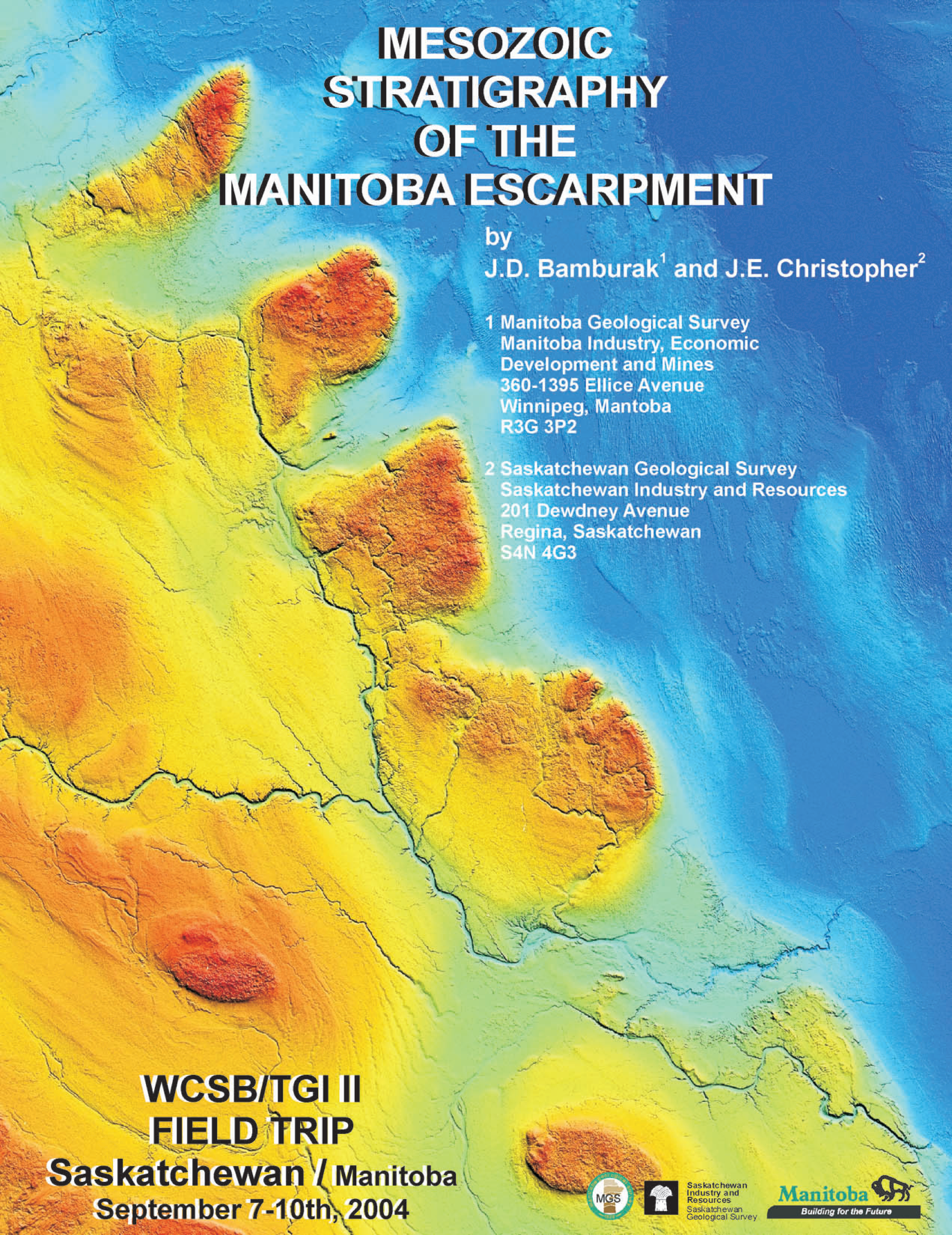

MESOZOIC STRATIGRAPHY OF THE MANITOBA ESCARPMENT

by

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WCSB/TGI II FIELD TRIP

Saskatchewan / Manitoba

September 7-10th, 2004

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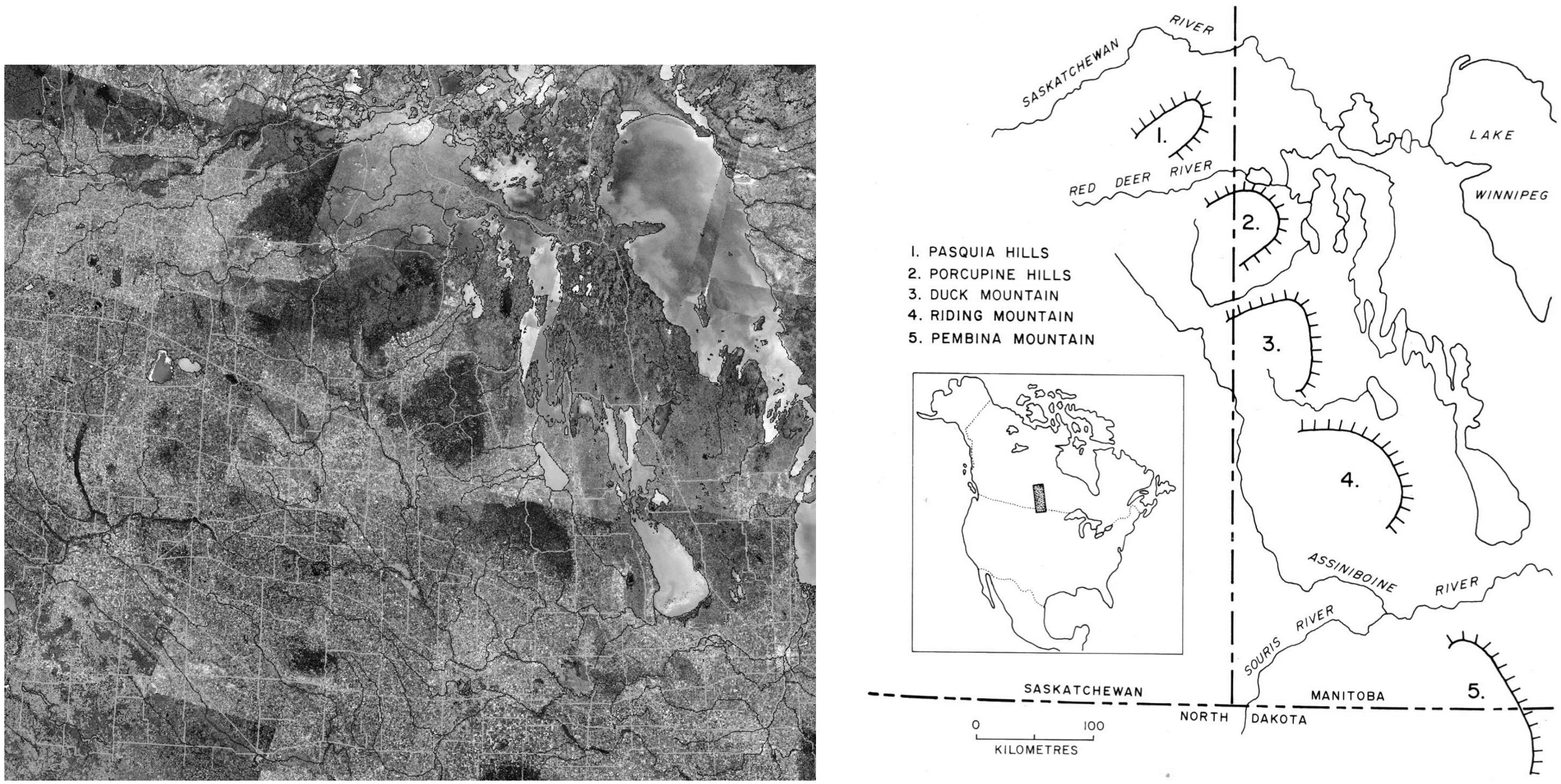

Figure 1: Manitoba Escarpment and upland components.
Left – LANDSAT 7 mosaic. Bands 1, 2, and 3 (visible spectrum) were assigned to the colours blue, green, and red (respectively), resulting in a close to real colour image. Cultural elements (roads and township grid) and geographic elements (rivers) were added to each image.
Right – Location map from McNeil and Caldwell (1981).

PART I: STRATIGRAPHIC SETTING

INTRODUCTION

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

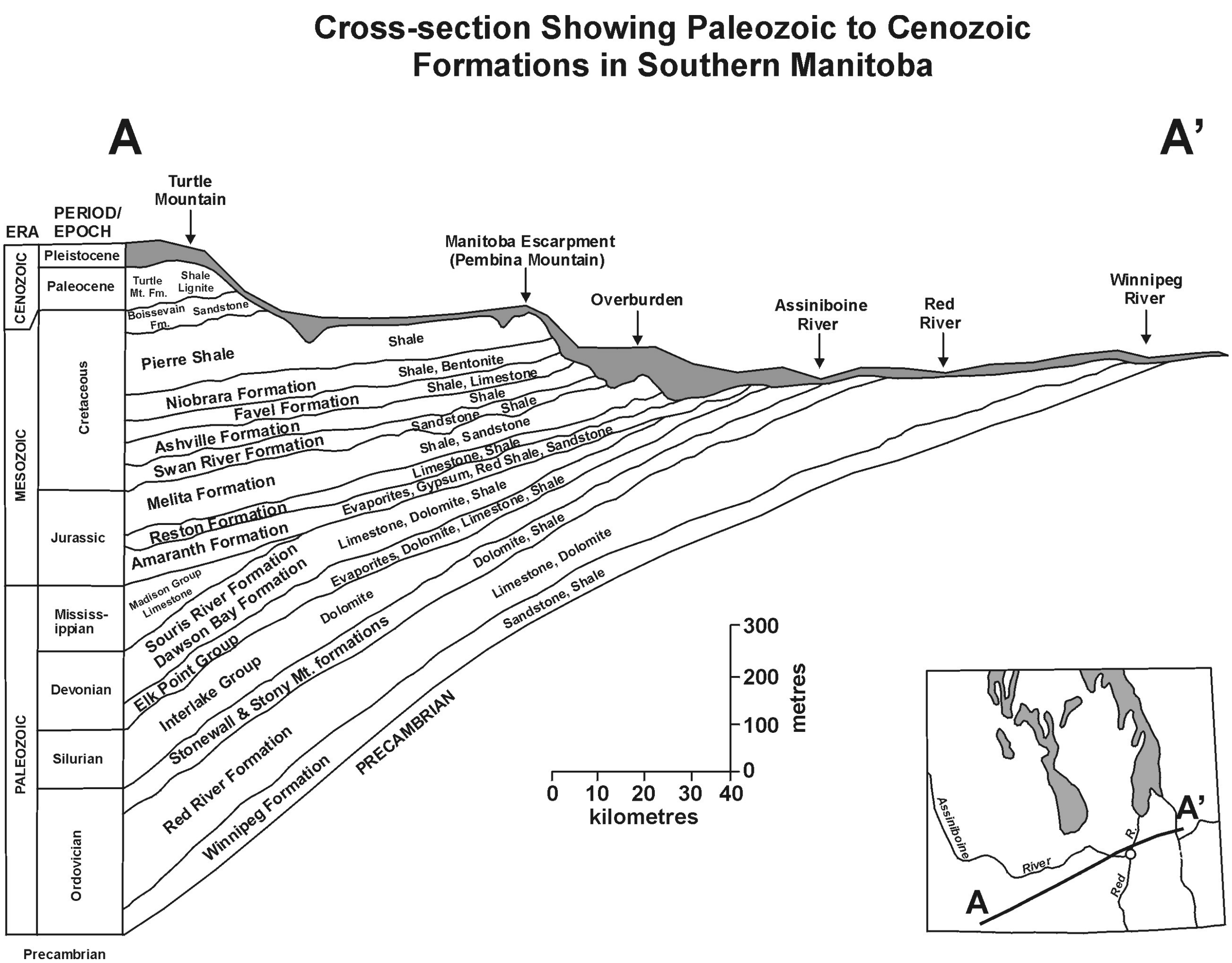

Figure 2: Structure cross section, southern Manitoba.

It should be noted that the Cretaceous stratigraphy that forms the face of the Manitoba Escarpment changes from north to south. In the Pasquia, Porcupine and Duck components (Fig. 1), the edge of the escarpment normally comprises the Favel Formation down to the Ashville Formation (Fig. 3). Whereas in the Riding and Pembina components, the escarpment edge is the Pierre Shale down to the Niobrara. Therefore, the Cretaceous beds that form most of the Manitoba Escarpment range in age from 75 to 125 million years old.

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

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

The Manitoba Escarpment is underlain by a foundation comprised of Devonian carbonate rock (Fig. 4a), dipping southwest at approximately 2.8 m/km; and in the south due to the angular unconformity, by an intervening sequence of shale, sandstone and anhydrite and/or gypsum of Jurassic age (Fig. 4b). Cretaceous sediment was draped over this foundation, as shown in Figure 4c and 4d. The combined thickness of Jurassic and Cretaceous beds at the Manitoba-Saskatchewan boundary with North Dakota attain a maximum thickness of about 1070 m. Dissolution of salt in evaporite beds (such as the Praiirie, Hubbard, Davidson and Amaranth evaporates) within the underlying Devonian and Jurassic sedimentary rocks (Figs. 3, 5) disrupted the normal sedimentation process of the overlying Cretaceous beds. The foundation of the Manitoba Escarpment is described briefly below.

DEVONIAN DEPOSITIONAL FRAMEWORK

Devonian deposition was marked by a major change in the tectonic framework of the Western Canada Sedimentary Basin. The Williston Basin, which had been the centre of subsidence during Ordovician and Silurian time, was no longer the centre of subsidence, but rather, Devonian deposition was related to the Elk

Point Basin, centered in south-central Saskatchewan (Fig. 4a), approximately 500 km northwest of the depocentre of the Williston Basin (Baillie, 1951b; 1953).

AGE Millions of years before present	ERA	PERIOD	EPOCH	FORMATION	MEMBER	MAX. THICK (m)	BASIC LITHOLOGY
	CENOZOIC	QUATERNARY	RECENT				TOP SOIL AND DUNE SANDS.
			PLEISTOCENE	GLACIAL DRIFT		140	CLAY, SAND, GRAVEL, BOULDERS AND PEAT.
		TERTIARY	PLIOCENE				
			MIOCENE				
			OLIGOCENE				
50			EOCENE				
65			PALEOCENE	TURTLE MOUNTAIN	PEACE GARDEN GOODLANDS	120	SHALE, CLAY, SAND, LIGNITE BEDS. LOCATED ONLY IN TURTLE MOUNTAIN.
	MESOZOIC	CRETACEOUS	UPPER	BOISSEVAIN		30	SAND AND SANDSTONE, GREENISH-GREY. LOCATED ONLY IN TURTLE MOUNTAIN.
				PIERRE SHALE	COULTER ODANAH MILLWOOD PEMBINA GAMMON FERRUGINOUS	340	SHALES, GREY, NON-CALCAREOUS, LOCAL IRONSTONE, BENTONITE NEAR BASE, GAS SHOW. SHALE, DARK GREY, CALCAREOUS, NON-CALCAREOUS, BENTONITIC BANDS.
				NIOBRARA		75	SHALE, GREY SPECKLED, CALCAREOUS, BENTONITIC, SLIGHTLY PETROLIFEROUS.
				MORDEN SHALE		55	SHALE, DARK GREY, NON-CALCAREOUS, RARE IRONSTONE CONCRETIONS, LOCAL SAND AND SILT.
			CRETACEOUS	FAVEL	ASSINIBOINE KELD	40	SHALE, GREY WITH HEAVY CALCAREOUS SPECKS, LIMESTONE BANDS AND BENTONITE.
100			LOWER	ASHVILLE	BELLE FOURCHE WESTGATE NEWCASTLE (ASHVILLE) SKULL CREEK	115	SHALE, DARK GREY, NON-CALCAREOUS, FINE-GRAINED QUARTZ SANDSTONE OR SAND "ZONE".
			CRETACEOUS	SWAN RIVER		75	SANDSTONE AND SAND, FINE-GRAINED WITH SILTS AND GREY, NON-CALCAREOUS CLAYS, PYRITIC, GLAUCONITIC.
150		JURASSIC	UPPER JURASSIC	WASKADA		200	BANDED, GREEN BENTONITIC SHALE AND CALCAREOUS, GLAUCONITIC SANDSTONE.
				MELITA	UPPER LOWER		BANDS OF SANDY LIMESTONE, VARI-COLOURED SHALE AND SANDSTONE.
			MIDDLE JURASSIC	RESTON		45	LIMESTONE, BUFF AND SHALES, GREY.
				AMARANTH	UPPER: EVAPORITE	45	ANHYDRITE AND/OR GYPSUM, WHITE AND BANDED DOLOMITE AND SHALE.
					LOWER: RED BEDS	40	SHALE, RED TO SILTSTONE, DOLOMITIC.
200		TRIASSIC	(?)	ST. MARTIN COMPLEX		300	CARBONATE BRECCIA AND TRACHYANDESITE (CRYPTO-EXPLOSION STRUCTURE).
250	PALEOZOIC	PERMIAN					
		PENNSYLVANIAN					
300		MISSISSIPPIAN		MADISON GROUP: CHARLES	DANDO EVAP.	20	MASSIVE ANHYDRITE AND DOLOMITE.
				MISSION CANYON	MC-3 (MC-3b, MC-3a) MC-2 MC-1	120	LIMESTONE, LIGHT BUFF, OOLITIC, FOSSILIFEROUS, FRAGMENTAL, CHERTY, BANDS OF SHALE AND ANHYDRITE.
				LODGEPOLE	FLOSSIE LAKE WHITEWATER LAKE VIRDEN SCALLION / ROUTLEDGE	185	LIMESTONE AND ARGILLACEOUS LIMESTONE, LIGHT BROWN AND REDDISH MOTTLED, SHALEY ZONES, OOLITIC, CRINOIDAL AND CHERTY.
				BAKKEN	UPPER MIDDLE LOWER	20	TWO BLACK SHALE ZONES SEPARATED BY SILTSTONE.
350		DEVONIAN		Qu'Appelle Group: THREE FORKS		35	SILTSTONE AND SHALE, RED, DOLOMITIC.
				SASK. GROUP: BIRDBEAR		40	LIMESTONE AND DOLOMITE, YELLOW-GREY, FOSSILIFEROUS, POROUS, SOME ANHYDRITE.
				SASK. GROUP: DUPEROW		170	LIMESTONE AND DOLOMITE, ARGILLACEOUS AND ANHYDRITIC IN PLACES.
				MAN. GROUP: SOURIS RIVER (FIRST RED)		120	CYCLICAL SHALE, LIMESTONE, DOLOMITE AND ANHYDRITE.
				MAN. GROUP: DAWSON BAY (SECOND RED)		65	LIMESTONE AND DOLOMITE, ANHYDRITIC. LOCAL RED AND GREEN SHALE.
				ELK POINT GROUP: PRAIRIE EVAP.		120	HALITE, POTASH, ANHYDRITE AND DOLOMITE INTERBEDDED.
				ELK POINT GROUP: WINNIPEGOSIS	UPPER (REEF)	75	DOLOMITE, LIGHT YELLOWISH-BROWN, REEFOID.
				ELK POINT GROUP: ELM POINT	LOWER (PLATFORM)		LIMESTONE, FOSSILIFEROUS, HIGH-CALCIUM.
400				ELK POINT GROUP: ASHERN		12	DOLOMITE AND SHALE, BRICK RED TO VARIGATED GREEN.
		SILURIAN		INTERLAKE GROUP		135	DOLOMITE, YELLOWISH-ORANGE TO GREYISH-YELLOW FOSSILIFEROUS, SILTLY ZONES.
		ORDOVICIAN		STONEWALL	UPPER	20	DOLOMITE, GREYISH-YELLOW, BEDDED.
					LOWER / WILLIAMS		DOLOMITE, YELLOWISH-GREY, SHALY.
				STONY MOUNTAIN	GUNTON PENITENTIARY	25	DOLOMITE, DUSKY-YELLOW, FOSSILIFEROUS.
					GUNN	20	SHALE, RED-GREEN, FOSSILIFEROUS LIMESTONE INTERBEDS.
450				RED RIVER	FORT GARRY SELKIRK CAT HEAD DOG HEAD	170	DOLOMITIC LIMESTONE, MOTTLED AND MOTTLED DOLOMITE.
				WINNIPEG	UPPER SHALE	60	SHALE, GREEN, WAXY, AND INTERBEDDED SANDSTONE.
500					LOWER SANDSTONE		SAND AND SANDSTONE, QUARTZOSE.
550		CAMBRIAN		DEADWOOD		60	SAND, BLACK TO GREEN-GREY, WAXY, GLAUCONITIC SILTSTONE AND SHALE, GREEN-GREY TO BLACK. LOCATED ONLY IN EXTREME SOUTHWEST CORNER OF MANITOBA.
	PRECAMBRIAN						ACID AND BASIC CRYSTALLINES AND METAMORPHICS.

Figure 3: Geological formations in southern Manitoba.

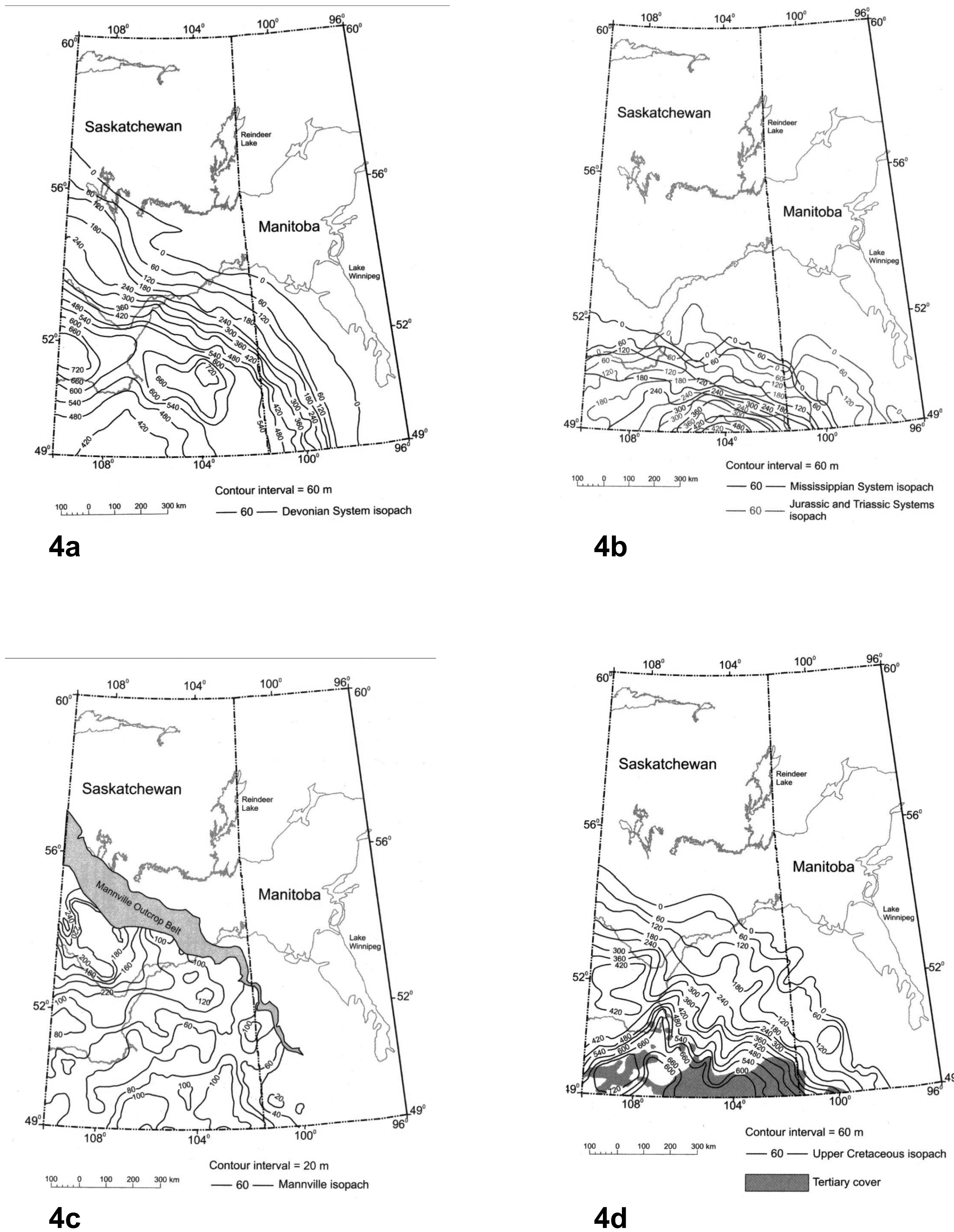

Figure 4: Isopach maps of Saskatchewan and Manitoba from Saskatchewan Geological Survey (2003).
a – Devonian strata (contour interval 60 m).
b – Mississippian System (solid lines) and the Jurassic and Triassic systems (grey lines) (contour interval 60 m).
c – Manville Group (contour interval 20 m).
d – Upper Cretaceous strata (contour interval 60 m). Also shown is the distribution of Tertiary rocks.

CRET. / JUR.	GROUP/FORMATION/MEMBER			M	DEPOSITIONAL THICKNESS (METRES) AND SUMMARY LITHOLOGY
DEVONIAN	SOURIS RIVER FORMATION		Sagemace Member	20+	Limestone, pale yellowish brown to reddish grey, microcrystalline, dense, minor argillaceous interbeds. Passes laterally to totally dolomitized sequence.
DEVONIAN	SOURIS RIVER FORMATION		basal shale	2-14	Shale, dolomitic, massive, medium brownish red with some greenish mottling.
DEVONIAN	SOURIS RIVER FORMATION		(evaporite dissolved)		(Davidson Evaporite)
DEVONIAN	SOURIS RIVER FORMATION	Point Wilkins Member	Upper Point Wilkins	10	Dolomite and dolomitic limestone, light grey to medium yellowish brown, partly mottled, coarsely microcrystalline, subsaccharoidal with remnant calcareous biomicrite.
DEVONIAN	SOURIS RIVER FORMATION	Point Wilkins Member	Middle Point Wilkins	14-21	Limestone (pure high-calcium), pale yellowish brown, faintly mottled, finely microcrystalline to cryptocrystalline, dense and tight (sublithographic), fossiliferous, in part intraclastic.
DEVONIAN	SOURIS RIVER FORMATION	Point Wilkins Member	Lower Point Wilkins	9-15	Limestone, slightly to moderately argillaceous with some interbeds calcareous shale, medium to light reddish and purplish grey, fossiliferous intramicrite, locally calcarenitic.
DEVONIAN	SOURIS RIVER FORMATION		First Red Beds	3-14	Shale, dolomitic, medium reddish grey to dark brownish red, in part mottled and brecciated. Several interbeds buff argillaceous limestone to brown argillaceous dolomite.
DEVONIAN	DAWSON BAY FORMATION		(evaporite dissolved)		(Hubbard Evaporite)
DEVONIAN	DAWSON BAY FORMATION		Upper Dawson Bay	6-17	Limestone, white to pale yellowish brown, highly fossiliferous with corals and stromatoporoids, in places grading to stromatoporoid biolithite. In part extremely pure high-calcium limestone (99.8% $CaCO_3$), but in places variably dolomitized, especially lower part of unit.
DEVONIAN	DAWSON BAY FORMATION		Middle Dawson Bay	11-18	Calcareous shale, fossiliferous, medium grey to dark greyish red, massive (recessive).
DEVONIAN	DAWSON BAY FORMATION		Lower Dawson Bay	9-25	Gradational sequence passing upward from brown partly laminated and bituminous dolomite to grey and reddish grey dense slightly argillaceous micrite and fossiliferous micrite, which in turn grades upward to highly fossiliferous brachiopod biomicrite at top. Lower two zones thin markedly to the north.
DEVONIAN	DAWSON BAY FORMATION		Second Red Beds	6-15	Red to greenish grey dolomitic shale, commonly brecciated as a result of salt collapse.
DEVONIAN	ELK POINT GROUP	WINNIPEGOSIS FORMATION	PRAIRIE EVAPORITE	0-129	Prairie Evaporite: dominantly salt with potash interbeds and minor anhydrite in basinal areas; entirely anhydrite in shelf areas (at present). Originally present throughout the entire Devonian outcrop belt, but subsequently removed by subsurface salt solution. Where preserved in subsurface, overlaps and completely buries Winnipegosis reefs with resultant thinning of evaporite section.
DEVONIAN	ELK POINT GROUP	WINNIPEGOSIS FORMATION	Upper Winnipegosis (reef)	0-90	Reefal facies: dolomite, very fine to medium crystalline, ranges from compact dense to subsaccharoidal, massive to medium/thick bedded, variably fossiliferous but texture largely obscured by dolomitization. Reef thicknesses tend to be relatively uniform in a given area.
DEVONIAN	ELK POINT GROUP	WINNIPEGOSIS FORMATION	Upper Winnipegosis (interreef)	35	Interreef facies: dolomite, brown to black, finely laminated with black bituminous partings, in places calcareous. Lamination best defined towards top of unit.
DEVONIAN	ELK POINT GROUP	WINNIPEGOSIS FORMATION	Lower Winnipeg-osis	10-20	Lower Winnipegosis: dolomite, fine to medium crystalline, moderately granular to saccharoidal, medium to thin bedded. In part calcareous and grades laterally to Elm Point limestone facies.
DEVONIAN	ELK POINT GROUP		ELM POINT FORM.	10-20	Elm Point: limestone, pale yellowish brown dense fine grained biomicrite. In part shows lighter yellowish dolomitic mottling. Pure high-calcium limestone to calcareous dolomite.
DEVONIAN	ELK POINT GROUP		ASHERN FORMATION	3-18	Argillaceous dolomite and dolomitic shale, medium to dark greyish and brownish red, in places reduced to greenish grey. Local basal dolomite breccia.
SIL.	INTERLAKE GROUP				Dolomite, white to pale yellowish buff, mostly microcrystalline dense, thin bedded, sublithographic, in part stromatolitic. Some porous biostromal interbeds towards top.

Figure 5: Detailed stratigraphic succession and lithology, Devonian formations

In general, the outcropping portion of the Devonian sequence comprises a series of complex carbonate-evaporite cycles, although in all cases the evaporites have subsequently been dissolved from the outcrop areas (Fig. 5). The first, thickest and best defined cycle comprises the Elk Point Group. The basal unit of this cycle consists of a red bed unit, the Ashern Formation, succeeded by the Winnipegosis/Elm Point Formation and the Prairie Evaporite. The second depositional cycle is represented by the Dawson Bay Formation, initiated by the Second Red Beds and culminating with the Hubbard Evaporite (in the central portion of the basin). The third cycle comprises the Point Wilkins Member of the Souris River Formation (Davidson Member of Saskatchewan), initiated by the First Red Beds, and culminating with the Davidson Evaporite (in the central portion of the basin). A fourth cycle consists of the Saskatchewan Group, including the Duperow and Birdbear formations.

ELK POINT GROUP

Ashern Formation

The red dolomitic shales and breccias of the Ashern Formation represent the basal deposits of the major Middle Devonian transgressive sequence. The irregular isopach pattern of the Ashern Formation reflects the gentle irregularity of the underlying Silurian erosion surface. The major period of uplift and erosion in late Silurian to early Devonian time, resulted in complete removal in Manitoba of the Upper Interlake strata, which attain a maximum thickness of about 175 m in the central part of the Williston Basin. However, despite the probable erosion of up to several hundred metres of upper Silurian strata in Manitoba, there is no evidence of any appreciable angular truncation of Silurian beds in southern Manitoba.

Locally, in the subsurface, some suggestion of incipient karst development has been noted at the erosion surface, although this is not obvious in the outcrop belt due to glacial scouring and infill. Minor infiltration of Ashern-related shale into the upper Silurian beds can be seen locally.

Winnipegosis/Elm Point Formation

The rather poorly defined depositional trends of the Elk Point Group, as shown by the Winnipegosis Formation isopach, appear to be approximately northeast. The general pattern is one of gradual, fairly uniform thickening to the west and northwest, up to a maximum of about 55 m. This facies was deposited in a shelf to fringing bank environment. West and northwest from this bank, the Winnipegosis Formation is seen to thin, in places very abruptly, to as little as 12 m, but with local areas of thickening to as much as 105 m. This latter area of variable thickness represents a basinal reef-interreef complex. Apparently, basin subsidence and differentiation was sufficiently rapid so that only in certain areas (original organic mounds?) was organic growth able to keep pace with subsidence. Reefs developed in these areas, but in the intervening interreef areas, the only (remaining) deposits are a thin sequence of dark, organic rich (5-6% TOC – total organic carbon content), finely banded to laminated sediments, referred to as bituminous laminites (= Ratner Member in Saskatchewan).

Stratigraphically, the Winnipegosis can be subdivided into two units, a Lower Winnipegosis Member which comprises a relatively uniform blanket type of deposit, or platform, and an Upper Winnipegosis Member which, in the more basinal areas, consists of either thick "reefal" carbonates or a thin sequence of interreef bituminous laminites.

Throughout the northern part of the outcrop belt, and in almost all of the subsurface, the Lower Winnipegosis consists entirely of a medium to coarsely crystalline granular to subsaccharoidal, vuggy, sparsely fossiliferous dolomite. The relict limestone facies of the Lower Winnipegosis has been named the Elm Point Formation (Kindle, 1914). Limited core data suggest that the degree of dolomitization of the platform beds (*i.e.* Lower Winnipegosis/Elm Point) may have been controlled by proximity to reef sites in the overlying Upper Winnipegosis.

A recent study by Chow and Longstaffe (1995) tentatively suggests that the microdolomites and microcrystalline dolomite of the Elm Point Formation are geochemically distinct from those of the Winnipegosis Formation, discounting any genetic linkage between these dolomites. The fabric-selective nature of the Elm Point dolomite suggests that the nature of the host rock, *i.e.*, intrinsic factors, played a major role in determining the extent of dolomitization within the Elm Point Formation. The implication that the Elm Point was not a major conduit for dolomitizing fluids into the Winnipegosis buildups in Manitoba contrasts the idea that there was a genetic connection.

The common occurrence of limestone in the Lower Winnipegosis (*i.e.* Elm Point) of the Manitoba outcrop belt probably is significant, inasmuch as this is the only area in the Elk Point Basin where such relict limestones are common, if not dominant. A possible explanation is that this area comprises the distal end of the Elk Point Basin, farthest removed from the area of influxing brines, which is believed to have been in northwestern Alberta. Consequently, the tendency for brine circulation and resultant dolomitization would have been minimized. Dolomitization possibly was reduced further by influx of fresh meteoric water from the hinterlands to the east and southeast. Also, the paleogeography of the northeastern flank of the basin is completely unknown. The preservation of a thick section of Elm Point limestone as a tectonic slump block within the Lake St. Martin crater structure (the most northeasterly known occurrence of Devonian strata) is additional evidence of reduced brine circulation on this flank of the basin.

Distinction between the Upper Winnipegosis and the Lower Winnipegosis is obvious in the basinal interreef areas where the massive granular vuggy dolomites of the Lower Winnipegosis platform pass sharply into the distinctive thinly bedded bituminous laminites of the Upper Winnipegosis. In marked contrast, for reefal areas, there is generally no appreciable lithologic change between Lower Winnipegosis platform beds and Upper Winnipegosis "reefal" facies. An increase in fossil content, especially corals and stromatoporoids may be evident but the extreme effects of dolomitization have, for the most part, obscured the primary textures, making stratigraphic separation of Lower and Upper Winnipegosis beds difficult. In effect, the Upper Winnipegosis reefs appear to comprise local thickening of the Lower Winnipegosis platform.

Salt Collapse Structures

Before further discussion of the relation of Devonian outcrops to the depositional basin, it is necessary to note the extreme effect of salt solution and collapse on the outcrop geology. As noted above, Devonian reefs occur from the Dawson Bay area south to The Narrows (Lake Manitoba). During late Elk Point time, all of these reefs were buried by evaporites (primarily halite) of the Prairie Evaporite, which overlapped an unknown distance from the fringing bank and shelf area. Flat-lying, uniform Dawson Bay strata were then deposited over the evaporites, with no evidence of influence by underlying reefs. The uniformity of the Dawson Bay beds shows that burial of Winnipegosis reefs was complete. In western Manitoba and Saskatchewan, within the remaining portion of the salt basin, reefs are overlain by 60 m to 100 m of salt, but there is no way to accurately estimate the original salt thickness (and hence the amount of salt collapse) in the area of the Manitoba outcrop belt.

Subsequent to burial by Dawson Bay strata, the Prairie Evaporite was dissolved from the entire outcrop area as well as a large portion of the subsurface. Most of this solution is believed to have occurred during the period of late Paleozoic to early Mesozoic uplift and erosion, but localized episodes of evaporite solution also occurred throughout late Paleozoic and Mesozoic time. The earliest (Late Devonian and Mississippian) collapse episodes appear to have been local features, possibly fracture or fault controlled, whereas the main pre-Mesozoic solution episode appears to have resulted from widespread regional solution, possibly related to regional groundwater flow through the underlying Winnipegosis and Interlake strata. The salt solution process is continuing at the present time, as evidenced by the outflow of brine from the numerous salt springs along the Devonian outcrop belt **(STOP 4).**

As a result of salt solution, all of the post-evaporite strata collapsed and were draped over the underlying Winnipegosis reef-interreef complexes. The <u>minimum</u> amount of subsidence or collapse in a given area is equal to the reef-interreef relief. All of the Dawson Bay and Souris River outcrop occurrences **(STOPS 3 and 5)** have thus been subjected to varying degrees of salt collapse, and more importantly, the <u>structural configuration shown by these strata reflects precisely the topography of the underlying Winnipegosis surface</u>. Local, reef-controlled structural relief ranges from 35 m in The Narrows area to 75 m in the Dawson Bay area. The superficial structure effectively masks the gentle uniform true structural dip, which averages only about 2.0 m/km (0.1°).

The process of salt collapse has been, in places, a series of two or more collapse events, rather than a single event. Collapse can be extremely uniform with no visible evidence of structural deformation, or it can be a "catastrophic" event giving rise to a chaotic mega-breccia. The salt collapse scenario is complicated further by the probable original occurrence of multiple salt horizons. In the deeper parts of the Elk Point Basin, additional evaporite units occur both at the top of the Dawson Bay Formation and at the top of the Point Wilkins Member of the Souris River Formation (Fig. 5). Breccia zones at these horizons in the Manitoba outcrop sequence indicate that these evaporites, as well as the Prairie Evaporite, extended throughout most, if not all of the outcrop belt. Dissolution of these younger evaporites occurred as well, but identification of collapse structures related specifically to these younger evaporites is not possible because of the lack of pre-evaporite paleotopographic relief.

Winnipegosis Reef Morphology (Subsurface) Swan River Area

Although some of the regional variations in Upper Winnipegosis reef configuration have been noted, the details as to size, shape and distribution of individual buildups are largely unknown. In the outcrop belt we have only a very limited insight, and even this is largely indirect, as will be described later. The only area where the size and shape of a portion of a reef complex can be determined (other than in seismic studies) is in the Swan River area, 80 km southwest of the Dawson Bay outcrop belt. In 1951-52, Shell Oil Co. drilled 108 shallow structure test holes to Devonian markers, mainly the Upper Devonian Souris River and Duperow formations. Seismic interpretations for salt solution areas are questionable because of the extremely complex velocity anomalies resulting from both primary lithofacies variations and secondary brecciation effects (McCabe, 1985). Two deep test holes were subsequently drilled by Shell to test structural highs outlined by this study, and still later, five additional deep test holes were completed (including 4 holes completely cored). All deep holes indicate a very uniform regional dip for pre-Winnipegosis strata, but complex structure is evident in the younger Devonian beds. All of this shallow structure can be attributed to variations in Winnipegosis thickness, as a result of younger Devonian strata being draped over Winnipegosis reefs due to post-Devonian solution of the Prairie Evaporite.

It is worth noting that reef thickness in the Swan River area falls well within the thickness range of the central-basin reefs of Saskatchewan, supporting the suggestion that the Swan River-Dawson Bay area of Manitoba represents a central basinal facies. In fact, the thickest reef sections in Manitoba (Shell Swan River 09-01-37-28W1, 107 m; Camperville South Quarry, 105 m, estimated) are close to the maximum reported for Winnipegosis reefs anywhere in the southeastern part of the Elk Point Basin.

The distribution of Winnipegosis reefs and reef-controlled structures, as seen in the outcrop areas, supports the concept of a relatively uniform reef height or thickness. Some Winnipegosis reefs appear to be small isolated "pinnacle-type" reefs, whereas others, in particular the larger reef complexes (*i.e.* Salt Point area), appear to be partly flat-topped, possibly atoll-like in configuration.

Effects of Reef Morphology on Outcrop Patterns

The above noted reef characteristics, as determined for the Swan River area, especially the uniformity in reef thickness, have had a pronounced effect on the Devonian outcrop patterns. Specifically, for the Dawson Bay area, where the regional dip is only 1.8 m/km, the 60 m of structural relief associated with reef development (and as reflected by subsequent salt solution) can give rise to an up dip or down dip shift of about 32 km in expected location of an outcrop unit. Because of the uniformity of reef thickness, two completely separate "outcrop belts" can be established for each unit; a structurally high, reef-supported belt, and a structurally low (normal) interreef outcrop belt. Thus, the interreef outcrop belt of the Souris River Formation, Point Wilkins Member **(STOP 5)** coincides with the reef-supported outcrop belt of the lower member of the Dawson Bay Formation **(STOP 3)**. Most Lower Dawson Bay occurrences along this reef-supported outcrop belt consist of structural/topographic domes, providing direct evidence of the underlying "pinnacle-type" reef. A few Lower Dawson Bay outcrops along this belt are seen to be flat-lying, indicating that they are underlain by flat-topped portions of a reef complex. Flat-lying Lower Dawson Bay outcrops in a "normal" or interreef setting, occur 32 km to the northeast, on Cameron and Pelican Bays (Lake Winnipegosis). Very few other stratigraphic intervals are represented within this "composite outcrop belt" indicating the relative scarcity of reef flank deposits or reefs other than "normal" thickness.

On the same basis, an outcrop belt of Upper Dawson Bay reef-supported structural-topographic domes occurs immediately down dip from the belt of Lower Dawson Bay domes, and coincident with the interreef outcrop belt of the upper part of the Point Wilkins Member. Similar outcrop patterns can be shown throughout the Devonian outcrop belt, but are not as well defined as in the Dawson Bay area because of the sparse well control.

Post-Reef Erosion, Sedimentation, and Diagenesis

One final comment must be made regarding reef morphology as reflected in the structure of the overlying beds. It has been noted that such structure reflects only the final configuration of the Winnipegosis reef. This configuration probably reflects some degree of post-Winnipegosis/pre-Prairie Evaporite erosion, depending on the amount of sea level drop (evaporitic drawdown?) in the basin before and during Prairie Evaporite time. Some workers (Fuller and Porter, 1969a; 1969b) have suggested that the lower part of the Prairie Evaporite sequence was deposited under sabkha conditions, in which case virtually the entire Winnipegosis reef succession would have been subaerially exposed and subjected to erosion and vadose diagenesis. Evidence of limited drawdown and associated vadose diagenesis, including development of vadose pisolites, has been documented for the upper parts of Winnipegosis reefs (Maiklem, 1971; Wardlaw and Reinson, 1971).

With regard to vadose diagenesis, the reported occurrence of stratigraphically defined halos of anhydrite (Wardlaw and Reinson, 1971) surrounding some central basin reefs in Saskatchewan may be significant. Such halos must reflect locally reduced salinity and a local increase in the supply of Ca^{++} ions in solution in waters surrounding the reef. Inasmuch as the reefs are completely enclosed in salt deposits, there have been no "reduced restriction" in these areas. The entire basin sea was saturated and precipitating halite at the same time the anhydrite halos were being emplaced. One explanation for the locally reduced salinity and anhydrite precipitation would be a supply of fresh (or less saline) water and Ca^{++} ions from the reef itself. This could have been supplied by at least two mechanisms. The first would involve a regional flow of subsurface formation waters (normal marine?) through underlying strata, presumably the Winnipegosis platform beds, with discharge from these beds through overlying reefs subaerially exposed due to evaporitic drawdown. Introduction of this lower salinity water into the evaporite basin would give rise to a halo of reduced salinity and anhydrite precipitation, and the stratigraphic level of the anhydrite beds should reflect the approximate position of sea level, and show the extent of reef exposure above sea level. The input area for the subsurface flow system could have been the Presqu'ile Barrier reef complex in northwest Alberta, which is believed to have caused regional restriction of the Elk Point Basin. The driving force for the subsurface flow system could have been the difference in "sea level" between the oceanic source and the drawdown level established in the Elk Point Basin (Maiklem, 1971). Alternatively, Jodry (1969) suggested that compaction of carbonates, especially in interreef areas, resulted in expulsion of pore fluid, with the fluid discharging through the reefs and causing dolomitization of the reefs. Alternatively, this expelled connate water also could have given rise to the anhydrite halos around the reefs.

A third explanation for the anhydrite halos would be to have the reefs subaerially exposed (by evaporitic drawdown) so that the reef acted as a freshwater catchment for rainfall, which would percolate through the reef, pick up Ca^{+2} ions while subjecting the reef to vadose diagenesis, and then precipitate the Ca^{+2} as $CaSO_4$, on contact with the brines surrounding the reef. Brines saturated to the point of precipitation of NaCl are in effect supersaturated with respect to SO_4^{-2}, relative to normal sea water, so any Ca^{+2} ions introduced into such a saline environment would be precipitated immediately as $CaSO_4$, at the same time reducing the salinity in the area surrounding the reef to a point below the NaCl saturation level.

All of the above mechanisms could have been operative at the same time. The apparently considerable areal extent of the anhydrite halos around the reefs would require a relatively large flow of "fresher" water, which would probably have been supplied more easily by a regional subsurface flow system. This would have to be through the Elm Point platform and would seem to be a logical mechanism for dolomitization.

A diagenetic model has also been suggested for the formation of reef-flank anhydrites, with the anhydrite being formed by replacement of reef-flank dolomites (as has been proposed for the Keg River reefs of Alberta). However, Kendall (1975) notes that there is little evidence of a replacement origin for the anhydrites associated with the Winnipegosis reefs in the Saskatchewan portion of the Elk Point Basin. He also notes that the halite beds of the Lower Prairie Evaporite (Whitkow Member) interfinger with the reef flank anhydrites, which provides further evidence of a primary origin for the reef-flank anhydrites.

The foregoing discussion of the origin of the Winnipegosis reefs is based on limited data and hence is rather speculative. Nevertheless, in view of the sparsity of outcrops and lack of definitive reefal exposures, the authors thought is necessary to provide a framework in which the field trip participants might better anticipate difficulties in correlation between Cretaceous sections, especially in the outcrop belt.

MANITOBA GROUP

Dawson Bay Formation

Dawson Bay strata comprise the second of the series of Devonian evaporite cycles. The formation is subdivided in the four units shown and described in Figure 5. These units show pronounced differences in resistance to erosion. The soft recessive shales of the Second Red Beds and the Middle Dawson Bay Member almost never occur in outcrop, whereas outcrops of the hard resistant strata comprising the brachiopod biomicrite zone of the Lower Dawson Bay Member, and the Upper Dawson Bay Member (coral-stromatoporoid beds) are common. Because these resistant beds are thin, uniform, persistent and easily identified, precise stratigraphic correlation and structural data can be determined from these outcrops.

The interbedding of resistant and recessive units coupled with reef-related salt solution collapse structures, has had a pronounced affect on the Devonian outcrop pattern. The soft shales overlying the resistant beds have been removed by glacial erosion, exposing a smooth bedding-plane surface of the underlying resistant beds. These bedding surfaces conform to the underlying Winnipegosis reef configuration, with the result that throughout much of the outcrop belt, the exposed bedrock topography reflects the structure of the Winnipegosis reefs. This effect is quite spectacular along the old Pelican Rapids Road, in the Dawson Bay area, where the road-bed in many places is a bedding-plane surface and road undulations directly reflect the reef topography.

Because of differential erosion of Dawson Bay strata, outcrop occurrences are limited to the resistant beds; consequently, Dawson Bay outcrops along the outcrop belt do not show any appreciable lithologic variation. However, lithologic changes, determined from corehole drilling appear to reflect the presence of a distinct sub-basin during Dawson Bay time, more or less coincident with the southern portion of the outcrop belt. The middle calcareous shale member, although persistent and uniform throughout the outcrop belt, disappears rapidly to the west in the subsurface by thinning and facies change to relatively clean carbonates. This fossiliferous shaly unit is not recognizable in the Saskatchewan succession (Lane, 1959), and probably represents a deeper-water, lower-energy deposit directly related to the sub-basin.

Considerable thickening of the Lower Dawson Bay Member is evident to the south, along the outcrop belt. This is due primarily to thickening of the lower part of the unit, which consists largely of dark brown, partly laminated and partly bituminous microgranular dolomites and slightly argillaceous micritic limestones. These beds are also indicative of deposition under relatively deeper-water, low-energy, more basinal conditions in a depositional sub-basin. The interbedding of relatively deeper water deposits (lower part of Lower Dawson Bay and Middle Dawson Bay) with shallower water deposits (upper part of Lower Dawson Bay and Upper Dawson Bay) indicates a subdued cyclical pattern of deposition during Dawson Bay time.

Two beds of high-calcium limestone occur within the Dawson Bay Formation. One bed exists within the Lower Dawson Bay Member and consists of dolomite overlain by dolomitic limestone that grades to a high-calcium limestone. This “Dawson Bay lower limestone zone” consists of micrite and highly fossiliferous brachiopod biomicrite. The second unit of high-calcium limestone occurs within the “Dawson Bay upper limestone zone”. It is present within the upper Dawson Bay Member and consists of a coral-stromatoporoid biolithite and is an almost chemically pure limestone (Bannatyne, 1975).

Souris River Formation

Only the lower portion of the Souris River Formation outcrops in Manitoba. Two members have been defined (Fig. 5), a lower Point Wilkins Member, and an upper Sagemace Member. Both units represent "evaporite cycles" comparable to the Dawson Bay cycle, and the Ashern-Winnipegosis-Prairie Evaporite cycle.

Point Wilkins Member

Outcrops of Souris River strata are sparse. The best exposure of the Point Wilkins Member are in the general area of "The Big Rock" (previously named Point Wilkins). The most accessible exposure is in the Mafeking Quarry of CBR Cement Ltd. **(STOP 5)**. Until recently, the limestone was used to make cement in Regina. Point Wilkins strata consist of a basal red shale unit, the First Red Beds, overlain by a sequence of extremely fine grained, sparsely fossiliferous, micritic/intraclastic high-calcium limestones. Some admixture of argillaceous and silty material is evident in the Lower Point Wilkins. The very fine sediment grain size and the delicate nature of the contained fauna suggest deposition under quiet, low-energy conditions, with periodic disruption indicated by the intraclastic beds. These strata probably were deposited under relatively deep water conditions, with periodic storm effects.

In the southern part of the outcrop belt exposures are sparse, and lithologic data have been obtained primarily from core. The Point Wilkins beds thin markedly to the south, from over 50 m in the Dawson Bay area to about 35 m in the Winnipegosis area, although correlations based on shaly marker beds are somewhat uncertain. The apparent southward thinning of the Point Wilkins portion of the Souris River Formation, shown by the coreholes, is not evident in the regional isopach pattern for the total Souris River sequence. Correlations and isopach variations are further complicated by extensive salt-collapse brecciation that occurs in many coreholes. Nevertheless, the lithology of the Point Wilkins strata appears to change markedly to the south, where stromatoporoidal calcarentic limestones become abundant, in places including coral biolithites and calcirudites. Local dolomitization is common but erratic, and lithofacies are quite variable. The lithology of this southerly area probably reflects a shallower-water, higher energy environment than for the Dawson Bay area. This is consistent with the pattern of regional basinward thickening to the north suggested for the Winnipegosis, but inconsistent with the pattern of local sub-basin development indicated for Dawson Bay strata.

Sagemace Member

The Sagemace Member comprises the second full depositional cycle of the Souris River Formation (Fig. 5). It occurs only in that portion of the outcrop belt near the Town of Winnipegosis.

The lithology of the Sagemace Member is highly variable, but is generally similar to that of the Point Wilkins Member in the same area; the Sagemace beds also are brecciated to varying degrees. An excellent example of a salt-collapse plug is seen in the central part of the Winnipegosis Quarry; it is the result of several separate episodes or periods of salt collapse.

JURASSIC STRATIGRAPHY

During late Paleozoic to early Mesozoic time, a period of differential uplift and erosion appears to have occurred in the same general area of southern Manitoba where isopach data indicate that differential subsidence had taken place in Ordovician time. The erosional event is evidenced by the distribution of Middle Jurassic red beds and evaporites which, at least locally, overstep deeply eroded Paleozoic strata to rest directly on Precambrian basement in the area southeast of Winnipeg. The Precambrian Shield of eastern Manitoba thus came into existence as a post-Cambrian paleogeographic feature at this time. Figure 4b shows the isopach of Jurassic beds in Saskatchewan and Manitoba.

AMARANTH FORMATION

Amaranth Evaporite

The Middle Jurassic Amaranth Evaporite is the most widespread anhydrite-gypsum formation in Manitoba. It is a basin marginal deposit underlain by red beds and overlain by limestone and dolomite.

The Amaranth Evaporite is not exposed at surface. Along its subcrop belt it is covered by drift ranging in thickness from 3 to 100 m. This subcrop belt, extends from Dauphin southeastward to the Dominion City Embayment. The evaporite bed dips at relatively constant 2 m/km toward the southwest. Gypsum occurs also in an outlier of the Amaranth Formation within the Lake St. Martin crater.

The evaporite shows a remarkably uniform thickness over most of its extent, averaging about 30 m. In the Dauphin area it shows some depositional thinning; towards the centre of the Williston Basin, it thickens to more than 40 m. As a result of an underlying ridge of Mississippian rocks, the evaporite is thin or absent along a northwest-trending belt passing south of Brandon and through Virden.

A typical subsurface section is given here, reproduced from Bannatyne (1959). It was measured from core recovered from the Dillman Kirkella 1-10-12-29W well from a depth of 675 to 712 m. At depths below 600 m gypsum is rarely found in nature, being usually converted to anhydrite.

Subsurface Section, Dillman Kirkella 1-10-12-29 WPM well

Depth in m	Lithology	Thickness (m)
	Jurassic Reston Formation	
670-	Upper part of formation, 670-675.14 m, not cored	5.18
675.14	Argillaceous, calcareous dolomite Amaranth Evaporite	1.52
676.66	Anhydrite, crystalline, with dolomite and shale	2.74
679.40	Shale, light grey massive	0.30
679.70	Predominantly greyish brown shale; some crystalline anhydrite and argillaceous dolomite	3.05
682.75	Interbedded dolomite and anhydrite	3.05
685.80	Dolomitic shale, brownish	1.22
687.02	Predominantly anhydrite, with a few thin bands of argillaceous dolomite	3.35
690.37	Shale, greyish brown, massive; several thin anhydrite interbeds	1.52
691.89	Anhydrite; several thin dolomite and shale interbeds	2.74
694.63	Shale, greyish brown, massive; slickensides	1.07
695.70	Anhydrite	1.07
696.77	Shale, brown, with anhydrite inclusions	0.70
697.47	Anhydrite	0.52
697.99	Shale, reddish brown, anhydrite inclusions	0.76
698.75	Anhydrite	6.10
704.85	Anhydrite (60 per cent) as large bands and inclusions in brownish red shale	3.81
708.66	Anhydrite	1.52
710.18	Anhydrite and red argillaceous dolomite, breccia-like structure	0.30
	Total Amaranth Evaporite	33.82 m
	Amaranth red beds (?)	
710.48	Red shale, dolomitic, anhydrite inclusions and breccia fragments of dolomite	1.22 m
	Mississippian Lodgepole Formation	

711.7- Dolomite, yellowish-brown, brecciated, anhydrite veinlets

Note: the thinness of the red bed section in this area is the result of an underlying topographic high formed by the Mississippian rocks.

At the present time (2004) one deposit is being worked for gypsum in the Amaranth Formation. West of Lake Manitoba, gypsum is being quarried by Westroc Industries Limited in E ½ 22-20-10W, east of the village of Harcus. This quarry will be examined at **STOP 20**. Originally, gypsum was recovered from underground mines, but these have been closed for more than 30 years.

RESTON FORMATION

The Jurassic Reston Formation (Fig. 3) consists of a maximum thickness of 45 m of buff limestone and grey shale. The only outcrop of the formation in Manitoba will be visited at **STOP 18**.

MELITA FORMATION

The Jurassic Melita Formation (Fig. 3) comprises bands of sandy limestone and vari-coloured shale and sandstone. The formation can be seen in a brick clay stockpile at **STOP 19**.

CRETACEOUS STRATIGRAPHY

Devonian and Jurassic strata are overlain with marked unconformity by Lower Cretaceous strata of the Swan River and Ashville formations (Table 1), which also are soft, recessive-weathering sands and shales and outcrop only rarely along the foot of the escarpment. These strata are in turn overlain by the Favel, Morden, Niobrara 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, and outcrops are common along the escarpment as well as in the southwestern upland area. For the most part, the Upper Cretaceous marine shale and thin limestone beds were removed by erosion east of the Manitoba Escarpment. Figure 6 shows the equivalent Cretaceous stratigraphy of Saskatchewan.

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

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

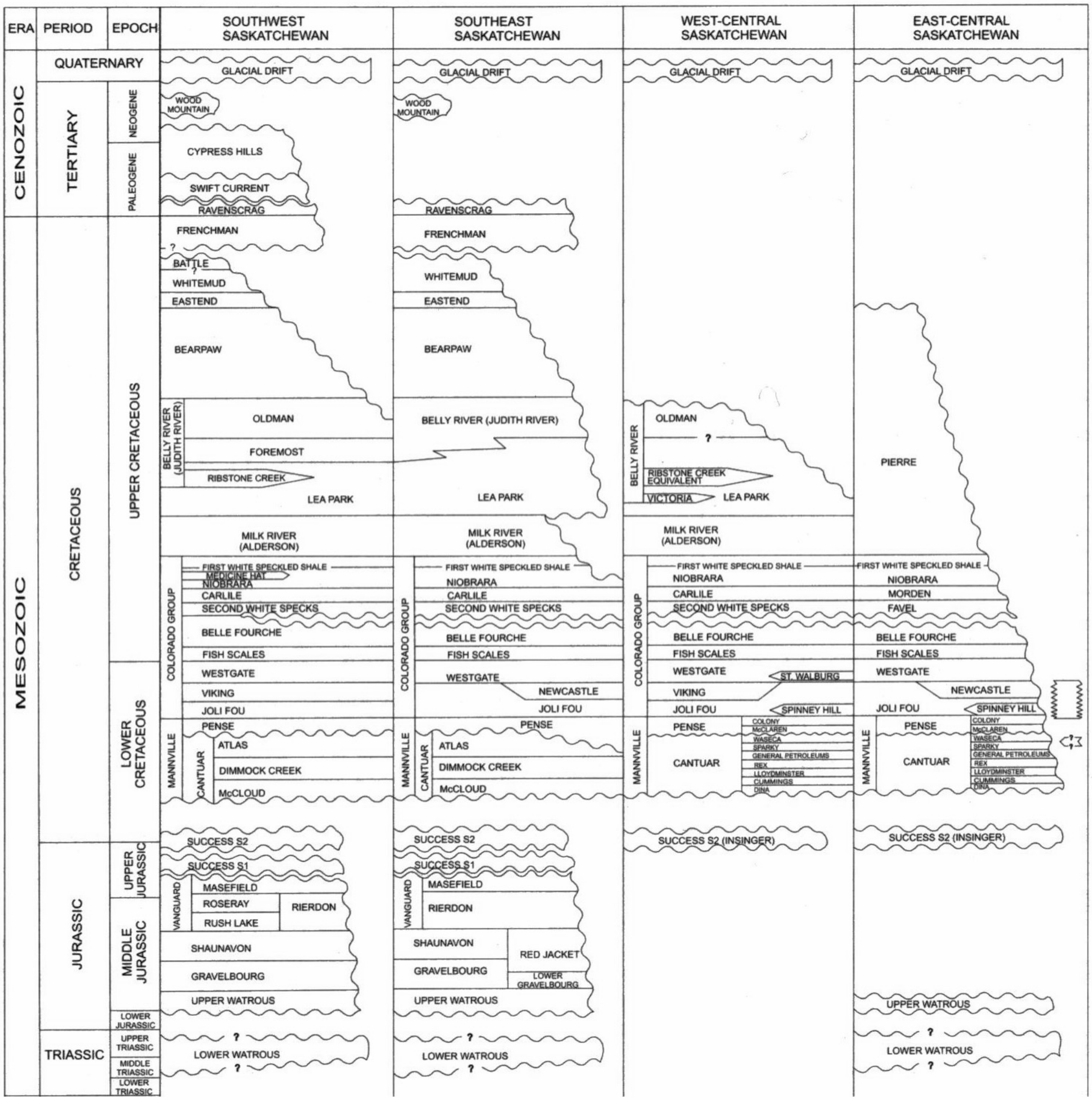

Figure 6: Mesozoic and Cenozoic formations of Saskatchewan (modified from Saskatchewan Geological Survey (2003).

Following deposition of the Jurassic Waskada Formation (Fig. 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.

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

McNeil and Caldwell (1981) interpret 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….first recognized in the mid-basin of eastern Colorado, western Kansas, and northeastern New Mexico where the cycles are most clearly expressed and most symmetrical. The transgressive phase (Fig. 7) of the Greenhorn cycle is represented by marginal-marine and marine sands of the Middle to Late Albian Swan River Formation, the non-calcareous shales of the Late Albian and Cenomanian Ashville Formation, and the chalk-speckled shales with shelly limestone stringers of the Early Turonian lower Keld Member of the Favel Formation. The regressive phase of the Greenhorn cycle is represented by the chalk-speckled shales with limestones of the early Middle Turonian upper Keld and Assiniboine Members of the Favel Formation and by non-calcareous shales of the late Middle Turonian Morden Shale. The transgressive phase of the Niobrara cycle is largely or wholly lost in unconformity (as it is in the mid-basin of the United States), but the long period of expansion of the Niobrara sea is recorded in the chalk-speckled shales, chalky shales, and marlstones of the Coniacian to Early Campanian Niobrara Formation. The largely non-calcareous shales of the Pierre Shale and sandstones of the Boissevain Formation form the sedimentary record of regression of the Niobrara sea. The Greenhorn sea well may have reached its transgressive peak in Manitoba in Early Turonian time, as it did the mid-basin of the United States, but whereas the Niobrara sea may have reached its transgressive peak in the mid-basin of the United States in Early Coniacian time, it may not have reached its transgressive peak in Manitoba until Early Campanian time.” (McNeil and Caldwell, 1981, p. 295).

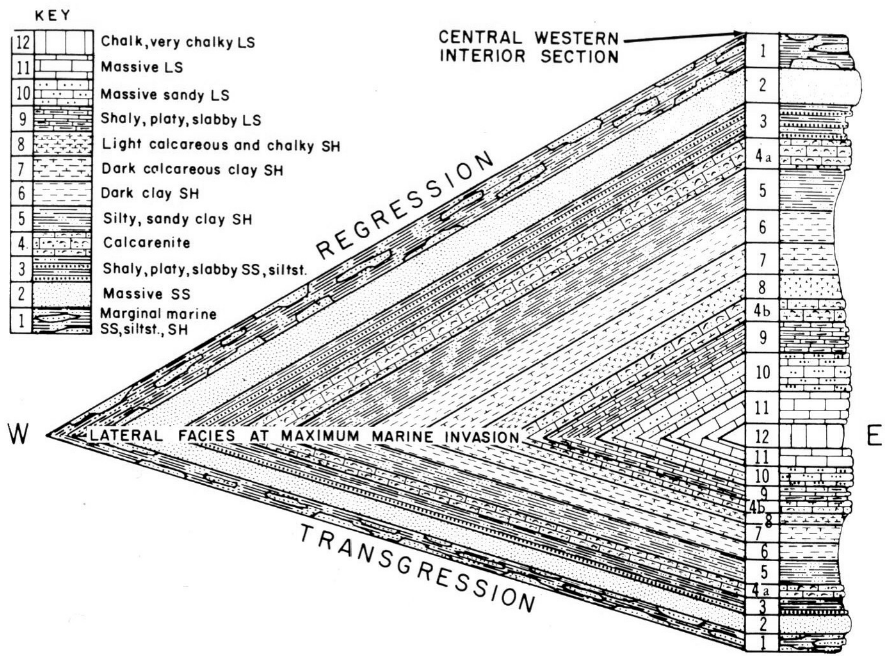

Figure 7: Ideal marine transgression and regression cycle from McNiel and Caldwell (1981).

They suggest also that other cycles that have been defined in other parts of the Western Interior, e.g. the Albian Kiowa-Skull Creek cycle and the Campanian Clagett and Bearpaw cycles, if recognized at all in Manitoba, "should be viewed as secondary transgressive-regressive pulses during primary Greenhorn transgression and primary Niobrara regression". (McNeill and Caldwell, 1981, p. 295).

SWAN RIVER FORMATION/MANNVILLE GROUP

The Lower Cretaceous Swan River Formation (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 name Mannville Group has been applied to equivalent strata in Saskatchewan and Alberta. Fig. 4c shows the upper surface of the Swan River Formation/Mannville Group and its thickness in Saskatchewan and Manitoba.

Swan River strata lie unconformably on a weathered surface of Jurassic and Devonian rocks, and are conformably overlain by shales of the Ashville Formation. In the southern part of Manitoba, the Swan River strata are probably of Lower Cretaceous age, but in the northern part of the area, some non-marine Jurassic strata may be included (Wickenden, 1945, p. 12). The Swan River Formation occurs in two areas separated by a broad belt extending eastward from the Saskatchewan boundary through the Virden area to beyond Brandon in which no Swan River deposits are known to occur (Fig. 4c). Both the Swan River and Waskada formations are included in the isopach map as the formations are difficult to distinguish on mechanical logs; similarly, the Swan River Formation north of township 19 may include some sands of the Melita Formation.

Locally, the sand was cemented by calcium carbonate to form sandstone. Large ovoid sandstone concretions are exposed at surface south of Swan Lake where they are referred to as kettle stones. A Manitoba Provincial Park has been proclaimed over the site. Outcrops of the formation are also known along Pine, Swan, and Roaring **(STOP 8)** 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.

ASHVILLE FORMATION

The Lower to Upper Cretaceous Ashville Formation (Table 1) overlies the Swan River Formation underlies the Favel Formation. It is made up mainly of dark grey to black carbonaceous shale. The Lower to Upper Cretaceous Ashville Formation is a noncalcareous, carbonaceous grey-black shale with small quantities of silt, sand and calcarenite. The formation has been divided into lower and upper members. The Lower Ashville comprises the interval from the base of the Fish Scale Zone to the base of the overlying Belle Fourche Member. If the Newcastle Sand Member is present within this interval, the Lower Ashville is usually subdivided into the Skull Creek, Newcastle and Westgate members (McNeil and Caldwell, 1981). The Lower Ashville is conformably overlain by the Upper Ashville.

The formation shows a fairly uniform thickening to the southwest. Of particular interest is the occurrence within the Lower Ashville of the Ashville Sand, which is correlative with the Viking Formation of Saskatchewan (Fig. 7). The Ashville Sand ranges up to 27 m in thickness, and because of differential compaction, shows highly erratic variations in thickness which are reflected in the isopach map. In general, the Ashville Sand occurs in a northwest trending belt sub-parallel to the isopach trend of the total Ashville unit; the sand passes sharply, by facies change, to shale on the downdip edge, and thins updip to a feather edge. No outcrops of the Ashville Sand are known. The general configuration of the Ashville Sand body suggests that it may possibly represent an offshore bar or beach deposit; with a source of clastics to the northeast.

The Upper Ashville is also named the Belle Fourche Member of the Ashville Formation (McNeil and Caldwell, 1981). 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.

Outcrops of the formation occur along the northeast and north slopes of Riding Mountain, along the Wilson River eastward from Ashville, and on the lower slopes of Duck and Porcupine mountains. The formation contains minor calcareous bands as well as numerous thin layers of bentonite. The base of the “Fish Scale” marker zone is picked as the contact between the Lower Ashville (Lower Cretaceous age) and Upper Ashville (Upper Cretaceous age).

The Upper Ashville or Belle Fourche Member is disonformably overlain by Favel Formation.

FAVEL FORMATION

The Upper Cretaceous Favel Formation (Table 1, Fig. 7) overlies the Ashville Formation and underlies the Morden Shale. The Upper Cretaceous Favel Formation is a calcareous olive-black shale, usually containing visible white specks. It is also referred to as the “Second White Speckled Shale”. Kirk (1930) subdivided the Favel into the lower Keld beds and upper Assiniboine beds. These beds were elevated to member status by McNeil and Calwell (1981), who also noted the presence of the Laurier Limestone beds, near the top of the Keld Member; and the Marco Calcarenite beds, near the top of the Assinboine Member. 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 the northern areas, 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. Kirk (1930) divided the formation into an upper member, the Assiniboine Beds, and a lower member, the Keld Beds.

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 Riding Mountain area, and from 30 to 40 m in Pembina Mountain area.

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

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

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

MORDEN SHALE

The Upper Cretaceous Morden Shale (Table 1, Fig. 7) (formerly, the lowest member of the Vermilion River Formation (Bannatyne, 1970)) is a thick sequence of dark grey to black carbonaceous noncalcareous shale. The Morden Shale is sharply and unconformably overlain by the Niobrara Formation.

The Morden Shale, which will be examined at **STOPS 10, 15, 16, 24, 30**. The Morden Shale shows little variation in lithology throughout its extent, either vertically or regionally. A few thin bentonite beds and partings occur within the Morden Shale but these are much less common than in the other upper Cretaceous strata.

The shale beds contain calcareous concretions, some septarian or turtle-back, and some as large as 1.8 m in diameter. Iron sulphide is present as concretions, in irregular masses, or as layers of fine crystals between the shale layers. The iron sulphide is probably responsible for the strong sulphur odor when the outcrop is wet. A considerable amount of selenite (gypsum) as flakes and crystals is associated with the iron sulphide. A coating of yellow material, possibly jarosite KFe3(S04)2(0H)6, is present in most exposures of the shale, and in places occurs as laminae between the thin layers of shale (14-33-3-6W, south of Miami, former Red River Brick and Tile shale pit, **STOP 30**).

The Morden shows little vertical variation in lithology along the bottom edge of the Escarpment. A strong sulphur odor, numerous gypsum prisms, jarosite-coated fracture surfaces and turtle-back concretions are characteristic of the Morden Shale. Thin bentonite seams may also be present. Excellent exposures of Morden Shale can be seen at **STOP 30** in road cuts where Shannon Creek crosses Townships 3 and 4, Range 6WPM.

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

According to Beck (1974), the Morden Shale appears to be missing or intermittently developed between the Niobrara and Favel north of Hudson Bay in the Pasquia Hills and in central Saskatchewan.

NIOBRARA FORMATION

The Upper Cretaceous Niobrara Formation (Table 1, Fig. 7) is a medium grey and buff calcareous or chalky shale, limestone, chalk or marlstone that overlies the Morden Shale. Numerous thin bands and partings of bentonite occur throughout the section. The Niobrara (formerly named the Boyne Member of the Vermilion River Formation (Bannatyne, 1970) is also known as the “First White Speckled Shale”. McNeil and Caldwell (1981) divided the Niobrara Formation of Manitoba into a lower calcareous member and an upper chalky member. The Niobrara Formation is unconformably overlain by the Gammon Ferruginous Member, or where it is absent, by the Pembina Member of the Pierre Shale.

The Niobrara is correlated with the "The First Speckled Shale" horizon of Saskatchewan (Fig. 7) and Alberta. The disconformable contact of the Niobrara with the Pembina Member will be examined at **STOP 29**. The top of the Niobrara rises from 385 m in the Pembina Valley in 18-1-6W to 391 m at Deadhorse Creek in 21-2-6W (Tovell, 1948), and to 396 m in drillhole M-8-77. Excellent exposures of the Niobrara can be seen in road cuts along Roseisle Creek (Snow Valley) **(STOP 23)**. The highly calcareous shale (37% Ca0, 1.5% Mg0) from this unit was used as late as 1924 in the production of natural cement.

The Niobrara/Morden contact is exposed on the south bank of the Pembina Valley in C3-4-1-6W and was penetrated in drillhole M-10-77. The position of the contact can also be roughly approximated between two outcrops along the south side of P.T.H. 23, 5 km west of Miami.

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

In the area along the east side of Riding Mountain, the upper highly calcareous shale of the Niobrara 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 (Fig. 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 Boissevain and Turtle Mountain Formation.

The Upper Cretaceous Pierrre Shale (Table 1) comprises in upward ascending order, the Gammon Ferruginous, Pembina, Millwood, Odanah and Coulter members (McNeil and Caldwell, 1981). Formerly, the Gammon Ferruginous and Pembina members were included within the Vermilion River Formation; and the Millwood, Odanah and an unnamed unit were included as members within the Riding Mountain Formation

(Bannatyne, 1970). The uppermost member of the Pierre Shale in southwestern Manitoba was named the Coulter Member by Bamburak (1978).

The Pierre Shale is undivided as shown in Figure 7 for East-central Saskatchewan.

Gammon Ferruginous Member

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

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

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

Pembina Member

The Pembina Member of the Pierre Shale (Table 1) overlies the Gammon Ferruginuous and/or Niobrara Formation. The Pembina Member is a distinctive interlayered sequence of thin buff bentonite seams and thin greyish black noncalcareous marine shale beds. The Pembina Member was formerly a member of the Vermilion River Formation.

A disconformable Pembina/Niobrara contact will be seen **STOP 29.** The contact can also be seen in gullies at the west end of an old quarry in SE11-6-2-5W and in a deep ravine in NW13-34-4-7W. It can be approximated in a road cut in 14-16-5-7W. According to Bannatyne (1963, p. 7), towards the top of the Pembina member the black shales pass graditionally upward into chocolate brown, more waxy, less organic shale and finally into the brownish green, waxy, non-carbonaceous shales of the Millwood beds.

The Pembina type shales thin markedly to the north, from 24 m in the Pembina Valley to 8 m in Deadhorse 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 25, 28 and 29**. At least 11 buff bentonite seams, ranging in thickness from 1 cm to 30 cm have been documented in previous investigations (Bannatyne, 1963, 1984; and Bannatyne and Watson, 1982). The seams are separated by similar thicknesses of black carbonaceous, pyritic shale. The bentonite seams thicken to the west, but the overburden rapidly increases in thickness to 12 to 15 m.

According to Bannatyne (1978), the volcanic ash from which the bentonite beds were formed resulted from eruptions in the Elkhorn Mountains of Western Montana, and a K-Ar date from equivalent strata in Montana indicates an age of 87.4 (ñ2,9) million years (Russell, 1970, CJES, Volume 7, p.1106).

Millwood Member

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

The Millwood outcrops in places along the Manitoba Escarpment and along the Souris, Pembina and Assiniboine River valleys, usually under a cover of hard Odanah shale. Rounded buttes of Millwood shale are common in the outcrop belt; an example will be examined at **STOP 28**. Outcrops show a distinctive “popcorn” or “cauliflower” weathered surface with little or no vegetation. Brown and reddish-brown ironstone and yellowish calcite concretions occur in layers within the Millwood Member. Although the lower Millwood/Pembina contact is not exposed because the soft "flowing" nature of the Millwood, an estimate of its position can be made at the break in slope at the base of the buttes.

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

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

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

Odanah Member

The predominant lithology of the Odanah Member of the Pierre Shale (Table 1) is light, hard siliceous shale which will be examined in a quarry exposure at **STOP 26**. The shale is steel grey or slightly greenish-grey when dry and dark greenish-grey when moist. The content of amorphous silica averages approximately 80 per cent. The shale occurs both as thin fissile beds, and as thick massive beds that are brittle and break with a subconchoidal fracture. The joints and bedding planes within the shale are usually stained brown or reddish to purplish brown from iron and manganese weathering products. Ironstone nodules of concretionary or septarian structure occur throughout the whole of the Odanah, but are more common in the upper part; Kirk (1930) reported that compact, ellipsoidal, grey limestone concretions are found in some exposures. Thin interbeds of bentonite and bentonitic shale are present, most commonly within the lower 33 m of the member.

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

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

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

Coulter Member

A bentonitic soft silty clay overlies the Odanah. These beds were informally named the Coulter Member of the Riding Mountain Formation, now the Pierre Shale (Table 1), by Bamburak (1978, p. 6) and are transitional upwards into the overlying sands of the Bossievain Formation. A former exposure of the Coulter at **STOP 34**, at the base of a Boissevain section, is no longer visible due to slumping of surrounding sediments.

The thickness of Coulter Member ranges from 37.2 m to 43.6 m and its upper surface rises from 481.6 m to over 506.0 m in three holes in the Turtle Mountain area (Bamburak, 1978).

BOISSEVAIN FORMATION

Greenish-grey sand with ovoid sandstone concretions of the Upper Cretaceous Boissevain Formation (Table 1) overlies the Pierre Shale. The crossbedded sands were deposited in a fluvial environment (Bamburak, 1978, p. 23, 24). The sands become kaolinitic upwards indicating an erosional unconformity. The Boissevain Formation is equivalent to the Eastend and Whitemud formations of Saskatchewan (Fig.7).

An excellent exposure of the Boissevain can be seen at **STOP 34**, in a gully south of P.T.H. 3, about 16 km west of Killarney, in NW15-35-2-19W.

The Boissevain Formation maintains a thickness of about 30 m across Turtle Mountain. Its upper surface rises from west to east from less than +499.9 to more than +530.4 m (Bamburak, 1978).

PART II: GENERAL ROADLOG AND OUTCROP DESCRIPTIONS

DAY 1: CRETACEOUS STRATIGRAPHY OF RED DEER RIVER VALLEY, PASQUIA AND PORCUPINE HILLS

Day 1 will focus on the Cretaceous stratigraphy of the Pasquia (Figs. 8 and 9) and Porcupine hills and the intervening Red Deer River Valley. In general, we will start the field trip on the Second Prairie Level near Hudson Bay, Saskatchewan and descend the Manitoba Escarpment, along the Red Deer River Valley, onto the First Prairie Level in Manitoba. Manitoba's second highest elevation is found on the Porcupine Hills (Hart Mountain, elev. 823.0 m.).

In the northern portion of the Manitoba Escarpment, the Cretaceous units were deposited upon a (First Prairie Level) foundation comprised of Devonian formations with numerous salt horizons. For this reason, a few Devonian stops will be made to provide a regional context for the Mesozoic depositional environment and the consequences of salt collapse and fluid flow. The complete stratigraphic succession and lithology are shown in Figure 9, including the stratigraphic position of all outcrop stops.

Figure 8: Pasquia Hills LANDSAT image (See: Figure 1).

Proceed north from Hudson Bay on Saskatchewan Highway 9 for 65 km, to Waskwei River bridge. Waskwei River outcrop is about 450 m upstream from Highway 9 (formerly, Otosquen road) and can be easily reached by a trail leading from the Saskatchewan Department of Natural Resources picnic site on the south bank of the river.

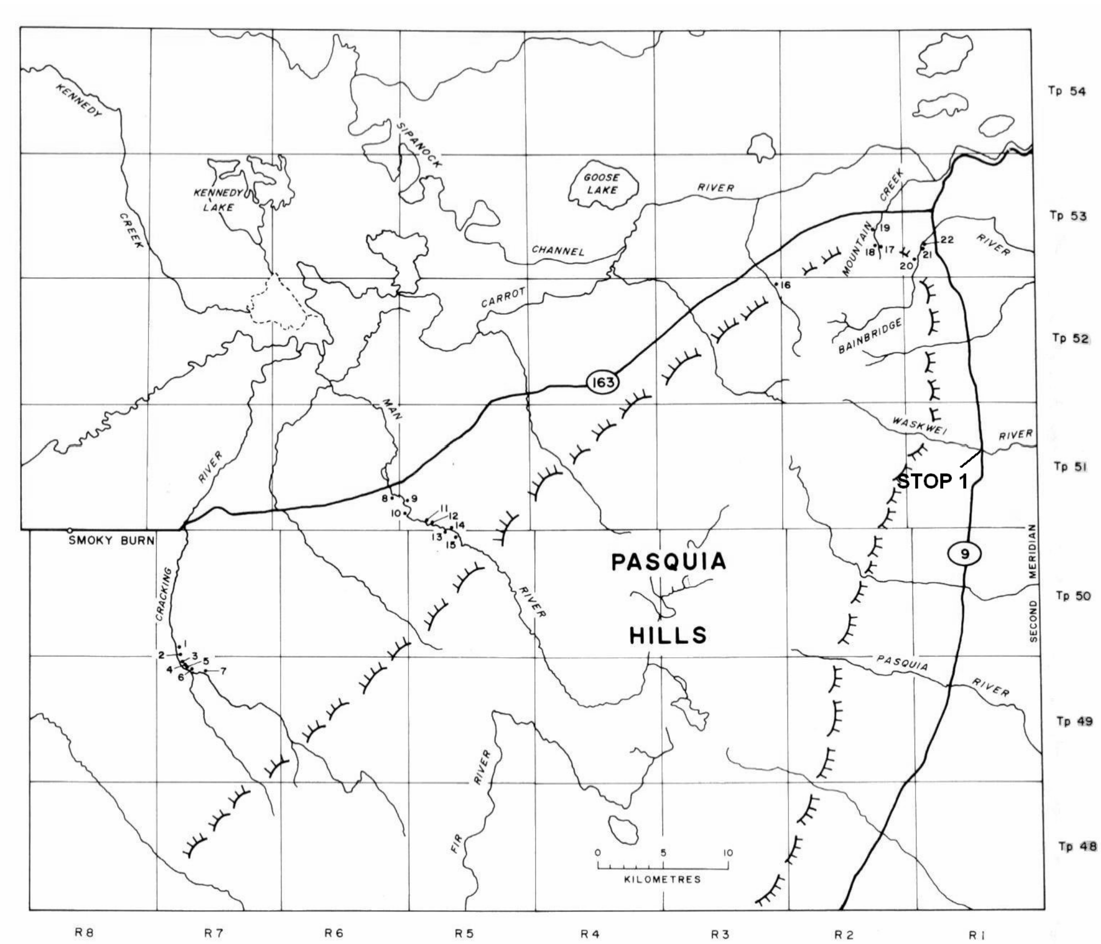

*Figure 9: Location map for **STOP 1** (modified from McNeil and Caldwell, 1981).*

STOP 1: WASKWEI RIVER OUTCROP

Cretaceous Speckled Shale (Favel and/or Niobrara formations ?). (Beck, 1974, Locality 3) in L.S. 13, Sec. 23, Twp. 51, Rge. 1, W 2nd Mer. (or 13-23-51-1W2), NTS 63E8E. The outcrop is situated within a stream valley on the northeast flank of the Pasquia Hills in Saskatchewan , 65 km north of Hudson Bay, Saskatchewan.

Stratigraphic Section of the Waskwei River exposure (modified from Beck, 1974, Table 4).

		Thickness (m)
6	Glacial overburden. Clay with abundant boulders.	3-5
	Speckled Shale (Favel and/or Niobrara formations ?)	
5	Thin bedded, grey, speckled calcareous shale with thin bentonite at base.	4.3
4	Flaggy impure limestone with abundant fish scales and thin bentonite at base.	2.0
3	Massive limestone with thin impersistent shale layers. Bentonite layer at base.	0.8
2	Flaggy calcareous shale with abundant Inoceramus and selenite. Thin bentonite layers.	1.6
1	Thin bedded, grey, speckled shale.	3.0
Measured thickness of Speckled Shale		**11.7**

References: (Beck, 1974).

Return to Hudson Bay on Highway 9 and turn east onto Saskatchewan Highway 3, for about 35 km. Junction with road to south to Roscoe, Saskatchewan, turn left (North) onto a meandering side road for about 20 km, roughly to the northeast, leading to the Red Deer Silica quarry.

STOP 2: RED DEER RIVER SILICA SAND QUARRY

Cretaceous Swan River Formation. (Beck, 1974, Locality 2) in 5-22-46-30-W1, NTS 63C13NE, NAD 27 Zone 14U 316023E, 5873289N. The quarry is situated on the east bank of the meandering Red Deer River, about 40 km north of Roscoe, Saskatchewan.

Swan River Formation	**Thickness (m)**
Silty shale interbedded with oxidized silica sand	1.5 m
Cross bedded silica sand with minor shale	5.0 m
Measured thickness of Swan River Formation	6.5 m

Red Deer Silica Inc. has produced small amounts of silica sand for use in golf course bunkers, stucco sand and sandblasting sand from 1992 to 2001.

References: (Beck, 1974).

Figure 10: E-logs with Field Trip Stops set in stratigraphic position (modified from McNeil and Caldwell, 1981).

Return to Highway 3 and proceed east to Manitoba boundary , where road becomes Manitoba 77. Continue east until junction with Highway 10 and turn north. Cross the new Red Deer River Bridge and turn east at a small approach road leading to wayside stop, northwest of old bridge.

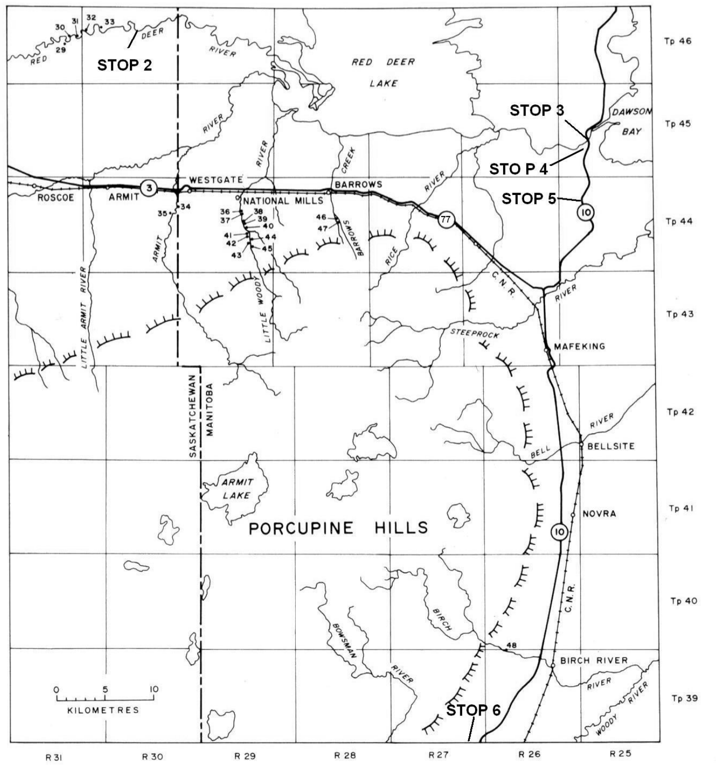

Figure 11: Location map for ***STOPS 2-6*** *(modified from McNeil and Caldwell, 1981).*

STOP 3: RED DEER RIVER BRIDGE OUTCROP

Devonian Dawson Bay Formation. (Middle and Lower members). (Bezys and Bamburak, 2004, Stop 25) in 7-17-45-25W1, NTS 63C14NE. The outcrop is situated northeast of the Porcupine Hills (Fig. 12) on the north bank of the Red Deer River in Manitoba, approximately 100 m west of the old bridge on P.T.H. 10.

Outcrop extends for about 30 m with beds dipping to the southwest at about 6°, exposing a 10 m section of fossiliferous limestone, argillaceous limestone and calcareous shale. These strata represent a portion of a truncated structural (reef-supported) dome. Estimated minimum thickness of the underlying Winnipegosis reef is about 80 m. A small brine flow is evident at the northwest edge of the picnic area.

Two test holes were drilled a short distance upstream, one (M-18-77) on the top of a reef-supported structural dome of Lower Dawson Bay strata, and the other (Husky Mafeking 11-8-45-25WPM) on a large salt flat. Both holes intersected Winnipegosis reefs 96 m thick. In contrast, two other holes drilled 7 km upstream intersected thin interreef Winnipegosis sequences of 24.1 and 32.7 m. Thus minimum reef-interreef relief in this area is 72 m.

Several other Lower Dawson Bay reef-supported structural domes can be seen in this general area, as ditch outcrops along Highway 10 and as riverbank outcrop a short distance downstream from the old bridge.

<u>References:</u> Corehole M-10-72; Baillie (1951a, p.40); McCammon (1960); Norris *et al.* (1982); Bezys and Bamburak (2004), Fedikow *et al.* (2004).

Figure 12: Porcupine Hills LANDSAT image (See: Figure 1).

Return to Highway 10. Turn south for 0.7 km to small creek crossing road, south of new bridge. Park on west shoulder of road and walk toward salt flat on the west. Ground is spongy in places especially after rain.

STOP 4: MCARDLE SALT FLAT

Recent brine springs. 11-8-45-25W1, NTS 63C14SE, 52°51' and 101°03'. Salt flat is located 300 m south of the Red Deer River, and 2 km west of Dawson Bay on Lake Winnipegosis.

Brine flows to surface at several points within the poorly-vegetated reddish-coloured McArdle salt flat, which is roughly about 100 by 300 m in area. Drainage is to the northwest and east into the Red Deer River. L.J. McArdle drilled a well to a depth of 71.8 m on behalf on the Northern Salt Company. The brine originated from Devonian carbonates at a depth of 24.3 m, with increase flow to the bottom of the well. The brine flowed at a rate of 216.6 litres per minute with a salinity of 24 to 26%. A small evaporation plant was built on the north side of the salt flat. In late July and August 1941, approximately 22.6 tonnes of salt was produced for the local market. Attempts to operate the salt works were done up to 1952.

References: Manitoba Mineral Inventory Card 63C/14SE SLT 1.

Continue south on Highway 10 for 3.8 km. Park on west shoulder of road and walk 200m to quarry on the west.

STOP 5: MAFEKING NORTH HIGH-CALCIUM LIMESTONE QUARRY

Devonian Souris River Formation (Point Wilkins Member). (Bezys and Bamburak, 2004, Stop 29) in 7&10-32-44-25W1, NTS 63C14SE. Two high-calcium limestone quarries were formerly operated by CBR Cement Canada Limited. The quarries are short distance west of P.T.H. 10, 16 km north of Mafeking, Manitoba.

The quarries supplied high-calcium limestone, used in the manufacture of Portland cement, in Regina. The South Quarry has been infilled (rehabilitated). It provides a good view of the gentle structural undulation affecting Point Wilkins strata; this structure reflects Winnipegosis interreef paleotopography. Detailed descriptions of the 27 m of section exposed in the South Quarry are presented by Bannatyne (1975).

The North Quarry exposes the same sequence as seen in the upper part of the South Quarry, except for a 3 m cap of brown granular dolomite that occurs above the limestone and forms the uppermost unit of the Point Wilkins Member (Norris et al., 1982). These dolomites are the youngest Devonian strata known to occur in the area. The main quarry beds consist of light yellowish brown, faintly mottled, dense, micritic limestones. The lower part of the Point Wilkins Member consists of 10 m of reddish to purplish grey, mottled, argillaceous limestone, which was also quarried in the South Quarry. However, these argillaceous beds are of lower grade and were not being utilized in the North Quarry.

Large sand-filled caves were intersected during quarry operations and some were believed to represent pre-Mesozoic karstic solution, with infilling by Cretaceous (Swan River?) quartzose sand. However, recent studies (Fedikow *et al.*, 2004) have shown that many of these caves are in fact “fossil” salt spring vent structures.

The quarry beds have been subjected to a minimum of about 70 m of salt collapse, but associated disruption is relatively minor. Estimated thickness of the underlying Winnipegosis (interreef) strata is approximately 44 m. This thickness is somewhat unusual in comparison with the "normal" interreef thickness of 25-35 m. No coreholes have been drilled to the base of the Devonian in the quarry area because of potential problems with high pressure astesian salt water.

If similar salt collapse has occurred beneath the Cretaceous beds, present about 10 km southwest of the quarry, disruption of the normal stratigraphic sequence could be expected over short lateral distances. This could make correlation between drillholes and outcrops difficult within the Mesozoic section.

CBR Cement Canada Limited has maintained its quarry leases over the area, since the operations were discontinued. In the last few years, a limited amount of stone has been quarried for highway construction.

References: Coreholes M-9-70, M-9B-70; Bannatyne (1975); Norris et al. (1982); Fedikow *et al.* (1996); Bezys and Bamburak (2004), Fedikow *et al.* (2004).

Continue south on Highway 10 for 60 km. Much of the roadbase is built on the eastern flank of the Porcupine Hills, within an area that is prone to landslides (Nielsen, 1988, p.30). Turn right (West) onto side road, before Highway 10 heads due south towards Swan River. Park on south shoulder of road before rise, outcrop to north.

STOP 6: DIGGER DAN ROADCUT

Cretaceous Favel Formation (Assiniboine Member). (McCabe and Bannatyne, 1970, Stop 11) in 2-2-39-27W1, NTS 63C6SE. The roadcut is on the southeast flank of the Porcupine Hills, 13 km southwest of Birch River, Manitoba.

The roadcut on north side of road, and within the road bed, exposes approximately 3.7 m of shale of the Cretaceous Favel Formation. This outcrop is unusual because of its buff and pink (weathered) colors; the only other outcrop of a similar nature is that on the Valley River **(STOP 13)**. The outcrop consists of buff-weathering calcareous speckled shale overlying a layer of blocky limestone with partings composed of selenite crystals, black shale, and light brownish and purple altered bentonite. The limestone is underlain by black shale and grey shale, altered to red in places. McCabe and Bannatyne (1970) reported that Inoceramus shells were present in the outcrop.

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

Return to Highway 10. Turn right (South) and drive towards Swan River. Junction with PR 279, continue driving west on PR279 for 14.4 km. Turn left (South) onto PR 588 for 1.6 km. Pull to right and park at top of Lambert Hill.

STOP 7: LAMBERT HILL OUTCROP

Cretaceous Ashville Formation. 4-31-37-28W1 and 1-36-37-29W1, NTS 63C3NW. The outcrop rises above the surrounding plain within the Swan River Valley, 18 km northwest of Swan River, Manitoba. It has been bisected by a section road, which lies about 10 m below the crest of the hill.

According to Nielsen (1988), Lambert Hill is one of four ice-thrusted hills in the Swan River Valley. The other hills are: Thunder Hill, Kenville Hill and Minitonas Hill **(STOP 9)**. The orientation of all four ice thrust blocks indicates ice flow was toward the southwest, parallel to the axis of the Swan River Valley. At Lambert Hill, the ice-thrusted Ashville Formation beds dip to the south. A distinct bentonite seam can be seen near the north end of the outcrop, also dipping to the south.

Numerous small selenite crystals can be found on the surface of the road cut, as well as fossil bone.

References: Nielsen (1988), Klassen (1979), Bannatyne (1970).

Proceed South on PR 588 for 11.2 km. Junction with PR 275, turn left (East) for 12.8 km to Swan River. Turn right (South) and drive through town and stop at local museum at junction with P.T.H. 10. Check out sandstone "kettle". Drive north on P.T.H. 10 to Westwood Hotel.

End of Day 1 - Overnight at Skyline Motel in Swan River.

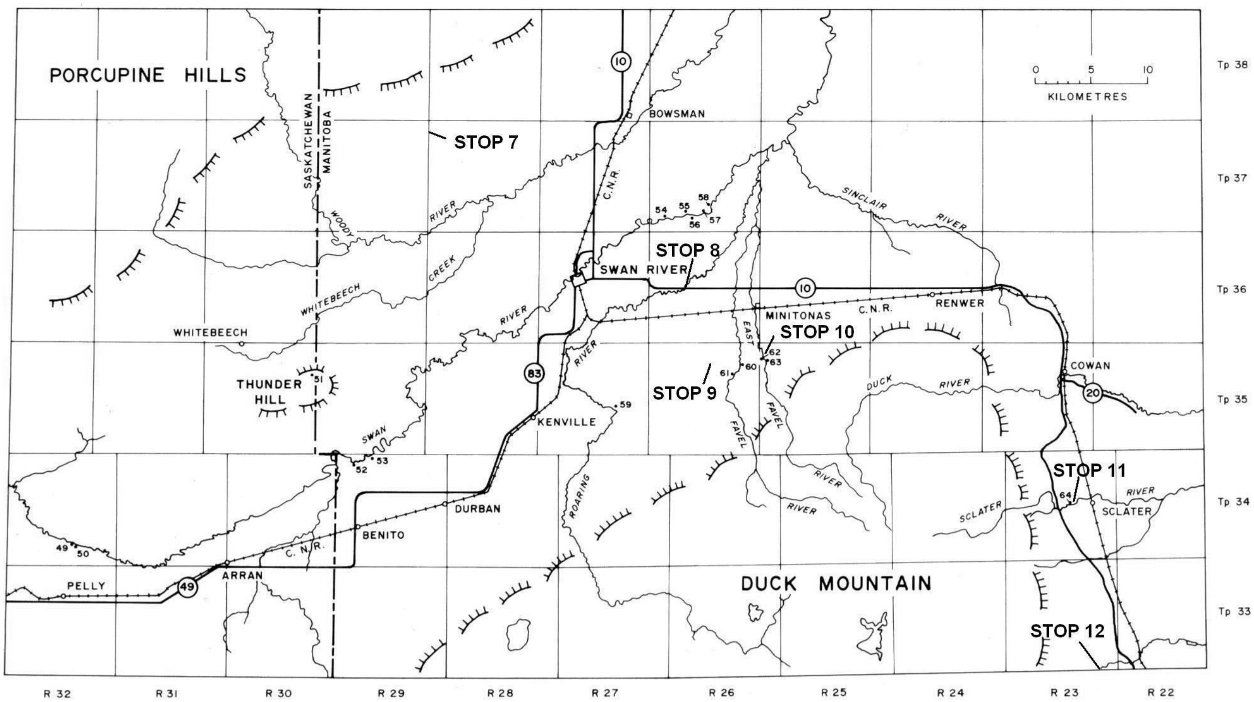

*Figure 13: Location map for **STOPS 7-12** (modified from McNeil and Caldwell, 1981).*

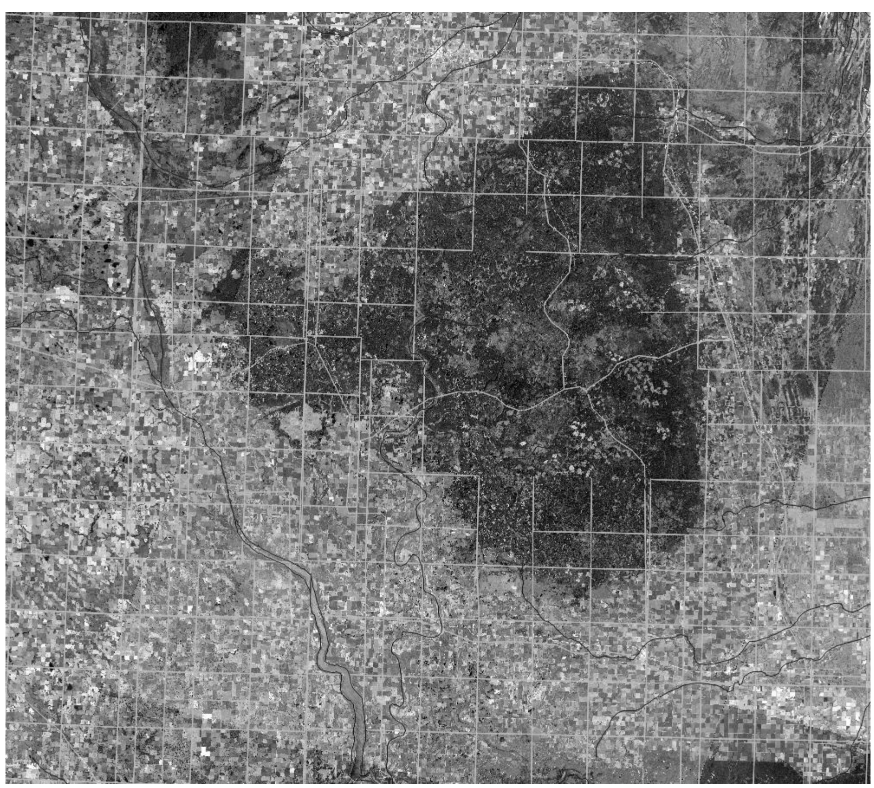

Figure 14: Duck Mountain LANDSAT image (See: Figure 1).

DAY 2: CRETACEOUS STRATIGRAPHY OF SWAN RIVER VALLEY, DUCK AND RIDING MOUNTAINS

Day 2 will continue yesterday's brief introduction to the Cretaceous stratigraphy of the Swan River Valley and extend to cover Duck (Fig. 14) and Riding mountains, forming the eastern edge of the Manitoba Escarpment. Much of the route between Cowan and Dauphin, Manitoba will extend along Glacial Lake Agassiz beaches that developed along the Escarpment. Manitoba's highest elevation is found to the west on Duck Mountain (Baldy Mountain, elev. 831.2 m.). The complete stratigraphic succession and lithology are shown in Figure 9, including the stratigraphic position of all outcrop stops.

Proceed east from Swan River on P.T.H. 10 for 8 km to Roaring River bridge. Make a U-turn after crossing bridge and park on shoulder on north side of road. Roaring River outcrop is about 100 m downstream from Highway 10 bridge) and can easily be reached by walking northeast to the riverbank.

STOP 8: ROARING RIVER OUTCROP

Cretaceous Swan River Formation.. 1-20-36-26W1, NTS 63C3SE. Resistant sandstone outcrops on the east bank of the Roaring River, within the Swan River Valley, 8 km east of Swan River, Manitoba.

Textbook ripple marks are preserved in a 1 m thick sandstone ledge, which caps the eastern riverbank (Gunter, 1989). A succession of overlapping ripples, within the thin bedded sandstone, shows that shallow water conditions must have been present during Cretaceous time for a long period. A unique "grapeshot" texture can be seen within the masses of sandstone, where calcium carbonate has cemented silica grains. The sandstone weathesr into an aggregate of 1-3 cm spheroidal concretions.

Unconsolidated glauconitic sand can be seen on the south bank apparently overlying the sandstone.

References: Gunter (1989).

Return to the vehicles, cross the bridge to the west and make a U-turn at the top of valley. Proceed east on P.T.H. 10 for 4.8 km to Junction with PR 366. Turn right (South) towards Minitonas, for 8 km. Junction with PR 485, turn right (West) for 3.2 km and turn right (North) at section road. Drive up on east flank of Minitonas Hill and park at the top.

STOP 9: MINITONAS HILL OUTCROP

Cretaceous Favel Formation. 8-27-35-26W1, NTS 63C3SE. The ice-thrusted outcrop is situated in the Swan River Valley, 10 km south-southwest of Minitonas, Manitoba.

As mentioned yesterday, Minitonas Hill is another one of four ice-thrusted outcrops within the Swan River Valley, (Nielsen, 1988). The other hills are: Thunder Hill, Kenville Hill and Lambert Hill **(STOP 7)**.

Note: the scenic view of the east end of Porcupine Hills directly to the north and Duck Mountain immediately to the south.

References: Nielsen (1988), Klassen (1979), Bannatyne (1970).

Make a U-turn and return to PR 485. Turn left (East) and drive across PR366 for 3 km to East Favel River, pull off road and park. Outcrop is about 300 m downstream, need boots to walk in shallow stream bed.

STOP 10: EAST FAVEL RIVER OUTCROP

Cretaceous Morden Shale overlying Favel Formation (Assiniboine Member with Marco Calcarenite). (McNeil and Caldwell, 1981, Outcrop Section 62) in the west-central portion of L.S. 3, Sec. 30, Twp. 35, Rge. 25W 1st Mer. (or 3-30-35-25W1) in NTS 63C3SE. The outcrop well exposed on west bank of East Favel River, approximately 6.1 km south of Minitonas, Manitoba. The East Favel River drains the northern flank of Duck Mountain.

Morden Shale		**Thickness (m)**
6	Shale, greyish black, weathering medium light grey, greyish-yellow jarosite on some weathered surfaces; non-calcareous; soft, flaky, uniform; brown fibrous organic material common along planes of lamination, a 0.5 cm-thick bed of macerated organic material at base of unit; minor amounts of fine- to medium-sized crystals of selenite and acicular crystals of melanterite or epsomite on weathered surfaces; unit weathers recessively; lower contact sharp	1.27
Measured thickness of Morden Shale		**1.27**
Favel Formation (component-lectostratotype)		
Assiniboine Member		
5	Calcarenite, dark grey, weathering light brown to dusky yellow; very fine-grained calcite; relatively uniform; fish fragments common; breaks into thin, irregular beds; very hard; weathers very resistantly; lower contact sharp. Marco Calcarenite (top)	0.38
4	Calcarenite (60%) and shale (40%) interbedded: Calcarenite, lithologically as in unit 5, calcarenite in 5 to 15 cm-thick beds; calcarenite well consolidated, but one bed only weakly consolidated. Shale, as in unit 3. Unit weathers resistantly; lower contact sharp. Marco Calcarenite (bottom)	0.83

3	Shale, olive black, weathering medium light grey to light grey, light-brown stain common; calcareous; chalk-speckled; relatively hard; weathers resistantly; lower contact sharp	0.60
2	Bentonite, bluish grey, weathering greyish yellow to light brown; soft, massive clay; unit weathers very recessively; lower contact sharp	0.05
1	Shale, olive black, weathering medium light to light grey, white non-calcareous powder common on weathered surfaces; calcareous; chalk-speckled; relatively hard; layers of prismatic calcite (probably of an inoceramid bivalve) common above 1.3 m; *Pseudoperna congesta* (Conrad) common above 1.3 m; medium-light-grey bentonite seams weathering grayish yellow at 1.0, 1.85, and 1.93 m above unit base; unit weathers resistantly; lower contact not exposed	3.00
Measured thickness of Keld Member		**4.86**

<u>References</u>: McNeil and Caldwell (1981), Bannatyne (1970).

Return to vehicles and make U-turn back to Junction with PR 366. Turn right (North) and drive back through Minitonas to P.T.H. 10 , 8 km. Turn right (East) and follow the Highway around the northeast flank of Duck Mountain for 42 km. Cross Sclater River bridge and turn left (East) at next section road. Drive to where powerline crosses road to Sclater and park on right side on shoulder. Sclater River Outcrop is to the north along the powerline. Slope is slippery when wet, but is well vegetated. Shallow stream will have to be crossed to get to outcrop.

STOP 11: SCLATER RIVER OUTCROP

Cretaceous Favel Formation (Assiniboine Member overlying Keld Member). (McNeil and Caldwell, 1981, Outcrop Section 64) in the north-central portion of 14-15-34-23W1, NTS 62N15NE. Outcrop is well exposed on north bank of Sclater River, approximately 2.1 km west of Sclater, Manitoba. The Sclater River drains the northeastern flank of Duck Mountain.

Oil shale has been noted near the base of the outcrop near the waterline.

<u>Favel Formation</u>

Assiniboine Member		**<u>Thickness (m)</u>**
15	Shale, olive black, weathering medium light grey; calcareous; fine, chalk specks abundant; hard, breaks into platy slabs; weathers recessively; soft and flaky at weathered surface; lower contact sharp	6.05
14	Bentonite, light grey, weathering greyish yellow to dark yellowish orange; soft,	

	massive clay; unit weathers very recessively; lower contact sharp	0.03
13	Shale, as in unit 15	0.55
12	Bentonite, as in unit 14	0.04
11	Shale, as in unit 15, but with greyish-yellow-weathering bentonite seam at 0.08 m above unit base	0.42
Measured thickness of Assiniboine Member		**7.09**

Keld Member

10	Shale, olive black, weathers medium light grey; calcareous; fine, chalk specks abundant; fairly hard with lenses of argillaceous limestone common; a yellowish-orange bentonite seam at 0.2 m above unit base; unit weathers moderately resistantly; lower contact sharp	0.50
9	Limestone, dark yellowish brown, weathering pale yellowish brown; argillaceous; fine chalk specks abundant; hard; bedding irregular, cleaves parallel to the sub-horizontally aligned abundant shells of *Mytiloides*; fish fragments common; unit weathers resistantly; lower contact sharp	0.23
8	Shale, olive black, weathering medium light grey, a white non-calcareous powder common on weathered surface; calcareous; fine, chalk specks abundant; a greyish-yellow, discontinuous, bentonite seam at 0.1 m above unit base; unit weathers recessively; lower contact sharp	0.15
7	Limestone, as in unit 9	0.58
6	Shale, olive black, weathering medium light grey; calcareous; fine, chalk specks abundant, fish fragments common; hard, platy; weathers resistantly; lower contact sharp	1.98
5	Bentonite, light grey, weathering greyish yellow to dark yellowish orange; soft massive clay with minor amounts of fine black grains; unit weathers very recessively; lower contact sharp	0.08
4	Shale, as in unit 6, but lower 0.2 m of unit is relatively soft and includes a greyish-yellow to dark-yellowish-orange bentonite seam at 0.13 m above the unit base	0.79
3	Shale, as in unit 6	0.08
2	Shale, black, weathering medium grey; greyish-yellow jarosite common on weathered surface; non-calcareous; soft, uniform, wet; weathers recessively; lower contact sharp	0.15
1	Shaly Limestone, olive black to olive grey, weathering medium light grey; calcareous; fine chalk specks abundant; argillaceous; hard; bedding irregular, cleaves along sub-horizontal surfaces parallel to the abundant shells of *Mytiloides*; unit weathers resistantly; lower contact not exposed	1.85

Measured thickness of Keld Member	**6.39**
Total measured thickness of Favel Formation	**13.48**

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

Return to vehicles and make U-turn back to P.T.H. 10. Turn left (South) and follow the Highway for 16 km. Cross Pine River and turn right (North) into undeveloped picnic site and park. Pine River Outcrop is immediately to the north, about 50 m downstream, along west side of river bank.

STOP 12: PINE RIVER OUTCROP

Cretaceous Morden Shale overlying Favel Formation (Assiniboine Member with Marco Calcarenite). 4-1-33-23W1, NTS 62N15SE. The outcrop is located on the north bank of the Pine River, approximately 4 km northwest of Pine River, Manitoba. The Pine River drains the northeastern flank of Duck Mountain.

Black non-calcareous Morden Shale, about 2 m thick, overlies a 0.25 m thick ledge of buff to grey Marco Calcarenite of the Assininboine Member of the Favel Formation. A 0.3 m thick bed of fissile rusty calcareous speckled shale underlies the calcarenite.

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

Return to vehicles and return back to P.T.H. 10. Turn right (South) and follow the Highway for 70 km. Note: we are traveling on a beach ridge from the time of Glacial Lake Agassiz. Cross Valley River bridge and turn left (North) on gravel road for 300 m. Turn right (East) and follow road bending to north. Park on left side of road and proceed west on foot, either on trail down to valley past road cut with well-exposed stratified glacial deposits, or proceed directly on trail down cliff face

STOP 13: VALLEY RIVER OUTCROP

Cretaceous Favel Formation overlying Ashville Shale. (McCabe and Bannatyne, 1970, Stop 13) in 13-35-25-21W1, NTS 62N1NW. Outcrop forms a cliff face on the east side of the Valley River, about 4 km north of Ashville, Manitoba. The Valley River forms part of the drainage basin between Duck Mountain to north and Riding Mountain to the south.

The outcrop consists of 6.7 m of Cretaceous Ashville and Favel formations; both units show highly abnormal appearance. The upper 2.4 m consist of grey thin-bedded fissile speckled calcareous shales of the Favel Formation which are “weathered” to light buff and pink; several thin white to greenish and purplish bentonitic (?) beds are present. The bottom 4.3 m are Ashville Formation consisting of non-calcareous slabby to fissile shale which is quite brightly colored shades of pink to buff, greyish red, yellow, and purplish red; one patch of black shale is present. This may represent a "burned" section of highly oxidized Ashville and Favel beds. The black shale probably represents an unoxidized remnant of the normal black petroliferous Ashville shale.

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

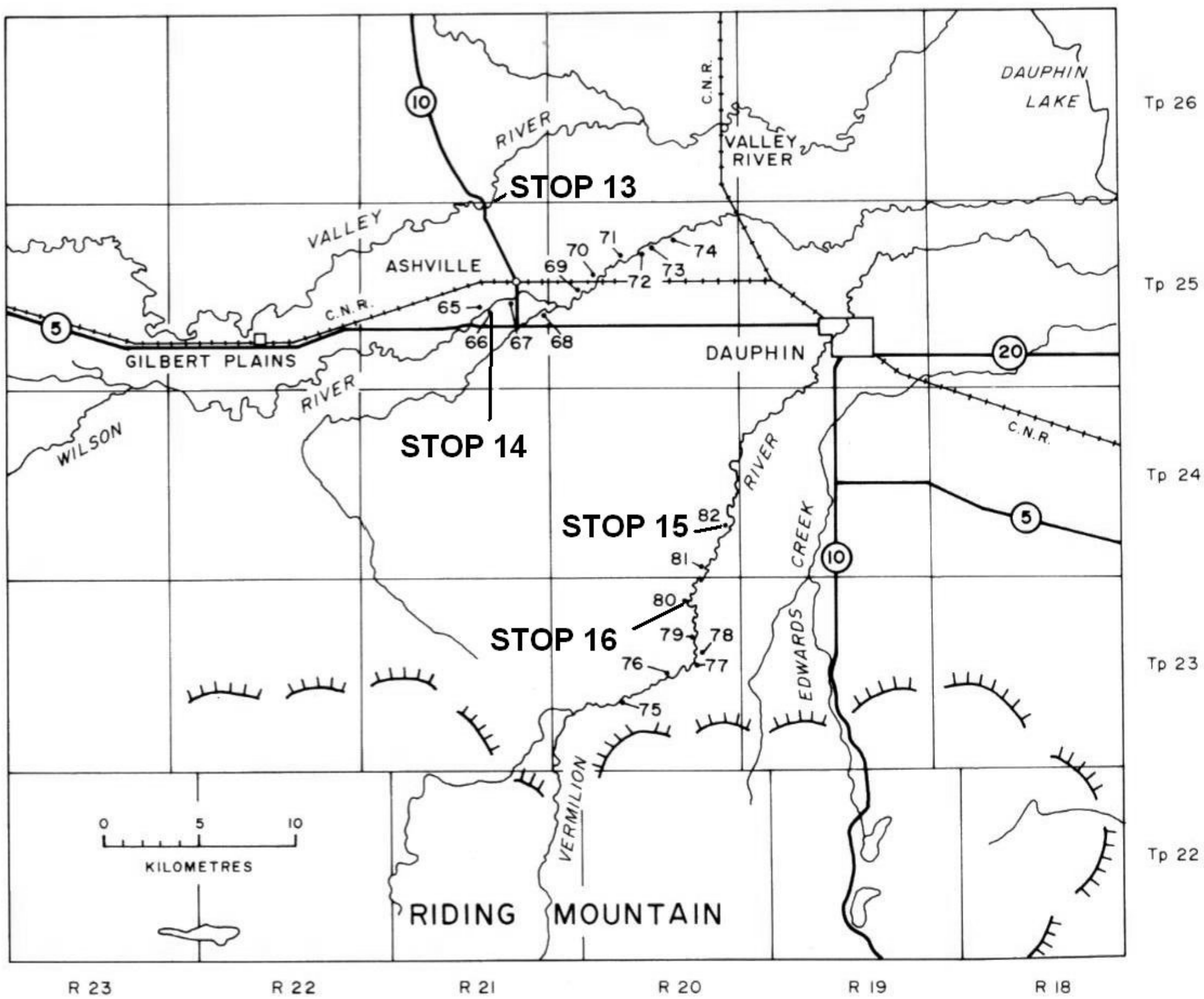

Figure 15: Location map for ***STOPS 13-16*** *(modified from McNeil and Caldwell, 1981).*

Return to vehicles and return back to P.T.H. 10. Turn left (South) and follow the Highway for 6.4 km. Junction with P.T.H. 5, turn right (West) for 3.4 km. Turn left (South) on trail and park. Proceed on foot south ton trail to small creek and follow creek valley to Wilson River,

STOP 14: WILSON RIVER OUTCROP

Cretaceous Ashville Formation (Upper beds). (McNeil and Caldwell, 1981, Outcrop Section 66) in the southwest portion of 12-14-25-21W1, NTS 62N1NW. Outcrop is well exposed on south bank of Wilson River about 16.7 km west of Dauphin, Manitoba. The Wilson River forms part of the drainage basin between Duck Mountain to north and Riding Mountain (Fig. 16) to the south.

Ashville Formation (component-lectostratotype)		Thickness (m)
Upper Ashville Formation		
6	Shale, dark to medium grey, weathering medium grey to medium light grey, coated in places with greyish-yellow jarosite; lower 30 cm of unit partly calcareous, very fine carbonaceous specks abundant, fish fragments common, very fine selenite common, prismatic fragments of bivalves common; a calcarenite lens, 30 cm in length and 4 cm in thickness, lithologically similar to calcarenite in unit 5, at 0.6 m above unit base; indeterminant bivalve replaced by selenite at 2.14 m above unit base, *Inoceramus arvanus* Stephenson common in calcarenite lens and rare at 1.0 m above unit base; unit weathers recessively; lower contact sharp	3.08
5	Calcarenite, medium grey, weathering yellowish grey to dark yellowish orange; very fine to fine calcite prisms in finely crystalline calcite matrix with minor amounts of clay and fish fragments; fish scales of *Hypsodon lowii* (Stewart) rare, *Ostrea beloiti* Logan abundant; thin irregular bedding; unit weathers resistantly; lower contact sharp	0.05
4	Bentonite, bluish grey, weathers light brown; clay, fine biotite and selenite crystals common; massive; chunky; unit weathers recessively; lower contact sharp	0.53
3	Calcarenite, as in unit 5; *Ostrea beloiti* Logan abundant; thin clay lenses common in lower 3 cm	0.13
2	Shale (70%) and calcarenite (30%) interbedded: Shale, dark grey, weathering medium light grey; calcareous, fine selenite crystals common, fish fragments common; unit weathers relatively recessively. Calcarenite, lithology as in unit 5, but in thin lenses, commonly with *Ostrea beloiti* Logan *in situ* at top of lens; lower part of unit contains several very thin-bedded, but relatively continuous, calcarenite beds. Unit weathers resistantly; lower contact sharp	0.68
1	Shale, greyish black, weathers medium grey; fish fragments common; unit weathers recessively; lower contact not exposed	0.30
Measured thickness of Upper Ashville Formation		**4.67**

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

Return to vehicles and return back to P.T.H. 5. Turn right (East) and follow the Highway for 9 km. Junction with PR274, turn right (South) for 9.6 km. Section corner, turn left (East) for 3.2 km, then right (South) for 0.6 km. Park and walk east across field, down to the Vermilion River.

Figure 16: Riding Mountain LANDSAT image (See: Figure 1).

STOP 15: VERMILION RIVER DOWNSTREAM OUTCROP

Cretaceous Favel Formation (Keld Member)/Ashville Formation (Belle Fourche Member. (McNeil and Caldwell, 1981, Outcrop Section 82) in the west-central portion of 10-12-24-20W1, on NTS 62N1SE. Outcrop is well exposed on the east bank of Vermilion River, approximately 10.5 km southwest of Dauphin, Manitoba. It is on the north flank of Riding Mountain.

Favel Formation		**Thickness (m)**
Keld Member		
13	Shale, medium grey, weathers light grey; calcareous; chalk specks abundant; hard; weathers in irregular slabs, cliff forming (unit not measured in detail); lower contact sharp	6.10
12	Shale, dark grey, weathers light grey with moderate-brown jarosite in places; calcareous; moderately hard; chalk specks abundant; thin discontinuous layers of prismatic calcite (inoceramid? fragments) common; unit weathers in irregular chunks, resistant; lower contact gradational	1.01
11	Bentonite, very light grey, weathers greyish yellow with minor dark yellowish brown patches; massive clay; minor amounts of fine biotite flakes and selenite; unit weathers recessively, lower contact sharp	0.20
10	Shale, dark grey, weathers medium grey with dark yellowish brown jarosite in places; calcareous; chalk specks abundant, fish fragments locally abundant; unit weathers moderately resistantly, breaks down to irregular chips and flakes; lower contact sharp	0.61
9	Bentonite, as in unit 11	0.08
Measured thickness of Keld Member		8.00

Ashville Formation		**Thickness (m)**
Belle Fourche Member		
8	Non-calcareous shale (50%) and calcareous shale (50%) interbedded: Non-calcareous shale, greyish black, weathers medium light grey with greyish-yellow jarosite common; relatively soft; fine selenite crystals common. Calcareous shale, dark grey, weathers medium light grey with dark yellowish-brown jarosite common; chunky; fine selenite common; slightly harder than non-calcareous shale interbeds. Unit weathers recessively to slightly resistantly; lower contact sharp	1.68
7	Bentonite, as in unit 11	0.03
6	Shale, dark grey to black, weathers medium light grey to light grey with minor patches of moderate- to light-brown jarosite; thin discontinuous layers of prismatic	

	calcite (inoceramid? derived) common, fish fragments common, fragile shells of *Inoceramus arvanus* Stephenson common in lowermost part of unit; clay-ironstone concretions common at about 7 m above base of unit, calcareous, dense, hard, ovoid, up to 0.15 cm in thickness and 30 cm in length, fish fragments up to 2 cm in length, weathered surface heavily coated with rusty residues and coarse selenite crystals; unit weathers recessively and breaks down to brittle flakes; lower contact gradational	8.37
5	Calcarenite, medium light grey, weathers yellowish orange to yellowish brown; composed predominantly of fine- to medium-sized calcareous prisms probably derived from *Inoceramus* and *Ostrea*; minor amounts of clay, quartz, sparry calcite, rusty specks, and fish fragments; *Ostrea beloiti* Logan common especially at the top of bedding planes; thin bedded; cross-laminae common; shaly laminae and lenses common near top; unit weathers resistantly; lower contact sharp	0.13
4	Bentonite, as in unit 11	0.79
3	Calcarenite, as in unit 5	0.13
2	Shale (80%) and calcarenite (20%): lithologically as in unit 1 and 5 respectively; calcarenite in very thin discontinuous beds and lenses; calcarenite yields rare fish scales of *Hypsodon lowii* (Stewart) and common *Ostrea beloiti* Logan; unit weathers moderately resistantly; lower contact sharp	0.50
1	Shale, greyish black, weathers medium grey with greyish-yellow to light-brown jarosite common; flaky to chunky; fine selenite crystals common; hydrogen sulphide odour present; unit weathers recessively; lower contact not exposed	1.42
Measured thickness of Belle Fourche Member		**13.05**

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

Return to vehicles and turn around. At section corner, turn left (West) for 1.2 km, then turn left (South) for 4 km and park. Cross field to the East and carefully descend into river valley.

STOP 16: VERMILION RIVER UPSTREAM OUTCROP

Cretaceous Morden Shale overlying Favel Formation (Assiniboine/Keld members). (McNeil and Caldwell, 1981, Outcrop Section 80) in the central portion of 5-35-23-20W1, NTS 62N1SE. Outcrop is well exposed on west bank of Vermilion River, approximately 13.5 km southwest of Dauphin, Manitoba. It is on the north flank of Riding Mountain.

Morden Shale		**Thickness (m)**
14	Shale, black, weathering medium light grey, greyish-yellow jarosite common; non-calcareous; flaky, relatively soft; unit weathers recessively; lower contact sharp and irregular, relief of up to 15 cm	0.71
Measured thickness of Morden Shale		**0.71**

Favel Formation

Assiniboine Member (holostratotype)

13	Shale, dark olive grey to dark yellowish brown, weathering medium light grey to yellowish or greyish brown; uppermost 30 cm of unit deeply weathered to a dark yellowish orange; calcareous; chalk-speckled; relatively soft; very thin calcarenite lenses common, particularly in lower 1.0 m of unit; layers of prismatic calcite (*Mytiloides*?) common; a 5 cm-thick bed of calcarenite (lithology as in unit 12) at 30 cm above unit base; unit weathers recessively; lower contact sharp	3.49
12	Calcarenite, yellowish brown, weathering greyish orange; very fine to fine grains of calcite; very hard; bedding thin, sub-horizontal; fish fragments common and concentrated along bedding planes; fossils include rare mosasaur teeth, *Actinocamax manitobensis* (Whiteeaves) common, *Inoceramus cuvieri* Sowerby common, *Pseudoperna bentonensis* (Logan) abundant, and the calcareous worm tubes of *Serpula semicoalita* Whiteeaves abundant and attached to *I. cuvieri*; unit weathers very resistantly; lower contact sharp. Marco Calcarenite (holostratotype-top)	1.20
11	Shale (80%) and calcarenite (20%) interbedded: Shale, as in unit 9. Calcarenite; lithologically as in unit 12; bedded in thin lenses. Unit weathers resistantly; lower contact sharp. Marco Calcarenite (holostratotype-bottom)	0.76
10	Bentonite, yellowish-grey, weathering greyish yellow to light brown; soft, massive clay; weathers very recessively; lower contact sharp	0.03
9	Shale, olive grey to greyish black, weathering medium light grey to light grey; calcareous; finely chalk-speckled; moderately hard but outer 30 cm or so weathers to flaky shale; light brown weathering bentonite seams at 2.1 and 5.6 m above unit base; unit weathers recessively; lower contact sharp	7.32
8	Bentonite, as in unit 10	0.03
7	Shale, olive black to dark grey, weathering medium light grey to light grey; calcareous; finely chalk-speckled; moderately hard; relatively uniform; fish fragments common; one 3 cm-thick bed of soft, medium dark grey shale (bentonitic?) at 20 cm below unit top; deeply weathered, light-brown, bentonite seams at 0.4 and at 1.5 m above unit base; thin limestone lenses (lithology as in unit 5) about 12 cm above unit	

	base; *Mytiloides subhercynicus* (Seitz) rare in upper 10 cm of unit; unit weathers recessively; lower contact sharp	2.86
Measured thickness of Assiniboine Member		**15.69**

Keld Member

6	Limestone, medium grey, weathering light grey to light olive grey; chalk specks abundant; argillaceous; very hard, massive, thinly bedded; fossils include common fish fragments, *Mytiloides labiatus* (Schlotheim) common, *Baculites yokoyamai* Tokunaga and Shimizu rare, and *Inoceramus cuvieri*(?) Sowerby rare; unit weathers very resistantly; lower contact sharp. Laurier Limestone Beds (top)	0.13
5	Shaly limestone, olive black, weathers medium light grey; calcareous; chalk specks abundant; very hard; shell material from *Mytiloides labiatus* abundant; sub-fissile, chunky to platy, cleaves along planes parallel to bivalve shells; a thin, discontinuous limestone bed (lithology as in unit 6) at 1.0 m above unit base; unit weathers resistantly; lower contact sharp	1.83
4	Limestone, lithologically as in unit 6. Laurier Limestone Beds (bottom)	0.05
3	Shaly limestone, as in unit 5, but lacking limestone beds	0.10
2	Bentonite, yellowish grey, weathering greyish yellow to light brown; soft, massive clay; unit weathers very recessively; lower contact sharp	0.03
1	Shaly limestone, as in unit 5, but lacking limestone beds; lower contact not exposed	0.58
Measured thickness of Keld Member		2.72
Total measured thickness of Favel Formation		**18.41**

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

Return to vehicles and head North to next section corner, 0.8 km, turn left (West) for 1.6 km, turn right North back onto PR274. Drive for 6.4 km to Spruce Creek Junction, turn right (East) for 6.4 km, turn right (South) for 1.6 km, turn left (East) for 4.8 km. Junction with P.T.H. 5 and 10. Drive straight across, do not turn.

Proceed on P.T.H. 5 for 21 km due East to Junction with P.R. 582. Turn right (South) on P.R. 582 for 8 km. Intersection. Turn left (East) on P.R. 582 for 300 m. Intersection. Turn right (South) on section road for 3.2 km. Road jogs right on correction line for 300 m. Road turns left (South) for 1 km. Can be very soft. Turn right (West) on section road. After 1 km road begins to wind along east bank of Ochre River for 1 km, then turns South for 1 km. Intersection. Trail to right (West) for 400 m to ford on Ochre River. Park; proceed to river, and follow the river downstream for about 400 m.

STOP 17: OCHRE RIVER OUTCROP

Cretaceous Favel Formation (Assiniboine Member overlying Keld Member). (McCabe and Bannatyne, 1970, Stop 14) in 2-30-22-17W1, NTS 62J13NW. The outcrop is situated on the bank of the Ochre River, about 18 km west-northwest of Laurier, Manitoba. It is on the northeastern flank of Riding Mountain.

Exposures comprise the top limestone bed of the Keld Beds (Laurier Limestone?), overlain by up to 15.2 m of the Assiniboine Beds of the Cretaceous Favel Formation. The Assiniboine Beds consist of dark grey speckled calcareous shale; in the upper 6.1 m, a 1.2 m bed of grey limestone, containing Inoceramus and other fossils, forms a prominent resistant ledge, and large slabs of this layer are scattered along the river's edge. A few thin limestone beds are interbedded with speckled and non-speckled shale. At the top of the exposure, 400 m northeast of the ford on the east bank of Ochre River, less than a metre of black carbonaceous shale of the Morden Shale is exposed, under the glacial drift cover.

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

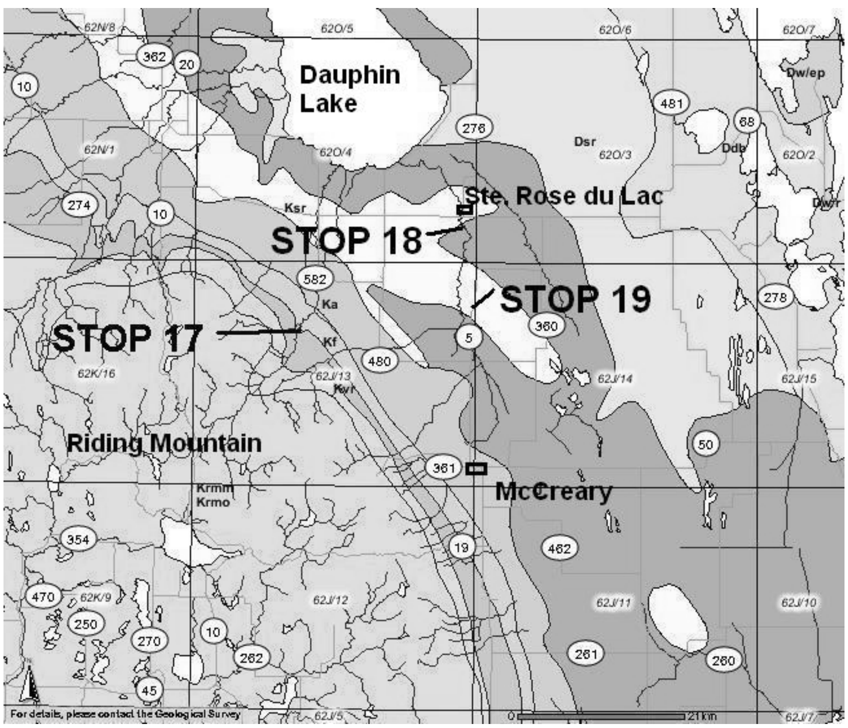

*Figure 17 Location map for **STOPS 17-19**.*

Return northward for about 17 km back to Junction with P.R. 582. Turn left (West) on P.R. 582 for 300 m, then turn to right (North). Travel 8 km back to Junction with P.T.H. 5, turn right (East) to Ste. Rose du Lac, 17.6 km.

End of Day 2 - Overnight in Ste. Rose du Lac

DAY 3: CRETACEOUS AND JURASSIC STRATIGRAPHY OF WESTLAKE PLAIN AND PEMBINA HILLS

Day 3 will introduce Jurassic beds which now occur between the Cretaceous and underlying Devonian stratigraphy. For the most part, the Jurassic is present throughout the southern portion of the Manitoba Escarpment. Stops will be made on the First Prairie Level Westlake Plain to view the Jurassic beds before moving southward into the Pembina Hills. The complete stratigraphic succession and lithology are shown in Figure 9, including the stratigraphic position of all outcrop stops.

Proceed South on section road due south of Ste. Rose du Lac for 1.6 km. Turn left (East) at intersection for 400 m to ford on Ochre River. Park; proceed to river, and follow the river downstream for about 200 m.

STOP 18: TURTLE RIVER OUTCROP

Jurassic Reston Formation. 4-4-24-15W1, NTS 62O4SE, NAD 27 Zone 14U 463696E 5653889N. The outcrop is located within the Westlake Plain, on the west bank of Turtle River, 200 m north of the road allowance, 1.6 km south of Ste. Rose du Lac.

Strike of outcrop 055°. Length of exposure along bank 10 m, width 1.5 m and height 0.76 m.

	Thickness (cm)
Vegetation, soil and sand	50
Reston Formation	
Limestone, slightly argillaceous, buff, flaggy	9
Limestone, slightly argillaceous, buff	44
Shale, calcareous, light grey	7
Limestone, slightly argillaceous, buff	7
Shale, calcareous, light grey	7
Total Section	**124**

Corehole M-10-70c
St. Rose du Lac
5-22-23-15WPM
5649685N
465135E
Elevation: 279.5 m
Total Depth: 94.0 m
Map sheet: 62J/14
Logged by H. R. McCabe

METRES	DESCRIPTION
0.0-22.3	**JURASSIC** **MELITA FORMATION:** Shale, calcareous sandstone.
22.3-28.7.0	**RESTON FORMATION:** Limestone, shale.

End of Hole

References: M-10-70c, Bannatyne (1975).

Return to vehicles, turn around and head West back to section road. Turn left (South) 8 km. Intersection with section road, turn left (East) and drive 1.2 km to entrance of former Ste. Rose du Lac Quarry and park.

STOP 19: FORMER STE. ROSE DU LAC QUARRY

Cretaceous Swan River Formation overlying Jurassic Melita Formation. (McCabe and Bannatyne, 1970, Stop 15) in 15-4-23-15W1, NTS 62J13NE. The former quarry is located on the Westlake Plain of the First Prairie Level, 300 m west of P.T.H. 5, 11 km south of Ste. Rose du Lac, Manitoba.

As of 1975, the Ste. Rose du Lac Quarry was 143.m long, 37 m wide and 20 m deep. The following section was described by Shayna (1975):

		Thickness (m)
6	Overburden – stripped off (4 m)	
Swan River Formation		
5	Stoneware clay - dark grey, uniform, fine-grained fairly plastic, massive with fossiliferous pyrite concretions. At the base is a thin carboanaceous zone with pyrite nodules and selenite crystals	3.0
Melita Formation (Lower)		
4	K1 – Kaolinized shale – light to dark grey with pyrite	3.7
3	K2 – Kaolinized shale – light to dark grey	3.7
2	K3 – Kaolinized shale – near white	2.1
1	HT Red clay – deep ochrous red	3.7
	Total Section	16.2

The strata have been deposited in a pre-Cretaceous channel eroded into the Jurassic Melita, Reston, and Amaranth formations (McCabe and Bannatyne, 1970 and Bannatyne (1971).

The clay was trucked 200 km to the company's face brick plant at Lockport, Manitoba (29 km north of Winnipeg). At the plant the clay was mixed with clay from **(STOPS 26 and 30)** to produce a variety of colours of face brick. I-XL Industries Ltd succeeded Medicine Hat in running Red River Brick and Tile Limited. Operations at the quarry ceased in 1992 with the closure of the Lockport plant, although a limited amount of clay is removed periodically from the surface stockpiles by I-XL.

Corehole M-09-78
Ste. Rose du Lac
15-4-23-15WPM
5645450N
464275E
Elevation: 283.0 m
Total Depth: 14.38 m
Map sheet: 62J/13
Logged by H. R. McCabe

METRES	**DESCRIPTION**
0.0-3.67	**OVERBURDEN:** Clay, till.
3.67-9.42	**MESOZOIC** **CRETACEOUS** **SWAN RIVER FORMATION:** May include some weathered Jurassic shale. Shale- kaolinitic, black to very light grey, minor pyrite specks, lignite fragments in 3 repeated cycles.
9.42-14.38	Shale- kaolinitic, mottled, light purplish grey to light grey. 0.3 m of soft red shale, sandy near base.

End of Hole

In 1972-73, Red River opened up a second pit about 1.6 km to the south on P.T.H. 5. This pit contained larger quantities of the stoneware clay, minor grey kaolinitic clay, and a 4 m thick HT Red clay at a depth of 5 m (Shayna, 1975).

References: M-9-78, McCabe and Bannatyne (1970), Bannatyne (1970, 1971, 1978), Shayna (1975).

Leave former quarry and turn right (East) for 400 m to Junction with P.T.H. 5. Turn right (South) for 21 km. Note Jurassic red clay pile about 1.6 km to the South on east side of road. This was another quarry site.

Junction with P.T.H. 50, turn left (East) 47 km to Silver Ridge Junction. Turn right (South), continuing on P.T.H. 50, for 6.4 km. Turn east on section road before (north of) bridge over drainage ditch on Highway 50. Proceed east for 4.8 km. Turn north for 0.5 km and turn west through gate to Westroc's Harcus gypsum quarry.

STOP 20: HARCUS GYPSUM QUARRY OF BPB CANADA INC.

Jurassic Amaranth Formation. (Bannatyne and Watson, 1982, Stop 5) in $E^{1}/_{2}$-22-20-10W1, NTS 62J10NW. The quarry is located on the First Prairie Level or Westlake Plain, 5.7 km northeast of the town of Harcus and 15 km north of Amaranth, Manitoba.

A section measured in 1980 is typical of the quarry face, although variations occur throughout the quarry (Bannatyne and Watson, 1982).

	Typical section – Harcus Quarry, Westroc Inc.	**Thickness (cm)**
9	Overburden – stripped off (4 to 6 m)	
	Amaranth Formation	
8	Gypsum; thin dolomitic stringers	70
7	Gypsum; interlayered 1 to 2 cm stringers of satin spar, green clay	21
6	Gypsum, abundant fragments of dolomite	30
5	Gypsum; variable dolomite content (to 20%); scattered pink to orange	
4	chalcedony; some areas of fine grained gypsum (alabaster)	275
3	Gypsum; orange translucent; associated with dolomite fragments; red clay in thin stringers and small pockets; satin spar in 0.6 to 1.2 cm layers	30
2	Gypsum; mainly covered with rubble to water level	61
1	A gypsum layer is reportedly left in place overlying the Amaranth red beds	92
	Total Gypsum	**579**

The thickness ratio of overburden to gypsum is about 1:1, and at the present quarry site, each is about 6 m thick. The gypsum is bedded, and exhibits some gentle arching. The presence of dolomite fragments as a penemosaic texture in some layers suggests deposition in a sabkha environment.

At various places in the quarry walls cross sections of till-filled sinkholes can be seen. These have walls of water-worn gypsum and are filled with poorly sorted till. The sinkholes observed in October, 1981 ranged in size from 0.5 m to more than 1.5 m in diameter.

For additional information on production from the quarry see: Economic Geology – Gypsum.

References: Bannatyne and Watson (1982).

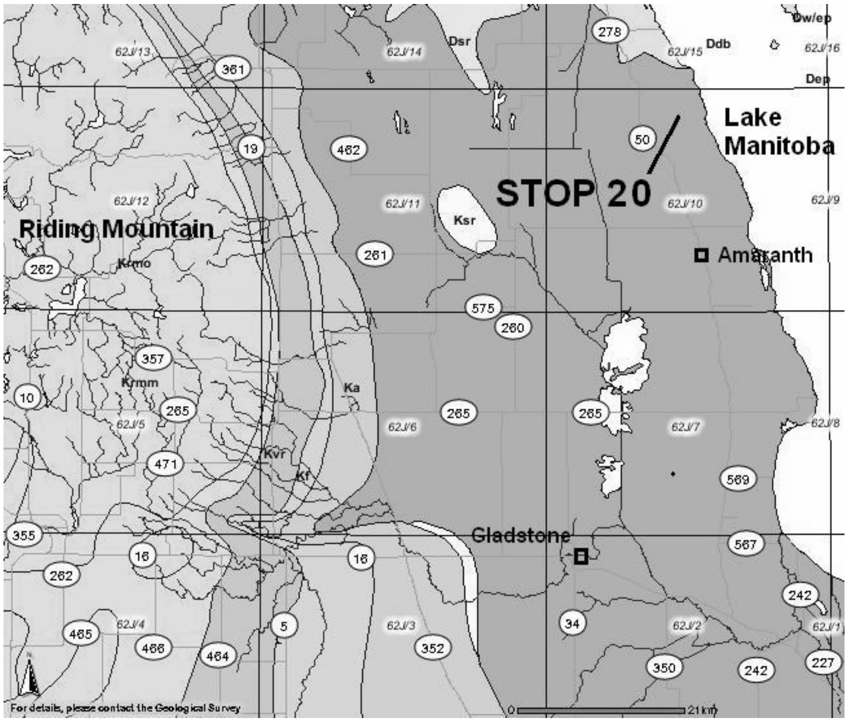

Figure 18 Location map for ***STOP 20****.*

Return to P.T.H. 50 and turn left (South) for 60 km. Junction with P.T.H. 4 (Yellowhead), turn right (West) for 20 km. Junction with P.T.H. 34, turn left (South) for 70 km. Junction with P.T.H. 2, turn left (East) for 11.2 km. Intersection with section road immediately before Treherne. Turn right (South) and drive toward rise, about 2 km.

STOP 21: TREHERNE SHALE AGGREGATE QUARRY

Cretaceous Pierre Shale (Odanah Member). 12-25-7-10W1, NTS 62G10SE, NAD 27, Zone 14U, 520900E, 5495600N. The quarry is located on a knoll, on the north flank of the Pembina Hills, about 2 km south of Treherne, Manitoba.

A 5.5 m section of well-bedded manganese-stained Odanah Member of the Pierre Shale is exposed on the east wall of a quarry south of Treherne. A 21 cm thick green swelling bentonite seam is found 1.5 m above the base of the quarry. The shale beds are thin bedded at the top and bottom of the section but appear to be more thickly bedded in the middle of the section. About 1.5 m of overburden is on top of the outcrop.

A major thrust plane indicates glacial disturbance and channel fill at the top of the knoll suggests that glacial meltwater once flowed on the top of the outcrop.

References: Bannatyne (1970).

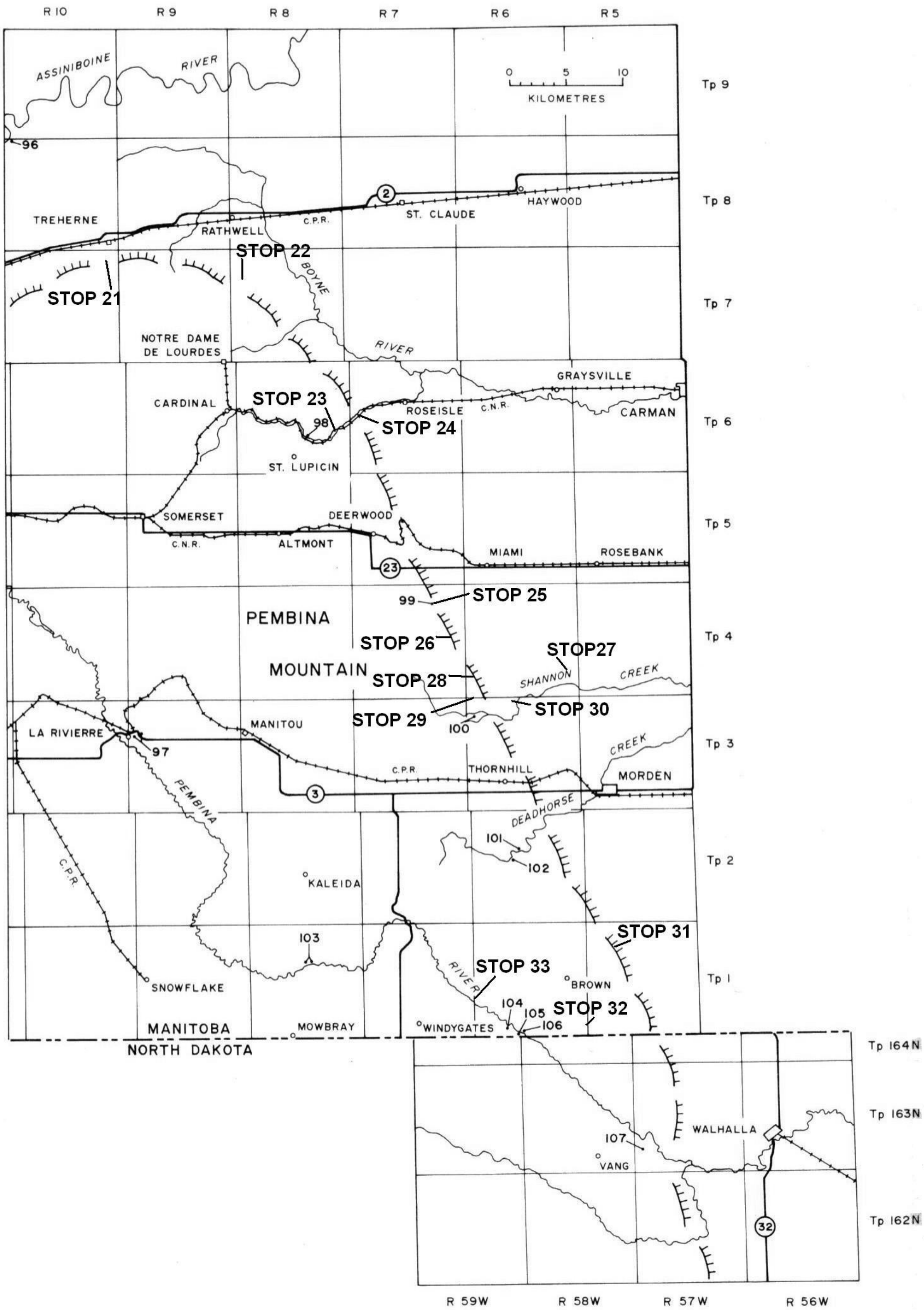

*Figure 19: Location map for **STOPS 21-33**(modified from McNeil and Caldwell, 1981).*

Continue South on section road for 0.8 km. Intersection with section road, turn left (East) for 0.8 km. Intersection with minor road, south of Treherne, turn right (South) for almost 5 km. Road merges with P.R. 242 for almost 3.5 km. Junction with P.R. 245, turn left (East) for 30 km. Notre Dame de Lourdes Junction with P.R. 244,245, turn left (North) on P.R. 244 for 6.4 km. Junction with section road, turn right (East) for 1.6 km. Intersection with section road, turn left (North) and then left again into farm.

STOP 22: BOSC FARM GAS WELL

Cretaceous Niobrara Formation overlying Morden Shale and Favel Formation. 1-30-7-8W1, NTS 62G10SE. The gas well is situated on the north flank of the Pembina Hills (Fig. 20), 6 km north-northeast of Notre Dame de Lourdes, on the farm of Norman and Guy Bosc.

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

The well produces natural gas, with a weak petroleum smell, that burns when ignited. The well recharges with 32 lbs. gas pressure every 12 hours when the valve is closed. The pressure drops to 3 lbs. after being opened for 0.5 hour. Poor quality drinking water has been encountered in all wells drilled in the entire Section.

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

<u>References:</u> Wallace (1925), Bannatyne (1970).

Return back to P.R. 244, turn left (South) and return to Notre Dame de Lourdes. Note: Niobrara outcrops along section road. Junction with P.R. 245, continue southward for 3.2 km. Road turns to East for 6.4 km. Intersection. Turn right (South) on section road to St. Lupicin. Road descends into Roseisle Creek (formerly Boyne River) Valley, but is also known as Snow Valley. Note outcrops on valley wall. Intersection at bottom of valley. Turn left (East) and proceed down Snow Valley. Park on side of road where safe.

STOP 23: ROSEISLE OUTCROPS

Cretaceous Niobrara Formation (with Chalky and Calcareous members). (McCabe and Bannatyne, 1970, Stop 17) in 13 to 16-10-6-8W1, NTS 62G8NW, NAD 27, Zone 14U, 539700E, 5479850N. The string of generally east-west trending outcrops line the north side of Roseile Creek or Snow Valley, within the Pembina Hills. The valley is located about 1.8 km northeast of St. Lupicin, Manitoba.

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

Calcareous shale from the Niobrara Formation has been used in the production of natural cement. The shale was recovered by room and pillar mining methods from 1907 to 1924 by way of an adit into the south slope of the valley, near Babcock station (about 0.5 km to the west of **STOP 23**).

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

Continue East on road for about 2 km. Leary's brick plant (abandoned) to right of road. Park and walk into plant site.

STOP 24: FORMER LEARY'S BRICK PLANT AND SHALE OUTCROP

Cretaceous Morden Shale. (McCabe and Bannatyne, 1970, Stop 18) in 6-13-6-8W1, NTS 62G8NW, NAD 27, Zone 14U, 541600E, 5480200N. The former brick plant is located a few hundred metres north of Roseisle Creek and the shale outcrop is on the south bank of the creek. Both are situated at the edge of the Pembina Hills, about 6 km southwest of Roseisle, Manitoba.

Brick Plant

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

Morden Shale

A 9 m high bank of black carbonaceous Morden Shale (formerly, a member of the Vermilion River Formation) is present on the south slope of Snow Valley, 60 m south of the brick plant. Note the well-developed large septarian concretions in the creek valley; these were discarded during the stripping operations.

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

Continue east on road for about 4 km. Intersection with section road. Turn right (South) for about 3 km. Intersection with diagonal road to southeast. Note: we are driving on a beach ridge of Glacial Lake Agassiz. Follow this road for about 5 km to Five Corners Junction. Turn right (South) on P.R. 240 for 6.4 km. Junction with P.T.H. 23, turn left (East) for 1.6 km. Intersection with section road, turn right (South) for 1.6 km. Morden Shale exposed near bridge. Intersection, turn right (West) for 0.8 km, follow road to South and go up rise. Park at top of hill.

STOP 25: ROBERT'S FARM FORMER BENTONITE QUARRY

Cretaceous Pierre Shale (Pembina Member). (McNeil and Caldwell, 1981, Outcrop Section 99) in the south-central portion of 3-35-4-7W1, NTS 62G8SW, NAD 27, Zone 14U, 550300E, 5462200N. The rehabilitated quarry is situated at the edge of the Pembina Hills, 5.6 km southwest of Miami, Manitoba on the Robert's Farm.

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

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

<u>References:</u> McNeil and Caldwell (1981), Bannatyne (1963, 1970), Bannatyne and Watson (1982).

Continue up the Escarpment towards the southwest. Millwood buttes can be seen at edge of Escarpment. Then go South on section road for 2.9 km, turn left (East) 1.6 km, turn left (North) 0.3 km, then turn East into shale quarry.

STOP 26: R.M. OF THOMPSON SHALE AGGREGATE QUARRY

Cretaceous Pierre Shale (Odanah Member). (McCabe and Bannatyne, 1970, Stop 21 and Bannatyne and Watson, 1982, Stop 3) in SW5-24-4-7W1, NTS 62G8SW, NAD 27, Zone 14U, 551300E, 5462500N. The quarry is located on the northeast flank of the Pembina Hills, 3 km southwest of Miami, Manitoba.

A 6 m section of hard grey siliceous shale that is typical of the Odanah Member is exposed in the Rural Municipality of Thompson quarry. Odanah shale contains 79 to 82% SiO_2, mainly amorphous silica mixed with illite with a montmorillonite component. The shale is well bedded and cut by joints that are stained with iron and manganese oxides. The municipality uses the shale as a crushed aggregate for surfacing roads.

Another quarry is located, across the section road to the west, in SE9-23-4-7W1. This quarry was operated from 1971 to 1992 by Red River Brick and Tile (a subsidiary of I-XL Industries Ltd.) to mine the Odanah to make face brick. The shale was transported over 160 km to Lockport, Manitoba (29 km north of Winnipeg) where it was mixed with other clays from **STOPS 19 and 30** to produce a variety of colours. With the shutdown of the Lockport plant, the quarry is now used by RM of Thompson for aggregate.

Note on the east wall of the quarry the contact with overlying fragmental and distorted shale-rich till, formed by cryoturbation (E. Nielsen, pers. comm.).

Corehole M-08-77

Pembina Mountain, Miami

5-24-4-7WPM

5462450N

551300E

Elevation: 434.3 m

Total Depth: 74.4 m

Map sheet: 62G/8

Logged by H. R. McCabe

METRES	DESCRIPTION
0.0-13.7	**MESOZOIC**
	CRETACEOUS
	PIERRE SHALE FORMATION
	(RIDING MOUNTAIN FORMATION)
	Odanah Member:
	Shale- siliceous.
13.7-32.6	Shale- bentonitic.
32.6-38.4	**(VERMILION RIVER FORMATION)**
	MilLwood Member:
	Shale- bentonite.
38.4-74.4	**NIOBRARA FORMATION (Boyne Member):**
	Calcareous and non-calcareous shale.

End of Hole

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

Continue down the Escarpment towards the northeast, past Twin Sisters "peaks" (buttes) to the northwest. Then, follow section road to East for 2.4 km, turn right (South) for 3.2 km, turn left (East) for 6.2 km and stop on section road beside large tree.

STOP 27: FAVEL PAVEMENT OUTCROP

Cretaceous Favel Formation (Assininboine Member with Marco Calarenite). 1-14-4-6W1, NTS 62G8SE, NAD 27, Zone 14U, 560850E, 5460400N. The outcrop is located on the First Prairie Level, 7 km east of the Pembina Hills component of the Manitoba Escarpment. The exposure is at the base of a shallow ditch on the north side of the road, and also appears as broken slabs in a small borrow pit to the south.

The outcrop consists of a 30 m long pavement of buff calcarenite, about 20 cm thick, overlying beige oxidized clay. Fish scales, Inoceramus and oyster shells, and shark vertebrae impressions have been found.

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

Corehole M-12-77

Miami SE

1-14-4-6WPM

5460500N

560900E

Elevation: 297.2 m

Total Depth: 45.1 m

Map sheet: 62G/8

Logged by H. R. McCabe

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

End of Hole

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

Make a U-turn and proceed due west on the section road towards "Mount" Nebo, 7.6 km. Turn right and park on approach road to former quarry.

STOP 28: MOUNT NEBO FORMER BENTONITE QUARRY

Cretaceous Pierre Shale (Millwood Member overlying Pembina Member. 4-18-4-6W1, NTS 62G8SW, NAD 27, Zone 14U, 553050E, 5460500N. The former quarry was opened at the base of Mount Nebo, one of the typical Millwood buttes, found at the edge of Pembina Hills as described for **STOP 25**. Mount Nebo is located about 8 km south of Miami, Manitoba.

Bentonite beds of the Pembina Member of the Pierre Shale were quarried by Pembina Mountain Clays Limited north and south of the section road at the base of Mount Nebo. However, several thin beds of bentonite can still be seen adjacent to the road allowance. The bentonite seams were very similar in appearance to those exposed during the mining operations at **STOP 25** 6 km to the northwest.

The quarry to the north has not been rehabilitated and is used by locals for dirt-bike riding, as is most of the flanks of Mount Nebo. The distinctive sparsely vegetated popcorn or cauliflower surface of the greenish-grey bentonitic shale of the Millwood Member can readily be seen, but the contact with the underlying Pembina Member is not exposed. Brown to purple manganiferous ironstone concretions are common. Shark's teeth and bone fragments have been found. Fragments of the hard grey siliceous shale of the Odanah Member have been reported to have been found at the top of the butte.

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

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

References: Bannatyne (1963, 1970).

Return to section road and continue West for about 1.6 km. Intersection, turn left (South) for 2.4 km. Intersection, turn left (East) for 1.6 km. Intersection, turn right (South) for 0.8 km. Intersection, turn left (East) for 1 km and park at side of road. Former quarry site to South.

STOP 29: O'DAY FORMER BENTONITE ADIT

Cretaceous Pierre Shale (Millwood Member/Pembina Member) overlying Niobrara Formation. 15-31-3-6W1, NTS 62G8SW, NAD 27, Zone 14U, 554000E, 5456800N. The elevation of the top of the outcrop is 392 m above sea level. The former adit was situated on the north side of Shannon Creek, a deep east-west trending valley similar to Snow Valley **(STOP 23)** that has cut deep into the Cretaceous stratigraphy of the Pembina Hills. The O'Day stop is about 11 km south of Miami, Manitoba.

In the vicinity of the former adit opened by J.O'Day (Bannatyne, 1963, p. 13), a southerly-trending ravine has been incised into the soft Cretaceous beds. Run-off from a large holding pond to the north of the section road, through a culvert and into Shannon Creek, has caused substantial downcutting of the bedrock.

On the east wall of the ravine, 2 m of glacially disturbed bentonite beds of the Pembina Member of the Pierre Shale can be seen overlying about 10 m of buff Niobrara Formation, with numerous thin bentonite seams. Plastic flow of the Niobrara Formation into Shannon Creek is evident at the south end of the exposure. The Gammon Ferruginous Member appears to be present as a 0.5 m thick bed between the underlying Niobrara and overlying Pembina Member. The Millwood Member is present on the west wall on the ravine, forming a low relief Millwood butte, above the Pembina Member.

References: Bannatyne (1963, 1970).

Continue East and down Escarpment for about 3 km. Brief stop, former brick shale quarry in field to South, waste bricks can be seen that were backhauled to make access road to former quarry. Then continue toward the East, across bridge and stop on rising outcrop.

STOP 30: REHABILITATED MORDEN SHALE BRICK QUARRY

Cretaceous Morden Shale. 14-33-3-6W1, NTS 62G8SE NAD 27, Zone 14U, 668960E, 6568260N. The rehabilitated quarry is situated about 1.6 km east of the Pembina Hills component of the Manitoba Escarpment, and about 11 km south-southeast of Miami, Manitoba. About 800 m to the east, a similar shale is exposed in a road cut and a full stop will be made there.

Quarry

The quarry was operated by Red River Brick and Tile (a subsidiary of I-XL Industries Ltd.) from 1971 to 1992, to mine the Morden Shale 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 (from **STOPS 19 and 26**) to produce a variety of colours. The quarry was rehabilitated with the shut down of the Lockport plant.

Outcrop

Morden Shale is exposed on both sides of a road cut, over a 300 m length. Abundant small selenite crystals and broken septarian concretions, similar to those at **STOP 24** are present on the surface of the weathered shale.

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

Continue East and for about 6 km. Junction with P.R. 432, turn right (South) for about 8 km and arrive at Morden.

End of Day 3 - Overnight in Morden. Recommended visit to Morden Museum (Cretaceous pleisiosaur and mosasaur fossils).

DAY 4: CRETACEOUS STRATIGRAPHY OF PEMBINA VALLEY AND TURTLE MOUNTAIN

Day 4 will take us up and over the edge of the Manitoba Escarpment into the Pembina Valley and then westward on top of the Second Prairie Level to the highest Cretaceous unit at the base of Turtle Mountain. The complete stratigraphic succession and lithology are shown in Figure 9, including the stratigraphic position of all outcrop stops.

Proceed South on P.R. 432, due south, of Morden for 6.4 km. Turn left (East) at intersection with section road for 3.2 km. Intersection, turn right (South) for 4.8 km, go up Escarpment and park on top of hill.

STOP 31: MORDEN SOUTH OUTCROP

Cretaceous Pierre Shale (Pembina Member) overlying Niobrara Formation. 1-29-1-5W1, NTS 62G1SE, NAD 27, Zone 14U, 566500E, 5434300N. The outcrop is located 13 km south of Morden at the edge of Pembina Hills.

Three bentonite seams probably representing the base of the Pembina Member of the Pierre Shale crop out at the top of slope, above the curving section road towards the north. The Pembina Member appears to overlie the Gammon Ferruginous Member, in a poorly exposed 2 m section. About 10 m further to the west and at slightly lower elevation, buff Niobrara Formation can also be seen.

Bannatyne (1970).

Proceed West on section road for 1.6 km. Turn left (South) at intersection with section road for 4.8 km. Note: former bentonite quarries at 2.2 km. Intersection, turn left (West) for 2 km. Shale quarry to South, if gate open, drive in and park.

STOP 32: BROWN AGGREGATE SHALE QUARRY

Cretaceous Pierre Shale (Odanah Member). 15-1-1-6W1, NTS 62G1SE, NAD 27, Zone 14U, 562900E, 5429200N. The quarry is located 3.2 km southeast of the former community of Brown, and 18 km south of Morden, Manitoba. The site is within a small northwest-trending creek valley on top of the Pembina Hills, roughly halfway between the Manitoba Escarpment edge to the east and the Pembina Valley to the west. The U.S. border is only 1.6 km to the south.

The Odanah Member of the Pierre Shale forms the caprock of the Manitoba Escarpment, as seen previously at **STOP 21**. The caprock is well exposed at this site, where at least 10 m siliceous shale forms near vertical quarry walls. The upper portion is a 5 m thick reddish-weathering shale that overlies a 5 m thick black (when wet) shale. The shale is well bedded and cut by joints that are stained with iron and manganese oxides.

References: Bannatyne (1970).

Proceed West on section road for 4.4 km. Turn right (North) at intersection with section road for 3.2 km. Junction with P.R. 201, turn left (West) for 4.8 km. Intersection, turn left (South) and drive down into Pembina Valley. Note: Odanah quarry and Millwood, Pembina and Niobrara outcrops along descent. Park at river bottom near bridge.

STOP 33: HOLO CROSSING OUTCROPS

Cretaceous Pierre Shale (Odanah/Millwood/Pembina members) overlying Niobrara Formation. (Tovell, 1951, Outcrop 27) in 1&8-13-1-7W1, NTS 62G1SW, NAD 27, Zone 14U, 553300E 5431050N. The outcrops occur along P.R. 201 road cuts on the south wall of the Pembina River Valley. The road distance from the bridge at the bottom of the valley to the top of the slope into the valley is about 1.3 km.

A large exposure of buff chalky Niobrara Formation is present on the west side of the road, north of the bridge. About 700 m to the north and up the slope is the approximate top of the Niobrara. The Gammon Ferruginous Member of the Pierre Shale may be present below the contact with the overlying Pembina Member. At least four Pembina Member bentonite seams, about 10 cm thick, are visible in small eroded channels cut into the bedrock and alluvium on the east side of the road. Solid pink plates of bentonite could be seen in the uppermost seam.

The approximate top of the overlying Millwood Member, with its distinctive popcorn or cauliflower weathered surface, is about 100 m further up slope. The typical popcorn or cauliflower weathered surface can be seen below disturbed Odanah Member. About 200 m further up slope, an aggregate quarry of Odanah Member can be seen on the east side of the road; and another 100 m up a roadcut of Odanah shale is present on the west side of the road.

References: Tovell (1951), Bannatyne (1970).

End of Formal Field Trip – Return to Winnipeg and Regina

For those continuing on the field trip, follow P.R. 201 to the West. Junction with P.T.H. 31. Do not turn South unless you want to enter the U.S., we are only 1.6 km from the border. Turn right (North) for about 20 km. Junction with P.T.H. 3, turn left (West) for about 120 km.
Make special note of the Junction with P.R. 346 leading North to Ninga, about 16 km West of Killarney. Next stop is 2.4 km West of the Junction with P.R. 346.

STOP 34: BOISSEVAIN ROAD GULLY

Cretaceous Boissevain Formation and Pierre Shale (Coulter Member). (Bamburak, 1978, Locality #3) in NE14-35-2-19W1, NTS 62G4NW, NAD 27, Zone 14U, 433150E, 5447250N. The outcrop, on the Second Prairie Level, is penetrated by a deep stream cut along drainage ditch on the south side of P.T.H. 3. Turtle Mountain is the upland area to the south. The elevation of the top of the outcrop is 527 m above sea level.

The stream cut in 1996 was 4.3 m in height, 10 m in length and 2.4 m in width. The cut was oriented 070°.

Boissevain Formation		**Thickness (m)**
25	Brown fine grained sand	0.24
24	Yellow clay	0.03
23	Brown fine-grained sand	0.15
22	Yellow clay	0.06
21	Brown fine-grained sand with minor sandstone	0.30
20	Yellow clay	0.03
19	Brown massive sand	0.73
18	Clay	0.09
17	Brown fine-grained sand	0.09
16	Orange-brown ironstone concretion layer	0.15
15	Brown silty sand	1.13
14	Compacted hard silt, laminated	1.83
13	Brown compacted hard sand, laminated	0.40
12	Orange-brown ironstone concretion layer	0.15
11	Brown fine-grained sand	0.15
10	Mixed silt and clay	0.15
9	Brown fine-grained sand	0.15
8	Clay	0.12
7	Brown fine-grained sand	0.37
6	Hard compacted sand	0.30
5	Crossbedded sand with indurated blocks and orange-brown ironstone concretion layers	1.83
4	Covered interval	0.91
3	Crossbedded reddish-orange sand	0.37
2	Grey crossbedded sand	2.59

Pierre Shale

Coulter Member

1. Grey fine-grained silty clay		0.30
	Total Section	**12.65**

References: Bamburak (1978).

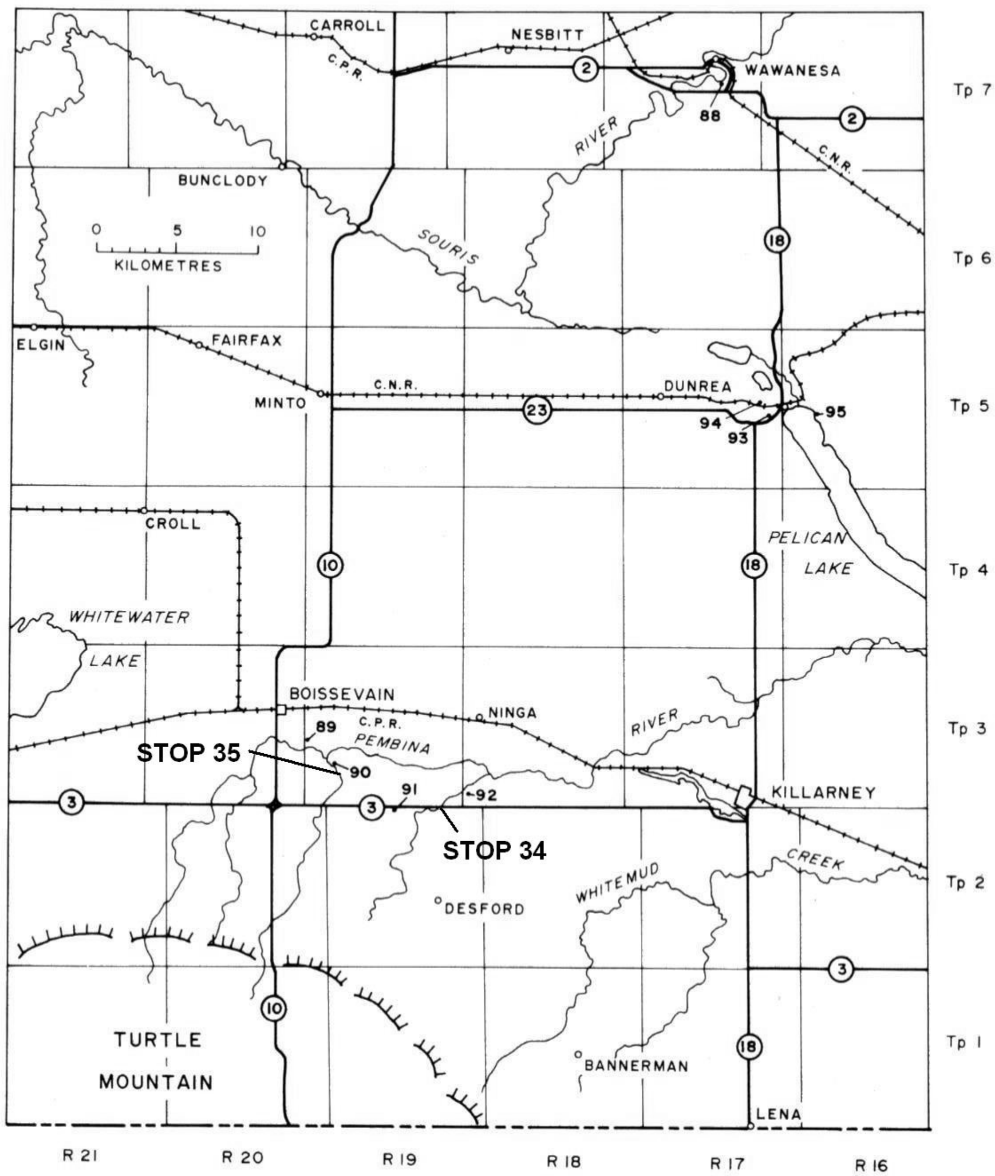

*Figure 20: Location map for **STOPS 34-3** (modified from McNeil and Caldwell, 1981).*

Continue West on P.T.H. 3 for 5 km. Intersection with section road, turn right (North) for 1.6 km. Intersection, turn left (West) for 1 km. Entrance road to Boissevain Reservoir is to the northwest. A gate may be in place. If so, park on side on road and walk along the old railway right-of-way.

STOP 35: BOISSEVAIN FORMER RAILROAD CUT

Cretaceous Boissevain Formation (Bamburak 1978, Locality #19) in 9-7-3-19W1, NTS 62F1NE. The outcrop, on the Second Prairie Level, is one of several outcrops that line a former railway right-of-way, which terminated to the northwest in Boissevain, Manitoba. The Boissevain Formation forms the base of the Turtle Mountain Upland (Fig. 21). area that is present to the south.

Two metre high calcium carbonate-cemented bosses of silica-rich sandstone were blasted during construction of the rail line from Mid-western U.S. to Boissevain in the late 1800s. Similar outcrops were quarried in the Boissevain area to build local houses and churches.

References: Bamburak (1978).

Continue West on section road for 3.6 km. Junction with P.T.H. 10, turn right (North) for 3.2 km and arrive in Boissevain.

End of Field Trip – Recommended lunch in Boissevain (visit sandstone buildings in town).

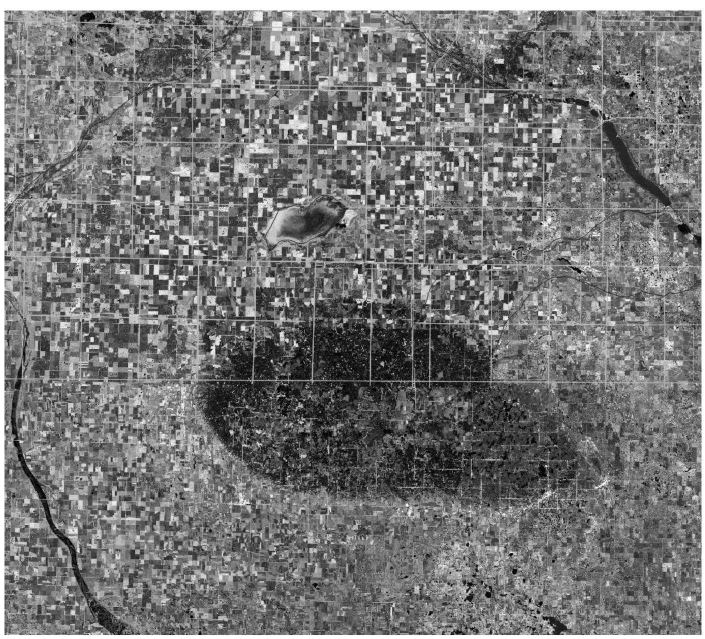

Figure 21: Turtle Mountain LANDSAT image (See: Figure 1).

ECONOMIC GEOLOGY

NON-SWELLING CALCIUM BENTONITE

From 1939 to December 1990, Pembina Mountain Clays Limited produced the only non-swelling natural and activated calcium montmorillonite clays in Canada. The bentonite was quarried, on a seasonal basis from May to October, by a contractor from at least 20 sites located 30 km northwest of Morden. The main processing plant (21,300 sq. ft.) was in Winnipeg; and the drying and crushing plant (10,000 sq. ft.) was in Morden (128 km southwest of Winnipeg). In 1990, twenty-three employees, with an annual payroll of $800,000, worked at the two plant sites. Goods and services purchased in the area totalled nearly $2.3 million; and more than $43,000 was paid in local taxes (Englehard Corporation, Fact Sheet, 1989).

Quarry Operation

The mining technique used by Pembina Mountain Clays remained similar throughout the life of the operation. The overburden and black shale were removed from the bentonite layers with small-scale scrapers and the bentonite carefully removed to minimize contamination by extraneous material. However, contamination was always a problem especially during inclement weather when the black clay would cake to the scrapers and the trucks hauling the bentonite. A front end loader was used to load the clay onto trucks at the quarry site for transport to a stockpile at the Morden plant.

Morden Plant

The typical mining season was from May to October. During the winter the normal frost depth is two to three metres and separation of the bentonite from the black shale is impossible. Poor ground conditions in the early spring and the late fall restrict the weight on haul roads. The raw clay from the quarries was stockpiled at the Morden plant; and after preliminary drying and crushing, some was sold as is and the remainder was transported by truck to Winnipeg for further processing.

Winnipeg Plant

In the Winnipeg plant, the raw clay was chemically treated with 93% virgin sulphuric acid and water. The mixture was heated until the reaction was completed. The resulting slurry was washed, dried and screened.

The activated finished product was the sold to producers of edible and inedible vegetable oils, in either bulk or bags, as a bleaching agent. The product was used as an absorbant to decolourize or to remove impurities from: tallow, animal fats, waxes, waste lube oils, petroleum feed stock, linseed oil, canola oil, soybean oil, palm oil, sunflower oil, coconut oil and peanut oil. Major consumers of the clay in Canada were: Proctor and Gamble, Canada Packers, Monarch Fine Foods and C.S.P. Foods. Some bentonite was also used to produce kitty litter.

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. The best quality material is in the Pembina Mountain area where the Millwood averages 19.8 m in thickness. Along the Assiniboine Valley in the Millwood-Binscarth area (northwest of the map area) an increase in Millwood thickness to over 91 m is accompanied by an increase in silt content.

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

Swelling Bentonite

A 17.5 to 35 cm bed of green swelling bentonite occurs near the contact between the Millwood and Odanah members of the Pierre Shale. It has been observed in numerous outcrops along Pembina Mountain, and also outside the map area in the Assiniboine Valley in the Oak Lake, Miniota, Beulah and Binscarth areas. Northwest of Beulah, it is locally up to 67.5 cm thick.

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

OTHER INDUSTRIAL MINERALS

Brick Shale

Learys Brick Plant

A brick-making plant operated in Roseisle Creek at Learys **(STOP 24)** in 1900, 1914-1917, 1947-1952 and in 1962. The raw material was quarried from a 10 m bank of Morden Shale (Bannatyne, 1970, p. 47).

Red River Brick and Tile

Face brick was produced by Red River Brick and Tile using raw material from the Rural Municipality of Thompson Odanah shale quarry **(STOP 26)** in SW05-24-4-7W and from Morden shale beds **(STOP 30)** in E14-33-3-6W.

Brick clays are mechanical mixtures of kaolinite, illite, quartz, carbonate, iron oxide and chlorite that form a hard, non-porous, non-glossy mass upon heating to fusion (Gunter, 1989). Over 40 brick plants have operated in the Province since 1871 utilizing Cretaceous, Pleistocene and Holocene clays. Shayna (1975) has documented a brief history of brick making. The most recent brick plant to be operated in the Province was I-XL Industries Ltd.'s Red River Brick and Tile plant at Lockport. From 1971 to 1992, over 16 million bricks were manufactured, in three different sizes as well as two sizes of paving brick (Gunter, 1989). Five quarries produced 8 types of clays and shales from which it was possible to make face brick in colours from red to near white, including variegations and browns, blacks, buff, tans, etc. (Shayna, 1975). Red River quarried Cretaceous and Jurassic clays near Ste. Rose du Lac, 200 km from the plant. Medicine Hat Brick and Tile Company Limited, a predecessor to I-XL, opened the Ste. Rose quarry in 1970. A second pit, 1.6 km to the south, was opened up in 1972-73. Small quantities of Morden Shale and Odanah Member of the Pierre Shale, quarried west of Miami (160 km from the plant), were added to the Ste. Rose clay to alter its properties. Some Pleistocene lacustrine clay was also used, which was quarried at Ladywood, north of Beausejour. Fine-grained sand, uncontaminated by limestone was quarried about 45 km from the plant near Brokenhead River (Shayna, 1975).

Gypsum

BPB Canada Inc.

Production of gypsum from the Jurassic Amaranth Formation at **STOP 20**, began by BPB Canada Inc. (formerly, Westroc Inc.) in 1978 and is probably now more than 150 000 tonnes of gypsum per year. The gypsum supplies wallboard plants in Winnipeg (Westroc) and Saskatoon (Truroc), as well as various cement plants.

Gypsum beds of the Amaranth Evaporite occur beneath 4 to 7 m of drift. During 1965 L. Zaseybida drilled 39 holes, outlining more than 14 million tonnes of mineable gypsum. Additional drilling was done in 1966. In 1977, Westroc Inc drilled 20 exploration holes on the property and obtained Quarry Mineral Leases on the area. In the same year a test pit was put down and 225 tonnes of gypsum was removed for testing.

Production of 100 000 tonnes per year began in July, 1978 following removal of 5.2 m of overburden and exposure of a 6.1 m section. The gypsum is crushed on the site, then hauled by truck to the company's plant in Winnipeg or the loading facilities on the C.P. Rail at the junction of Highways 16 and 50.

Amaranth Mines

Between 1929 and 1970, gypsum was mined south of Amaranth by BACM Industries Ltd. (1967 – 1970) and Western Gypsum Products Limited (1929 – 1963) (now BPB Canada Inc.). Both of these were underground mining operations using the room and pillar method.

At the Western Gypsum mine, vertical shafts were used to mine the interval from 29.3 to 39.9 m, beneath a 1.8 m roof of gypsum and about 27 m of glacial drift. The BACM mine operated at a similar interval but used a sloped decline for access.

Silver Plains Mine

(A third underground mining operation in the Amaranth Evaporite took place at Silver Plains in the Red River Valley about 50 km south of Winnipeg. That mine was operated by Westroc Industries from 1964 to 1975, producing from 60 000 to more than 130 000 tonnes per year. A section in the mine showed 32 m of glacial clay and till, 4.6 m of interbedded shale and gypsum, a 1.8 m layer of pure white gypsum, 16.8 m of gypsum with minor anhydrite. This is underlain by as much as 18 m of shale, dolomite and sandstone of the Amaranth red beds. The sandstone in this section is an aquifer under artesian pressure. During mining, flow of water from this aquifer gradually increased, and subsequent uncontrollable flooding resulted in the mine being abandoned).

Natural Cement Rock

Natural cement has also been produced from the highly calcareous (37% CaO, 1.5% MgO) Niobrara shale beds at Arnold, 3 km east of Deerwood from 1898? to 1904 and at Babcock from 1907 to 1924 (Bannatyne, 1970, p. 52). The Babcock deposits were leased by Lafarge Canada Inc. in 1992. The characteristics of the natural cement material were too variable to compete with Portland cement (Gunter, 1989).

Road Metal and Fill

Siliceous shale from the Odanah is currently used as fill and as road metal, extracted from over 50 pits and quarries **(STOP 32)**, located mostly in the south half of the Brandon area. The shale is found "in place", "glacially disturbed", as a shale-rich till, or as a combination of all three. Because the shale exfoliates so readily, no blasting is required. Only a short period of time is required for a new talus pile to develop at the base of an outcrop.

Calcareous shale from the Niobrara, obtained from a quarry in NW15-19-7-8W, has also been used as a fill in road construction.

Salt

Northern Salt Company

Salt brine was pumped to surface at the McArdle salt flat **(STOP 4)**, south of the Red Deer River, near Dawson Bay. The plant, operated by Northern Salt Company, Limited during 1941, consisted of two wooden vats, 1.5 m by 15.2 m and 1.5 m by 7.6 m. The vats contained steam coils fed by a small return-tube boiler. The brine was fed into the vats and after evaporation, the salt was scaped from the vats and piled on drying-racks above the steam coils. The product was a dirty-appearing, finely crystallized salt. Scales from the iron pipes of the steam coils had a deleterious effect (Manitoba Mineral Inventory Card 63C14NE SLT1).

Oil Shale

The Favel Formation was investigated by three oil companies in 1965 and 1966 as a possible source of oil shale. An earlier report by Ells (1921) had indicated oil contents of up to 37.5 litres per tonne in the Favel shale in the Riding Mountain and Porcupine Mountain areas. The recent work reported a maximum content of 60.0 litres per tonne in the Favel Formation in the Pembina Mountain area. However, average content of the tested section was 18.0 litres per tonne over a 48-metre interval. Samples from the Niobrara Formation, Morden Shale, and Ashville Formation were included in the analyses; the results showed maximum contents of 65.0, 24.0, and 59.5 litres per tonne.

According to Beck (1974), extensive test sampling of oil shales in the Pasquia Hills was done in 1964 and 1965 by Sun Oil Company. An estimated 2.6 billion barrels of oil was indicated by this work, assuming an average grade of 8 gallons per ton across an average thickness of 30 m.

Sandstone

Sandstone was also quarried south of Boissevain for building construction in the late 1890s. Several buildings including churches, residences and office buildings were constructed of blocks removed from the quarries.

REHABILITATION

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

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

FOSSILS

Mososaur fossils found during these early operations were taken to Ottawa and placed in the Geological Museum. Numerous fossils have been uncovered in the quarry operations including fish scales and shark teeth, but most importantly, plesiosaurs. A spectacular find was made in 1972 of the plesiosaur Dolichornychops in a quarry 0.6 km west and 8.2 km north of Thornhill. The fossil was recovered and placed on display in a museum at Morden by H. Isaak. Plesiosaur fossils are also in the Museum of Man and Nature in Winnipeg.

A recent plesiosaur discovery is documented in the following Winnipeg Free Press article:

Winnipeg Free Press
ONLINE EDITION

Monday, August 16th, 2004

Field yields fossilized sea monster

Monday, August 16th, 2004

By Bill Redekop

MORDEN -- One of the largest fossilized creatures ever found in Manitoba -- a giant plesiosaur that frolicked in the sea here 65 million years ago -- has been discovered by a man walking in a cow pasture.

Joe Brown was walking through a farm field, side-stepping cow paddies and cattle that had moved off to one side, when he noticed what looked like bone fragments on the ground.

"A cow had probably stepped on a piece of bone and crushed it," he said.

He kneeled down, began brushing away earth, and found a much larger bone underneath. He continued brushing away soil from the bone.

"It got bigger and bigger. And I got very excited."

Further exploration has shown Brown found a plesiosaur that could measure up to 25 feet long, said Anita Janzic, curator of the Morden Marine Museum. That would make it Manitoba's biggest fossil discovery since "Bruce," a 43-foot mosasaur found here in 1974, a replica of which is mounted in the museum.

The Morden museum has the largest collection of ancient marine creatures in Canada.

The new skeleton is remarkable for its size, completeness and excellent preservation, but also for its teeth: they're still sharp.

"The teeth are gorgeous!" said Janzic. They have recovered 15 molars in all, so far.

Also, good-sized fragments of jaw have been recovered, leading Janzic to believe the dig team could yet find a skull, a rare occurrence in excavations because heads tend to become separated from the rest of a skeleton. "That's like the cream of the crop," she said.

The skeleton is still in the field, imbedded in the earth, but much of it has been exposed by the museum's dig team. It's actually a fossilized skeleton where minerals in the groundwater have seeped into bone pores, and replaced and replicated the bone in rock form.

The skeleton is being left where it is for the time being to examine "the scene of the death," said Janzic. Excavation is expected to begin next month

About 80 million years ago, Manitoba had an equatorial climate and was buried under 200 metres of water, after the melting of polar ice caps. The inland sea divided North America down the middle, stretching from Florida to the Arctic Circle. The seaway's western shoreline was Alberta, which is why land dinosaurs are found there and sea reptiles are found in Manitoba.

There are two main types of plesiosaur. The long-necked plesiosaur is the model for mythical Nessie of Loch Ness fame. The Morden discovery is of a short-necked type. While long-necked plesiosaurs have small heads, the short-necked kind have very large heads, measuring two to three metres in length, and were much more ferocious.

Plesiosaurs had flippers for locomotion, and used their tails to steer. They also had breast plates and ribs. That has led to speculation they may have beached themselves like seals to lay eggs, or else the plates were protection from the predatory mosasaur, the T. Rex of the deep. The plesiosaur was primarily a fish eater.

Brown calls himself an amateur paleontologist, someone who took up fossil digging for recreation when he moved to Morden from Kenora four years ago. He searches for fossils in conjunction with the Morden Marine Museum, which has landowner permission to explore certain areas.

Brown has found other fossil sites but nothing comparable to this. His discovery was made last fall but it was too late in the year to start a dig program. The Morden museum has kept the dig a secret until now to allow it time to comprehend the discovery.

When Brown found the plesiosaur, he was on his way to a nearby field where he was digging remains of a mosasaur. The mosasaur site was small, amounting to only a spinal column and some bone fragments.

He started to brush away the earth from the plesiosaur bone with a paint brush. The large bone he discovered turned out to be the clavicle plate found in a plesiosaur's breast, the largest bone in the sea reptile.

"The first large clavicle plate, it was actually still attached to the other side of the chest. Like, they're parallel bones. Both of them were still exactly as they would be in life," he said.

"It was all within six to eight inches of the surface."

The Morden area is excellent grounds for finding fossils because it is near the escarpment -- the former shoreline of Lake Agassiz. Glaciers from the ice age scraped away much of the fossils within the Red River Valley itself, but not on the Pembina Hills.

Fossil discoveries took off here in the early 1970s after a mineral called bentonite, formed when volcanic ash from Montana mixed with Manitoba clays, was discovered. That led to the digging of quarries for bentonite, used as an abrasive in toothpaste and detergent, and subsequently the discovery of fossils.

The mining stopped in the mid-'80s. Brown said his discovery was nearby what had been an open pit mine before the mining company rehabilitated the pit by refilling it.

Today, the Morden museum has more than 1,000 shelves of bones and fossils. A plesiosaur is mounted in the museum but it's less than half the size of Brown's discovery.

The museum would like to transform itself into a national site, and the latest discovery could jump-start those efforts.

"It's literally buried treasure in the Pembina Hills," said Dave Wilkinson, a consultant hired by the museum to develop plans for an expanded museum. Wilkinson believes the Morden museum has potential to become like Royal Tyrell Museum in Drumheller, Alta., which is famous for its dinosaur fossils.

Wilkinson said the relative ease with which the latest plesiosaur was found indicates much more could be uncovered with a better-funded dig program. A small band of employees, summer students and volunteers works on the current dig program, operating on a shoestring budget.

"There's so much area here that hasn't been explored," said Janzic.

She said a covering is needed to protect the dig site, and the team would be grateful to anyone who could lend a 12-foot-by-12-foot tent.

The museum has not yet come up with a name for the plesiosaur, a tradition in archeology digs. A nickname is simpler than calling it by its registered name, which is usually a combination of a letter and a half-dozen numbers indicating where and when a skeleton was found.

For example, the museum's giant mosasaur was named Bruce by the dig team. The dig team would clean fossils at night while listening to Monty Python records. One Monty Python skit was about a party where everyone is named Bruce. Confusion reigns when someone named Michael arrives.

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An article is also reproduced from the Winnipeg Free Press, dated August 16, 2004.

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SELECTED REFERENCES

Baillie, A. D. 1951b. Devonian geology of the Lake Manitoba-Lake Winnipegosis area, Manitoba. Manitoba Mines Branch Publication 49-2, 72 p.

Baillie, A. D. 1953. Devonian system of the Williston Basin area. Manitoba Mines Branch Publication 52-5, 105 p.

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. 1996: Bentonite investigations and industrial mineral mapping of the Brandon map area (NTS 62G); in Report of Activities 1996, Manitoba Energy and Mines, Geological Services, p.127-133.

Bamburak, J.D., Bezys, R.K., Fedikow, M.A.F., and Hosain, I. 1997: Geology, geochemistry and geophysics of Prairie-type micro-disseminated mineralization in west central Manitoba (NTS 63C); in Report of Activities, 1997, Manitoba Energy and Mines, Geological Services, p. 112-117.

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

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

Bannatyne, B.B. 1971: Industrial minerals of the sedimentary area of southern Manitoba *in* The Geological Association of Canada, Special Paper No. 9, p. 243-251.

Bannatyne, B. B. 1975. High-calcium limestone deposits of Manitoba. Manitoba Mineral Resources Division, Publication 75-1, 103 p.

1977:MEA-13 - Industrial minerals drill program in Manitoba Mines, Resources and Environmental Management, Mineral Resources Division, Report of Field Activities 1977, p. 151.

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.

Beck, L.S. 1974. Geological investigations in the Pasquia Hills area; Saskatchewan Department of Mineral Resources, Saskatchewan Geological Survey Report No. 158, 16 p.

Bezys, R.K. 1996: Stratigraphic mapping (NTS 63G) and corehole drilling program 1996; in Report of Activities, 1996 Manitoba Energy and Mines, Geological Services, 1996, p. 96-102.

Bezys, R.K., Ducharme, E.B., Bamburak, J.D. and Fedikow, M.A.F., 1997: A geochemical study of saline brine sediments as a guide to Prairie-type micro-disseminated mineralization and other precious metals in west central Manitoba (NTS 63C); in Report of Activities, 1997 Manitoba Energy and Mines, Geological Services, p. 118-122.

Bezys, R.K. and McCabe, H.R. 1996: Lower to Middle Paleozoic stratigraphy of southwestern Manitoba - Field Trip Guidebook B4; Geological Association of Canada/Mineralogical Association of Canada Annual Meeting, Winnipeg, Manitoba, May 1996, 92 p.

Cumbaa, S.L. and Tokaryk, T.T. 1999. Recent discoveries of Cretaceous marine vertebrates on the eastern margins of the Western Interior Seaway, in Summary of Investigations 1999, Vol. 1, Saskatchewan Geological Survey, Sask. Energy and Mines, Misc. Rep. 99-4.1.

Fedikow, M.A.F., Bezys, R.K., Bamburak, J.D., and Abercrombie, H.J. 1996. Prairie-type micro-disseminated Au mineralization - a new deposit type in Manitoba's Phanerozoic rocks (NTS 63C/14); *In* Manitoba Energy and Mines, Minerals Division, Report of Activities 1996, p. 108.

Fedikow, M.A.F., Bezys, R.K., Bamburak, J.D., and Abercrombie, H.J. 1996: Prairie-type micro-disseminated Au mineralization - a new deposit type in Manitoba's Phanerozoic rocks (NTS 63C/14); in Report of Activities, 1996, Manitoba Energy and Mines, Geological Services, p. 108-121.

Fedikow, M.A.F., Bezys, R.K., Bamburak, J.D., and Conley, G.G. 1998: Geochemical database for Phanerozoic black shales in Manitoba; Manitoba Energy and Mines, Geological Services, Open File Report OF98-2, 123 p.

Fedikow, M.A.F., Bezys, R.K., Bamburak, J.D. and Garrett, R.G. 1997: Geochemical characterization of black shales in Manitoba's Phanerozoic; in Report of Activities, 1997, Manitoba Energy and Mines, Geological Services, p. 129-130.

Fedikow, M.A.F., Bezys, R.K., Bamburak, J.D., Hosain, I.T. and Abercrombie, H.J. 2004. Prairie-type microdisseminated mineralization, in the Dawson Bay area, west-central Manitoba (NTS 63C14 and 15); Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, Geoscientific Report GR2004-1, 76 p.

Guillet, G.R., 1989: Mineralogical study of the Miami/Morden bentonites; A study conducted for Energy, Mines and Resources Canada under Contract 23230-8-0033/01-3SF, 34p.

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

McCabe, H.R. 1967: Tectonic framework of Paleozoic formations in Manitoba; Transactions of the Canadian Institute of Mining and Metallurgy, v. 70, p.180-189.

1971: Stratigraphy of Manitoba, an introduction and review; in Geoscience studies in Manitoba, ed. A.C. Turnock; Geological Association of Canada, Special Paper no. 9, p.167-187.

McCabe, H.R., 1977: GS-18 - Stratigraphic core hole programme in Manitoba Mines, Resources and Environmental Management, Mineral Resources Division, Report of Field Activities 1977, p. 93, 94.

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.

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.

Norris, A. W., Uyeno, T. T., and McCabe, H. R. 1982. Devonian rocks of the Lake Winnipegosis - Lake Manitoba outcrop belt, Manitoba. Geological Survey of Canada, Memoir 392. Manitoba Mineral Resources Division Publication 77-1, 280 p.

Saskatchewan Geological Survey 2003: Geology and mineral and petroleum resources of Saskatchewan: Saskatchewan Industry and Resources, Miscellaneous Report 2003-7, 173p.

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.

Tovell, W.M., 1951: Geology of the Pembina Valley-Deadhorse Creek area; Manitoba Mines and Natural Resources, Mines Br. Publ. 47-7,