement Co. operated the plant on the, then, Canadian Northern railway line from 1907 to 1924 (Wallace, 1925a, p. 31; 1925b, p. 16; 1927, p. 16; Wallace and Greer, 1927, p. 22-24; Goudge, 1944, p. 28, 29). Please note that the former plant site is situated on private land, which is presently not accessible.

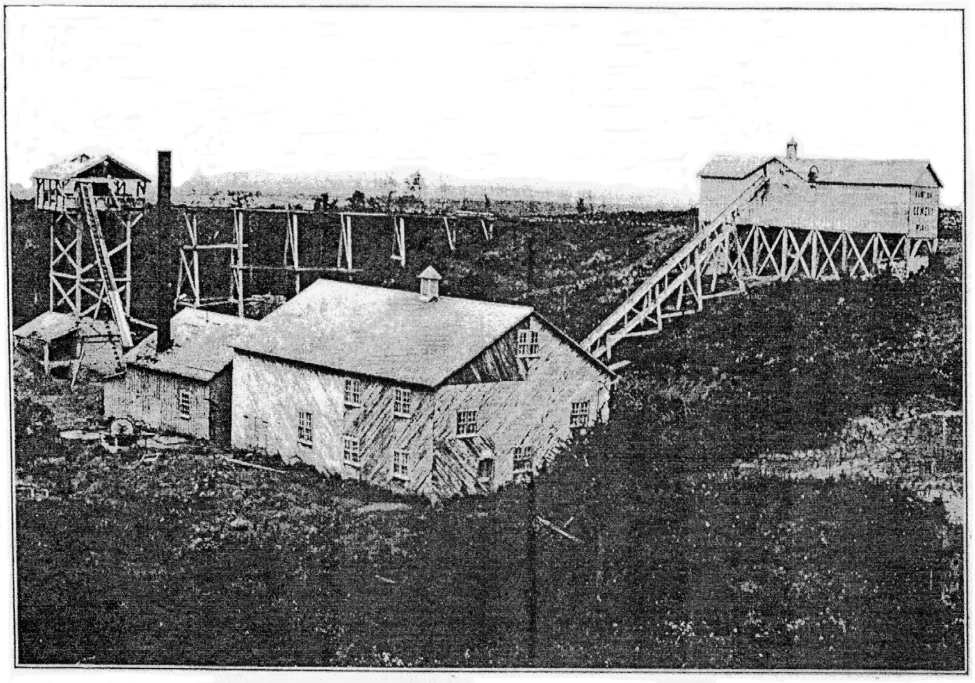
The raw material for the plant was recovered from the Babcock beds by room and pillar mining methods, by way of an adit into the south slope of the Roseisle Creek valley (Wallace and Greer, 1927, p. 22-24; Goudge, 1944, p. 28, 29). The cement rock was then transported over a trestle (constructed over the, now removed, railway track) to the kiln, where it was calcined to form a clinker, which was then crushed into cement. Reported production from the plant in 1908 was 11,234 barrels worth $16,851, in 1909 was 8,600 barrels worth $8,600 and in 1910 was 18,561 barrels worth 21,995 (Dominion Bureau of Statistics, 1957).

The Babcock area deposits (one of which can be seen at **STOP 22B**, Figures 6, 7 and 22B) were leased by Lafarge Canada Inc. in 1992, but were cancelled by the company in 2004.

Oil

Oil shows occur through the stratigraphic sequence in Manitoba from the Ordovician Winnipeg Formation to the Cretaceous Pierre Shale formation. It has been produced in Manitoba since 1951 from the Madison Group of the Mississippian, since 1963 from the (lower) Amaranth Formation, since 1985 from the Bakken Formation, since 1993 from the Melita Formation, and since 2003 from the Torquay Formation. As of November 2012, Manitoba has produced over 50 million m^3 of oil.

A number of oil fields can be seen on this field trip these are the Whitewater, Waskada, Regent and Souris Hartney Fields producing from the Mississippian Lodgepole Formation (Whitewater, Regent, Souris Hartney Fields) and the Lower



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

Figure 39: *Arnold natural cement plant in the Pembina Hills, east of Deerwood, c1904 (Wells, 1905b, Plate 2).*

Amaranth (Whitewater and Waskada Fields). Figure 8 shows oil fields that are located in the general vicinity of this field trip. Figure 40 shows a typical drilling set-up at a wellsite in southwestern Manitoba.

Oil shale

According to Bannatyne (1970, p. 44), in 1965 and 1966, three oil companies investigated the Favel Formation along the Manitoba Escarpment as a possible source of oil shale. Ells (1923) had earlier indicated oil contents of up to 37.5 litres per tonne (L/t) in the Favel shale in the Riding Mountain and Porcupine Mountain areas. The 1965/66 work in the Pembina Hills area indicated a maximum of 60.0 L/t 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 L/t over a 48-metre interval. Samples from the Boyne and Morden members of the Carlile Formation and the Ashville Formation were also included in the analyses. The results showed maximum contents of 65.0, 24.0, and 59.5 L/t, respectively.

In 1983, L.J. Kovac collected 37 samples (1 kg in size) at 15 outcrops in five geographic areas along the Manitoba Escarpment to evaluate their oil shale potential (Kovac, 1983; Kovac and Last, 1991). A weathered sample of the Keld Member of the Favel Formation, collected from the southeast bank of the Assiniboine River in 13-31-8-10W1, had an oil content of 21.36 L/t and total organic carbon (TOC) of 6.06%. Two

Figure 40: *Typical petroleum wellsite drilling set-up (Sinclair Field, located west of the map area shown in Figure 8) (2010-06-02).*

samples were collected from the chalky beds within the Boyne Member of the Carlile Formation, 7 m below surface on the north bank of Deadhorse Creek in 11-21-2-6W1. The weathered sample returned 17.67 L/t and TOC of 5.15%; and the unweathered sample reported 12.94 L/t and TOC of 4.30%.

Additional information useful for the evaluation of oil shale potential along the Manitoba Escarpment can also be found in Nicolas and Bamburak (2009, 2011, 2012) and Nicolas et al. (2010). While the intention of the sampling carried out by the MGS since 2008 has been for the evaluation of unconventional shale gas (See: Shale gas, below), these reports contain the organic geochemical results of numerous Cretaceous samples for TOC and petroleum potential ($S_1 + S_2$), which can be utilized in oil shale potential studies.

Rare earth elements

According to Bamburak et al. (2012a, p. 141), geochemical investigations on the Gammon Ferruginous Member of the Pierre Shale have indicated that the member is relatively enriched in several rare earth elements (REEs) and in Th and U compared with most other Upper Cretaceous units in the southern part of the Manitoba Escarpment. Further studies are ongoing at present to determine the quantity, quality and nature of this mineralization.

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 southwestern Manitoba (Bamburak, 2008; Nicolas, 2008; Fedikow et al., 2009; Nicolas and Grasby, 2009; Nicolas and Bamburak, 2009, 2011, 2012; Nicolas et al., 2010; Hosseininejad, 2012).

Treherne area

The shallow gas show near Treherne is derived from the Babcock beds of the Boyne Member of the Upper Cretaceous Carlile Formation (Wallace and Greer, 1927, p. 71). A well was sunk in 1913, 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 cooking on a small heater. Figure 41 shows an oil well being drilled in 1926 (southeast of the Haskell gas well), but in the same quarter section.

Rathwell-Notre Dame de Lourdes area

The shallow gas shows south of Rathwell and northeast of Notre Dame de Lourdes are derived from the Babcock beds of the Boyne Member of the Upper Cretaceous Carlile Formation. According to Wallace and Greer (1927, p. 71), as of 1927 shallow gas from a well in SW21-7-8W1, on the farm of F. Bosc, had been used to light a kitchen for 6 years. There is no current production from the well, but the old casings are still exposed on surface. Another old water well has intermittently produced gas since 1936 on the farm of N. and G. Bosc in 1-30-7-8W1 (**STOP 21**).

The "Babcock" beds in the Notre Dame de Lourdes-Treherne area correlate with the gas-producing reservoir unit in the town of Kamsack, Saskatchewan (See: Kamsack area, Saskatchewan, below).

Manitou area

Two capped gas wells in the Pembina Valley southwest of Manitou are producing from the Assiniboine Member of the Favel Formation in SE23-2-9W1. Drilling of the first well (shown in Figure 42), originally for oil by the Manitou Syndicate, was done in 1906 and 1907. A gas pocket was struck (below 58 m) in July 1907 (Manitoba Free Press, 1907-07-31); and in September of the same year, at a depth of 274 m, the flow of "gas was so strong that it roared out and burned to height of 15 to 25 feet" (Manitoba Free Press, 1913-10-28). This well became "known far and wide as the Gas Jet", the glow of which could be seen in the night sky, 13 km away in Manitou (as described, in unpublished photocopied notes provided by P. Lea, 2008).

The second gas well (shown in Figure 22) was drilled in 1930/31 in 2-23-2-9W1 by Commonwealth Petroleum Limited (for Pembina Valley Gas and Oil Company). This well located a short distance to the southwest of the 1906/07 well, will be visited at **STOP 14**. Indications of gas were found at several

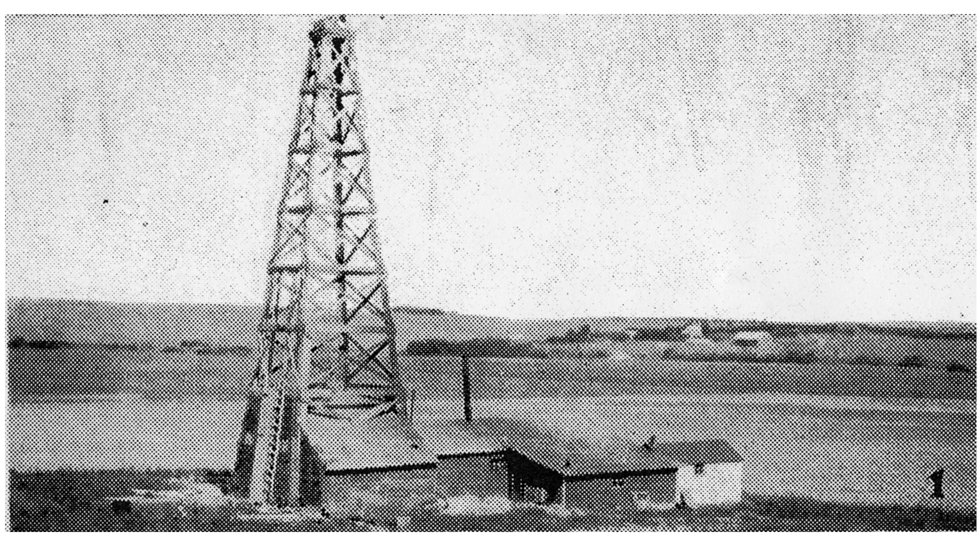


***Figure 41:** Well drilled in 1926 on the farm of E.C. Haskell in NE28-7-10W1 (Wallace and Greer, 1927, Plate IV, photo 1). The farm buildings in the background were likely those of E.C. Haskell (c1926).*

Figure 42: *Drilling set-up at the Manitou wellsite in 1907. Lea family and friends shown at the site (provided by late P. Lea, 2008).*

depths in the hole (Manitoba Department of Mines and Natural Resources 1930, p. 41, 42).

Kamsack area, Saskatchewan

Commercial production of gas from the Boyne Member of the Carlile Formation was achieved at Kamsack, Saskatchewan in the early to mid 1900s. The gas was produced in 8 wells from a 60 m deep reservoir called the Boyne Sand Pool (Simpson, 1970), which is stratigraphically equivalent to the sand beds in southwestern Manitoba (Nicolas and Bamburak, 2009). From 1941 to 1953, 4.7 million m^3 of shale gas was produced with an approximated gas production of 151 mcf/day/well (Simpson, 1970).

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 (**STOP 7**).

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

Mosasaur fossils found during early quarrying operations were taken to Ottawa and placed in the Geological Museum. Numerous fossils have been uncovered in the quarry operations including fish and fish scales, shark teeth, plesiosaurs and mosasaurs. According to Bannatyne and Watson (1982, p. 45), in 1972 a spectacular find of the plesiosaur Dolichornychops was made in a quarry 0.6 km west and 8.2 km north of Thornhill (Figure 6). 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 on display in the Morden museum (Figure 43), as well as in the Museum of Man and Nature in Winnipeg and in the Cretaceous Menagerie at the Wallace Building at the University of Manitoba.

McNeil and Caldwell (1981) described in great detail the use of foraminfera, ammonites and molluscs found in Cretaceous strata of the Manitoba Escarpment to develop a biostratigraphic system for the Western Interior Seaway. Nicholls (1988) conducted the first detailed study of marine vertebrates of the Pembina Member of the Pierre Shale of Manitoba and analyzed their biogeographical distribution in the Western Interior Seaway during the Early Campanian. And recently, a report by Hatcher and Bamburak (2012, p. 178-185) describes the use of fossil pollen and spores to correlate bentonite seams in an effort to study vertebrate fossils within their respective stratigraphic horizons.

Acknowledgments

The authors would like to acknowledge the constructive review of the manuscript for this field trip guidebook by P. Fulton-Regula of the Petroleum Branch of MB Innovation, Energy and Mines.

References

Bamburak, J.D., 1978: Stratigraphy of the Riding Mountain, Boissevain and Turtle Mountain Formations in the Turtle Mountain area, Manitoba; Manitoba Mines, Resources and Environmental Management, Mineral Resources Division, Geological Survey, Geological Report 78-2, 47p.

Bamburak, J.D. 2008: Geochemistry of Upper Cretaceous shale in southwestern Manitoba (NTS 63F, G, H4): potential reservoir rocks for shallow unconventional shale gas; *in* Report of Activities 2008, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 180–184.

***Figure 43:** Bruce, the 13.1 m long Mosasaur, on display over the 2012 Winter Holidays at the CFDC (2012-11-28).*

Bamburak, J.D. and Nicolas, M.P.B. 2009: Revisions to the Cretaceous stratigraphic nomenclature of southwest Manitoba (parts of NTS 62F, G, H, J, K, N, O, 63C, F); *in* Report of Activities 2009, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 183–192.

Bamburak, J.D., Hatcher, J. and Nicolas, M.P.B. 2012a: Chemostratigraphy, paleontology and mineral potential of the Gammon Ferruginous Member of the Cretaceous Pierre Shale in southwestern Manitoba (parts of NTS 62F, G, H, J, K, N, O, 63C, F); *in* Report of Activities 2012, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 141–150.

Bamburak, J.D., Hatcher, J. and Nicolas, M.P.B. 2012b: Visual correlation of bentonite seams in the Upper Cretaceous Pembina Member in the Pembina Hills area, Manitoba and North Dakota; Poster presented at Manitoba Innovation, Energy and Mines, Mining and Minerals Convention 2012, Winnipeg, November 15-17, 2012.

Bannatyne, B.B., 1963: Cretaceous bentonite deposits of Manitoba; Manitoba Mines and Natural Resources, Mines Br. Publ. 62-5, 44p.

Bannatyne, B.B. 1970: The clays and shales of Manitoba; Manitoba Mines and Natural Resources; Mines Br., Publ. 67-1, 107 p.

Bannatyne, B.B. 1978: Industrial minerals drill program; in Report of Field Activities 1978, Manitoba Department of Mines, Resources and Environmental Management; Mineral Resources Division, p. 127-130.

Bannatyne, B.B. and Watson, D.M. 1982: Field Trip 11 - Industrial minerals of the Pembina Mountain-Interlake area, Manitoba; GAC-MAC Winnipeg, 1982 Field Trip Guidebook, 52p.

Bell, J.S., Price, P.R. and McLellan, P.J. 1994: In-situ stress in the Western Canada Sedimentary Basin *in* Geological Atlas of the Western Canada Sedimentary Basin. G.D. Mossop and I. Shetsen (comps.) Calgary, Canadian Society of Petroleum Geologists and Alberta Research Council, p. 439-446.

Braman, D.R., Sweet, A.R. and Lerbekmo, J.F. 1999: Upper Cretaceous – lower Tertiary lithostratigraphic relationships of three cores from Alberta, Saskatchewan, and Manitoba, Canada; Canadian Journal of Earth Sciences, v. 39, p. 669–683.

Ells, S.C., 1923: Cretaceous shales of Manitoba and Saskatchewan: their economic values as a possible source of crude petroleum; Mines Branch, Canada, Report 586, p. 34-41.

Fedikow, M.A.F., Bezys, R.K., Nicolas, M.P.B., and Prince, P. 2009: Preliminary results of soil geochemistry surveys in support of shallow gas exploration, Manitou area, Manitoba (NTS 62G2); *in* Report of Activities 2009, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p.193-206.

Gill, J.R. and Cobban, W.A. 1965: Stratigraphy of the Pierre Shale, Valley City and Pembina Mountain Areas, North Dakota; U.S. Geological Survey, Professional Paper 392-A, 20 p.

Goudge, M.F. 1944: Limestones of Canada: their occurrence and characteristics, Part V, Western Canada; Mines and Geology Branch, Bureau of Mines, Canada, Report 811, 233 p.

Gunter, W.R. 1989: Industrial minerals mapping, Swan River-Mafeking area (63C and 62O); *in* Report of Field Activities 1989, Manitoba Energy and Mines; Minerals Division, p. 127-131.

Hatcher, J. and Bamburak, J.D. 2010: Stratigraphic correlation of multiple bentonite horizons from the Upper Cretaceous Pierre Shale (Pembina Member) of Manitoba (part of NTS 62G1, 2); in Report of Activities 2010, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 178–185.

Hosseininejad, S., Pedersen, P.K., Spencer, R.J., Nicolas, M.P.B. 2012: Mineralogy, geochemistry and facies description of a potential Cretaceous shale gas play in western Manitoba (part of NTS 63K12); *in* Report of Activities 2012, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 151–159.

Kirk, S.R. 1930: Cretaceous stratigraphy of the Manitoba Escarpment; Geological Survey of Canada, Summary Report 1929, pt. B, p. 112-135.

Kovac, L.J. 1983: Examination of Upper Cretaceous oil shales along the Manitoba Escarpment: an assessment of regional variation in mineralogy, organic richness and organic type; Project 820037: unedited report, Geological Survey of Canada, Open File 975, 34p.

Kovac, L.J. and Last, W.M. 1991: Mineralogy and geochemistry of Cretaceous oil shales in Manitoba; *in* Sixth international Williston Basin symposium, Christopher, J.E. Haidl, F.M. (ed.), Saskatchewan Geological Society, Sixth international Williston Basin symposium, Regina, SK, Special Publication 11, p. 275-282.

MacLean, A., 1915: Pembina Mountain; Geological Survey of Canada, Summary Report 1914B. p.69-71.

Matile, G.L.D., Keller, G.R. and Thorleifson, L.H. 2011: Three-dimensional geological mapping in Manitoba: overview and products; *in* Report of Activities 2011, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 171-176.

McCabe, H.R. 1963: Mississippian oil fields of southwestern Manitoba; Manitoba Mines and Natural Resources; Mines Branch, Publication 60-5, 31 p.

McCabe, H.R. and Bannatyne, B.B. 1970. Paleozoic and Mesozoic of the Dawson Bay area and Manitoba Escarpment; Geological Association of Canada/Mineralogical Association of Canada Field Trip Guidebook 1970, No. 6, 30p.

McLearn, F.H. and Wickenden, R.T.D. 1936: Oil and gas possibilities of the Hudson Bay Junction area, Saskatchewan; Geological Survey of Canada, Paper 36-8, 11 p.

McNeil, D.H. and Caldwell, W.G.E. 1981: Cretaceous rocks and their Foraminifera in Manitoba Escarpment; The Geological Association of Canada, Special Paper No. 21, 439 p.

Miami Museum Incorporated, 1974: Pembina Country, Land of Promise; D. Brown (ed.), Miami Museum Incorporated, 116 p.

Nicholls, E.L. 1988: Marine vertebrates of the Pembina Member of the Pierre Shale (Campanian, Upper Cretaceous) of Manitoba and their significance to the biogeography of the Western Interior Seaway; Ph.D. thesis, University of Calgary, 337 p.

Nicolas, M.P.B. 2008: Summary report on petroleum and stratigraphic investigations, southwestern Manitoba; *in* Report of Activities 2008, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 171-179.

Nicolas, M.P.B. 2009: Williston Basin Project (Targeted Geoscience Initiative II): Summary report on Mesozoic stratigraphy, mapping and hydrocarbon assessment, southwestern Manitoba; Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Geoscientific Paper GP2009-1, 19 p.

Nicolas, M.P.B. and Bamburak, J.D. 2009: Geochemistry and mineralogy of Cretaceous shale, Manitoba (parts of NTS 62C, F, G, H, J, K, N): preliminary results; *in* Report of Activities 2009, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p.165–174.

Nicolas, M.P.B. and Bamburak, J.D. 2011: Geochemistry and mineralogy of Cretaceous shale, southwestern Manitoba (parts of NTS 62F, G, J, K, N, 63C): phase 2 results; *in* Report of Activities 2011, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 143-149.

Nicolas, M.P.B. and Bamburak, J.D. 2012: Update on the Shallow Unconventional Shale Gas Project, southwestern Manitoba (parts of NTS 62C, F, G, H, J, K, N, O, 63C); *in* Report of Activities 2012, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 134–140.

Nicolas, M.P.B. and Grasby, S.E. 2009: Water and gas chemistry of Cretaceous shale aquifers and gas reservoirs of the Pembina Hills area Manitoba (parts of NTS 62G); *in* Report of Activities 2009, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 175-182.

Nicolas, M.P.B., Edmonds, S.T., Chow, N. and Bamburak, J.D. 2010: Shallow unconventional Cretaceous shale gas in southwestern Manitoba: an update (parts of NTS 62C, F, G, H, J, K, N); *in* Report of Activities 2010, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 159–169.

Parks, W.A. 1916: Report on the building and ornamental stones of Canada - v. 4, Provinces of Manitoba, Saskatchewan, and Alberta; Canada, Department of Mines; Mines Branch, Report 388, 333 p.

Shayna, M. 1975: Clays of Manitoba and specific clays used by Red River Brick and Tile for brick products. CIM Bulletin, Vol. 68, No. 761, p. 81-84.

Shetty, S. 1994: Industrial minerals. Manitoba Energy and Mines, Mines Branch, Internal Report, 14p.

Simpson, F. 1970: Low depth Saskatchewan prospect; Oilweek, March 30, 1970.

Tovell, W.M., 1948: Geology of the Pembina Valley-Deadhorse Creek area; Manitoba Mines and Natural Resources, Mines Br. Publ. 47-7, 7 p.

Tyrrell, J.B. 1890: The Cretaceous of Manitoba; The American Journal of Science, v. XL, no. 237, p. 227-232.

Tyrrell, J.B. 1892: Report on North-Western Manitoba; *in* Annual Report of the Geological Survey of Canada (1890–91), v. V, pt. 1, p. 153E-171E.

Wallace, R.C. 1925a: The geological formations of Manitoba; Natural History Society of Manitoba, 58 p., map.

Wallace, R.C. 1925b: The mineral resources of Manitoba; Manitoba, Industrial Development Board, 48 p., map

Wallace, R.C. 1927: The mineral resources of Manitoba (second edition); Manitoba, Industrial Development Board, 58 p., map

Wallace, R.C. and Greer, L. 1927: Non-metallic mineral resources of Manitoba; Industrial Development Board of Manitoba, 93 p.

Wells, J.W. 1905a: Preliminary report on the limestones and the lime industry of Manitoba; Mines Branch; Department of the Interior, Preliminary Report 7, 68 p.

Wells, J.W. 1905b: Industrial value of the clays and shales of Manitoba; Mines Branch; Department of the Interior, Preliminary Report 8, 41 p.

Wells, J.W. 1905c: Preliminary report on the raw materials, manufacture and uses of hydraulic cements in Manitoba; Mines Branch, Canada, Report 9, 70 p.

Westcore Energy Ltd. 2012a: Westcore announces initial resource evaluation at Panther coal property; October 29, 2012 Press Release; Westcore Energy Ltd., 3p., URL <http://westcoreenergy.ca/wp-content/uploads/2012/10/WESTCORE-Press-Release-Panther-Resource-final.pdf [January 25, 2013].

Westcore Energy Ltd. 2012b: Westcore announces initial resource evaluation at Black Diamond coal property; November 26, 2012 Press Release; Westcore Energy Ltd., 4p., URL <http://westcoreenergy.ca/wp-content/uploads/2012/11/WESTCORE-Press-Release-43-101-Black-Diamond.pdf> [January 25, 2013].

Wickenden, R.T.D. 1945: Mesozoic stratigraphy of the eastern plains, Manitoba and Saskatchewan; Geological Survey of Canada, Memoir 239, 87 p. incl. Maps 637A, 638A & 713A.

Young, H.R. and Moore, P.R. 1994: Composition and depositional environment of the siliceous Odanah Member (Campanian) of the Pierre Shale in Manitoba; in Perspectives on the eastern margin of the Cretaceous Western Interior Basin, Shurr, G.W. Ludvigson, G.A. Hammond, R.H. (ed.), Geological Society of America (GSA), Special Paper 287, p. 175-195.