



MANITOBA
DEPARTMENT OF MINES, RESOURCES AND ENVIRONMENTAL MANAGEMENT

MINERAL RESOURCES DIVISION
GEOLOGICAL SURVEY
GEOLOGICAL REPORT 78-2

STRATIGRAPHY OF THE RIDING MOUNTAIN,
BOISSEVAIN AND TURTLE MOUNTAIN FORMATIONS
IN THE TURTLE MOUNTAIN AREA, MANITOBA

By
J.D. Bamburak

1978



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ABSTRACT

The Turtle Mountain map-area is situated on the northeastern rim of the Williston Basin, a negative structure on the craton. During the last Cretaceous marine transgression and regression, the Riding Mountain and Boissevain Formations were deposited. In the Paleocene, after a short erosional interval, deposition of Turtle Mountain Formation occurred.

The Riding Mountain Formation consists of three members. The Millwood Member, the lowest unit, is a soft, greenish-brown, bentonitic, slightly silty clay. The Odanah Member, the middle unit, is a hard, grey, siliceous, clay shale. The Coulter Member, as proposed in this report, is the upper unit, a light grey to buff, bentonitic, fine-grained clayey silt. The Riding Mountain Formation is correlated with the Bearpaw Formation of Saskatchewan and the upper part of the Pierre Shale of North Dakota. All of these formations were deposited in less than 60 m of water.

The overlying Boissevain Formation is composed of a thick lower unit of crossbedded, buff, quartz-rich, medium-grained, "salt and pepper" sand, and a thin upper unit of massive, white kaolinitic, fine-grained silt or clay. The Boissevain Formation is equated to the Fox Hills Formation of North Dakota and the Eastend, Whitemud, and Battle Formations of Saskatchewan. Deposition of the Boissevain Formation occurred at the mouths of rivers which emptied into a basin. An easterly direction of sediment transport is indicated by crossbedding measurements in the Boissevain Formation.

The overlying Turtle Mountain Formation consists of two members, as proposed in this report. The Goodlands Member, a lower assemblage of thin, discontinuous lignite seams erratically distributed within bentonitic sands, silts, and clays, is correlated with the Hell Creek and Frenchman Formations of North Dakota and Saskatchewan, respectively. This member was deposited in a lagoonal environment. The Peace Garden Member, an upper assemblage of grey silty clays with minor greenish sand and silt beds, was deposited, for the most part, in a shallow water marine environment during readvance of the sea in the Paleocene. These marine beds are equivalent to the Cannonball Formation, a part of the Fort Union Group of North Dakota. The Peace Garden Member, as a unit, is correlated with the Fort Union Group and the Ravenscrag Formation of Saskatchewan.

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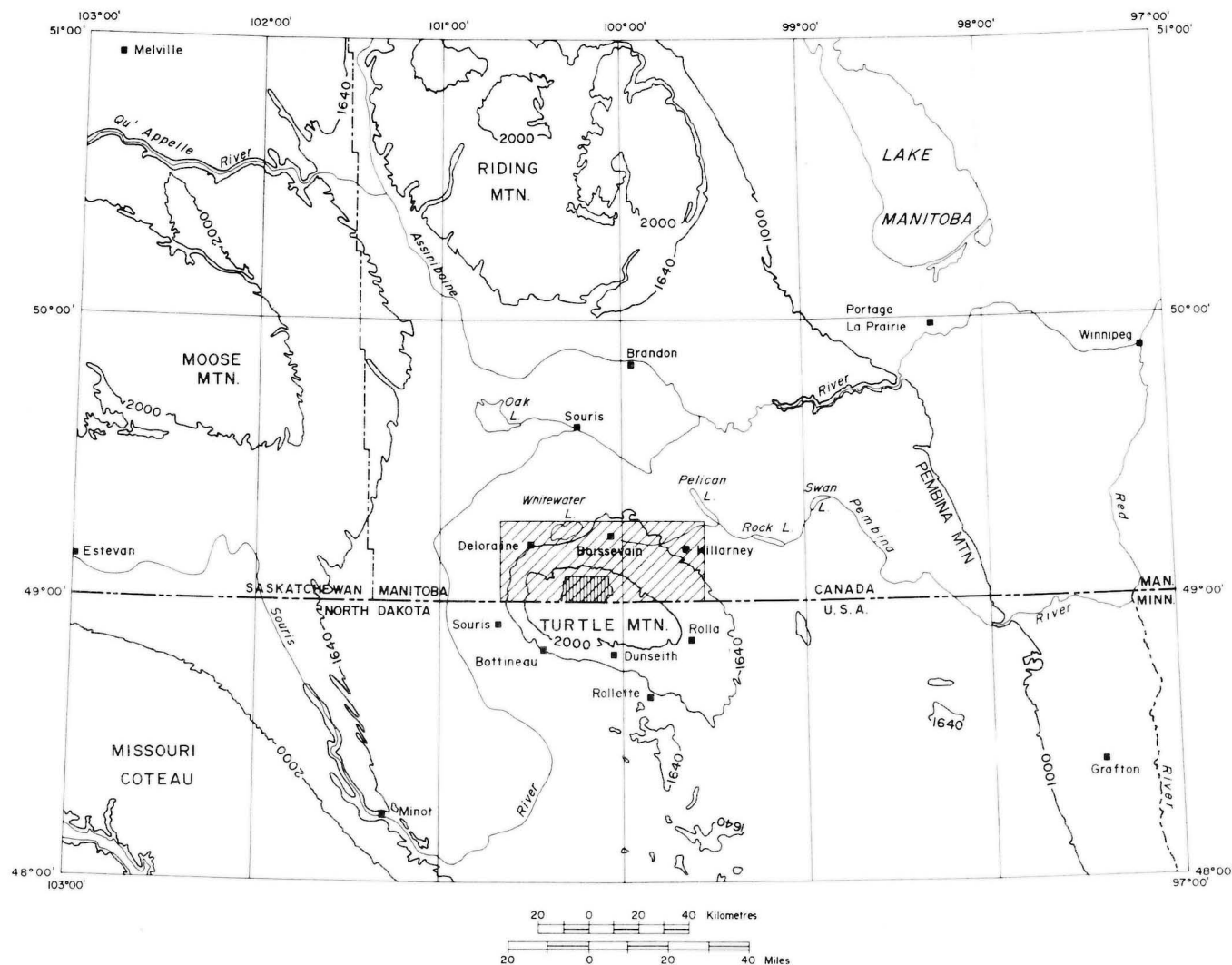


Figure 1. Index map for the Turtle Mountain area (diagonal cross-hatching) showing Turtle Mountain Provincial Park (vertical cross-hatching). Topographic contours drawn at 1000, 1640, and 2000 feet (305, 500, and 610 metres, respectively) above sea level.

INTRODUCTION

The objectives of this report are to describe the Upper Cretaceous and Paleocene stratigraphy of the Turtle Mountain area, to correlate strata across the map-area and into adjacent regions, and to interpret the history of sedimentation.

Location, Access, Physiography and Industry

The Turtle Mountain area is located in southwestern Manitoba, approximately 190 km southwest of Winnipeg and 60 km south of Brandon. The 1984 square km area, bounded by longitude 99°37' and 100°38' west, and by latitudes 49°00' and 49°15' north, extends from Range 17 WPM to Range 24 WPM, and from the International Boundary to Township 3 North (Figure 1).

Four main provincial highways cross the map-area (Figure 2). Three major centres of population, Killarney, Boissevain and Deloraine, are served also by Canadian Pacific Railway.

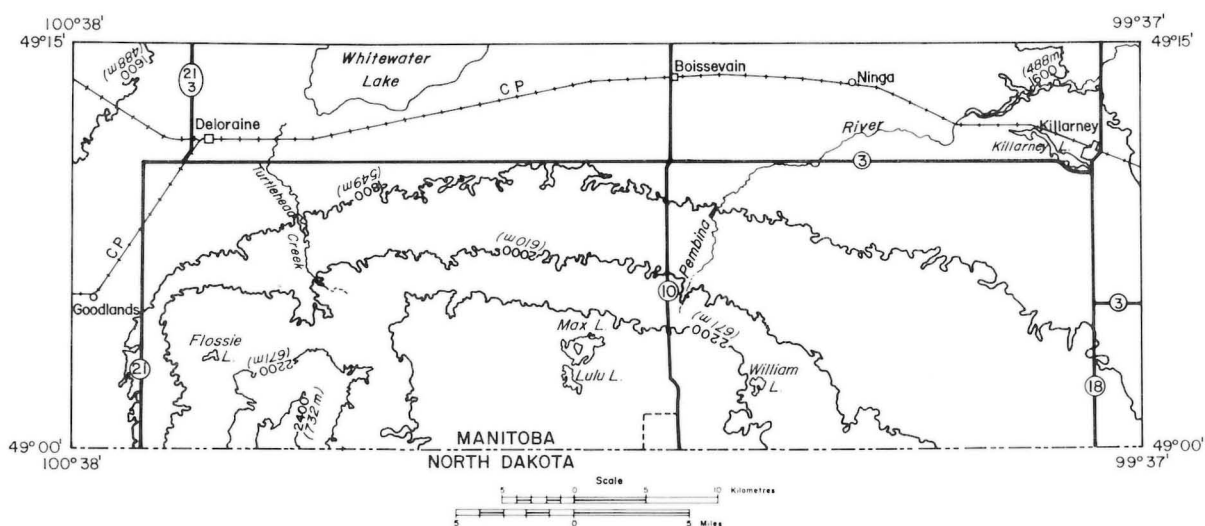


Figure 2. Turtle Mountain area. Contour interval 200 feet (61 metres).

Two distinct physiographic regions are present within the map-area. Boissevain Plain lies approximately between the 450 and 575-metre contours and forms a crescent around Turtle Mountain Upland lying above the 575-metre contour. Relief on the almost treeless Boissevain Plain is moderate, ranging from rolling to gently undulating and level. On Turtle Mountain Upland relief is usually less than 45 m, but locally ranges from 45 to 120 m. Dense stands of broad-leaved and coniferous trees crown Turtle Mountain Upland.

Surface drainage from Turtle Mountain flows in small tributaries to the two main rivers, the Souris and Pembina. Whitewater Lake on the Boissevain Plain, is very shallow and alkaline with no apparent drainage in or out. Numerous small shallow lakes, most less than 6 m in depth, on the Upland are poorly connected and apparently drain very slowly through groundwater systems.

Principal industry in the map-area is farming. Main crops are wheat, oats, barley, flax and hay. Dairy farming and raising of beef cattle are also important. Producing oil wells are located in the map-area within the Lulu Lake and Whitewater Fields (McCabe, 1963). Tourism is of economic importance because of Turtle Mountain Provincial Park and the International Peace Garden.

Previous Work

The map-area has a history of exploration dating for almost 250 years. During this time several different phases of exploration can be distinguished.

The first phase began in 1783 when La Verendrye visited the map-area and referred to the topographic feature now known as Turtle Mountain as his "second mountain"; the first being Pembina Mountain situated to the east. Sixty years later, La Verendrye's "second mountain" was named "Turtle Hill" and "Turtle Mountains" by David Thompson. The pluralized name is

currently in use in North Dakota, but in Manitoba the name Turtle Mountain (singular) was coined in 1806 by Alexander Henry, the Younger. The Palliser Expedition of 1865 explored the flanks of Turtle Mountain and they produced a map depicting "The Head, The Heart and the Tail of Turtle Mountain".

The second phase of exploration commenced in 1874 during the surveying of the , International Boundary, which bisects Turtle Mountain Upland. G.M. Dawson (1875) made geologic observations along the Forty-ninth parallel, but they were restricted to glacial drift in the map-area because of the lack of bedrock exposures. Further work on the nature of the glacial drift of southern Manitoba by Upham (1896) indicated the role that Turtle Mountain had played in successive glaciations and deglaciations.

The third phase of exploration was economically orientated. Water, coal, and building stone were the desired commodities which provided a need for detailed bedrock studies.

The first deep drill hole in the map-area, the Deloraine Well, was logged by Tyrrell (1892). This hole was drilled in the search for a water supply for the Town of Deloraine, and although the water found was not of good quality, the log of the well has been used in many subsequent stratigraphic correlations.

Lignite seams found at various mining locations on the west side of Turtle Mountain were described by Selwyn (1881-95). Twenty years after Selwyn's initial descriptions, Dowling (1906) mapped the distribution of lignite seams along the western and northern slopes of Turtle Mountain Upland. Dowling compiled his information from well data, outcrop localities, and mining locations.

Sandstone found in outcrop a few miles south of the Town of Boissevain was used as a building stone in the 1890's. Parks (1916) described in detail many sandstone and unconsolidated sand outcrops. In addition, Parks performed the first laboratory tests on bedrock from the map-area. The tests determined the structural qualities of the sandstone. Approximately 10 years after Parks' tests, Quinn (1928) and Wallace and McCartney (1928) made petrographic and grain size analyses on the same stratigraphic unit. These analyses mark the end of third phase and for the most part, the last detailed studies in the map-area for the next forty years.

The fourth phase consisted of regional studies which were done over a much larger area than that of the map-area. Kirk (1930) described the stratigraphy of the marine Cretaceous along the Manitoba escarpment and made correlations with the Turtle Mountain area. Johnson (1934) mapped the surface deposits of the Winnipeg map-area and interpreted the relation of groundwater flow to these deposits and the underlying bedrock. In 1940 and 1943, Shafer and Ellis made reconnaissance soil surveys of southwestern Manitoba. The physiographic subdivisions of Turtle Mountain and its immediate vicinity were recognized in these surveys. A thesis on Turtle Mountain by Greenlee (1942), ignored the bedrock outcrops in the map-area and concentrated on well log description of holes drilled in North Dakota. A report by Wickenden (1945) on the Mesozoic stratigraphy of Manitoba has become the guidebook for subsequent stratigraphic studies. Garden (1949) wrote a thesis on Turtle Mountain from a few bedrock samples collected by W.M. Tovell. Cameron (1949) summarized all the known data on lignite deposits in Manitoba to 1949. The surficial geology of the eastern portion of the map-area, previously mapped by Johnson (1934), was updated by Elson (1960) and the groundwater was studied in detail by Halstead (1959). The first bedrock topography map for the eastern portion of the map-area was also constructed by Halstead. Three lignite exploration programs were carried out in 1952, 1955 and 1956, in an effort to find economic lignite deposits. West Canadian Collieries Limited and C.F. Doerr were involved in these programs. Stratigraphic nomenclature problems of the Missouri Coteau, lying to the southwest of the map-area, were discussed by Lemke (1960) and he correlated beds on Turtle Mountain with those on the Coteau. Freeze (1962) constructed a groundwater probability map of the western portion of the map-area. Two geological cross-sections through Turtle Mountain were also included. The surficial geology of the western portion of the Turtle Mountain area was mapped by Elson (1962).

The fifth phase, the present one, was initiated by Klassen, Wyder and Bannatyne (1970) and Klassen and Wyder (1970) who produced very detailed bedrock topography maps of the Turtle Mountain area using data derived in part from a drilling program. Bannatyne (1970) set the stage for the present study in a report on the clays and shales of Manitoba. The first structure contour and isopach maps of Upper Cretaceous and Paleocene sediments in the map-area appeared in his report.

The geology of Rollete County, North Dakota, located southeast of the map-area, was studied by Deal (1970). Deal postulated that the bedrock of Turtle Mountain was not in place, but instead was a large glacial erratic. This, however, appears unlikely from the present study. In 1972, Luscar Limited conducted the fourth lignite exploration program in the map-area. Kohut (1972) completed a thesis on the hydrogeologic aspects of Turtle Mountain and Whitewater Lake. These aspects and their relation to genetic soil distribution in the map-area were studied by Eilers (1973). The basic information for this report was obtained from the author's M.Sc. thesis on the Upper Cretaceous and Paleocene sediments of the map-area (Bamburak, 1973). A detailed study of the lignite deposits of Turtle Mountain has been carried out by Bannatyne (1978), and is based on the four lignite exploration programs mentioned above.

Present Work

Field Work was done in the summer of 1971, and the map-area was revisited in the summer of 1974. Bedrock exposures in the map-area (Figure 3) were described and sampled (Appendix A). Only five detailed stratigraphic sections (Appendix B) were measured because most of the outcrops are too poor to permit a more detailed examination. Samples were examined under a binocular microscope and X-ray diffractograms were made at the Department of Earth Sciences, University of Manitoba. Selected samples were sieved and textural parameters were calculated according to Folk (1968) (Appendix C). The terminology of grain sizes follows the Wentworth scale. Crossbed measurements were made at three locations in the map-area (Appendix D). Mean paleocurrent directions were determined by the formulae of Potter and Pettijohn (1963). Preliminary lithologic logs were constructed on-site for three holes drilled by the Manitoba Mineral Resources Division (Appendix F). Field trips were made into North Dakota and Saskatchewan to examine Upper Cretaceous and Paleocene sections. In 1975, an additional hole was drilled by the Manitoba Mineral Resources Division (McCabe, 1975) in an attempt to intersect a postulated formation contact indicated by Bamburak (1973).

The resistivity and spontaneous potential of 52 electric logs, together with gamma and neutron radiation curves, where available, were used to define the nature of formations and their contacts in the subsurface (Appendix E). Isopach and structure contour maps were prepared mainly from this information, which was obtained by the Manitoba Mineral Resources Division from companies exploring for oil in Mississippian strata and from the Manitoba Water Resources Branch which drilled in the map-area in 1974. Locations of drill holes are shown in Figure 3.

B.R. North of the University of Saskatchewan at Saskatoon conducted a micropaleontological study on samples collected from outcrops and six drill holes, to determine their depositional environment and relative age.

Samples from outcrop and core from drill holes are stored in the Manitoba Mineral Resources Division core and sample library.

Acknowledgements

Grateful acknowledgement is extended to B.B. Bannatyne, originator of the Turtle Mountain Project, who has given much valuable advice and constructive criticism of this report.

The writer is indebted to the Geological Survey of Canada which provided invaluable samples for petrological and micropaleontological study. These studies were carried out by B.R. North at the University of Saskatchewan and without which this report would have been far from complete.

Companionship and assistance, for a few weeks of the field season, were provided by C.V. Boreski and by drillers L. Beauchamp and D. Speers during the Manitoba Mineral Resources Division core hole program. Maps and diagrams were draughted under the direction of R. Sales.

And to my wife, Wilma I give my thanks for typing this report and for being patient and understanding until the job was done.

TABLE 1
Evolution of the Stratigraphic Nomenclature
of the Turtle Mountain Area

	Dowling 1906	Dowling 1920	Greenlee 1942	Wickenden 1945	Bannatyne 1970	This Report 1978		
PALEOCENE ?	"lignite Tertiary"	"Turtle Mountain coal-bearing series" P	"Upper Ravenscrag" "Boissevain Member" "Lower P Ravenscrag" UK Whitemud Formation Eastend Formation	Turtle Mountain Formation P	Turtle Mountain Formation P	Turtle Mountain Fm. P	Peace Garden Member Goodlands Member	
	"Fox Hill sandstones" P	UK "Boissevain Sandstone"		UK Boissevain Formation	UK ? Boissevain Formation	UK Boissevain Formation		
UPPER CRETACEOUS ?	UK "gray shale"	"Pierre" "Odanah" "Millwood"		Bearpaw Formation	Riding Mountain Formation	Riding Mountain Fm. Odanah Member ? (soft) Odanah beds (hard) Odanah beds Millwood Member	Riding Mountain Fm.	Coulter Member Odanah Member Millwood Member

P/UK indicates Paleocene/Upper Cretaceous contact as proposed by various authors.

STRATIGRAPHY

Introduction

In the Turtle Mountain area, a maximum of 2060 m of post-Precambrian sediments overlie the Precambrian basement. These sediments consist of two principal lithological sequences. The lower sequence consists of 900 m of Paleozoic limestone and dolomite with minor sandstone and shale. The Mississippian erosion surface forms the top of this sequence. The upper sequence, consists of 850 to 1040 m of Mesozoic and Cenozoic shale and siltstone and is capped by up to 120 m of glacial drift (McCabe, 1963).

Upper Cretaceous and Paleocene sediments were recognized in the map-area many years ago (Table 1). However, the exact stratigraphic position of the Paleocene/Upper Cretaceous contact has been in dispute because of lack of fossil evidence. Correlation has been made solely on lithological similarities to formations in North Dakota and Saskatchewan.

Dowling (1906) placed the Paleocene/Upper Cretaceous contact between a "gray shale" and a sand unit which he correlated with the Fox Hills Formation of North Dakota. Lignite-bearing sediments were placed with some reservation, in the "lignite Tertiary". Later, Dowling (1920) updated his previous nomenclature, re-naming the "gray shale" as the "Pierre" (after Tyrrell, 1890), the sand unit as the "Boissevain Sandstone" (after Parks, 1916), and the "lignite Tertiary" as the "Turtle Mountain coal-bearing series".

The stratigraphic nomenclature and position of the Paleocene/Upper Cretaceous contact adopted by Greenlee (1942) was that used in Saskatchewan by Fraser et al (1935). The "gray shale" of Dowling (1906) was called the "Bearpaw" by Greenlee. He placed the Boissevain as a member within the Ravenscrag, well above the Paleocene/Upper Cretaceous contact.

Wickenden (1945) applied the name Riding Mountain Formation to the "gray shale" of Dowling (1906), and regarded the "Odanah" of Tyrrell (1890) as only a "peculiar lithologic phase". The "Boissevain Sandstone" of Parks (1916) was renamed the Boissevain Formation by Wickenden (1945) and he reported that Kirk had renamed the "Turtle Mountain coal-bearing series" of Dowling (1920) as the Turtle Mountain Formation. The Paleocene/Upper Cretaceous contact was placed between the Boissevain and Turtle Mountain Formations by Wickenden (1945).

The stratigraphic nomenclature and position of the Paleocene/Upper Cretaceous contact of Wickenden (1945) was retained by Bannatyne (1970); however, Bannatyne used Tyrrell's (1890) subdivisions, the "Odanah" and "Millwood", as members of the Riding Mountain Formation. Bannatyne also subdivided the Odanah Member into an upper "soft Odanah" and lower "hard Odanah".

The last column in Table 1 shows the nomenclature used throughout this report and the position proposed for the Paleocene/Upper Cretaceous contact.

Riding Mountain Formation

Definition and Description

Within the map-area, the Riding Mountain Formation is generally a 290-metre thick assemblage of grey marine clays occurring between the marine Upper Cretaceous Vermilion River Formation and the overlying Upper Cretaceous Boissevain Formation. The Vermilion River Formation, outside the scope of this report, was described in detail by Bannatyne (1970).

The Riding Mountain Formation is composed of three major lithologies: a lower unit of slightly silty clay, the Millwood Member; a middle unit of clay shale, the Odanah Member; and an upper unit of clayey silt, the Coulter Member (Table 1).

Millwood Member

The Millwood Member is a soft greenish brown bentonitic slightly silty clay which lies between the Vermilion River Formation and the overlying Odanah Member. The type locality of the Millwood Member (Tyrrell, 1890) is located 190 km northwest of Turtle Mountain in the Assiniboine River Valley at Millwood, Manitoba. A type section has not been described for the Millwood Member.

The Millwood Member is not exposed at surface in the Turtle Mountain area. In the subsurface, the thickness of this member ranges from 23 m in the southeast to 76 m in the northwest (Bannatyne, 1970). In chip samples, the Millwood Member is a bentonitic slightly silty clay composed mainly of partly swelling montmorillonite. The chips have a "popcorn" or

“cauliflower” surface which is characteristic of the Millwood Member where it has been mixed with water during drilling or exposed to weathering.

The upper contact of the Millwood Member with the overlying Odanah Member is placed at the abrupt lithological change from bentonitic clay to the overlying hard siliceous clay shale. This contact is clearly recognizable in chip samples and on gamma-ray and resistivity curves (Figure 4). Bentonite absorbs heavy radioactive elements (Lynch, 1962) and its presence in the highest Millwood beds would account for the higher radioactivity. The upper contact was chosen as a stratigraphic horizon for correlation between drill holes across the Turtle Mountain area.

Odanah Member

The Odanah Member is the middle member of the Riding Mountain Formation. This hard grey siliceous clay shale member occurs between the Millwood Member and the overlying Coulter Member. The type locality of the Odanah Member (Tyrrell, 1890) is 130 km north of Turtle Mountain, at the abandoned village of Odanah, near Minnedosa, Manitoba. A type section has not been described.

The Odanah Member is not exposed at the surface in the map-area. In the subsurface, its thickness increases from 170 m to over 230 m radially outward from the center of Turtle Mountain. Chip samples show that it is siliceous, steel grey when dry and dark greenish grey when moist. Many of the chips are stained reddish to purplish brown. At Dand, 13 km north of Deloraine, and at Ninette, 26 km north of Killarney, the Odanah Member outcrops as thin fissile beds and/or thick beds with conchoidal fracture.

With the exception of its uppermost beds, the Odanah Member has the highest resistivity and the lowest radioactivity of the three members of the Riding Mountain Formation (Figure 4). The low radioactivity within the lower beds is attributed to its siliceous composition which prevents the absorption of heavy radioactive elements.

The hard grey siliceous shale of the Odanah Member grades into the overlying light grey to buff clayey silt of the Coulter Member within a stratigraphic interval of about 15 m. The base of the interval is usually marked by the presence of a thin bentonite bed, an increase in radioactivity, and a decrease in resistivity (Figure 4). The top of the interval is indicated by the absence of the hard grey siliceous shale, a slight decrease in radioactivity and a minimum in the resistivity curve. The top of the interval, usually the first appearance of the Odanah Member in drill hole cuttings, is chosen as the position for the Odanah-Coulter contact.

Coulter Member

Bannatyne (1970) included the “soft” beds outcropping in the Souris Valley near the town of Coulter, Manitoba, 39 km west of Turtle Mountain, within the Odanah Member (Table 1). Because these beds can be recognized as a distinctive lithological unit at surface and in the subsurface, it is proposed that the light grey to buff, fine-grained clayey silt occurring between the Odanah Member and the overlying Boissevain Formation be named the Coulter Member of the Riding Mountain Formation. Drill hole #21, not in the type area, penetrated the uppermost beds of the Coulter Member and its lithological description is given in Appendix F.

The only Coulter Member outcrop in the map-area, Locality #1, has been disturbed by slumping and/or ice-thrusting. In the subsurface the thickness of this member decreases from 55 m to 20 m across the southwest portion of the map-area, but maintains an average 45-metre thickness across the southeast portion. The Coulter Member, in chip samples, generally resembles the Millwood Member. The clayey silt of the Coulter Member is bentonitic and generally tends to have a “popcorn” or “cauliflower” surface. The presence of bentonitic material is indicated by the high radioactivity in its lower beds (Figure 4). The resistivity of the Coulter Member increases slowly upward, with an attendant increase in grain size, whereas the spontaneous potential remains constant.

The fine-grained clayey silt of the Coulter Member is gradational upward into the sand of the Boissevain Formation. The contact is defined at the base of the first recognizable sand bed above the clayey silt of the Coulter Member. This sand bed, usually 1½ m thick, is represented in Figure 4 by a sharp resistivity high on a low background, approximately 14 m below the major 15-metre thick sand unit of the Boissevain Formation.

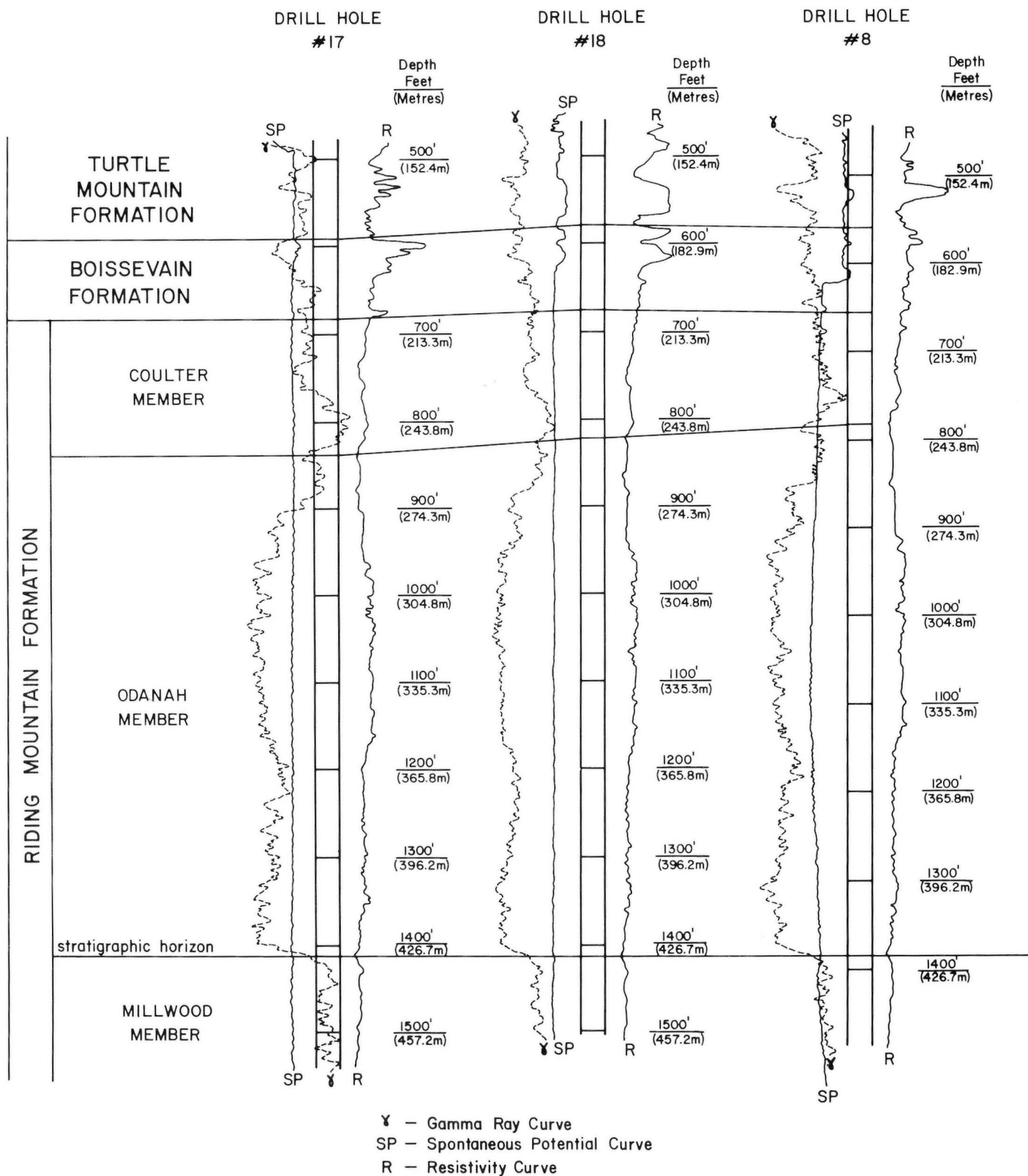


Figure 4. Correlation between drill holes by means of radioactivity, spontaneous potential, and resistivity logs.

Age and Correlation

Diagnostic fossils have not been found in the Riding Mountain Formation within the Turtle Mountain area. However, north and east of the map-area at Dand, Millwood, and Wawanesa, foraminifera have been identified which indicate a Late Cretaceous age for this formation (Wickenden, 1945).

The Riding Mountain Formation was correlated with the Bearpaw Formation of Saskatchewan (Table 2) by Wickenden (1945) and was recognized in the Melville Area, Saskatchewan by Christiansen (1971). On a cross-section of the Melville Area, the latter showed the Odanah Member lying within the Riding Mountain Formation.

The correlation of the Riding Mountain Formation with the Pierre Shale of North Dakota was made by Wickenden (1945). This was supported by Lemke (1960), who found sediments equivalent to the Pierre shale outcropping just west of Turtle Mountain, in the Souris Valley near Coulter, Manitoba. Gill and Cobban (1965) equated the Gregory and DeGrey Members of the Pierre Shale with the Millwood Member. In addition, they correlated the Verendrye Member and lower beds of the Virgin Creek Member of the Pierre Shale with the Odanah Member (Table 2). The relative position of the Coulter Member in the stratigraphic section and its lithology suggests that it can be correlated with the upper beds of the Virgin Creek Member as defined by Searight (1937).

Boissevain Formation

Definition and Description

The Boissevain Formation is dominantly sand with minor amounts of clay, silt, and sandstone within the map-area. It occurs between the Upper Cretaceous Riding Mountain Formation and the overlying Paleocene Turtle Mountain Formation. Lignite-bearing beds which are conspicuous in the overlying Turtle Mountain Formation are not present in the Boissevain Formation.

A type area for the Boissevain Formation has not been designated. It is proposed that the south halves of Tp. 3, Rges. 19 and 20, and the north half of Tp. 2, Rge. 19 be designated as the type area. A section at Locality #3 (Table 3) is selected as the type section of the Boissevain Formation. Drill hole #21, not in the type locality, penetrated the entire thickness of the Boissevain Formation and a lithological description is given in Appendix F.

In Manitoba, the Boissevain Formation is restricted in extent to the Turtle Mountain area where it maintains an average 30-metre thickness. Across the northern part of the area (Figure 3), the Boissevain outcrops as a cross-bedded buff quartz-rich medium-grained "salt and pepper" sand. In the middle of the area at Locality #35 the Boissevain Formation consists of a massive white kaolinitic fine-grained silt or clay (Plate 1). Samples from drill hole #28 (described in Appendix F) indicate that the buff sand is transitional upward into white silt and clay. The lowest beds of the Boissevain Formation, not exposed at surface, consist mainly of sand interbedded with thin units of silt and clay which become more numerous with depth.

Ovoid concretionary masses of cemented sandstone with average sizes 7 m by 2 m by 1 m are characteristic of the Boissevain Formation (Plate 2). Crossbedding passes without disturbance through these concretionary masses and into the surrounding sand. The Boissevain Formation also contains thin discontinuous partially purple-stained orange concretionary ironstone layers which usually follow, for several metres, the bedding planes in the sand.

TABLE 2
Correlation of Formations and Members of Saskatchewan
and North Dakota With Those of Manitoba

	SASKATCHEWAN		southwestern MANITOBA	central NORTH DAKOTA	
	southwestern	southeastern			
PALEOCENE	Ravenscrag Formation		Peace Garden Member	Sentinel Butte Fm.	
				Tongue River Fm.	
				Cannonball Fm.	
				Ludlow Fm.	
?	P		P		
UPPER CRETACEOUS	Frenchman Formation		Turtle Mountain Formation	UK	
				Goodlands Member	
				Huff Member	
				Fort Rico Member	
					Breien Member
					Crowghost Member
	?		P		
	Battle Fm.		UK		
	Whitemud Fm.				Colgate Member
	Eastend Formation		Boissevain Formation	Fox Hills Fm.	
Bullhead Member					
Timber Lake Member					
Bearpaw Fm.	Riding Mountain Fm.	Riding Mountain Fm.	Coulter Member		
			Virgin Creek Member		
	Odanah Member		Odanah Member	Odanah Member	
			Millwood Member	Verendrye Member	
			Pierre Shale	De Gray Member	
				Gregory Member	

P/UK indicates Paleocene/Upper Cretaceous contact as proposed by various authors.

TABLE 3
Type Section of Boissevain Formation,
L.S. 14, Sec. 35, Tp. 2, Rge. 19 WPM

Lithology	Thickness (metres)
Sand, brown, fine-grained interbedded with yellow clay; minor sandstone	1.74
Ironstone concretion layer, orange-brown	0.15
Sand, brown, silty	1.13
Silt, compacted	1.83
Sand, brown, laminated, compacted	0.40
Ironstone concretion layer, orange-brown	0.15
Sand, brown, fine-grained; minor thin layers of silt and clay	0.95
Sand, compacted	0.30
Sand, crossbedded; lithified sandstone blocks; orange-brown ironstone concretion layers	1.83
Covered interval	0.91
Sand, reddish-orange, crossbedded	0.37
Sand, grey, crossbedded	2.59
TOTAL	12.35
Coulter Member of the Riding Mountain Formation	0.30

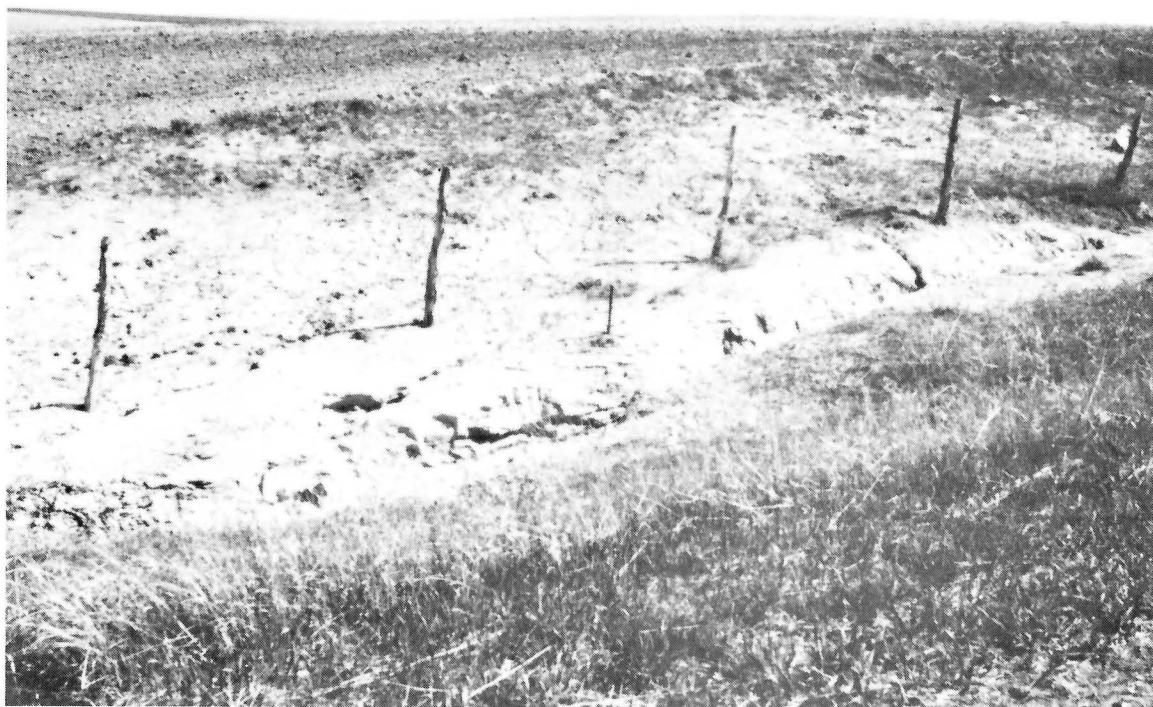


PLATE 1. Massive white kaolinitic fine-grained silt or clay at Locality #35; Boissevain Formation.

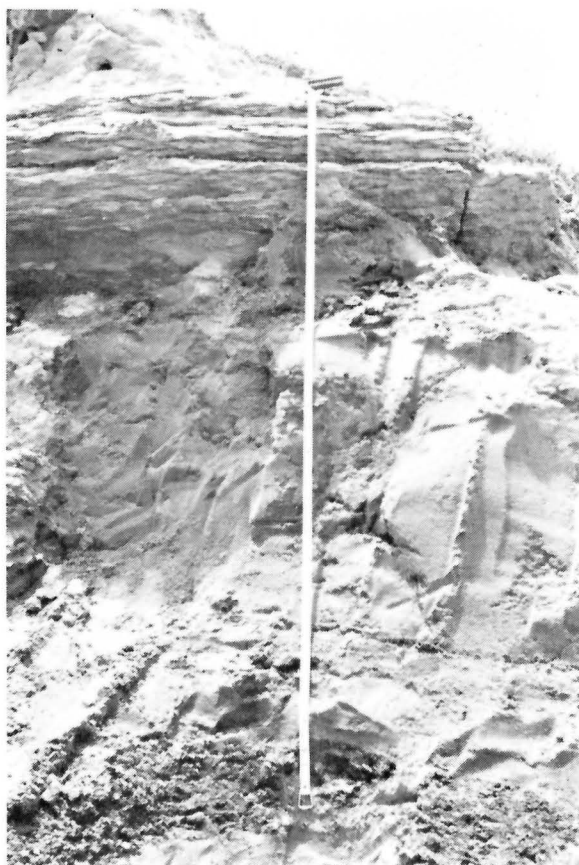


PLATE 2. Sandstone concretionary masses at Localities #3 (Upper) and #19 (Lower); Boissevain Formation.

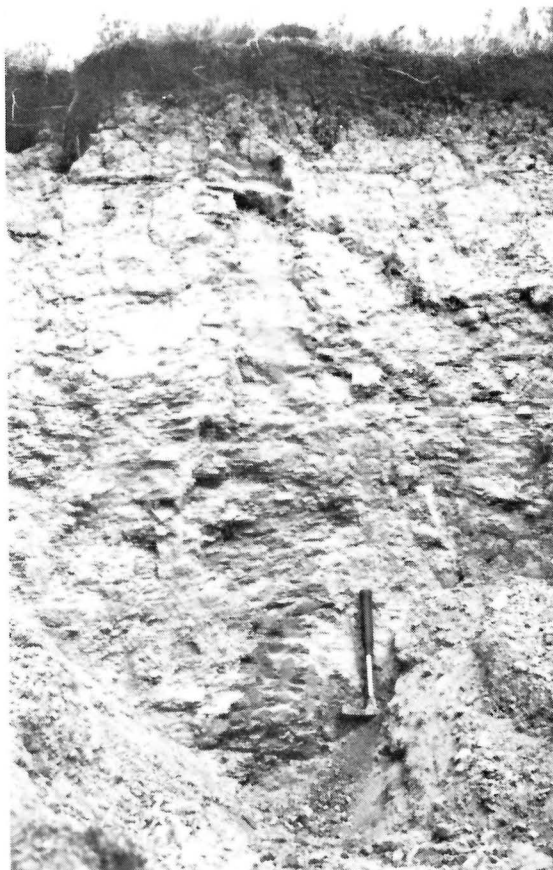


PLATE 3. Dark greenish-red clay bed with abundant plant and lignite fragments at Locality #12; Goodlands Member of the Turtle Mountain Formation, about 1 metre above the Boissevain-Turtle Mountain contact. The heads of the hammers mark the top of this bed and the hammers were situated approximately 3 metres apart.

Thick sand units within the Boissevain Formation are more permeable than the thinner, more compact clay beds. This can be seen in Figure 4 where the sand units are represented by high spontaneous potential and resistivity over long intervals in contrast to short intervals of low spontaneous potential and resistivity in clays. The change from positive spontaneous potential in drill holes #8, #17, #18 to the negative spontaneous potential in drill holes #19 and #21 resulted from the contrast between the drilling mud filtrate salinity and that of the formation water. Gamma-ray curves indicate that a moderate upward decrease in radioactivity is present in the Boissevain Formation; however, sharp decreases in radioactivity occur at the position of the sand units (Figure 4). These decreases may reflect a decrease in the amount of bentonitic material and an increase in grain size of the sand.

The contact of the Boissevain Formation with the overlying Turtle Mountain Formation is placed at the base of either the first lignite seam or a dark greenish-red clay bed containing abundant plant and lignite fragments. The latter is recognizable in outcrop at Locality #12 (Plate 3). In the subsurface, the first appearance of medium-grained sand in the chip samples or the top of the first major increase in resistivity and spontaneous potential below the lignite-bearing Goodlands Member of the Turtle Mountain Formation (Figure 4) marks the position of the contact.

Age and Correlation

The Boissevain Formation is sparsely fossiliferous (Wickenden, 1945). Any determination of its age is dependent on its relative position in the stratigraphic section and possible correlation with equivalent strata in Saskatchewan and North Dakota.

The relative position of the Boissevain Formation above the Riding Mountain Formation is the same as the Eastend Formation above the Bearpaw Formation in Saskatchewan and the Fox Hills Formation above the Pierre Shale in North Dakota (Table 2). Sedimentation was continuous between formations as shown by the gradational change from grey clay shales to buff sand in both areas (Caldwell, 1968; Feldmann, 1972).

The upper contacts of the Boissevain and Fox Hills Formations with the overlying Turtle Mountain and Hell Creek Formations respectively (Table 2) are placed at the base of the first prominent lignite seam or lignitic shale, although Feldmann (1972) stated that a surface of unconformity may separate the Hell Creek and Fox Hills Formations. A widespread erosional interval following deposition of the Fox Hills and Boissevain Formations would account for the irregular distribution of massive white kaolinitic fine-grained silt or clay in upper beds of the Boissevain Formation (Plate 1). Although lignite beds are present in basal beds of the Frenchman Formation in Saskatchewan, Furnival (1946), stated that the contact between the Frenchman and underlying formations is a widespread surface of unconformity.

Dowling (1920) was the first to correlate the Boissevain Formation with the Fox Hills Formation of North Dakota (Table 1). His correlation is supported by Lemke (1960) and by S.R. Moran and L. Clayton of the North Dakota Geological Survey (personal communications, 1973). The crossbedded concretionary sands of the Timber Lake Member of the Fox Hills Formation are similar to the lower sand beds of the Boissevain Formation. The upper white kaolinitic fine-grained silt or clay beds of the Boissevain Formation can be directly correlated with fine-grained silty sands of the Colgate Member of the Fox Hills Formation.

Russell (1933) correlated the lower beds and the Colgate Member of the Fox Hills Formation of North Dakota with the Eastend and Whitemud Formations, respectively, of Saskatchewan. The green and brown sands, silts, and clays of the Eastend Formation (Byers, 1969) are similar to the lower beds of the Boissevain Formation, and the light grey kaolinitic sands, silts, and clays of the Whitemud Formation (Byers, 1969) are nearly identical to the sediments in the upper Boissevain beds. Samples (63-19) and (63-21) from these beds, collected stratigraphically above the top of drill hole #25 by B.B. Bannatyne of the Mineral Resources Division, have almost the same X-ray pattern as that of a sample of the Whitemud Formation.

According to Feldmann (1972), the Fox Hills Formation is not everywhere of the same age. He suggests that members of the Fox Hills Formation, as well as the overlying Hell Creek and underlying Pierre Formations, were being deposited at the same time in different areas and that they represent facies of one another. However, Feldmann concluded that the length of time during which this penecontemporaneous deposition occurred was of a short duration and that for the purposes of regional correlation the Fox Hills Formation in North Dakota should be considered to be essentially the same age throughout its area of outcrop. Feldmann assigned a Late Cretaceous age to the Fox Hills Formation after extensive studies of fossil cephalopods and clams, and if the above correlations are correct the Boissevain Formation must also be Late Cretaceous.

Turtle Mountain Formation

Definition and Description

Wickenden (1945) defined the Turtle Mountain Formation as the Paleocene series of shale, sandstone, and lignite-bearing beds which overlie the Upper Cretaceous Boissevain Formation in the Turtle Mountain area. From new information, it is proposed that this formation be divided into two members, a lower Goodlands Member and an upper Peace Garden Member. The Goodlands Member is generally an assemblage of non-marine bentonitic carbonaceous sands, silts, and clays. The Peace Garden Member is generally a marine silty clay with minor thin very fine-grained sand beds.

The upper contact of the Turtle Mountain Formation is a surface of unconformity which is overlain by Pleistocene glacial drift and recent sediments. The maximum known thickness of the Turtle Mountain Formation is 158 m.

Goodlands Member

The Goodlands Member is an assemblage of bentonitic carbonaceous sands, silts, and clays occurring between the Boissevain Formation and the Peace Garden Member.

Within the western and eastern halves of Tp. 1, Rge. 23 and Tp. 1, Rge. 24, respectively, most of the upper 30 m of the Goodlands Member of the Turtle Mountain Formation can be found in scattered outcrops and this has been chosen as the type area. A section at Locality #43 (Table 4) has been selected as the type section of the Goodlands Member. Drill hole #21 penetrated a 33-metre thick section of the Goodlands Member and its lithology is described in Appendix F.

In Manitoba, the Goodlands Member is present only within the Turtle Mountain area. Its average thickness in the western portion is 40 m. Lignite seams ranging in thickness from 0.15 m to 1.83 m occur throughout the member. Sediments between lignite seams are for the most part bentonitic carbonaceous grey silty clays with a few crossbedded grey sand units. A light grey underclay is usually present directly beneath lignite (Plate 4).

TABLE 4
Type Section of Goodlands Member, L.S. 2,
Sec. 25, Tp. 1, Rge. 24 WPM

Lithology	Thickness (metres)
Clay, brown, blocky, silty with yellow stains becoming thin bedded upwards	1.04
Clay, light grey in part mottled with yellow and orange stains	0.06
Lignite, brown, soft	0.21
Clay, grey	0.18
Lignite, brown, soft	0.21
Clay, light grey	0.15
Clay, brown, carbonaceous with yellow stains	0.15
Lignite, black, brittle	0.24
Clay, grey-brown	0.15
Sand, yellow-grey, silty	0.64
Silt, yellow interlayered with grey clay	0.82
Sand, yellow and orange stained	1.13
TOTAL	4.98

The Goodlands sand beds and lignite seams are indicated by short interval highs in the resistivity curves (Figure 4). Near the base of the sand beds, radioactive elements have been concentrated as shown by a sharp increase in radioactivity. The concentration of the radioactive elements was possibly caused by downward percolation of groundwater through the sand beds.

The change from the bentonitic, carbonaceous, grey silty clay to the overlying non-bentonitic, non-carbonaceous, yellow-weathering, grey silt marks the position of the contact between the Goodlands Member and the overlying Peace Garden Member. At Locality #40, the contact is a surface of unconformity between a yellow-weathered, well-bedded, flat-lying silt and an underlying eroded, massive, dark grey silt. Relief on the erosion surface is approximately 30 centimetres (Plate 5).

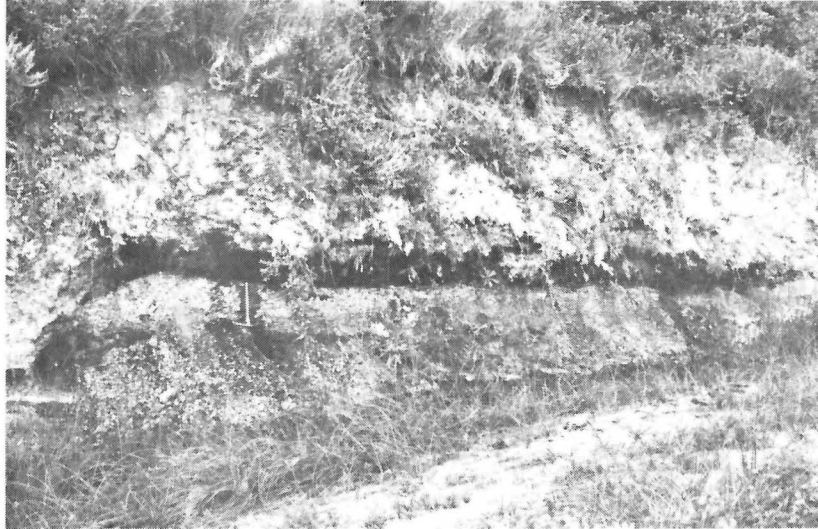


PLATE 4. Lignite seams separated by underclay at Locality #42; Goodlands Member of the Turtle Mountain Formation.

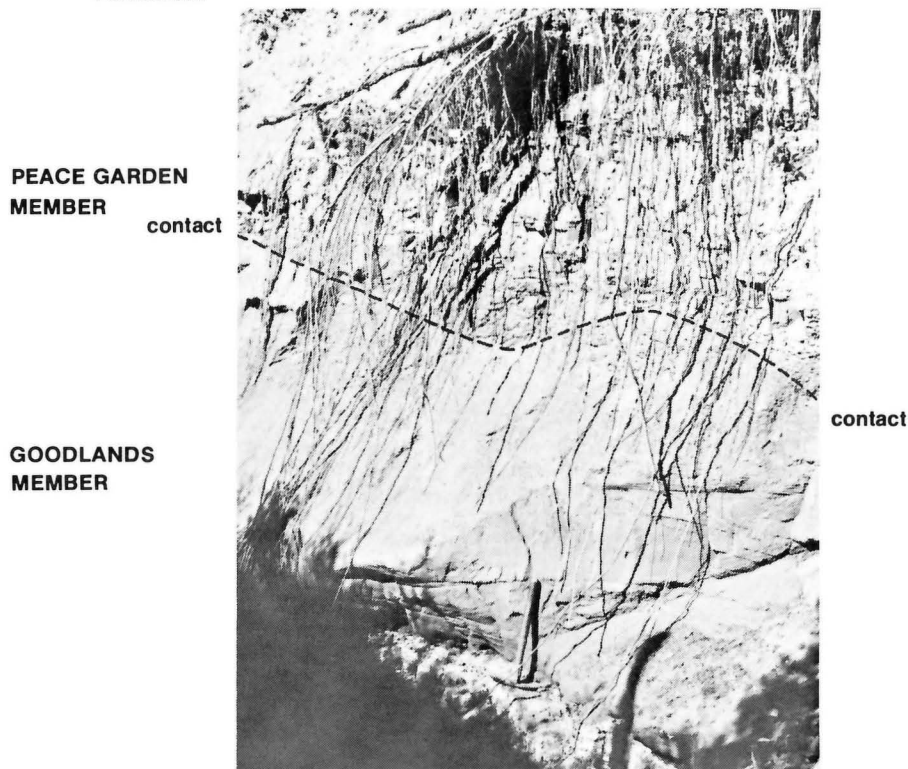


PLATE 5. Contact between Goodlands and Peace Garden Members of the Turtle Mountain Formation; Locality#40.

Peace Garden Member

The Peace Garden Member comprises an assemblage of grey silty clay with minor greenish sand and silt which overlie the Goodlands Member.

A composite type section for the Peace Garden Member is proposed from drill holes #19 and #21 (Table 5) because this member is not well-exposed in the map-area.

The Peace Garden Member is known to outcrop only at three localities in the Turtle Mountain area. A yellow-weathering grey silty clay is exposed in the basal beds of the Peace Garden Member at Locality #40 (Plate 5). The beds are thin-bedded with an average thickness of 13 millimetres. Siltstone beds, cemented by calcium carbonate, cap an outcrop at Locality #36 (Plate 6). Very fine-grained greenish sand beds are exposed at Locality #30 (Plate 7).

The resistivity curves from drill holes #19 and #21 (Figure 4), show short interval highs at the position of thin sand and silt beds and long interval lows at the position of silty clays. The spontaneous potential and gamma-ray curves indicate gradually decreasing values upward from the base of the member; however, sharp decreases occur at the sand and silt beds.

The Peace Garden Member of the Turtle Mountain Formation is unconformably overlain by Pleistocene glacial drift and recent sediments. Glacial sediments are present in chip samples from many drill holes and in the sidewall samples in the upper 38 m of drill hole #19. Overburden thicknesses of more than 120 m are reported in the Max Lake-Lulu Lake area.

Age and Correlation

According to W.G.E. Caldwell, University of Saskatchewan (personal communications, 1971 and 1972), foraminifera which are strongly suggestive of a Paleocene age have been identified in drill hole samples from the Turtle Mountain Formation in Manitoba. He reported the following marine foraminifera:

Drill hole	
#19	<i>Polymorphina</i> sp. at 52 m
#21	<i>Protelphidium</i> at 53 m
#22	<i>Nodosaria</i> sp. and <i>Guttulina</i> sp. from 7.6 — 13 m
#24	<i>Protelphidium</i> cf. <i>sublaeve</i> , <i>Anomalinoides</i> sp., (?) <i>Anomalinoides</i> sp. or (?) <i>Gavelinella</i> sp. (indistinct) (?) <i>Rectoglandulina</i> sp. (broken specimen) <i>Haplophragmoides</i> spp. and <i>Ammodiscus</i> sp. (broken) from 3.3 — 11.8 m; <i>Haplophragmoides</i> sp. and <i>Saccammina</i> sp. 11.8 — 30.1 m.
#31	<i>Protelphidium</i> cf. <i>sublaevis</i> from 9 — 11 m; and <i>Haplophragmoides</i> spp. from 30 — 32 m.

This would seem to confirm the probable Paleocene age applied to the Turtle Mountain Formation by Wickenden (1945).

According to S.R. Moran and L. Clayton, North Dakota Geological Survey (personal communication, 1973), the stratigraphic position (Table 2) and lithology of the Boissevain Formation and the overlying Goodlands Member of the Turtle Mountain Formation are identical to those of the Fox Hills Formation and the overlying Hell Creek Formation, respectively. Frye (1969) has described the Hell Creek Formation as an assemblage of lignitic and bentonitic grey unconsolidated clay, silts, and fine to medium-grained sand. Feldmann (1962) stated that the lower contact of the Hell Creek Formation is placed at the base of the first prominent lignite or lignitic shale, and according to Frye (1969) the upper contact is selected at the base of a "yellow bed" (a light yellowish brown bed of silt and sand in a sequence of dark somber coloured beds) or at the top of the uppermost bentonitic sediments. The Goodlands Member is correlated with the Hell Creek Formation because of the above similarities in lithology, stratigraphic position, and nature of upper and lower contacts. Byers (1969) equated the Frenchman Formation of southern Saskatchewan (Table 2) to the Hell Creek Formation.

TABLE 5
Composite Type Section of
Peace Garden Member
L.S. 5, Sec. 20, Tp. 1, Rge. 22 WPM and
L.S. 15, Sec. 32, Tp. 1, Rge. 22 WPM

Lithology	Thickness (metres)
Sand, olive, very fine-grained, iron stained	4.88
Silt, grey, fine-grained	4.88
Missing interval	0.30
Clay, light grey, silty	6.71
Missing interval	2.44
Sand, olive, fine-grained, iron-stained interbedded with silty olive clay	9.76
Missing interval	0.30
Clay, grey, silty, kaolinitic	2.74
Missing interval	0.30
Sand, grey, fine-grained	16.46
Missing interval	1.52
Clay, grey, silty, interbedded with light brownish grey calcareous clay	3.05
Missing interval	1.80
Clay, light grey, kaolinitic	0.03
Missing interval	1.80
Sand, light brown, fine-grained	0.03
Missing interval	0.88
Clay, carbonaceous and grey fine-grained sand	0.03
Missing interval	1.83
Sand, grey, very fine-grained with minor yellow clay	7.32
Missing interval	2.71
Sand, grey, fine-grained and grey clay	0.03
Unknown interval	?
Sand, grey, silty, very fine to medium-grained	4.88
Missing interval	0.91
Silt, grey, clayey, very fine-grained	5.79
Missing interval	1.52
Sand, grey, fine-grained	10.67
Missing interval	0.30
Silt, grey, clayey, very fine-grained	4.27
Missing interval	0.30
Clay, grey, silty	2.74
Missing interval	0.61
Sand, grey, very fine-grained	1.22
TOTAL	103.92+
Goodlands Member of the Turtle Mountain Formation	46.94



PLATE 6. Thin siltstone concretionary masses capping the outcrop at Locality #36; Peace Garden Member of the Turtle Mountain Formation.



PLATE 7. Highest known outcrop in map-area (608 metres above sea level) at Locality #30; Peace Garden Member of the Turtle Mountain Formation.

Although the entire Hell Creek Formation in Montana and North Dakota has been assigned a Late Cretaceous age, Frye (1969) states that the base of this formation becomes progressively younger in an eastward direction. This then would explain why the equivalent Goodlands Member contains Paleocene foraminifera and why a Paleocene age must be applied to the Goodlands Member at Turtle Mountain.

The marine beds of Paleocene age in the Peace Garden Member can be correlated with the Cannonball Formation of North Dakota (W.G.E. Caldwell, University of Saskatchewan, personal communication, 1972). However, S.R. Moran and L. Clayton, North Dakota Geological Survey (personal communication, 1973) stated that they recognized sediments equivalent to the non-marine Tongue River Formation within the Turtle Mountain area. The Cannonball and Tongue River Formations form part of the Fort Union Group in North Dakota (Table 2) and because further subdivision of the Peace Garden Member is not possible at this time with the data available, all that can be stated is that the Peace Garden Member of the Turtle Mountain Formation is the equivalent of the Fort Union Group. The Ravenscrag Formation of Saskatchewan was correlated with the Fort Union Group by Byers (1969).

SEDIMENTATION

General Statement

The provenance areas and depositional environments of the Riding Mountain, Boissevain, Turtle Mountain Formations are indicated by their grain size distributions, sedimentary structures, mineralogy, and petrology. The terminology of Krumbein and Sloss (1963) is used to describe the environments of deposition.

Physical and Chemical Properties

Grain size Distribution

Sediments of the Riding Mountain Formation are generally clays (less than 8.0 ϕ), except within the uppermost member where the mean grain size gradually increases toward the contact with the sand-sized sediment in the overlying Boissevain Formation.

Quinn (1928) and Garden (1949) made mechanical analyses of sands from the Boissevain and their results agree with those of the present report. The mean grain size of 15 Boissevain Formation sand samples (Appendix C) has a range from 2.46 ϕ to 3.5 ϕ . On the average these sands are moderately well sorted, 0.51 ϕ to 0.77 ϕ ; strongly fine-skewed, -0.02 to +0.66; and very leptokurtic, 1.09 to 2.93.

The mean grain size of 3 sand samples from the overlying Goodlands Member of the Turtle Mountain Formation has a range from 2.84 ϕ to 3.29 ϕ , which is within the mean grain size range of the Boissevain Formation. The sands of the Goodlands Member on the average are moderately well sorted, 0.38 ϕ to 0.85 ϕ ; strongly fine-skewed, +0.10 to +0.50; and leptokurtic, 0.93 to 1.50. Grain size parameters are similar to those of the Boissevain Formation sands. The overlying Peace Garden Member of the Turtle Mountain Formation is mostly composed of silty clays, usually finer than 8.0 ϕ , and very fine-grained sand, 3 to 4 ϕ .

Sedimentary Structures

Sedimentary structures such as crossbedding, ripple marks, and concretionary masses are best developed in the Boissevain Formation. The mean paleocurrent directions for three Localities #3, #19, #24 where abundant crossbedding is present are shown in Figure 5. Also shown are the grand mean of paleocurrent directions, 069° (Appendix D), and the distribution of dips of the cross-bed measurements.

At Locality #4 wave-oscillation ripple marks are preserved within a sandstone concretionary mass (Plate 8). The ripples have an amplitude of 1.3 centimetres and a wave length of 2.5 centimetres.

Sandstone concretionary masses at Localities #3, #4, #6, #7, #9, #19, are positioned about 1.5 and 9 m below the Boissevain-Turtle Mountain contact. At Locality #19 seven concretionary masses have an average length of 7 m, width of 2 m, and thickness of 1 m. The long axes of these near-horizontal masses are nearly parallel and strike approximately 120°.

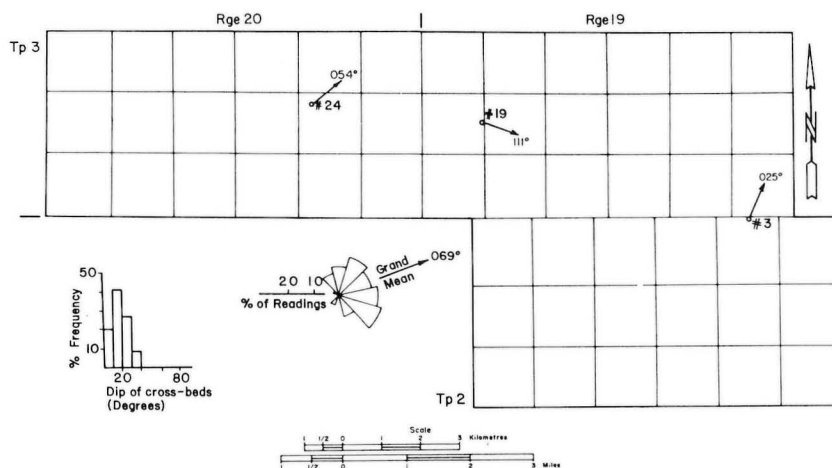


Figure 5. Vector means, rose diagram, and histogram for crossbedding in the Boissevain Formation. Turtle Mountain area.



PLATE 8. Ripple marks at Locality #13; Boissevain Formation.

Mineralogy and Petrology

Although the Upper Cretaceous and Paleocene sediments of the Turtle Mountain area vary in grain size, the composition of these sediments is generally consistent. The Millwood Member, as determined by X-ray diffraction methods, is a clay composed largely of montmorillonite with moderate amounts of quartz and cristobalite (Bannatyne, 1970). In addition, a microscopic examination by Ross and Buchanan (1962) indicated the presence of minor amounts of goethite, carbonate, mica, zeolite and gypsum. X-ray diffractograms of the Odanah Member show almost no crystal structure and according to Bannatyne (1970) amorphous silica is the major constituent. Only small amounts of quartz and cristobalite can be identified in an Odanah sample from 276 m below surface in drill hole #13. X-ray diffractograms of two samples of the Coulter Member, drill hole #13 at 212 m and drill hole #21 at 119 m, indicate that quartz is dominant with minor amounts of plagioclase, illite, and zeolite. Bentonite, not shown on the X-ray diffractograms, is probably present only in small amounts within the samples tested.

Wallace and McCartney (1928) examined a 25 g sample of the Boissevain Formation from an outcrop south of the Town of Boissevain (Table 6). Feldspar is present in considerable quantities in light residues which comprise 96.05 per cent of the sample. The assemblage of heavy minerals is dominated by hornblende. Biotite and magnetite each account for 10 to 25 per cent. Although the Boissevain sands are generally fresh and angular, well rounded, distinctly pleochroic rose and purple zircons were noted also.

Garden (1949) examined two samples from lower beds of the Boissevain Formation near Locality #12. His results, shown in Table 8, correspond closely to those of Wallace and McCartney except that percentage of biotite exceeds that of hornblende. Garden also examined two samples from upper beds of the Boissevain Formation near Locality #37, and in contrast to the lower beds hornblende exceeds biotite. The variability in hornblende-biotite ratios could possibly be explained by low total percentages of the two samples from the lower beds of the Boissevain Formation which may indicate loss of a portion of the samples. From thin section studies, Garden reported that all of his samples contained 80 to 85 per cent quartz, 2 to 4 per cent orthoclase, and 4 to 10 per cent plagioclase. All the indurated samples contained finely crystalline or fibrous carbonate. Garden reported that magnetite, limonite and leucoxene totalled at least 30 per cent of the heavy minerals in all samples. He also found the grains to be generally uncorroded and very angular. Some of the quartz grains showed flamboyant structure.

In four samples from lower beds of the Boissevain Formation (Locality #3, JB 37; Locality #12, JB 28; drill hole #13, depth 184 m; and drill hole #21, depth 101 m), X-ray diffractograms show that quartz is the dominant mineral with a moderate amount of plagioclase and a minor amount of illite. Calcite is indicated in a lithified sample, JB 28, and hornblende is shown to be present in JB 37. Samples from the highest Boissevain beds contain moderate amounts of kaolinite in addition to abundant quartz and minor plagioclase.

TABLE 6

**HEAVY MINERAL ANALYSES OF SAMPLES FROM THE
BOISSEVAIN FORMATION AND THE GOODLANDS MEMBER OF THE TURTLE MOUNTAIN FORMATION**

Boissevain Formation						Turtle Mountain (Goodlands Member)	
Mineral	Wallace & McCartney (1928) 25 g sample 3.05% "heavies" south of Boissevain (?)	Garden (1949) 20 g samples 5-8% "heavies"				Garden (1949) 20 g samples 5-8% "heavies" L.S. 10, Sec.13, Tp.1, Rge. 24WPM	
		Lower beds SE¼, Sec.2, Tp.3, Rge. 19WPM		Upper beds N½, Sec.7, Tp.2, Rge. 23 WPM			
		Base 518.4 m	Top	Base	Top	Top 543.1 m	Top 543.1 m
Anatase	1 - 5						
Apatite	1 - 5	3.0	6.0	5.1	5.0	3.0	5.0
Biotite	10 - 25	33.0	52.0	38.0	23.0	41.0	46.0
Epidote	5 - 10			7.5	2.5	3.0	3.5
Garnet	5 - 10	6.5	0.1	3.0	5.0	5.0	3.5
Glaucophane		13.5		2.5	2.5	6.5	8.5
Hornblende	50	19.0	35.0	41.0	58.0	29.0	25.5
Idocrase						3.0	
Ilmenite	5 - 10						
Kyanite	1		0.1			3.5	
Magnetite	10 - 25						
Rutile	1						
Titanite	1						
Tourmaline	1 - 5						
Zircon	1 - 5	3.0		2.5	2.5	4.0	3.5
Total %		78.0	93.2	99.6	98.5	98.0	95.5

Heavy minerals of two samples from the Goodlands Member close to Locality #45 were studied by Garden (1949). His results (Table 6) show that this member is mineralogically similar to the lower beds of the Boissevain Formation with biotite exceeding hornblende, but different in that epidote is present in the Goodlands Member. According to Garden, sands of the Goodlands Member in thin section appear to be nearly identical to those of the Boissevain Formation. Wicks (1963) analyzed a silty shale sample from the Goodlands Member near Locality #43. The shale consists of mixed-layer illite-montmorillonite with minor kaolinite and/or chlorite. Non-clay minerals are quartz, plagioclase, and a trace of pyrite. A small amount of organic matter is present.

Two samples, JB 4 and JB 5, from the sandy beds of the Peace Garden Member at Locality #30 have nearly identical X-ray patterns except for abundant calcite in the lithified sample JB 5. Both samples contain abundant quartz with minor plagioclase, illite, and zeolite.

Calcium carbonate is the usual matrix in lithified sediments of the map-area.

Provenance Areas

Garden (1949) concluded that heavy mineral suites from sands of the Boissevain and Turtle Mountain Formations (Table 6) indicated that both were derived from the same metamorphic and igneous provenance area. Crossbedding measurements in the Boissevain Formation (Appendix D) indicate an eastward direction (Figure 5) of sediment transport and this suggests that the provenance area was to the west. According to Byers (1969), the Eastend, Whitemud and Frenchman Formations of Saskatchewan (Table 2) had their source in Upper Cretaceous metamorphic rocks and Paleozoic carbonates of Montana. If correlation of the above formations with the sediments of the Turtle Mountain area is correct, then the provenance area of at least the Boissevain Formation was also in Montana.

Depositional Environments

Riding Mountain Formation

Wickenden (1945) attributed a marine depositional environment to the Riding Mountain Formation from fossils obtained at Dand and Wawanesa 19 and 52 km, respectively north of Turtle Mountain. He also stated that in the type locality of the Millwood Member the bivalve *Inoceramus* was identified. According to Gill and Cobban (1966) present-day bivalves comparable to the size attained by *Inoceramus* are not found in deep water, and assuming this to be sufficient evidence, the Millwood Member was probably deposited in a shallow water marine environment.

The Odanah Member appears to be lithologically similar to the siliceous Mowry Shale of South Dakota. According to Rubey (1928), this shale was deposited slowly on the sea floor as a very fine-grained, highly siliceous volcanic ash. The Odanah Member may have the same origin.

Bentonite is present in the Millwood and Coulter Members. Rubey (1928) stated that bentonite in the siliceous Mowry Shale represents rapid volcanic ash deposition on the sea floor. Because of the close association of the Millwood and Coulter Members with the Odanah Member, a similar origin is likely for these members. The upward increase in grain size within the Coulter Member may indicate a gradual decrease in water depth.

Gill and Cobban (1966) and Caldwell (1968) stated that the upper members of the Pierre Shale and the Bearpaw Formation, respectively, (Table 2) were deposited at depths less than 60 m, and it is probable that the members of the Riding Mountain Formation were also deposited at similar depths.

Boissevain Formation

Garden (1949) concluded that the bedding, crossbedding, grain size, angularity of the grains, lack of corrosion, presence of carbonaceous matter and unstable heavy minerals in sands of the Boissevain Formation suggest deposition in a swampy basin at the mouth of a river.

A fluvial origin is indicated for the sands of Boissevain Formation in Figure 6. Although these sands appear to have a bimodal distribution (Figure 5), which would not indicate a "pure fluvial deposit" (Selley, 1968), the 60° spread between the modes is less than that in most "modern" fluvial environments (J.T. Teller, University of Manitoba, personal communication, 1973).

In Saskatchewan, the Eastend and Whitemud Formations (Table 2) were deposited in fluvio-deltaic and flood plain environments, respectively (Caldwell, 1969). The equivalent lower members of the Fox Hills Formation and Colgate Member were deposited in a shallow marine environment and an intertidal, shallow water, or beach environment, respectively (Feldmann, 1972).

A gradual change from a shallow marine environment at the base of these formations to near-shore marine conditions near their tops is suggested by the above interpretations. In addition, the change appears to have occurred first in the west and later in the east.

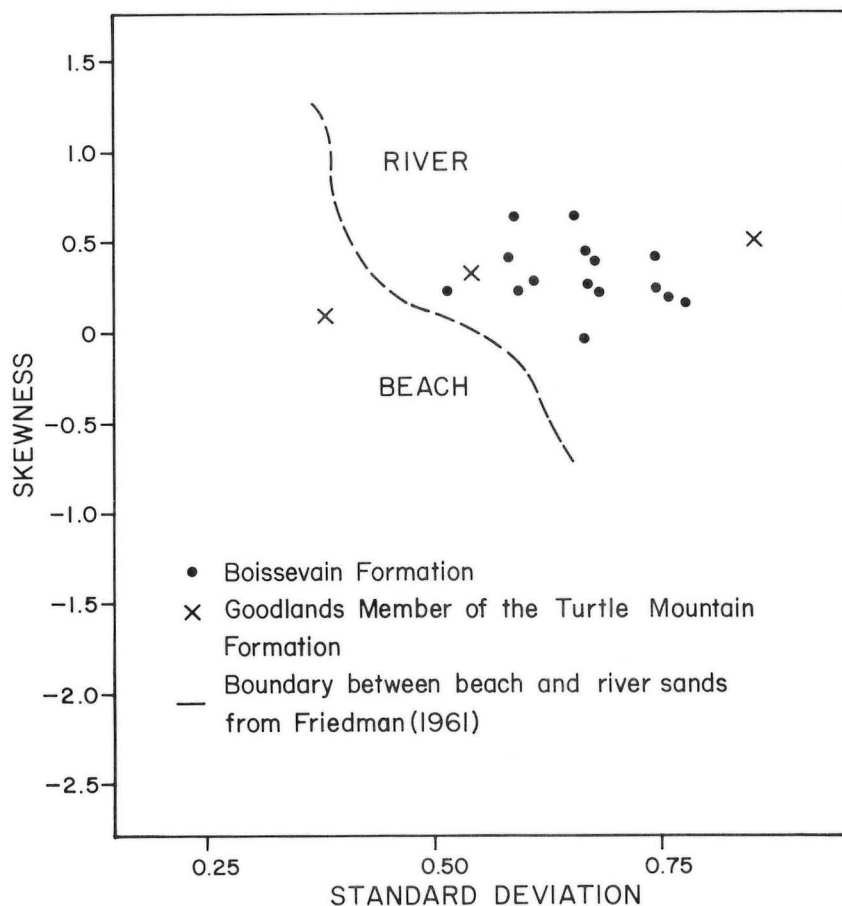


Figure 6. Plot of skewness and standard deviation for samples from the Boissevain Formation and Goodlands Member of the Turtle Mountain Formation.

Turtle Mountain Formation

Textural parameter plots of Goodlands sand samples (Figure 6) do not indicate a specific depositional environment. Lignite seams, relatively abundant in the Goodlands Member, are discontinuous laterally and vary in position vertically indicating that plant growth existed in a fluctuating depositional environment. Fossil plants that have been identified are *Sequoia nordenskioldi* Heer, *Taxodium occidentale* Newberry, and *Cladophlebis* sp. (Wickenden, 1945). Marine conditions were present at least during deposition of the lower part of this member as shown by the foraminifera *Polymorphina* sp. found at 52 m in drill hole #19. The numerous lignite seams, organic rich sediment, and at least one marine fauna suggest that circulation was poor and shallow water conditions existed. Krumbein and Sloss (1963) stated these conditions occur within a lagoon, and this was probably the environment in which the Goodlands Member was deposited. In comparison, the Hell Creek Formation (Table 2) according to Frye (1969) is a complex of lagoonal, brackish water, fresh water, and flood plain deposits. However the Frenchman Formation is a non-marine alluvial flood plain deposit (Byers, 1969), which may indicate a gradual change east to west of marine to non-marine conditions.

The Peace Garden Member of the Turtle Mountain Formation was deposited mainly under marine conditions. The following marine micro-fossils have been identified by B.R. North (W.G.E. Caldwell, University of Saskatchewan, personal communications, 1972 and 1973):

Drill hole

- #19, 21, 22
- 24, 31 various foraminifera (see page 16)
- #24 Ostracoda: from 3.3 - 11.8 m
 (?) *Orthonotocythere* sp. (molt)
 Fragments of specimens similar
 to above. Echinodermata: from
 3.3 — 11.8 m (?) Plates of asteroids
- #31 Few diatoms and seed cases
 2 — 9 m;
 Few diatoms, spores and fragmental
 ostracods 23 — 30 m

Shallow water conditions are indicated by the unusually small size, poor preservation, and sparseness of the foraminifera. Beds equivalent to the Peace Garden Member (Table 2) have been studied in North Dakota and Saskatchewan by various authors. Frye (1969) stated that the Cannonball Formation was deposited in a shallow water marine environment which grades laterally to the southwest into the littoral-lagoonal sediments of the Ludlow Formation. Both formations are overlain by the non-marine alluvial flood plain deposits of the Tongue River and Sentinel Butte Formations (Royse, 1971). According to Byers (1969), the Ravenscrag Formation (Table 2) was deposited in an alluvial flood plain environment. The above interpretations indicate that within the Peace Garden Member, and in beds equivalent to it in North Dakota and Saskatchewan, there was an upward change from marine to non-marine conditions during Paleocene time. In addition, this change appears to have occurred earlier in the west and later in the east.



Figure 7. Structural-stratigraphic correlations in the Turtle Mountain area.

STRUCTURAL GEOLOGY

Regional Setting

The Turtle Mountain area is located on the eastern limb of a shallow syncline which plunges gently toward the centre of the Williston Basin. The approximate southwestward dip of the upper surface of the Millwood Member is 1 m per km; of the Coulter Member, 0.6 m per km; and of the Boissevain Formation, 0.3 m per km. In Saskatchewan and North Dakota, on the western limb of the syncline, the equivalent strata dip to the southeast (Hansen, 1967).

Structural Deformation

Irregular minor structures which include abrupt steepening or flattening of the dips, small faults, and minor undulations are superimposed upon the regional synclinal structure (Fraser et al, 1935). Many of these types of structural irregularities are shown in Figures 7 to 11.

One notable irregularity is a minor undulation with a structural relief of approximately 15 m which is present between drill holes #20 and #1. Another is the anomalous situation where the Odanah Member appears to thicken, while the Coulter Member thins between drill holes #23 and #20 (Figure 7). These structural deformations and others in the Turtle Mountain area may have been produced by any or all of the following causes:

(a) Tectonic deformation

Laird (1964) placed the junction of the Churchill, Peace River and Superior Precambrian Provinces at the western boundary of the map-area. Movements along the province boundaries may have deformed the overlying sediments.

(b) Salt solution

Salt beds of the Devonian Prairie Evaporite are believed to have underlain the map-area, but have since been dissolved (H.R. McCabe and B.B. Bannatyne, Mineral Resources Division, personal communication, 1973). Slow collapse of the overlying strata may have taken place during the solution of these salt beds.

(c) Differential compaction

A total of 850 to 1040 m of shale and siltstone were deposited upon the Paleozoic carbonate sequence of sediments (McCabe, 1963). Some compaction of the sediments since the end of the Paleocene likely has occurred.

(d) Glacial compaction

Several ice sheets covered the map-area during the Pleistocene (Halstead, 1959). The weight of these ice sheets may have added to the differential compaction.

Disturbed bedrock outcrops which may have resulted from minor faulting, ice-thrusting, or slumping have been observed on the western slope of Turtle Mountain in Manitoba and North Dakota (S.R. Moran, North Dakota Geological Survey, personal communication, 1973). On the northern slope, at Locality #1 the beds of the Coulter Member dip steeply north, in contrast to the gently undulating upper surface of the Coulter Member (Figure 10). Also, in drill hole #31, the sediments of the Turtle Mountain Formation lack bedding planes and instead have fractures at 45 to 60 degrees to the horizontal.

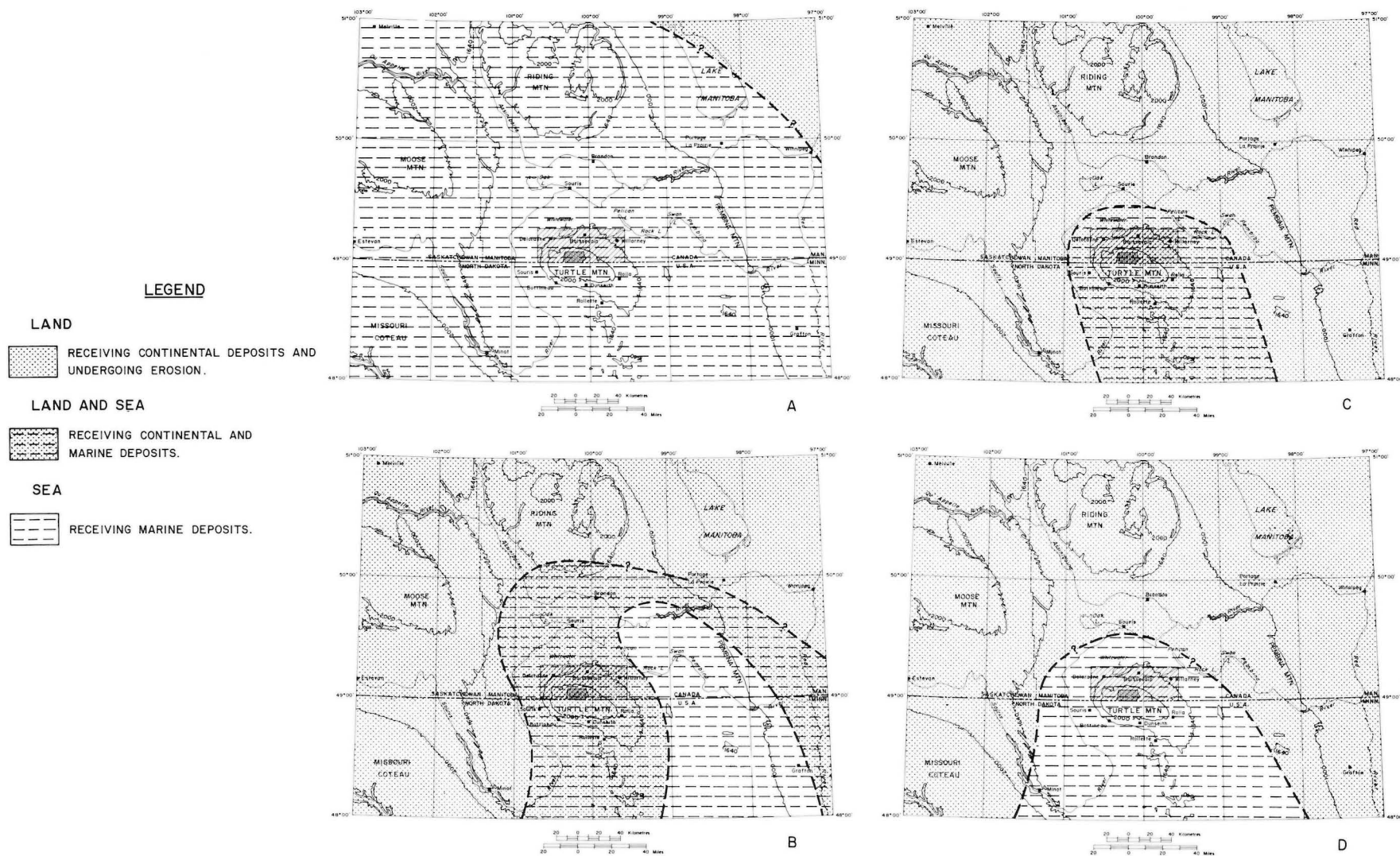


Figure 12. Late Cretaceous and Paleocene History of the Turtle Mountain area and immediate vicinity. Configuration of land and sea during deposition of: A, Millwood and Odanah Member; B, Coulter Member and Boissevain Formation; C, Goodlands Member; and D, Peace Garden Member.

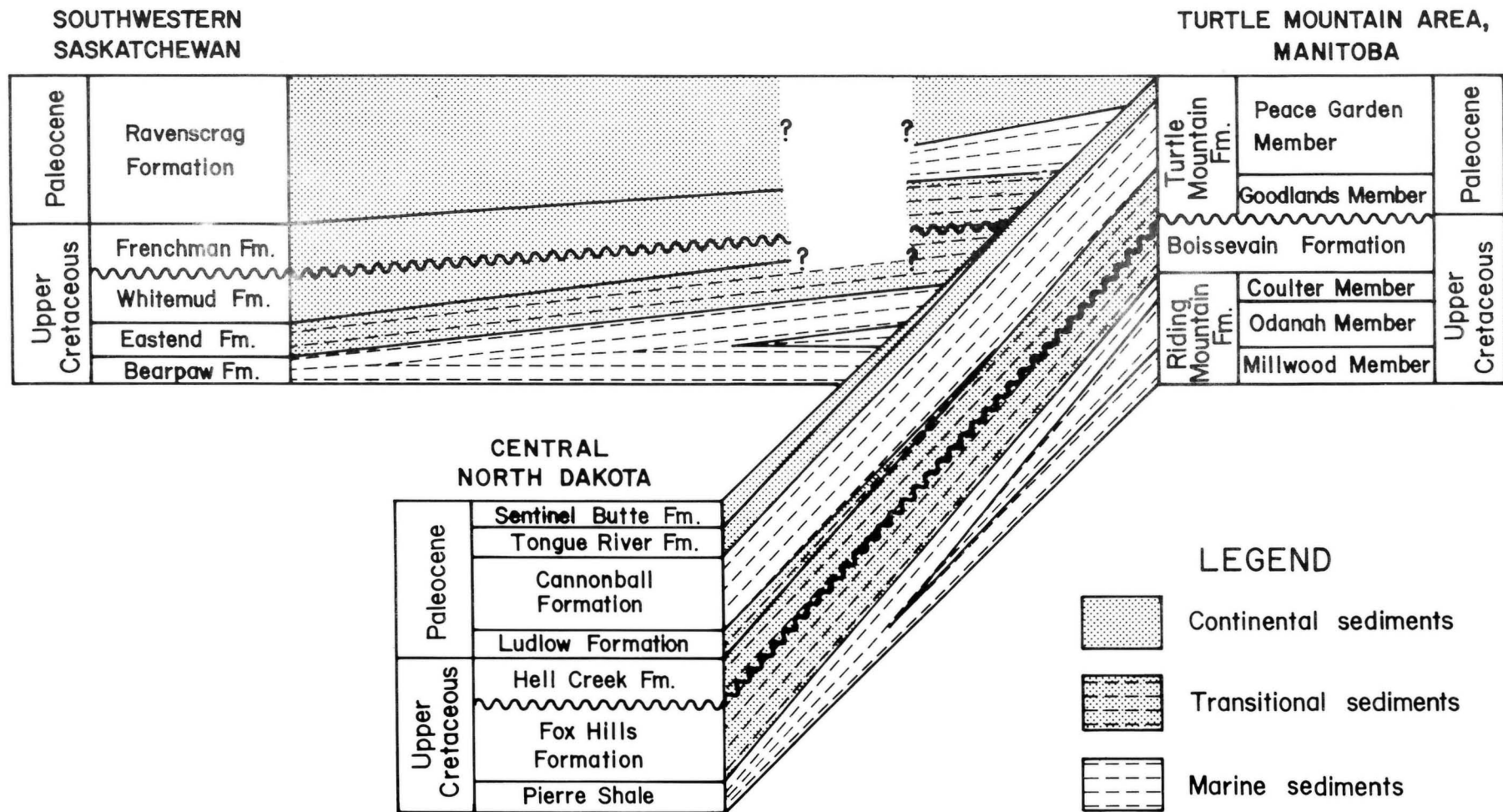


Figure 13. Reconstructed simplified geologic cross-sections of Upper Cretaceous and Paleocene (continental, transitional, and marine) sediments of Saskatchewan, North Dakota, and Manitoba showing their intertongued relationships.

GEOLOGICAL HISTORY

Introduction

The map-area is situated on the northeastern rim of the Williston Basin, a negative structure on the craton. During Late Cretaceous and Paleocene time, basinal subsidence and emergence resulted in deposition of marine and non-marine sediments. During post-Paleocene time, uplift had reached a maximum and erosion predominated with vast quantities of earlier deposited sediments being removed.

Late Cretaceous and Paleocene

The Late Cretaceous and Paleocene geologic history of the North Dakota and Saskatchewan portions of the Williston Basin have been described by Gill and Coban (1966) and by Caldwell (1968), respectively. The depositional history of the Turtle Mountain sediments can be described in terms of those of North Dakota and Saskatchewan.

According to Gill and Cobban (1966) the Western Interior region of North America during the Late Cretaceous was the site of an epicontinental sea. The Millwood, Odanah, and Coulter Members were deposited in this sea. The maximum probable extent of the sea is shown in Figure 12A. The nature and position of the northeastern shoreline is uncertain. With local and continental uplift, the sea gradually withdrew southward (Figure 12B) and a transitional depositional environment formed around the shoreline. The Boissevain Formation was deposited during this time as a regressive sand. Further uplift resulted in the slow withdrawal of the marine environment from the map-area.

As the seas withdrew, continental plant growth became established, marking the beginning of the Paleocene in the map-area (Figure 12C). The plants later formed the lignite seams, fossil plants, and carbonaceous material in the sediments of the Goodlands Member. With increased uplift several periods of erosion may have occurred and previously deposited beds may have been removed locally.

At some unknown time later in the Paleocene, local and continental subsidence resulted in a marine transgression and subsequent regression (Figure 12D). This Paleocene sea may have had a southern connection with the Gulf of Mexico (Fox and Ross, 1942) and/or a northern connection with the Arctic (Lemke, 1960). The exact upper and lower limits of the marine transgression and regression cannot be specified in the stratigraphic sequence because of lack of diagnostic fossils.

The intertongued relationships of sediments deposited in North Dakota, Saskatchewan and the map-area during the Late Cretaceous and Paleocene are shown in Figure 13. Also indicated in the figure are the depositional environments of the sediments.

Pleistocene and Recent

In post-Paleocene time uplift resulted in a high base level and Turtle Mountain was left as a erosional remnant, an outlier of the Missouri Coteau (Figure 14). A north-trending valley was cut into Turtle Mountain, extending from south of Sharpe Lake northward towards the west end of Whitewater Lake. This is a continuation of the valley "extending from the vicinity of Dunseith through Willow Lake" in North Dakota noted by Deal (1972).

During the Pleistocene the change to colder climatic conditions resulted in glacial sediments and in the Recent these sediments have, in part, been reworked and a soil cover established. Crustal down-warpage due to the weight of the ice sheets occurred in the Pleistocene and rebound has occurred in the Recent.

ECONOMIC GEOLOGY

Boissevain Sandstone

Cemented sandstone slabs, quarried from the Boissevain Formation, were used in building construction in the map-area. Parks (1916) described in detail the suitability of this stone for construction purposes.

The lack of other building stones and timber in the map-area resulted in the construction, in the 1890's, of buildings which had sandstone slab exteriors. The slabs were obtained south of Boissevain, where small-scale quarries were opened on the sides of ravines and coulees. The quarries were situated where ovoid concretionary masses of cemented sandstone contained within the Boissevain outcropped.

The sandstone slabs were trimmed into rectangular blocks of various sizes and a wall constructed by stacking blocks of similar sizes into rows. A concrete-like mortar was placed between the blocks. This method of construction was used for at least eight buildings in Boissevain, and a few south of the town. Parks (1916) also reported that buildings in Ninga and a mill in old Deloraine (Sec. 30, Tp. 2, Rge. 22) were constructed of Boissevain sandstone.

Competition of other building materials, the broken character of the stone and overburden thickness were the reasons why the stone has not been used in building construction since the late 1800's (Parks, 1916).

Goodlands Lignite

Lignite seams in the Goodlands Member of the Turtle Mountain Formation have been mined to supply local needs. The lignite exploration and development history of the map-area has been described in detail by Bannatyne (1978).

Two periods of lignite production have occurred in the map-area. From 1883 to 1908, five small-scale mining operations were located on the west side of Turtle Mountain. Total production from these operations was only in the 10's of tonnes. From 1931 to 1943, lignite was produced at five localities. A total of 28,000 tonnes of lignite was removed from these shallow mines and open pits. For both periods of production, mining was hampered by discontinuous lignite seams, poor roof conditions and water problems.

Three lignite exploration programs were conducted in the map-area from 1952 to 1956. West Canadian Collieries Limited drilled 10 holes in 1952 and 101 holes in 1956. Twelve drill holes were put down in 1955 by C.F. Doerr. In 1972, Luscar Limited completed a fourth lignite exploration program, in which 26 holes were drilled. It was concluded from these programs that a strip mining operation would be uneconomic because of thick overburden and a lack of a sufficient thickness of lignite. Bannatyne (1978) also concluded that even if strip mining was assumed to be economical, probable reserves would be only a few million tonnes.

SUMMARY AND CONCLUSIONS

The stratigraphy of the Turtle Mountain area consists of a variable succession of clay, silt and sand units deposited in fluctuating marine and near-marine environments during the Late Cretaceous and Paleocene. This succession of sediments, correlated with equivalent strata in North Dakota and Saskatchewan, was influenced by the relative position of the shoreline which was controlled by basinal movements.

Riding Mountain Formation

The Riding Mountain Formation, not exposed in situ within the map-area, can be subdivided into three units, the Millwood, Odanah and Coulter Members, on the basis of their lithologies and electric log characteristics. The Coulter Member is the name proposed in this report for the clayey silt beds formerly included in the upper part of the Odanah Member by Bannatyne (1970).

A Late Cretaceous age is assigned to the Riding Mountain Formation on fossil evidence (Wickenden, 1945). This formation is equivalent to the upper part of the Pierre Shale of North Dakota and to the Bearpaw Formation of Saskatchewan.

Boissevain Formation

Only the upper half of the Boissevain Formation outcrops within the northern and central portions of the map-area. The lower beds of this half of the Boissevain Formation are exposed on both sides of Highway No. 3, 6 km southeast of Boissevain. The upper beds are exposed 8 km south of Deloraine.

The Boissevain Formation is correlated with the Fox Hills Formation of North Dakota and with the Eastend, Whitemud, and Battle Formations of Saskatchewan. Feldmann (1972) stated that a Late Cretaceous age is indicated for the Fox Hills Formation on the basis of diagnostic cephalopods and clams, and if the above correlation is valid then the Boissevain Formation is also Late Cretaceous.

Turtle Mountain Formation

The outcrops of the Turtle Mountain Formation are sparse and are confined, with one exception, to the western slopes of Turtle Mountain. The Goodlands and Peace Garden Members are proposed new subdivisions of the formation. The Goodlands Member is correlated with the Hell Creek and Frenchman Formations of North Dakota and Saskatchewan, respectively. The marine beds of the Peace Garden Member are equivalent to the Cannonball Formation of North Dakota. The entire Peace Garden Member is correlated with the Fort Union Group of North Dakota and with the Ravenscrag Formation of Saskatchewan.

Wickenden (1945) assigned a Paleocene age to the Turtle Mountain Formation on the basis of a few fossil plants. This has been confirmed by B.R. North, who identified diagnostic foraminifera in drill core from the same formation in the map-area (W.G.E. Caldwell, University of Saskatchewan, personal communication, 1971 and 1972). However, the basal beds of the Goodlands Member may be Late Cretaceous as are the equivalent beds in North Dakota and Saskatchewan.

History of Sedimentation

The Upper Cretaceous and Paleocene sediments of North Dakota, Saskatchewan, and the Turtle Mountain area are time-transgressive, becoming gradually younger eastward. Frye (1969) and Feldmann (1972) state that deposition of the Pierre Shale, Fox Hills Formation and Hell Creek Formation in North Dakota occurred contemporaneously and that the nature of sediments deposited in any area was dependent upon the relative position of the shoreline. Similarly, the sediments of the Riding Mountain Formation were deposited in a shallow epicontinental seaway, during the last Cretaceous marine transgression. The sediments of the Boissevain Formation, deposited at the mouths of eastward flowing rivers, formed the margins of the sea during its regression. The basal sediments of the Goodlands Member of the Turtle Mountain Formation, deposited in a fluctuating lagoonal environment, marked the beginnings of continental sedimentation accompanied by abundant plant growth. This is also assumed to be the start of the Paleocene in the map-area. The sediments of the Peace Garden Member of the Turtle Mountain Formation were deposited in a shallow water environment during

Paleocene transgression and regression. According to Fox and Ross (1942) and Lemke (1960) the equivalent Cannonball Formation may have been deposited in a sea which invaded the central continental area from either the Gulf of Mexico, the Arctic, or both.

Structure

The Turtle Mountain area is located on the east limb of a shallow southward plunging regional synclinal structure which forms part of the northeastern rim of the Williston Basin. The sequence of marine regression-transgression-regression in the map-area and adjacent regions was controlled by corresponding upward-downward-upward basinal movements.

Irregular minor structures which include abrupt steepening or flattening of the dips, small faults and minor undulations are superimposed on the regional structure. The deformations may have been produced by tectonism, salt solution, differential compaction, ice-thrusting, slumping, or any combination of these causes.

Sandstone and Lignite

Sandstone and lignite have been produced on a small scale for local use in the map-area. At least ten buildings in the vicinity of Boissevain were built using Boissevain Sandstone slab exteriors. 28 000 tonnes of lignite were removed from shallow mines and open-pits. Under present conditions both commodities are uneconomic.

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APPENDIX A
LIST OF OUTCROP LOCALITIES

1. Location of outcrops is shown in Figure 3.

Outcrop LOCATION					Outcrop LOCATION				
Locality #	L.S.	Sec.	Tp.	Rge.	Locality #	L.S.	Sec.	Tp.	Rge.
1	13	6	3	18	25	5	11	3	20
2	4	1	3	19	26	4	6	3	20
3	14	35	2	19	27	13	33	2	21
4	13	35	2	19	28	4	3	3	21
5	1	2	3	19	29	15	32	1	22
6	16	34	2	19	30	3	5	2	22
7	15	34	2	19	31	4	11	2	23
8	3	2	3	19	32	1	15	2	23
9	4	34	2	19	33	15	15	2	23
10	14	34	2	19	34	4	16	2	23
11	1	3	3	19	35	4	17	2	23
12	2	3	3	19	36	15	5	2	23
13	15	33	2	19	37	15	7	2	23
14	14	33	2	19	38	2	36	1	24
15	4	3	3	19	39	13	30	1	23
16	16	32	2	19	40	8	25	1	24
17	5	5	3	19	41	4	30	1	23
18	1	17	3	19	42	1	25	1	24
19	9	7	3	19	43	2	25	1	24
20	13	7	3	19	44	16	24	1	24
21	13	18	3	19	45	13	13	1	24
22	14	12	3	20	46	13	7	1	23
23	5	13	3	20	47	4	7	1	23
24	13	11	3	20					

APPENDIX B

SELECTED OUTCROP DESCRIPTIONS

1. Colour descriptions are those of moist sediments.
2. For outcrop locations see Figure 3.

Locality #3

NE¼ of L.S. 14, Sec. 35, Tp. 2, Rge. 19 WPM, stream cut along drainage ditch on south side of Hwy. 3, about 2½ km east of Locality #4. Elev. of top 527 m above sea level. (TYPE SECTION FOR BOISSEVAIN FORMATION)

		Thickness		Sample
		ft.	m	JB-
BOISSEVAIN FORMATION				
24.	Brown fine grained sand	0.8	0.24	72
23.	Yellow clay	0.1	0.03	71
22.	Brown fine-grained sand	0.5	0.15	70
21.	Yellow clay	0.2	0.06	69
20.	Brown fine-grained sand with minor sandstone	1.0	0.30	67 - 68
19.	Yellow clay	0.1	0.03	
18.	Brown massive sand	2.4	0.73	66
17.	Clay	0.3	0.09	65
16.	Brown fine-grained sand	0.3	0.09	64
15.	Orange-brown ironstone concretion layer	0.5	0.15	63
14.	Brown silty sand	3.7	1.13	61 - 62
13.	Compacted hard silt, laminated	6.0	1.83	59 - 60
12.	Brown compacted hard sand, laminated	1.3	0.40	57 - 58
11.	Orange-brown ironstone concretion layer	0.5	0.15	56
10.	Brown fine-grained sand	0.5	0.15	55
9.	Mixed silt and clay	0.5	0.15	54
8.	Brown fine-grained sand	0.5	0.15	53
7.	Clay	0.4	0.12	52
6.	Brown fine-grained sand	1.2	0.37	51
5.	Hard compacted sand	1.0	0.30	50
4.	Crossbedded sand with indurated blocks and orange-brown ironstone concretion layers	6.0	1.83	43 - 49
3.	Covered interval	3.0	0.91	
2.	Crossbedded reddish-orange sand	1.2	0.37	38
1.	Grey crossbedded sand	8.5	2.59	37, 74
RIDING MOUNTAIN FORMATION				
(COULTER MEMBER)				
1a.	Grey fine-grained silty clay	1.0	0.30	
Total		41.5	12.65	

Locality #4

NE corner of L.S. 15, Sec. 33, Tp. 2, Rge. 19 WPM, contact of Boissevain and Turtle Mountain Formations; road cut on south side of Hwy. 3. Elev. of top 530 m above sea level.

TURTLE MOUNTAIN FORMATION (GOODLANDS MEMBER)		Thickness		Sample JB-
		ft.	m	
25.	Light green thin bedded silt, slightly oxidized near top ..	1.0	0.30	130
24.	Orange clay with 0.6 cm ironstone concretion layer near base	0.8	0.24	131
23.	Grey-buff clay with iron-stained fracture surfaces	2.8	0.85	132
22.	Olive clay gradually becoming silty downwards	1.0	0.30	133
21.	Olive clay and yellow silt interlayered, layers 5 cm thick	1.5	0.46	134
20.	Orange-brown ironstone concretion layer	0.3	0.09	135
19.	Olive clay to silt downwards	1.4	0.43	136
18.	Orange-brown ironstone concretion layer	0.5	0.15	137
17.	Yellow clay and tan silt interlayered	0.5	0.15	138
16.	Dark olive clay with iron-stained fracture surfaces	0.6	0.18	139
15.	Light olive clay with iron-stained fracture surfaces	0.5	0.15	140
14.	Yellow silt and olive clay interlayered, beds 0.6 to 1.3 cm	1.7	0.52	141
13.	Light and dark olive clay, thin bedded	0.8	0.24	142
12.	Orange-brown concretion layer	0.2	0.06	143
11.	Dark olive clay with blocky iron-stained fracture surfaces and lignite fragments	1.5	0.46	144
10.	Olive sand, compacted with silt bands and lignite frag- ments	3.2	0.98	145
9.	Olive clay and yellow silt interlayered	0.8	0.24	146
8.	Orange-brown ironstone concretion layer	0.4	0.12	147
7.	Olive clay and yellow silt interlayered	1.0	0.30	148
6.	Dark olive pink clay with plant and lignite fragments, and iron-stained fracture surfaces	1.8	0.55	149

BOISSEVAIN FORMATION

5.	Olive silt gradational downward into fine-grained olive sand	1.3	0.40	150
4.	Orange-brown ironstone concretion layer	0.2	0.06	151
3.	Olive thin bedded silt and sand with minor clay	3.5	1.07	152
2.	Blue-grey to brown, iron-stained sand with "salt and pepper" texture	1.0	0.30	153
1.	Brown oxidized sand, crossbedded with minor sand- stone	4.0	1.22	154 - 155
Total		32.3	9.82	

Locality #30

SE¼ of L.S. 3, Sec. 5, Tp. 2, Rge. 22 WPM, highest known outcrop in the Turtle Mountain area, abandoned road cut on south facing valley wall. Elev. of top 608 m above sea level.

TURTLE MOUNTAIN FORMATION (PEACE GARDEN MEMBER)		Thickness		Sample JB-
		ft.	m	
6.	Olive sand interlayered with orange ironstone concretion layer	2.0	0.61	7
5.	Olive fine-grained sand	2.0	0.61	6
4.	White to grey, fractured sandstone, oxidized in part	1.0	0.30	5
3.	Olive fine-grained sand with minor clay	0.6	0.18	4
2.	Brown ironstone concretion layer	0.5	0.15	3
1.	Olive sand	1.0	0.30	2
Total		7.1	2.15	

Locality #40

SE¼ of L.S. 8, Sec. 25, Tp. 1, Rge. 24 WPM, contact of Goodlands and Peace Garden Members of the Turtle Mountain Formation; in deep ravine crossing old road, 9 m west of Hwy. 21.

	Thickness ft.	m	Sample JB-
TURTLE MOUNTAIN FORMATION (PEACE GARDEN MEMBER)			
4. Yellow weathering thin bedded to blocky silt with iron-stained fracture surfaces	3.5	1.07	187
TURTLE MOUNTAIN FORMATION (GOODLANDS MEMBER)			
3. Grey iron-stained clay	0.5	0.15	188
2. Dark grey, laminated, crossbedded sand and silt, oxidized in part; contains 20 cm clay tongue	6.0	1.83	189 A - B
1. Dark grey carbonaceous clay	3.6	1.10	190
Total	<u>13.6</u>	<u>4.15</u>	

Locality #43

NE¼ of L.S. 2, Sec. 25, Tp. 1, Rge. 24 WPM, on south side of stream cut about 400 m west of Hwy. 21 and Locality #40. (TYPE SECTION FOR GOODLANDS MEMBER)

	Thickness ft.	m	Sample JB-
TURTLE MOUNTIAN FORMATION (GOODLANDS MEMBER)			
12. Brown blocky silty clay, yellow stained, thin bedded upwards	3.4	1.04	161
11. Light grey clay mottled with yellow and orange stains ...	0.2	0.06	162
10. Poor quality peaty lignite	0.7	0.21	163
9. Grey underclay	0.6	0.18	164
8. Poor quality peaty lignite	0.7	0.21	165
7. Light grey underclay	0.5	0.15	166
6. Brown carbonaceous clay with yellow stains	0.5	0.15	167
5. Black, brittle lignite	0.8	0.24	168
4. Grey-brown underclay	0.5	0.15	169
3. Yellow-grey silty sand	2.1	0.64	170
2. Yellow silt interlayered, with grey clay	2.7	0.82	171
1. Yellow and orange stained sand	3.7	1.13	172
Total	<u>16.4</u>	<u>4.98</u>	

APPENDIX C

GRAPHICAL PARAMETERS FROM GRAIN SIZE ANALYSES OF SAMPLES FROM THE BOISSEVAIN FORMATION AND THE GOODLANDS MEMBER OF THE TURTLE MOUNTAIN FORMATION

Sample	Median	Mean	Standard Deviation	Skewness	Kurtosis
Boissevain Formation					
JB22	2.40	2.46	0.59	+0.24	1.44
JB37	2.48	2.54	0.51	+0.25	1.87
JB43	2.75	2.81	0.61	+0.30	1.57
JB46	2.32	2.47	0.59	+0.66	2.93
JB47	2.50	2.67	0.66	+0.46	1.86
JB50	2.57	2.76	0.74	+0.45	1.13
JB53	3.18	3.26	0.68	+0.25	1.12
JB57	3.49	3.48	0.66	-0.02	1.43
JB60	3.07	3.12	0.65	+0.65	1.30
JB62	3.00	3.14	0.58	+0.44	1.65
JB64	3.10	3.20	0.77	+0.18	1.09
JB72	3.42	3.50	0.75	+0.21	1.56
JB119	2.40	2.51	0.67	+0.40	1.55
JB125	2.53	2.59	0.74	+0.26	1.35
JB153B	2.98	3.07	0.67	+0.30	1.31
Turtle Mountain Formation — Goodlands Member					
JB108	3.20	3.29	0.54	+0.33	1.39
JB160	2.85	2.85	0.38	+0.10	0.93
JB172	2.65	2.84	0.85	+0.50	1.50

APPENDIX D
COMPUTATION OF GRAND MEAN OF LARGE-SCALE CROSS-BED MEASUREMENTS
IN THE BOISSEVAIN FORMATION FROM
LOCALITIES #3, #19, and #24

Azimuth Classes	Midpoint e	Locality #3			Locality #19			Locality #24			Total No. of Readings	% of Readings
		No. of Readings n(e)	n(e) sin e	n(e) cos e	No. of Readings n(e)	n(e) sin e	n(e) cos e	No. of Readings n(e)	n(e) sin e	n(e) cos e		
015-045	030	5	2.5000	4.3300	-	-	-	2	1.0000	1.7320	7	15.9
045-075	060	1	0.8660	0.5000	3	2.5980	1.5000	2	1.7320	1.0000	6	13.6
075-105	090	1	1.0000	0.0000	5	5.0000	0.0000	1	1.0000	0.0000	7	15.9
105-135	120	1	0.8660	-0.5000	2	1.7320	-1.0000	5	4.3300	-2.5000	8	18.2
135-165	150	-	-	-	4	2.000	-3.4640	-	-	-	4	9.1
165-195	180	-	-	-	-	-	-	-	-	-	-	0.0
195-225	210	-	-	-	2	1.0000	-1.7320	-	-	-	2	4.5
225-255	240	-	-	-	-	-	-	-	-	-	-	0.0
255-285	270	-	-	-	-	-	-	-	-	-	-	0.0
285-315	300	-	-	-	-	-	-	1	-0.8660	0.5000	1	2.3
315-345	330	2	-1.0000	1.7320	-	-	-	2	-1.0000	1.7320	4	9.1
345-015	360	3	0.0000	3.0000	-	-	-	2	0.0000	2.0000	5	11.4
Total		13	4.2320	9.0620	16	12.3300	-4.6960	15	6.1960	4.4640	44	100.0

Mean Preferred

$$\begin{aligned}\bar{x} &= \arctan \frac{4.2320}{9.0620} \\ &= \arctan 0.4670 \\ &= 025^\circ\end{aligned}$$

$$\begin{aligned}\bar{x} &= \arctan \frac{12.3300}{-4.6960} \\ &= \arctan 2.6260 \\ &= -249^\circ \text{ or } 111^\circ\end{aligned}$$

$$\begin{aligned}\bar{x} &= \arctan \frac{6.1960}{4.4640} \\ &= \arctan 1.3880 \\ &= 054^\circ\end{aligned}$$

Grand Mean

$$\begin{aligned}\bar{X}_g &= \frac{\sum n(e) \sin e}{\sum n(e) \cos e} \\ &= \arctan \frac{4.2320 + 12.3300 + 6.1960}{9.0620 + (-)4.6960 + 4.4640} \\ &= \arctan 2.5773 \\ &= 069^\circ\end{aligned}$$

APPENDIX E DRILL HOLE DATA

- Locations of drill holes are described as L.S. - Sec. - Tp. - Rge., and all are WPM. (Example: 13-36-1-18).
- Numbers in vertical columns are elevations above sea level in metres and feet, and refer to the top of the respective formations and members. (Example: Drill Hole #1, Turtle Mountain Formation, upper surface is 557.2 metres (1828 feet above sea level)).

Drill Hole No	Drill Hole Name	Location (WPM)	Ground Level		Tops									
					Turtle Mountain	Goodlands	Boisesevain	Coulter	Odanah	Millwood				
			ft	m	ft	m	ft	m	ft	m	ft	m	ft	m
1	Green Hills Killarney	13-36-1-18	1828	557.2	1739	530.0	-	-	-	-	877	267.3	-	-
2	Water Resources Br. B-28	1-20-1-19	2165	659.9	1861	567.2	-	-	-	-	-	-	-	-
3	Cleary Calstan Prov	6-21-1-19	2144	653.5	1879	572.7	1701	518.5	1602	488.3	1459	444.7	838	255.4
4	Water Resources Br. B-29	8-25-1-19	1950	594.4	1848	563.3	1702	518.8	1616	492.6	1494	455.4	-	-
5	Amerada Turtle Mtn. Prov "M-A"	16-4-1-20	2201	670.9	1731	527.6	1738	529.7	1561	475.8	1411	430.1	826	251.8
6	Dome Calstan Lulu Lake	9-6-1-20	2238	682.1	-	-	1651	503.2	1564	476.7	1397	425.8	829	252.7
7	Homestead et al Turtle Mtn. No. 1	10-26-1-20	2236	681.5	1890	576.1	1662	506.6	1581	481.9	1437	438.0	837	255.1
8	Cities Services East Max Lake No. 1	14-29-1-20	2223	677.6	1893	577.0	1681	512.4	1579	481.3	1445	440.4	850	259.1
9	Royalite Triad et al Lulu Lake	9-14-1-21	2248	685.2	-	-	1675	510.5	1582	482.2	1414	431.0	842	256.6
10	Royalite Triad et al Lulu Lake	14-14-1-21	2277	694.0	-	-	1674	510.2	1585	483.1	1423	433.7	844	257.3
11	Royalite Triad et al Lulu Lake No. 3	15-14-1-21	2259	688.5	-	-	1683	513.0	1585	483.1	1416	431.6	843	257.0
12	Royalite Triad et al Lulu Lake No. 1	16-14-1-21	2286	696.8	1915	583.7	1661	506.3	1578	481.0	1428	435.2	844	257.3
13	Northern Nellie Lake	3-17-1-21	2226	678.5	-	-	1658	505.4	1564	476.7	1428	435.2	845	257.6
14	Royalite Triad et al Lulu Lake	2-23-1-21	2271	692.2	-	-	1680	512.1	1596	486.5	1420	432.8	850	259.1
15	Geog. Chagos Lulu Lake	6-23-1-21	2288	697.4	-	-	1686	513.9	1610	490.7	1434	437.1	861	262.4
16	Geog. Chagos Lulu Lake	16-23-1-21	2323	708.1	1885	574.6	1678	511.5	1587	483.7	1439	438.6	853	260.0
17	Royalite Triad Lulu Lake	6-24-1-21	2279	694.6	1809	551.4	-	-	1695	516.6	1605	489.2	875	266.7
18	Royalite Triad et al Max Lake No. 1	4-36-1-21	2278	694.3	1828	557.2	1687	514.2	1606	489.5	1460	445.0	875	266.7
19	Geol. Surv. Can. 68-33	5-20-1-22	2310	704.1	2185	666.0	-	-	-	-	-	-	-	-
20	Baysel Calstan Sharpe Lake	3-27-1-22	2170	661.4	-	-	1623	494.7	1561	475.8	1411	430.1	818	249.3
21	Mines and Natural Resources No. 1	15-32-1-22	1970	600.5	1967	599.5	1857	566.0	1705	519.7	1605	489.2	-	-
22	Man. Mines Br. M-3-71	15-32-1-22	1968	599.9	1964	598.6	-	-	-	-	-	-	-	-
23	Cleary Flossie Lake	10-21-1-23	2141	652.6	-	-	1668	508.4	1561	475.8	1481	451.4	781	238.1
24	Man. Mines Br. M-11-70	8-25-1-24	1820	554.7	1820	554.7	1781	542.1	-	-	-	-	-	-
25	Water Resources Br. B-27	3-9-2-18	1820	554.7	1762	537.1	-	-	1747	532.5	1648	502.3	1517	462.3
26	Chevron Max Lake	4-7-2-20	2102	640.7	-	-	-	-	-	-	1482	451.7	862	268.8
27	Jumping Pound et al Horton	8-15-2-20	1903	580.0	-	-	-	-	-	-	-	-	863	263.0
28	Man. Mines Br. M-1-71	13-33-2-21	1768	538.9	-	-	1768	538.9	-	-	-	-	-	-
29	Owen No. 1	8-11-2-22	2118	645.6	-	-	-	-	1614	492.0	1476	449.9	879	267.9
30	Midwest Imperial Liege	2-3-2-23	2118	645.6	-	-	1687	514.2	1569	478.2	1506	459.0	815	248.4
31	Man. Mines Br. M-2-71	15-5-2-23	1873	570.9	1873	570.9	1833	558.7	-	-	-	-	-	-
32	Calstan Deloraine	10-31-2-23	1634	498.0	-	-	-	-	-	-	-	-	831	253.3
33	Calstan South Ninga	9-6-3-18	1699	517.9	-	-	-	-	-	-	-	-	897	273.4
34	Man. Min. Res. Div. M-1-75	4-1-3-19	1717	523.4	-	-	1717	523.4	1687	514.2	-	-	-	-
35	Baysel Calstan Boisesevain	3-20-3-19	1675	510.5	-	-	-	-	-	-	-	-	927	282.6
36	Samedan Hamel Boisesevain	10-6-3-20	1765	538.0	-	-	-	-	-	-	-	-	952	290.2
37	Dome Naco South Whitewater	2-2-3-21	1778	541.9	-	-	-	-	-	-	-	-	945	288.0
38	Samedan	9-14-3-21	1652	503.5	-	-	-	-	-	-	-	-	974	296.9
39	Madison Whitewater	4-16-3-21	1656	504.8	-	-	-	-	-	-	-	-	948	289.0
40	Madison Whitewater	5-16-3-21	1648	502.3	-	-	-	-	-	-	-	-	956	291.4
41	Calstan Whitewater	11-16-3-21	1652	503.5	-	-	-	-	-	-	-	-	981	299.0
42	Cal. Standard Whitewater	12-16-3-21	1654	504.1	-	-	-	-	-	-	-	-	974	296.9
43	Northern Whitewater	13-16-3-21	1638	499.3	-	-	-	-	-	-	-	-	960	292.6
44	Sweet Grass Whitewater	14-16-3-21	1639	499.6	-	-	-	-	-	-	-	-	975	297.2
45	Calstan Whitewater	8-17-3-21	1644	501.1	-	-	-	-	-	-	-	-	968	295.1
46	Calstan Whitewater	9-17-3-21	1649	502.6	-	-	-	-	-	-	-	-	968	295.1
47	Calstan Whitewater	10-17-3-21	1638	499.3	-	-	-	-	-	-	-	-	963	293.5
48	Calstan Whitewater	16-17-3-21	1636	498.7	-	-	-	-	-	-	1590	484.6	961	292.6
49	Colorado Whitewater	1-20-3-21	1629	496.5	-	-	-	-	-	-	-	-	968	295.1
50	Calstan Whitewater	2-20-3-21	1628	496.2	-	-	-	-	-	-	-	-	968	295.1
51	Northern Whitewater	4-21-3-21	1635	498.4	-	-	-	-	-	-	-	-	971	296.0
52	Soc. Agrola N Whitewater	2-27-3-21	1630	496.8	-	-	-	-	-	-	-	-	977	297.8
53	Kanata et al Whitewater	15-28-3-21	1626	495.6	-	-	-	-	-	-	-	-	972	296.3
54	J.P. Owens Ellis	3-10-3-22	1644	501.1	-	-	-	-	-	-	-	-	919	280.1
55	Sapphire West Whitewater	8-14-3-22	1632	497.4	-	-	-	-	-	-	-	-	930	283.5
56	Deloraine Well	10-3-3-23	1644	501.1	-	-	-	-	-	-	1550	472.4	857	261.2
57	Dakota Leighton	5-23-3-24	1582	482.2	-	-	-	-	-	-	-	-	824	251.2

APPENDIX F

SELECTED DRILL HOLE LOG DESCRIPTIONS

1. Colour descriptions are those of dry sediments. Colours of wet sediments follow immediately afterward and are enclosed in parentheses.
2. For drill hole locations see Figure 3.

Drill Hole #19

L.S. 5, Sec. 20, Tp. 1, Rge. 22 WPM, Geological Survey of Canada borehole 68-33, surface elev. 704 m above sea level, first 38 m is glacial drift. (UPPER PART OF COMPOSITE TYPE SECTION FOR THE PEACE GARDEN MEMBER)

Depth ft.	Thickness m	TURTLE MOUNTAIN FORMATION Peace Garden Member
125-141	4.88	Sand, very fine-grained, quartzose, micaceous, non-calcareous, <i>Polymorphina</i> sp. at 170 feet.
141-157	4.88	Silt, fine-grained, micaceous, grey, 2.5Y7/2.
158-180	6.71	Clay, silty, micaceous, light grey, 5Y7/2 (4.2Y4/2), foram <i>Polymorphina</i> sp. at 170 feet.
188-220	9.76	Sand, fine-grained, iron-stained, olive, 5Y6/3 (5Y3/2), interbedded with clay, silty, olive, 2.5YN3/.
221-230	2.74	Clay, silty, kaolinitic, grey, 5Y6/1 (10YR2/1).
231-285	16.46	Sand, fine-grained, micaceous, grey, 5Y6/1 (5Y3/1).
290-300	3.05	Clay, silty, grey, 5Y6/1 (4.2Y3/2) interbedded with clay, calcareous, light brownish grey.
306	?	Clay, kaolinitic, light grey, 5Y6.5/1 (2.5Y3/2).
312	?	Sand, fine-grained, light brown, 2.5Y6/2.
315	?	Clay, carbonaceous and sand, very fine-grained, grey, (5Y4/1).
321-345	7.32	Sand, very fine-grained, grey, 5Y7/1 (5Y3/1) with minor yellow clay, 2.5Y7/2 (5Y6/1) at 321 feet.
354	?	Sand, fine-grained, grey, 5Y7/1 (5Y4/1) mixed with clay, grey, 5Y6/1 (5Y2/1).

Drill Hole # 21

L.S. 15, Sec. 32, Tp. 1, Rge. 22 WPM, Manitoba Mines and Natural Resources borehole #1, surface elev. 600 m above sea level. (LOWER PART OF COMPOSITE TYPE SECTION FOR THE PEACE GARDEN MEMBER)

Depth ft.	Thickness m	TURTLE MOUNTAIN FORMATION Peace Garden Member
3-19	4.88	Sand, silty, very fine to medium-grained, micaceous, grey, 5Y6/1 (5Y3/2).
21-40	5.79	Silt, clayey, very fine-grained, micaceous, grey, 5Y5/1 (5Y3/1).
45-80	10.67	Sand, fine-grained, non-calcareous, grey, 5Y5.5/1 (5Y4/2.5).
81-95	4.27	Silt, clayey, very fine-grained, grey 5Y5/1 (5Y2/1).
96-105	2.74	Clay, silty, grey, 5Y5/1 (5Y2/1).
107-111	1.22	Sand, very fine-grained, grey, 5Y5.5/1.

Depth ft.	Thickness m	TURTLE MOUNTAIN FORMATION Goodlands Member
113-115	0.61	Clay, silty, grey, 5Y6/1 (5Y3/1), bentonitic at 34.8 m.
117-125	2.44	Sand, very fine-grained, grey, 5Y5/1 (5Y3/1).
126-140	4.27	Silt, very fine-grained, grey, 5Y6/1 (5Y3/2).
141-180	11.89	Sand, very fine-grained, upper part calcareous, grey, 5Y6/1 (5Y4/2), foram <i>Protelphidium</i> at 53.0 m.
183-192	2.74	Silt, very fine-grained, light grey, 5Y6/1 (3.2Y3/2).
195-201	1.83	Sand, very fine-grained, grey, 5Y6/1 (3.2Y3/2).
203-230	8.23	Silt, very fine-grained, light grey, 5Y6/1 (5Y3/1), carbonaceous and kaolinitic in places.
231-234	0.91	Clay, silty, carbonaceous, grey, 5Y2/1, minor pyrite.
234-235	0.30	Lignite, black 2.5YN2/0.
236	?	Silt, very fine-grained, light grey, kaolinitic, 5Y7/1.
237-246	2.74	Sand, very fine-grained, light grey, 5Y6/1 (5Y3.5/1).
249-252	0.91	Clay, silty, light grey, 5Y6/1 (5Y3.5/1).
253	?	Lignite, black, 2.5YN2/0.
255-258	0.91	Clay, silty, olive, 5Y4.5/1 (5Y2/1), with thin lignite fragments.
259-264	1.52	Silt, medium-grained, olive, 5Y5/1 (5Y2/1.5).

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265-275	3.05	Sand, medium-grained, "salt and pepper," non-calcareous, grey, 5Y6/1 (5Y5/2).
276	?	Clay, silty, light grey, 5Y5.5/1.
279-321	12.80	Sand, fine to medium-grained "salt and pepper," non-calcareous, grey, 5Y6/1 (5Y5/2).
324	?	Clay, silty, grey, 5Y5/1.
325-350	7.62	Sand, very fine to fine-grained, "salt and pepper," grey, 5Y6/1.
351-363	3.66	Silt, grey, medium-grained, "salt and pepper," grey, 5Y6/1 (5Y4/2).

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365-391	7.92	Silt, very fine-grained, yellow-grey, 5Y6/3 (5Y3/3), minor fine-grained sand.
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Drill Hole #22

L.S. 15, Sec. 32, Tp. 1, Rge. 24 WPM, Manitoba Mines Branch drill hole M-3-71, surface elev. 599 m above sea level.

Depth ft.	Thickness m	TURTLE MOUNTAIN FORMATION Peace Garden Member
5.0-10.0	1.52	Clay, light grey.
10.0-20.0	3.05	Silt, fine-grained, greenish-grey, minor clay.
20.0-43.3	7.10	Clay, greenish-grey, minor silt. (From 7.6 m — 13.1 m, forams <i>Nodosaria</i> sp. and <i>Guttulina</i> sp.).
43.4-77.9	10.52	Sand, medium-grained, grey, minor clay.

Drill Hole #24

L.S. 8, Sec. 25, Tp. 1, Rge. 24 WPM, Manitoba Mines Branch drill hole M-11-70, surface elev. 555 m above sea level. Peace Garden — Goodlands contact.

Depth ft.	Thickness m	TURTLE MOUNTAIN FORMATION Peace Garden Member
7.4-10.8	1.04	Silt, clayey, coarse-grained and very fine-grained, grey, (olive), partly oxidized to yellow, lignite flecks, biotite flakes.
10.8-32.4	6.58	Clay, silty, becoming siltier downwards, grey (olive), very finely laminated, lignite fragments, muscovite flakes, micro-fossils: ostracods, forams, echinoderms, (From 3.3 m to 38.8 m, forams <i>Protelphidium</i> cf. <i>sublaeve</i> , <i>Anomalinoides</i> sp., <i>Haplophragmoides</i> sp., and <i>Ammodiscus</i> sp.).
32.4-38.75	1.94	Silt, greenish-grey (olive), finely laminated, lignite fragments, micro-fossils: ostracods, forams, echinoderms.
TURTLE MOUNTAIN FORMATION Goodlands Member		
38.75-45.0	1.91	Clay, buff becoming dark brown (dark olive) downwards, very finely laminated, large lignite fragments, (From 11.8 m to 30.1 m, forams <i>Haplophragmoides</i> sp. and <i>Saccamina</i> sp.).
45.0-45.8	0.24	Clay, silty, grey, very finely laminated.
45.8-46.3	0.50	Lignite, black, poorly developed thin laminations.
46.3-60.0	4.18	Clay and silt, very fine-grained, interlayered, light grey to buff (light olive), finely laminated, abundant lignite fragments, micro-fossils: ostracods and forams.
60.0-64.25	1.30	Silt and clay, interlayered, dark grey (black), carbonaceous, very finely laminated.
64.25-69.0	1.45	Sand, fine to medium-grained, dark greyish-green (olive), muscovite fragments.
69.0-74.2	1.58	Silt, fine-grained, dark greyish-green (olive).
74.2-74.4	0.06	Clay, dark grey (dark grey).
74.4-77.3	2.90	Silt, fine-grained, dark grey (olive), with irregular blebs of silt, medium-grained, light grey.
77.3-87.0	2.96	Silt, becoming sand, fine-grained, downward, light grey (light olive), finely laminated with abundant lignite fragments along laminations in lower part.
87.0-88.5	0.46	Clay, minor silt, light grey (dark olive), manganese stains.
88.6-92.75	1.26	Lignite, black, finely laminated.
92.75-93.75	0.30	Sand (slump ?), light grey (light olive).
93.75-96.3	0.78	Lignite, black, finely laminated.
96.3-97.0	0.21	Clay, silty, brownish-grey (light olive).
97.0-98.8	0.55	Sand, light grey (light olive), laminated.

Drill Hole #28

L.S. 13, Sec. 33, Tp. 2, Rge. 21 WPM, Manitoba Mines Branch drill hole M-1-71, surface elev. 539 m above sea level.

Depth ft.	Thickness m	BOISSEVAIN FORMATION
0.0-2.0	0.61	Sand, light grey (grey).

Depth ft.	Thickness m	
2.0-4.75	0.84	Clay, buff (yellow).
4.75-12.3	2.30	Silt, light buff (yellow) with minor two ironstone layers, brown.
12.3-26.0	13.70	Sand, cream-colored, "salt and pepper" texture, minor clay, pyrite.
26.0-30.0	1.22	Clay (slumped ?), buff (yellowish-green).
30.0-44.4	4.39	Sand, fine-grained, light bluish-grey (blue), becoming clayey near base with minor thin brown layers.
44.5-52.0	2.29	Sand, medium-grained, grey (blue) with minor sandstone fragments.
52.0-55.2	0.98	Clay, silty, dark greenish-brown.
55.2-57.3	0.64	Sand and clay, interlayered, buff.
57.3-62.0	1.43	Clay, buff (greyish-green).

Drill Hole #31

L.S. 15, Sec. 5, Tp. 2, Rge. 23 WPM, Manitoba Mines Branch drill hole M-2-71, surface elev. 571 m above sea level. Peace Garden — Goodlands contact.

Depth ft.	Thickness m	TURTLE MOUNTAIN FORMATION Peace Garden Member
1.2-2.9	0.52	Siltstone, clayey, buff, oxidized, manganese stains, lignite fragments.
2.9-26.9	7.32	Clay and silt, interlayered, dark grey, finely laminated, mottled due to oxidation, abundant lignite and minor plant fragments. (From 1.8 m to 9.5 m micro-fossils: diatoms and seed cases).
26.9-31.0	1.25	Silt, minor clay, grey, partly oxidized to yellow, finely laminated.
31.0-34.0	0.91	Clay, silty, grey. (From 9.5 m to 11.0 m foram <i>Protelphidium</i> cf. <i>sublaevis</i>).
34.0-39.5	1.68	Silt, grey, oxidized to yellow in lower part, finely laminated.

TURTLE MOUNTAIN FORMATION **Goodlands Member**

39.6-42.0	0.73	Clay, brownish-grey, finely laminated.
42.0-43.0	0.30	Clay, light grey.
43.0-43.3	0.09	Clay-shale lignitic.
43.3-52.9	2.93	Silt, clayey, dark grey, lignite fragments.
52.9-70.7	5.43	Silt and siltstone, grey, finely laminated.
70.7-73.9	0.98	Silt and clay, buff, oxidized.
73.9-77.0	0.94	Silt, grey, muscovite flakes. (From 22.9 m to 30.5 m, micro-fossil: diatoms, spores and fragmental ostracods).
77.0-80.0	0.91	Silt, dark grey, massive, lignite fragments.
80.0-82.0	0.61	Clay-shale, dark grey, fractured 60° to horizontal, bedding parallel to fractures.
82.0-83.9	0.58	Silt, dark grey, 60° fractures.
83.9-85.0	0.34	Sand (slump ?), light grey.
85.0-87.9	0.88	Clay-shale, minor silt, grey, 60° fractures.

Depth ft.	Thickness m	
87.9-95.9	2.44	Silt, dark grey, massive.
95.9-99.5	1.10	Silt, clay, sand (slump ?), light grey.
99.5-100.9	0.43	Silt, dark grey. (From 30.5 m to 32.3 m foram <i>Haplophragmoides</i> spp.).
100.9-102.0	0.34	Clay, grey and sandstone fragments (slump ?).
102.0-106.3	1.31	Silt, light grey, lignite fragments.
106.3-108.0	0.52	Clay, silty (slump ?), light grey.
108.0-110.0	0.61	Silt, carbonaceous, horizontal, laminations.
110.0-111.0	0.30	Silt and sand, fine-grained, interlayered, light grey.
111.0-112.3	0.40	Sand, dark grey and large siltstone fragments (slump ?).
112.3-112.75	0.14	Clay, silty, light grey.
112.75-113.2	0.14	Lignite, dark black and oily residue?

