THE UPPER CRETACEOUS AND PALEOCENE STRATIGRAPHY OF TURTLE MOUNTAIN, MANITOBA

A Thesis
Submitted to
the Faculty of Graduate Studies
University of Manitoba

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
in the Department of Earth Sciences

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by

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October 1973

ABSTRACT

The Turtle Mountain study 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 paper, 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 200 feet 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 paper. The Goodlands Member, a lower assemblage of bentonitic, lignite-bearing 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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CHAPTER I

INTRODUCTION

AREA OF STUDY

The 1050 square mile, Turtle Mountain study area is located in southwestern Manitoba (Fig. 1). The area extends from Range 16 WPM to Range 24 WPM, and from the International Boundary to Township 4 North (Fig. 2). Within this area is the northern half of Turtle Mountain, an 800-foot high oval-shaped upland.

A mantle of Pleistocene glacial drift and Recent sediments is draped over the Upper Cretaceous and Paleocene bedrock of the study area. Bedrock exposures are few and are primarily confined to roadcuts and deep ravines on the western and northern flanks of Turtle Mountain. It was from these bedrock exposures that sandstone was quarried in the late 1800's for use in the construction of buildings. Lignite was mined intermittently in the Turtle Mountain area from 1879 to 1943.

OBJECTIVES AND METHODS OF INVESTIGATION

The objectives of this thesis are to describe the Upper Cretaceous and Paleocene stratigraphy of the study area, to correlate strata across the study area and into adjacent regions, and to interpret the history of sedimentation. To accomplish these objectives a combination

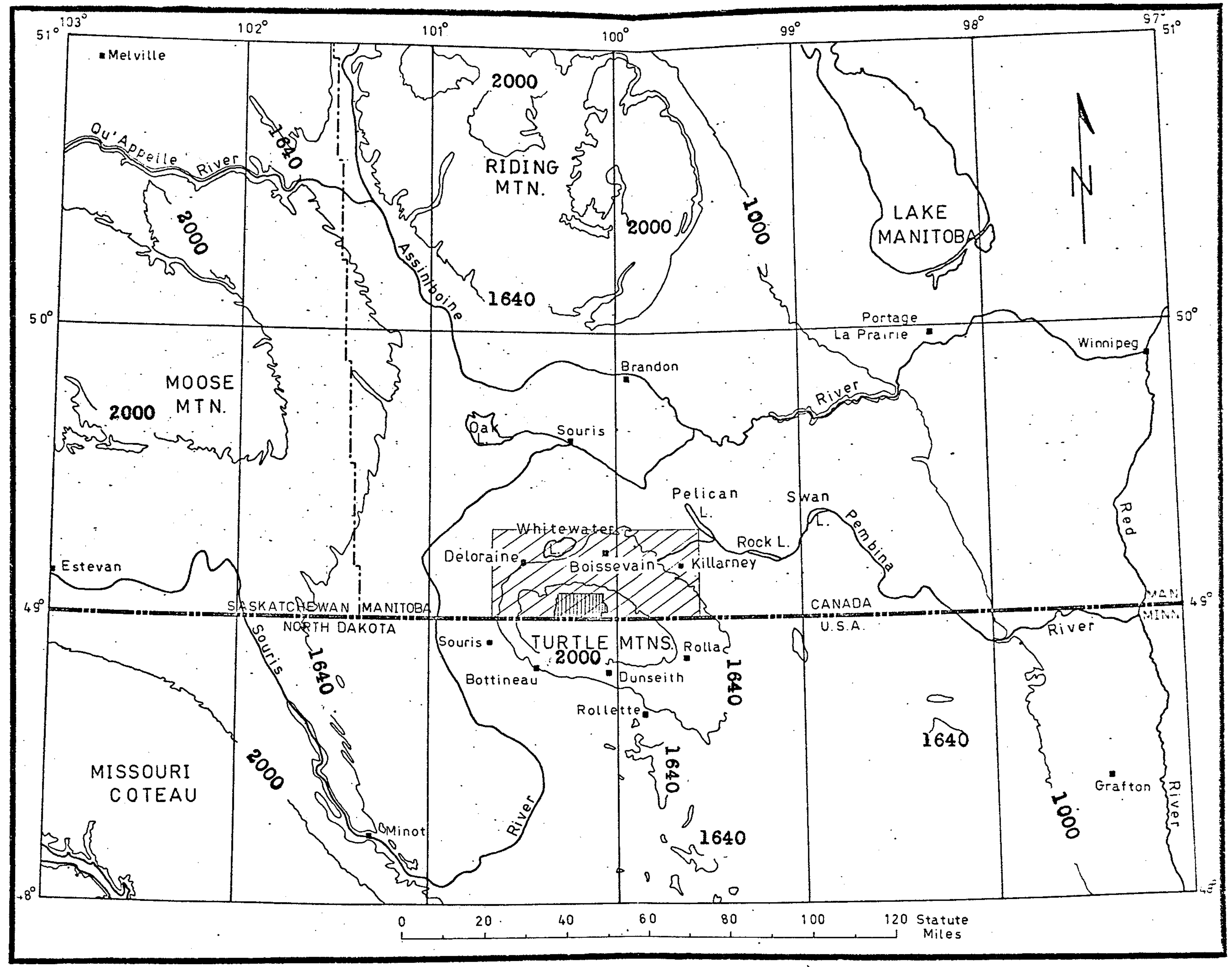


Figure 1. Index map for the Turtle Mountain study area (diagonal cross-hatching) showing Turtle Mountain Provincial Park (vertical cross-hatching). Topographic contours drawn at 1000, 1640, and 2000 feet above sea level.

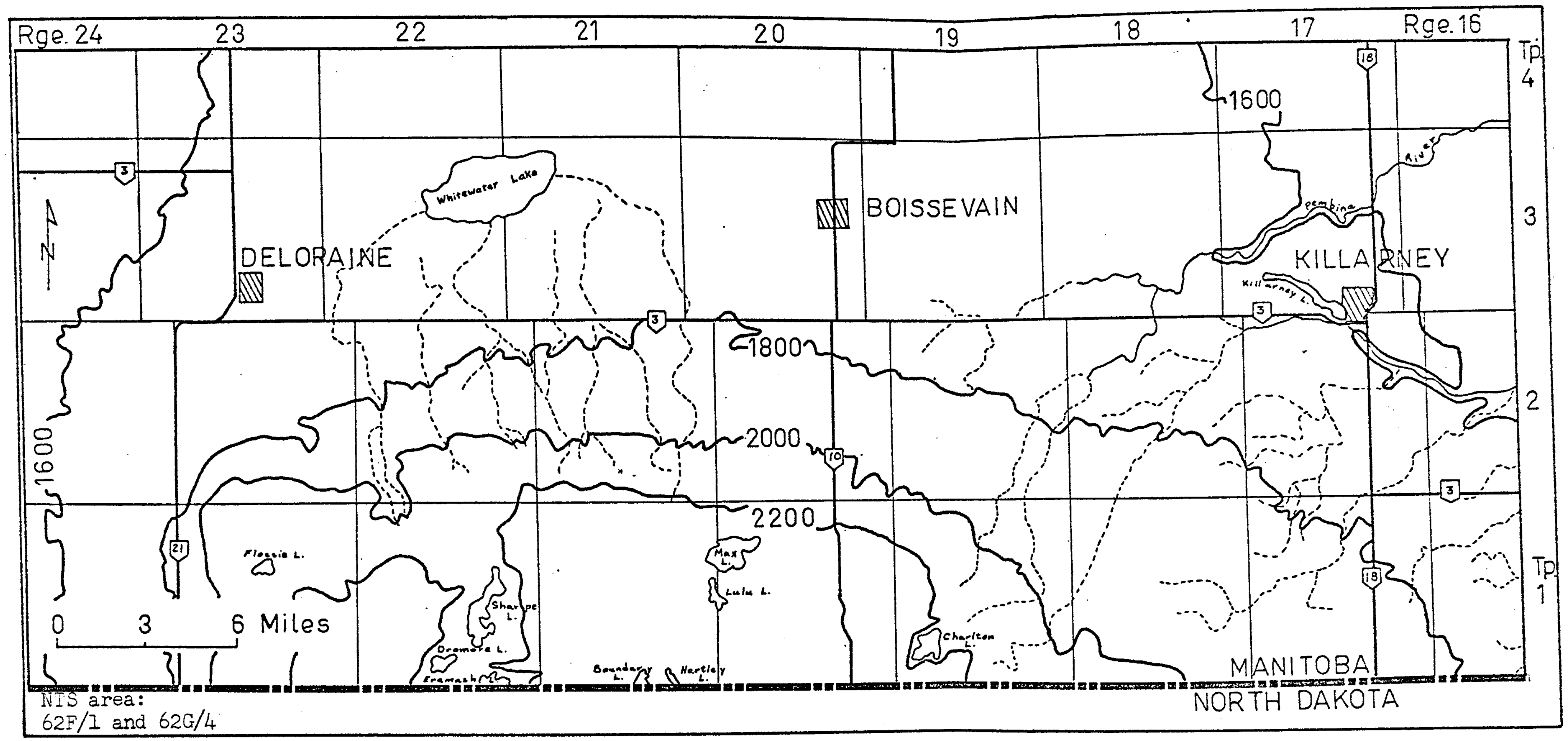


Figure 2. Turtle Mountain study area. Topographic contour interval, 200 feet.

of field work and laboratory study was completed.

During the 1971 field season bedrock exposures in the study area (Fig. 3) were described and sampled; preliminary lithologic logs were constructed on-site from three Manitoba Mines Branch cored drill holes; and field trips were made into North Dakota and Saskatchewan.

Samples from outcrops and drill holes collected in the study area are stored in the Manitoba Mines Branch core and sample library.

To distinguish between formations (and constituent members) the grain size, mineralogy, and electric log characteristics were studied. Procedures of sieving analysis and methods of textural parameter calculation followed are those of Folk (1968, p. 32-52). Wentworth size classes are used to describe the sediments. The mineralogy of the samples was determined under a microscope and through the use of X-ray diffractograms made at the Department of Earth Sciences, University of Manitoba. 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 the formations and their contacts in the subsurface. Isopach and structure contour maps were prepared mainly from this information. Locations of drill holes are shown in figure 3.

Crossbed measurements were used to determine mean paleocurrent directions according to the formulas of Potter and Pettijohn (1963, p. 254).

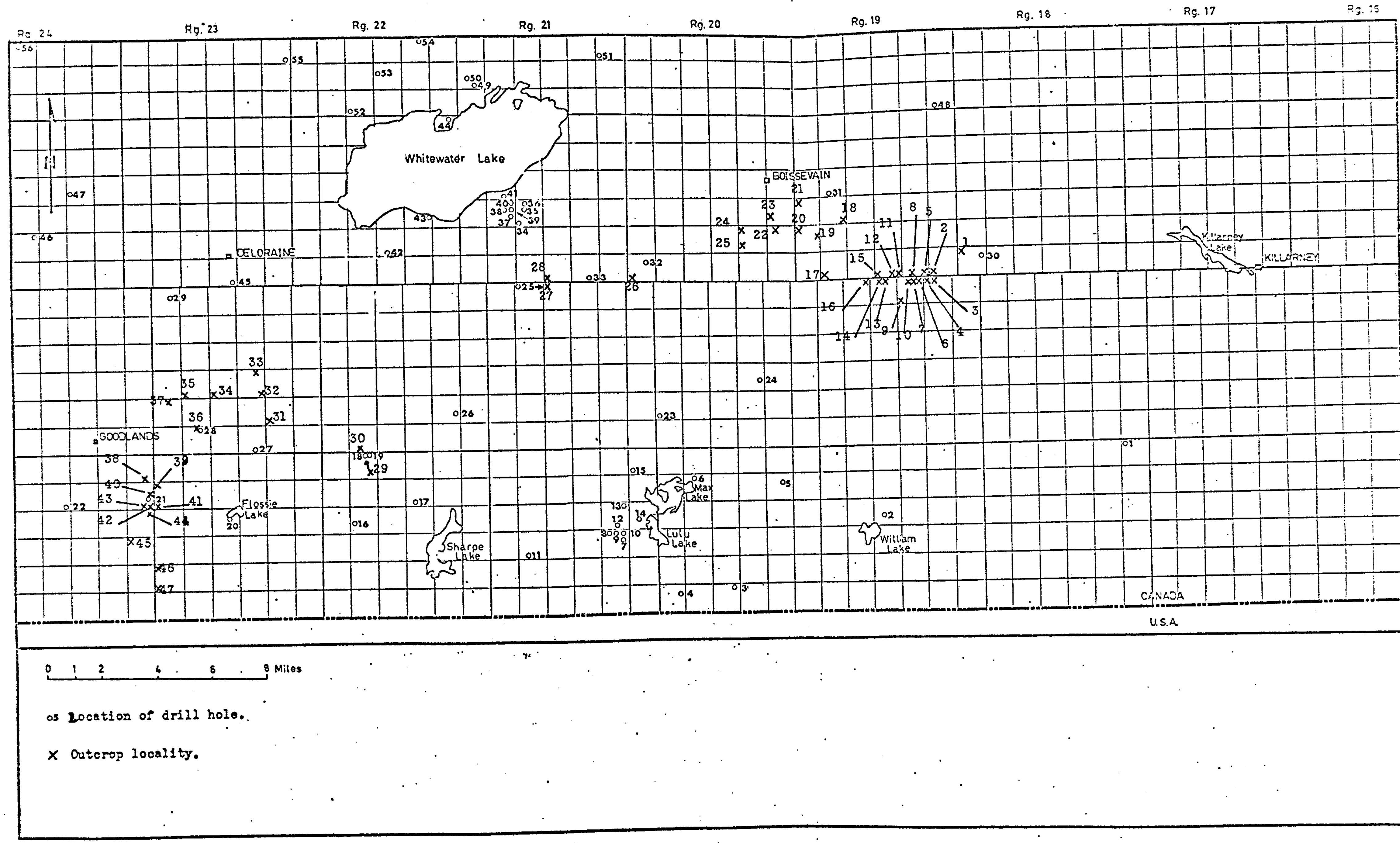


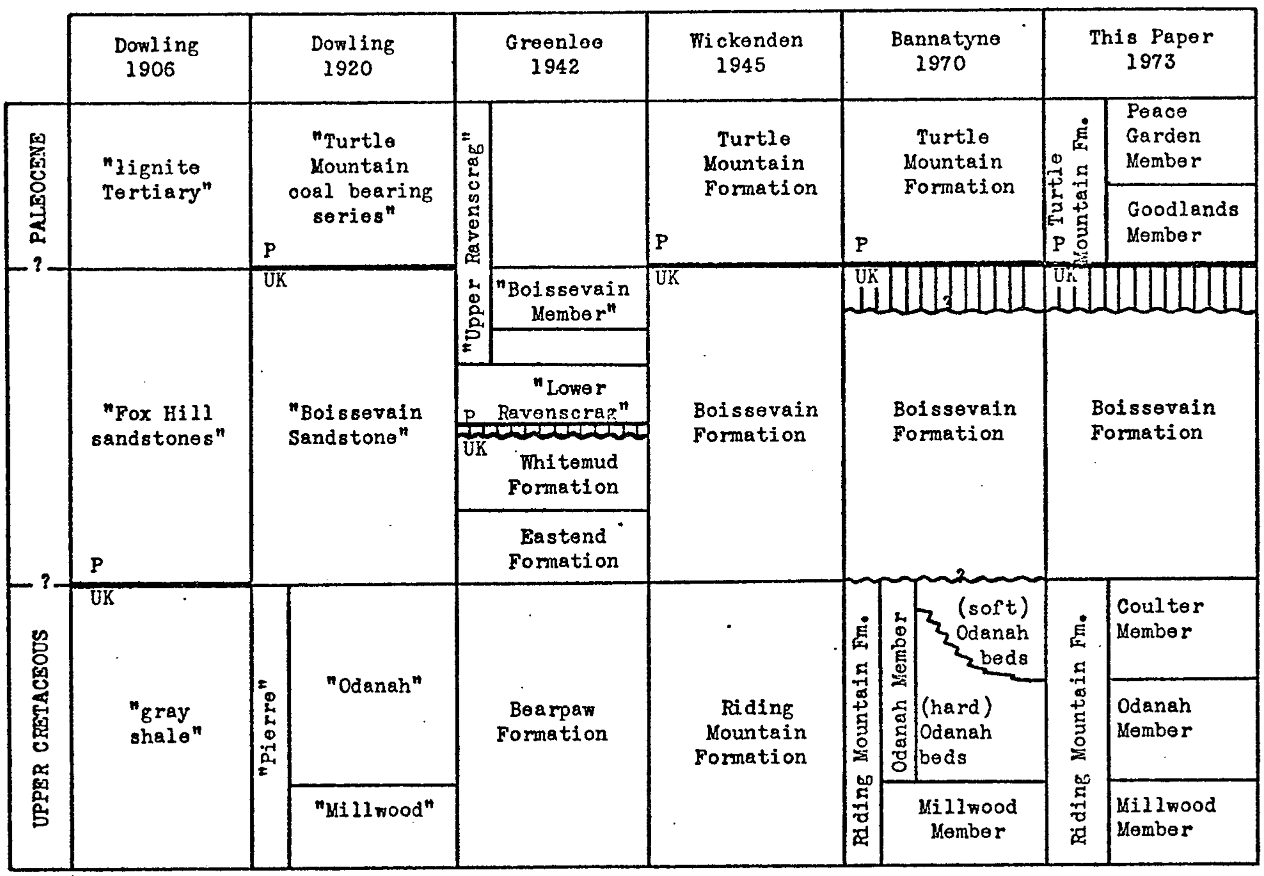
Figure 3. Outcrop and drill hole location map.

B. R. North at 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.

PREVIOUS WORK

In the study area, 3000 feet of post-Paleozoic sediments were deposited on the Mississipian erosion surface (McCabe, 1963). Mesozoic and Cenozoic formations are a sequence of shale and sandstone ranging in age from Jurassic to Paleocene (Wickenden, 1945). The stratigraphic nomenclature of beds deposited during the Late Cretaceous to Paleocene interval has been revised many times (Fig. 4). Locally derived formation names and those of North Dakota and Saskatchewan have been used. Because of a lack of fossil evidence and correlation solely on the lithologic similarities to formations in North Dakota and Saskatchewan, the position of the Paleocene/Upper Cretaceous contact has been in dispute (Fig. 4).

Dowling (1906) was the first to describe the bedrock of the Turtle Mountain area. He 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 into the "lignite Tertiary". In 1920 Dowling updated his previous nomenclature, renaming the "gray shale" as the "Pierre" (after Tyrrell, 1890, p. 230), the



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

Figure 4. Evolution of the stratigraphic nomenclature of the Turtle Mountain area.

sand unit as the "Boissevain Sandstone" (after Parks, 1914), and the "lignite Tertiary" as the "Turtle Mountain coal bearing series". The Paleocene/Upper Cretaceous contact was elevated to a position between the "Boissevain Sandstone" and the "Turtle Mountain coal bearing series".

The geology of the North Dakota portion of Turtle Mountain was described by Greenlee (1942). The Manitoba portion was commented upon only briefly; however, the nomenclature and position of the Paleocene/Upper Cretaceous contact adopted by Greenlee 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 high in the Ravenscrag Formation.

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, p. 50) 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 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 Figure 4 shows the nomenclature used throughout this thesis and the position proposed for the Paleocene/Upper Cretaceous contact.

ACKNOWLEDGEMENTS

I would like to thank the Manitoba Mines Branch, my employers during the 1971 field season, for permission to use data collected within the Turtle Mountain study area for my thesis. Acknowledgements are due also to the National Research Council and the University of Manitoba for a graduate assistantship. Much advice came from E. I. Leith and J. T. Teller (Department of Earth Sciences, University of Manitoba) and B. B. Bannatyne (Manitoba Mines Branch), my advisors for this thesis.

Special thanks are directed to the Geological Survey of Canada and the Manitoba Mines Branch for the use in petrological and micropaleontological studies, of drill hole samples from the Turtle Mountain area. My appreciation is extended to W. G. E. Caldwell and his associates, in particular B. R. North, at the University of Saskatchewan who conducted micropaleontological studies for this thesis.

Assistance and information in the field were obtained from D. W. Deal and S. R. Moran of the North Dakota Geological Survey, G. Lammers of the Manitoba Museum of Man

and Nature, M. Zwarich of the Manitoba Soil Survey, and C. V. Boreski, junior assistant, of the Manitoba Mines Branch.

CHAPTER II

STRATIGRAPHY OF THE RIDING MOUNTAIN FORMATION

DEFINITION AND DESCRIPTION OF FORMATION

Within the study area, the Riding Mountain Formation is generally a 950-foot thick assemblage of grey marine clays occurring between the marine Upper Cretaceous Vermilion River Formation and the overlying Upper Cretaceous Boissevain Formation.

The 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 (Fig. 4).

DEFINITION AND DESCRIPTION OF MEMBERS

Millwood Member

The Millwood Member of the Riding Mountain Formation is a soft greenish brown bentonitic slightly silty clay occurring between the Vermilion River Formation and the overlying Odanah Member of the Riding Mountain Formation.

The type locality of the Millwood Member (Tyrrell, 1890) is located about 120 miles 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 the surface in the study area. In the subsurface, the thickness of this member ranges from 75 feet in the southeast to 250 feet in the northwest (Bannatyne, 1970, p. 57). 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 at the surface.

The upper contact of the Millwood Member with the overlying Odanah Member is placed at the abrupt lithologic change between the distinctive soft greenish brown bentonitic slightly silty clay and the overlying hard grey siliceous clay shale. This contact is clearly recognizable in chip samples and on gamma-ray and resistivity curves. Bentonite absorbs heavy radioactive elements (Lynch, 1962) and its presence in the highest Millwood beds would account for their higher radioactivity. The upper contact was chosen as a stratigraphic datum for correlation between drill holes across the Turtle Mountain area (Fig. 5).

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 of the Riding Mountain Formation.

The type locality of the Odanah Member (Tyrrell, 1890) is approximately 80 miles north of Turtle Mountain, at the

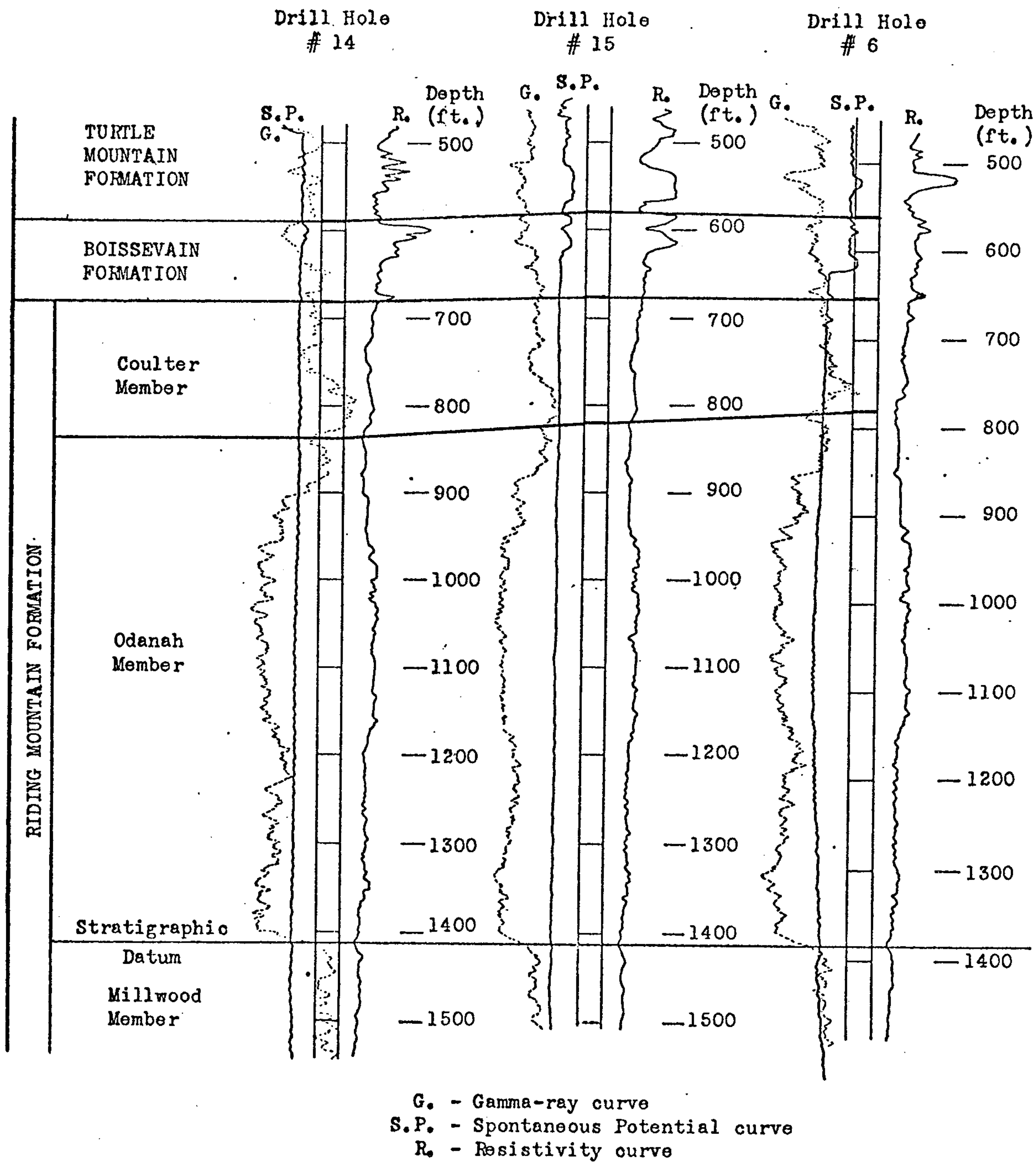


Figure 5. Correlation between drill holes by means of radioactivity, spontaneous potential, and resistivity logs.

abandoned village of Odanah, near Minnedosa, Manitoba. A type section has not been described for the Odanah Member.

The Odanah Member is not exposed at the surface in the study area. In the subsurface its thickness increases from 560 to over 640 feet radially outward from the center of Turtle Mountain. Chip samples of the Odanah Member show that it is siliceous, and it is steel grey when dry and dark greenish grey when moist. Many of the chips are stained a reddish to purplish brown colour. In outcrop, just outside the Turtle Mountain area at Dand, 8 miles north of Deloraine, and at Ninette, 16 miles north of Killarney, the Odanah Member appears 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 (Fig. 5). 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 50 feet. 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 (Fig. 5). The top of the interval is indicated by the absence of the hard grey siliceous shale, another increase in radioactivity and a minimum in the resistivity curve. The top of the interval is chosen as the position for the Odanah-Coulter contact.

Coulter Member

Bannatyne (1970, p. 58) included the "soft" beds outcropping in the Souris Valley near the town of Coulter, Manitoba, 24 miles west of Turtle Mountain, within the Odanah Member (Fig. 4). Because these beds can be recognized as a distinctive lithologic 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 of the Riding Mountain Formation and the overlying Boissevain Formation be named the Coulter Member of the Riding Mountain Formation. Drill hole #18, not in the type area, penetrated the uppermost beds of the Coulter Member and its lithologic description is given in the Appendix.

The only Coulter Member outcrop in the study area, Locality #1, has been disturbed by slumping and/or ice-thrusting. In the subsurface the thickness of this member decreases from 180 to 60 feet across the southwest portion of the study area, but maintains an average 150-foot thickness across the southeast portion. The Coulter Member, in chip samples, generally resembles the Millwood Member. The clayey silt of the Coulter 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 (Fig. 5). The resistivity of the Coulter Member increases slowly upward, paralleling an 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 five feet thick, is represented in figures 5 and 6 by a sharp resistivity high on a low background, approximately 45 feet below the major 50 foot thick sand unit of the Boissevain Formation.

AGE AND CORRELATION

Diagnostic fossils have not been found in the Riding Mountain Formation within the study area. However, north and east of the study area at Dand, Millwood, and Wawanesa, foraminifera have been identified (Wickenden, 1945, p. 49) which indicate a Late Cretaceous age for this formation.

Wickenden (1945) correlated the Riding Mountain Formation with the Bearpaw Formation of Saskatchewan (Fig. 7). This was substantiated by the mapping of the Riding Mountain Formation and its constituent, the Odanah Member in the Melville Area, Saskatchewan by Christiansen (1971). West of that area, the Odanah Member has not been recognized and the equivalent sediments are placed in the Bearpaw Formation.

Wickenden's (1945) correlation of the Riding Mountain Formation with Pierre Shale of North Dakota was supported

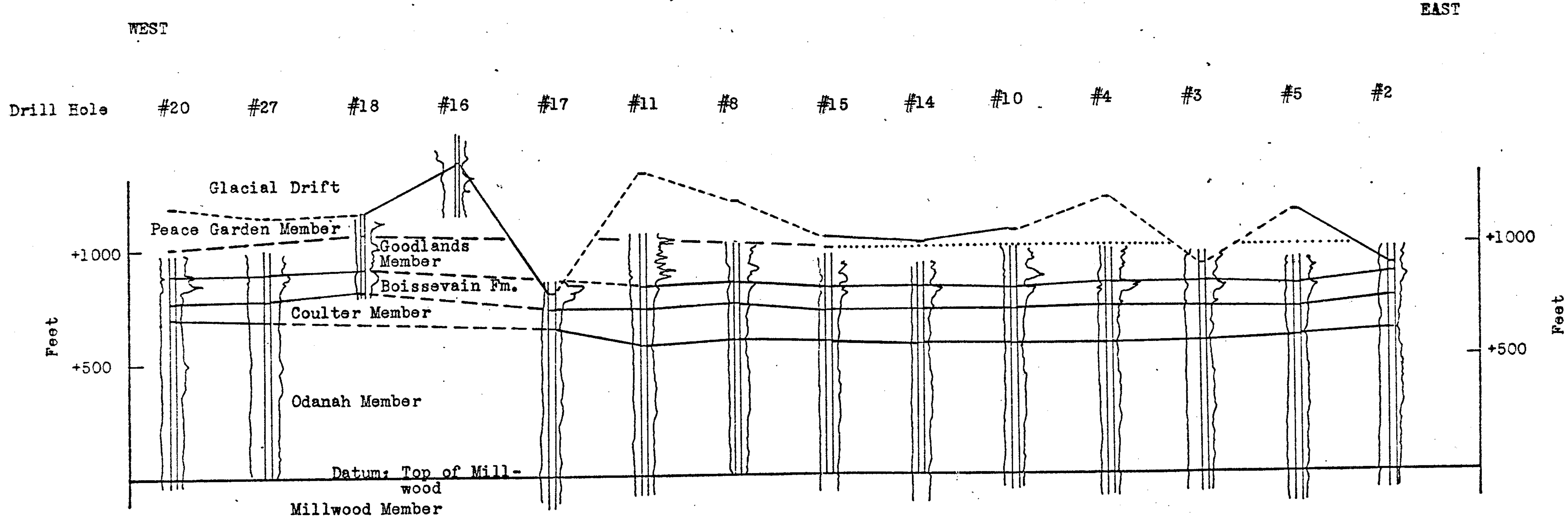
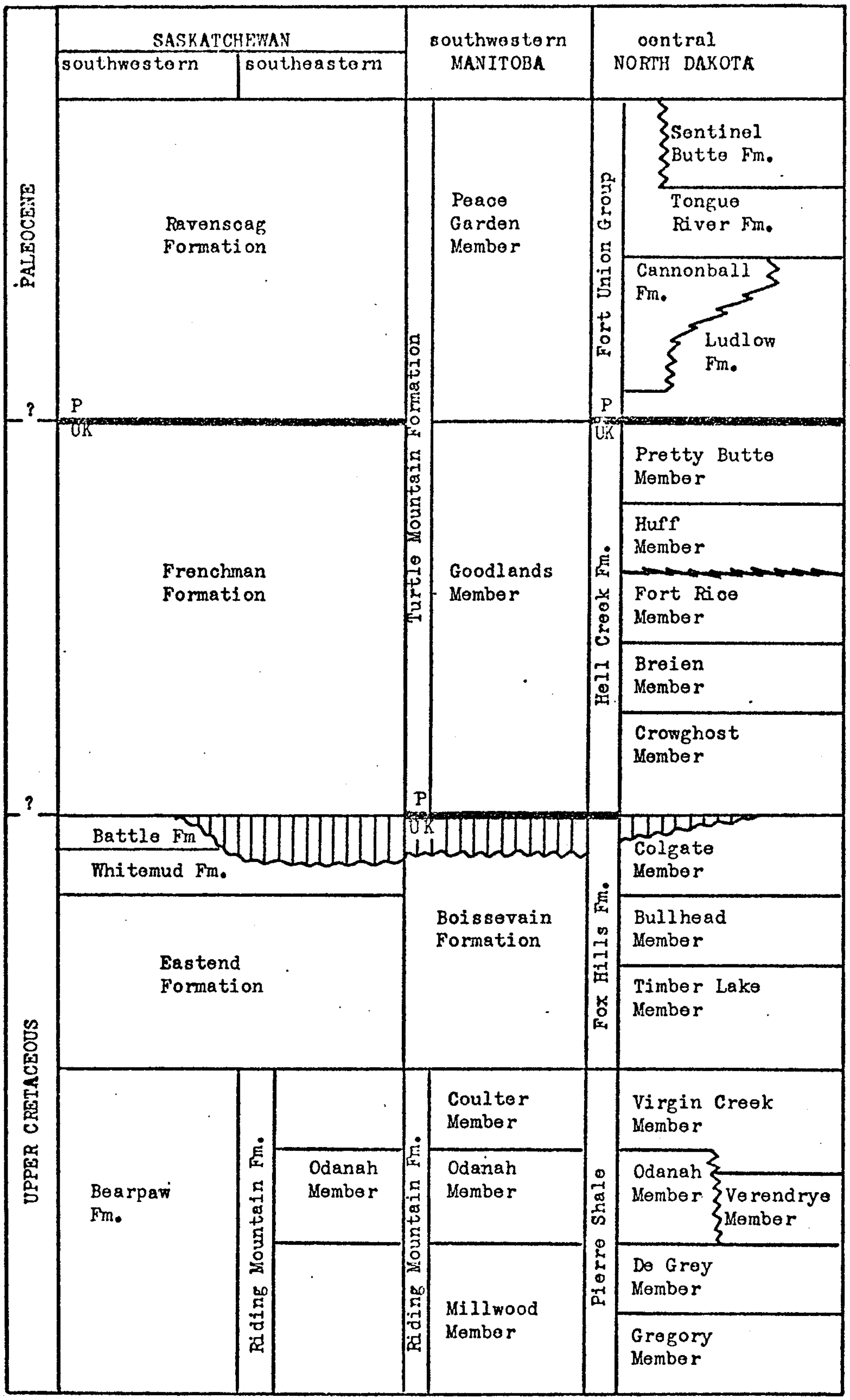


Figure 6. Stratigraphic correlations in the Turtle Mountain area based on electric log interpretation.



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

Figure 7. Correlation of formations and members of Saskatchewan and North Dakota with those of Manitoba.

by Lemke (1960), who stated that sediments equivalent to the Pierre Shale outcrop just west of Turtle Mountain, in the Souris Valley near Coulter, Manitoba. Gill and Cobban (1965) equated the Gregory and De Grey Members of the Pierre Shale with the Millwood Member, and the siliceous lower beds of the Virgin Creek Member of the Pierre Shale with the Odanah Member (Fig. 7). 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).

CHAPTER III

STRATIGRAPHY OF THE BOISSEVAIN FORMATION

DEFINITION AND DESCRIPTION OF FORMATION

The Boissevain Formation is dominantly sand with minor amounts of clay, silt, and sandstone within the study 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 yet been designated; therefore it is proposed that the south halves of Tp. 3, Rges. 19 and 20, and the north half of Tp. 2, Rge. 19 (Fig. 3) be the type area. A section at Locality #3 (described in the Appendix) is selected as the type section of the Boissevain Formation. Drill hole #18, not in the type locality, penetrated the entire thickness of the Boissevain Formation and its lithologic description is in the Appendix.

In Manitoba, the Boissevain Formation is restricted in extent to the Turtle Mountain area. The thickness of the formation decreases from 120 to 60 feet northward across the study area. Across the northern part of the study area (Fig. 3), the Boissevain outcrops as a cross-bedded buff quartz-rich medium-grained "salt and pepper" sand. In the middle of the study area at Locality #42 the Boissevain Formation consists of a massive white kaolinitic fine-grained silt or clay (Fig. 8). Samples from drill hole #25 (described in the Appendix) indicate that the buff sand is transitional upward into the white silt and clay. The lowest beds of the Boissevain Formation, not exposed at surface, consist mainly of sand that contains thin units of silt and clay which become more numerous with depth.

Ovoid concretionary masses of cemented sandstone with an average size of 24 feet by 7 feet by 4 feet are a characteristic feature of the Boissevain Formation (Fig. 9). Crossbedding passes without disturbance through these concretionary masses and into the surrounding sand. The Boissevain Formation also contains thin discontinuous partially purple-stained orange ironstone concretionary layers which usually follow, for several feet, the bedding planes in the sand.

Thick sand units within the Boissevain Formation are more permeable than the thinner tighter clay beds. This can be seen in figure 5 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. In drill holes #14, 15, and 6 the spontaneous potential has positive values, but in drill holes #16 and 18 they are negative. This difference in response is due to the relative salinity of the drilling mud filtrate with respect

Figure 8. Boissevain Formation. Locality #35. Massive white kaolinitic fine-grained silt or clay.

Figure 9. Boissevain Formation. Sandstone concretionary masses. Upper, Locality #3. Lower, Locality #19.

to 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 (Fig. 5). These decreases may reflect the decreases in the amount of bentonitic material as a function of increasing grain size.

The contact of the Boissevain Formation with the overlying Turtle Mountain Formation is placed at the base of 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 (Fig. 10). In the subsurface, the first appearance of medium-grained sand in the chip samples and/or the top of the first major increase in resistivity and spontaneous potential below the lignite-bearing Goodlands of the Turtle Mountain Formation (Fig. 5) marks the position of the contact.

AGE AND CORRELATION

The Boissevain Formation is sparsely fossiliferous (Wickenden, 1945) and any determination of its age is dependent upon 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

Figure 10. Goodlands Member of the Turtle Mountain Formation. Locality #12. A few feet above the Boissevain-Turtle Mountain contact. Head of hammer marks the position of top of dark greenish-red clay bed with abundant plant and lignite fragments.

North Dakota (Fig. 7). Sedimentation was continuous between formations as evidenced by the gradational change from grey clay shales to buff sand in each case (Caldwell, 1968; Feldmann, 1972).

The upper contacts of the Boissevain and Fox Hills Formations with the overlying Turtle Mountain and Hell Creek Formations respectively (Fig. 7) are placed at the base of the first prominent lignite seam or lignite shale, although Feldmann (1972) stated that a surface of unconformity may separate the Hell Creek and Fox Hills Formations. A widespread erosional interval following the deposition of the Fox Hills and Boissevain Formations would account for the irregular distribution of the massive white kaolinitic fine-grained silt or clay in the upper beds of the Boissevain Formation. Although lignite beds are present in the 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 (Fig. 7).

Dowling (1920) was the first to correlate the Boissevain Formation with the Fox Hills Formation of North Dakota. His correlation was supported by Lemke (1960) and by S. R. Moran and L. Clayton of the North Dakota Geological Survey (personal communication, 1973). The crossbedded concretionary sands of the Timber Lake Member of the Fox Hills Formation is 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 the fine-grained silty sands of the Colgate Member of the Fox Hills Formation.

Russell (1933) correlated the lower beds and the Upper 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) collected stratigraphically above the top of drill hole #25 by B. B. Bannatyne of the Manitoba Mines Branch have almost the same X-ray pattern as that of a sample of Whitemud Formation collected by E. I. Leith of the University of Manitoba.

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 extension studies of fossil cephalopods and clams, and if the above correlations are correct the Boissevain Formation must also be Late Cretaceous in age.

CHAPTER IV

STRATIGRAPHY OF THE TURTLE MOUNTAIN FORMATION

DEFINITION AND DESCRIPTION OF FORMATION

Wickenden (1945) defined the Turtle Mountain Formation as the Paleocene series of shale, sandstone, and lignite-bearing beds which overlies the Upper Cretaceous Boissevain Formation in the Turtle Mountain area. In view of 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 on 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 519 feet.

DEFINITION AND DESCRIPTION OF MEMBERS

Goodlands Member

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

Within the western and eastern halves of Tp. 1, Rge. 23 and Tp. 1, Rge. 24, respectively, most of the upper 100 feet of the Goodlands Member of the Turtle Mountain Formation can be found in scattered outcrops and this area has been chosen as the type area. A section at Locality #43 (described in the Appendix) has been selected as the type section of the Goodlands Member. Drill hole #18 penetrated a 109-foot thick section of the Goodlands Member and its lithology is described in the Appendix.

In Manitoba, the Goodlands Member is present only within the Turtle Mountain area. Its average thickness, in the western portion of the study area, is 130 feet. Lignite seams ranging in thickness from 6 inches to 6 feet occur throughout the member. The sediments between the 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 the lignite (Fig. 11).

The Goodlands sand beds and lignite seams are indicated by short interval highs in the resistivity curves (Fig. 5). 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,

Figure 11. Goodlands Member of the Turtle Mountain Formation. Locality #42. Pick at the position of an underclay separating two lignite seams.

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 1 foot (Fig. 12).

Peace Garden Member

The Peace Garden Member of the Turtle Mountain Formation is the assemblage of grey silty clay with minor greenish sand and silt beds overlying the Goodlands Member of the Turtle Mountain Formation.

A composite type section for the Peace Garden Member is proposed from drill holes #16 and #18 (lithologic description in Appendix) because this member is not well-exposed at surface in the study area. The 369-foot composite section includes all but 29 feet of beds between the bottom of drill hole #16 and the top of drill hole #18.

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 (Fig. 12). The beds are thin-bedded with an average thickness of one-half of an inch. Siltstone beds, cemented by calcium carbonate, cap an outcrop at Locality #36 (Fig. 13). Very fine-grained greenish sand beds are exposed at Locality #30 (Fig. 14).

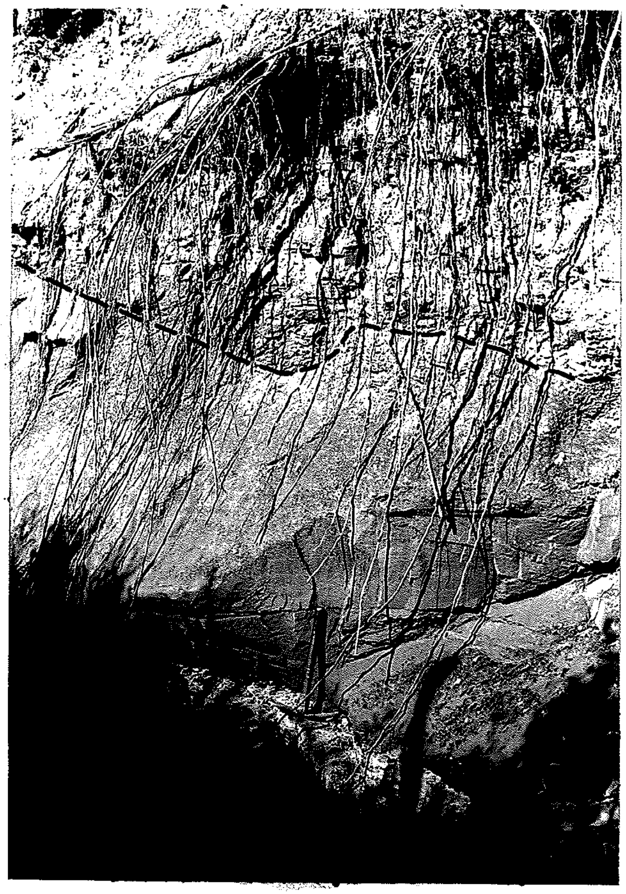


Figure 12. Contact between Goodlands and Peace Garden Members of the Turtle Mountain Formation. Locality #40.

Figure 13. Peace Garden Member of the Turtle Mountain Formation. Locality #36. Thin siltstone concretionary masses which cap the outcrop.

Figure 14. Peace Garden Member of the Turtle Mountain Formation. Locality #30. Highest known outcrop in the study area (1995 feet above sea level).

The resistivity curves from drill holes #16 and #18 (Fig. 5), 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 125 feet of drill hole #16.

AGE AND CORRELATION

According to W. G. E. Caldwell, University of Saskatchewan (personal communication, 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 the study area. He reported the following marine foraminifera:

Drill hole	
#16	*Polymorphina* sp. at 170 feet
#18	*Protelphidium* at 174 feet
#19	*Nodosaria* sp. and *Guttulina* sp. from 25-43 feet

#21 Protelphidium cf. sublaeve,
Anomalinoides sp.,
(?) Anomalinoides sp. or (?) Gavelinella sp. (indistinct),
(?) Rectoglandulina sp. (broken specimen),
Haplophragmoides spp.
and Ammodiscus sp. (broken) from 10'10" - 38'9";

Haplophragmoides sp. and Saccammina sp. from 38'9" - 98'10".

#28 Protelphidium cf. sublaevis from 31-36 feet; and Haplophragmoides spp. from 100-106 feet.

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 (Fig. 7) 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 (Fig. 7) to the Hell Creek 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 within the study area a Paleocene age must be applied to the Goodlands Member.

The marine beds of Paleocene age in the Peace Garden Member of the Turtle Mountain Formation 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 (Fig. 7) 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).

CHAPTER V

SEDIMENTATION

GENERAL STATEMENT

The provenance areas and depositional environments of the Riding Mountain, Boissevain, and Turtle Mountain Formations are indicated by their grain size distributions, sedimentary structures, and mineralogy. The terminology of Krumbein and Sloss (1963, p. 250-262) is used to describe the environments of deposition.

PHYSICAL AND CHEMICAL PROPERTIES OF THE STUDY AREA SEDIMENTS

Grain-size Distribution

Sediments of the Riding Mountain Formation are generally clays (less than 8.0 Ø), 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 study. The mean grain size of 15 Boissevain Formation sand samples (Table I) has a range from 2.46 Ø to 3.5 Ø. On the average these sands are moderately well sorted, 0.51 Ø to 0.77 Ø; strongly fine-skewed, -0.02 to +0.66; and very leptokurtic, 1.09 to 2.93.

TABLE I

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

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

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 15. Also shown are the grand mean of paleocurrent directions, 067° (Table II), and the distribution of dips of the crossbed measurements.

At Locality #4 wave-oscillation ripple marks are preserved within a sandstone concretionary mass (Fig. 16). The ripples have an amplitude of a half inch and a wave length of one inch.

Sandstone concretionary masses can be found at Localities #9, #7, #6, #4, #3, and #19 positioned about 5 and 30 feet below the Boissevain-Turtle Mountain contact.

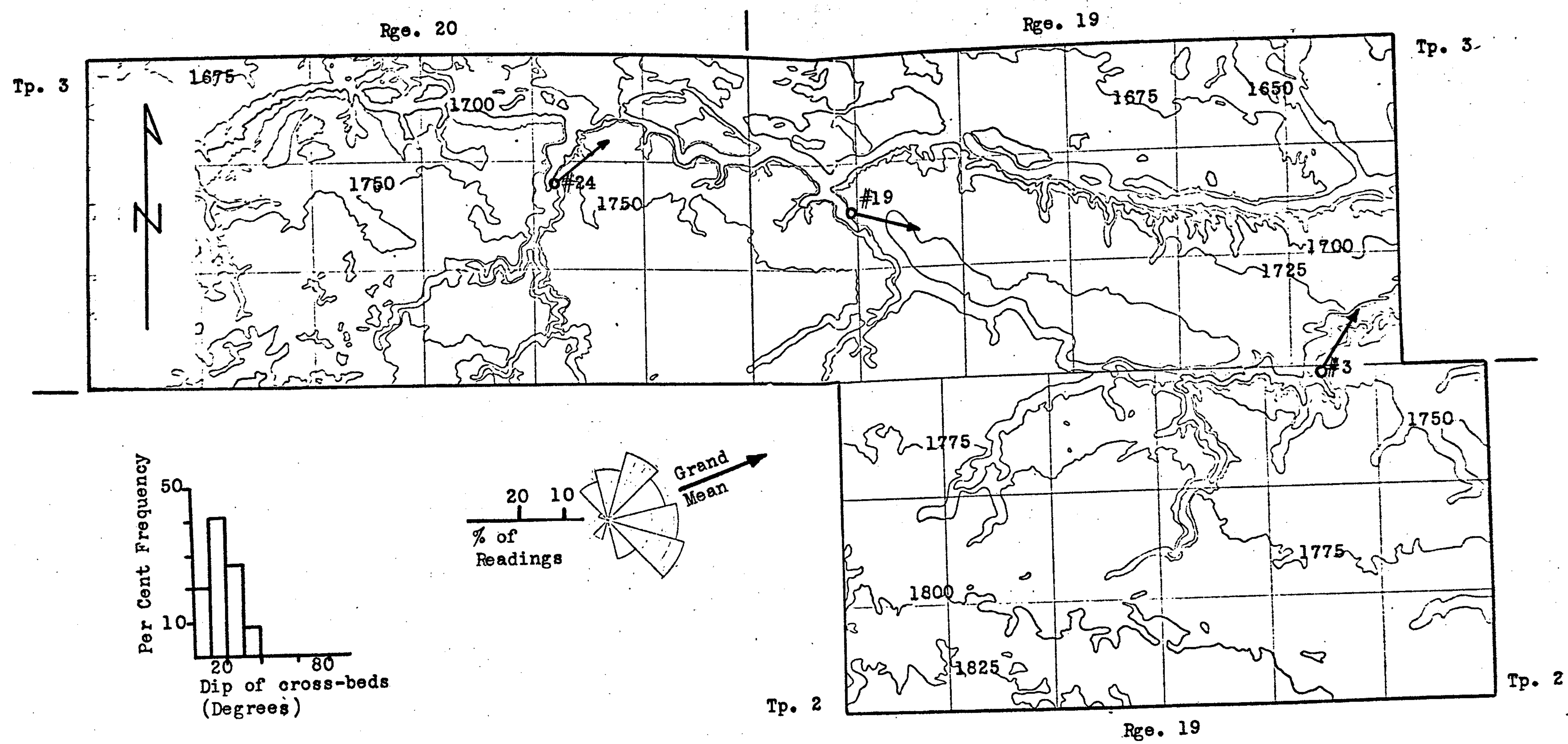


Figure 15. Vector means for cross-bed measurements in the Boissevain Formation at Localities #13, 19, and 24. Histogram shows dip distribution. Type area for the Boissevain Formation.

TABLE II

SUMMARY OF LARGE-SCALE CROSS-BED MEASUREMENTS IN THE BOISSEVAIN FORMATION FROM LOCALITIES #3, #19, and #24

Azimuth Class	No. of Readings (n)	
15 - 45	7	15.9%
45 - 75	6	13.6%
75 - 105	7	15.9%
105 - 135	8	18.2%
135 - 165	4	9.1%
165 - 195	-	0
195 - 225	2	4.5%
225 - 255	-	0
255 - 285	-	0
285 - 315	1	2.3%
315 - 345	4	9.1%
345 - 15	5	11.4%

$$\text{Grand Mean, } \bar{X}_g = \frac{\Sigma\ n\ (\theta)\ \sin\theta}{\Sigma\ n\ (\theta)\ \cos\theta}$$

$$= \frac{23.7580}{9.8300}$$

$$= 2.4169$$

$$= 067^\circ$$

Figure 16. Boissevain Formation. Locality #13.
Ripple marks.

At Locality #19 seven concretionary masses have an average length of 24 feet, width of 7 feet, and thickness of 4 feet. The long axes of these near-horizontal masses are nearly parallel and strike approximately S 60° E.

Mineralogy

Although the sediments of the study area vary in grain size, the composition of these sediments is generally consistent. The Millwood Member of the Riding Mountain Formation, 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) indicates the presence of minor amounts of goethite, carbonate, mica, zeolite, and gypsum. X-ray diffractograms of the Odanah Member of the Riding Mountain Formation show almost no crystal structure and according to Bannatyne (1970, p. 59) amorphous silica is the major constituent. Only small amounts of quartz and cristobalite can be identified in an Odanah sample from 905 feet below surface in drill hole #11. X-ray diffractograms of two samples of the Coulter Member of the Riding Mountain Formation, drill hole #11 at 695 feet and drill hole #18 at 391 feet 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 gram sample of the Boissevain Formation from an outcrop south of the town of Boissevain (Table III). Feldspar is present in considerable quantities in the light residues which account for 96.05% of the sample. The assemblage of heavy minerals is dominated by hornblende. Biotite and magnetite each account for 10-25%. Although the Boissevain sands are generally fresh and angular, well rounded, distinctly pleochroic rose and purple zircons were also noted.

Garden (1949) examined two samples from the lower beds of the Boissevain Formation near Locality #12. His results shown in Table III, correspond closely to those of Wallace and McCartney except that the percentage of biotite exceeds that of hornblende. Garden also examined two samples from the upper beds of the Boissevain Formation near Locality #37, and in contrast to the lower beds hornblende exceeds biotite. The variability in the hornblende-biotite ratio could possibly be explained by the low total percentages of the two samples from the lower beds of the Boissevain Formation. This may indicate loss of a portion of the samples. In addition, Garden's percentages exclude magnetite, limonite, and leucoxene although he stated that they total at least 30% of the total heavy minerals in all samples. From thin section studies, Garden reported that all of his samples contained 80-85% quartz, 2-4% orthoclase, 4-10% plagioclase, and the indurated samples, finely crystalline or fibrous carbonate.

TABLE III

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

Mineral	Wallace & McCartney (1928) -25 gm. sample 3.05 heavies south of Boissevain (?)	Boissevain Formation Garden (1949) 20 grams samples 5-8% heavies Lower beds SE¼,sec.2, Tp.3, Rge.19WPM		Upper beds N½,sec.7,Tp.2,Rge.23WPM		Turtle Mountain (Goodlands Mbr.) Garden (1949) 20 gram sample 5-8% heavies Elev. of Top 1782 lsd 10, sec. 13,Tp.1,Rge.24WPM	
		Base 1701 ft.	Top	Base	Top	Top 1782 ft.	Top 1782 ft.
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
		78.0*	93.2*	99.6	98.5	99.0	95.5

* See page 45.

Garden also found the grains to be generally uncorroded and very angular. Some of the quartz grains showed flamboyant structure.

In four samples from the lower beds of the Boissevain Formation (Locality #12, JB 28; Locality #3, JB 37; drill hole #11, depth 605 feet; and drill hole #18, depth 333 feet), 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.

The heavy minerals of two samples from the Goodlands Member of the Turtle Mountain Formation close to Locality #45 were studied by Garden (1949). His results (Table III) 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, the 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 sample is a 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 the 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 the lithified sediments of the study area.

PROVENANCE AREAS

Garden (1949) concluded that the heavy mineral suites in the sands of the Boissevain and Turtle Mountain Formations (Table III) indicated that both were derived from the same metamorphic and igneous provenance area. Crossbedding measurements in the Boissevain Formation (Table II) indicate an easterly direction (Fig. 15) of sediment transport and this suggests that the provenance area of this formation was to the west of the study area. According to Byers (1969), the Eastend, Whitemud, and Frenchman Formations of Saskatchewan (Fig. 7) had their source in the Upper Cretaceous metamorphic rocks, and Paleozoic carbonates of Montana. Assuming the correlation of the above formations with the sediments of the study area to be correct this would imply that the provenance area of at least the Boissevain Formation was also in Montana.

Riding Mountain Formation

Wickenden (1945) attributed a marine depositional environment to the Riding Mountain Formation from fossils obtained in the formation 12 and 32 miles north of the study area, at Dand and Wawanesa, respectively. He also stated that in the type locality of the Millwood Member the bivalve *Inoceramus* was identified. According to Gill and Cobban (1966, p. A38), 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, the middle member of the Riding Mountain Formation, 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 of the Riding Mountain Formation. 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, p. A38) and Caldwell (1968) stated that the upper members of the Pierre Shale and the Bearpaw Formation, respectively, (Fig. 7) were deposited at depths less than 200 feet, 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, and the presence of carbonaceous matter and unstable heavy minerals in the sands of the Boissevain Formation and the Goodlands Member of the Turtle Mountain Formation suggest deposition in a swampy basin at the mouth of a river.

A plot of skewness versus standard deviation for 15 Boissevain sand samples (Fig. 17) shows a concentration of points on the "river side" of Friedman's (1961) boundary which may indicate a fluviatile origin. But, a pure fluviatile deposit, according to Selley (1968), has a unimodal paleocurrent pattern and the Boissevain Formation appears to have a "bimodal" pattern with both modes within 60° of one another (Fig. 15). However, J. T. Teller, University of Manitoba (personal communication, 1973) suggested that this spread was not sufficient to indicate "bimodality" because an even greater spread would be expected

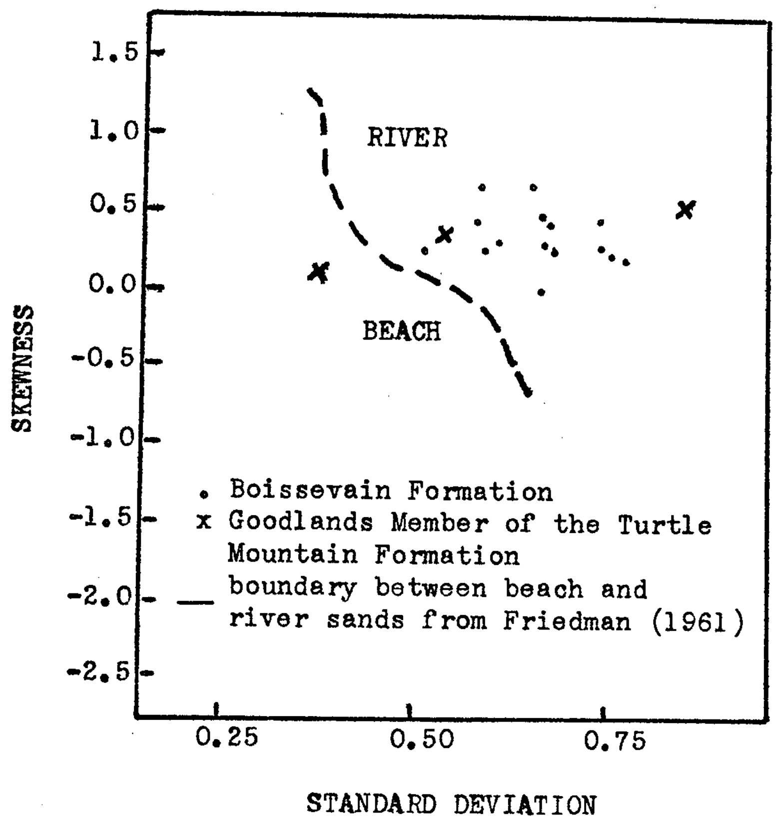


Figure 17. Plot of skewness and standard deviation using Ø scale for samples from the Boissevain Formation and Goodlands Member of the Turtle Mountain Formation.

in a "modern" fluvial environment.

A plot of standard deviation against mean grain size (Fig. 18) does not give a clear separation of points and may indicate either a "dune" or "river" origin. The angularity of the grains and lack of corrosion (Garden, 1949); however, would seem to favour a river origin.

Assuming the above to be sufficient evidence, Garden's (1949) interpretation that the Boissevain Formation was deposited in a swampy basin at the mouth of a river would appear to be correct. It is possible though, that deposition occurred in several river mouths, as is suggested by Caldwell's (1969) interpretation that the Eastend and Whitemud Formations (Fig. 7) were deposited in fluviodeltaic and flood plain environments, respectively. In comparison the lower members of the Fox Hills Formation (Fig. 7) were deposited in a shallow marine environment and the Colgate Member may represent an intertidal, shallow water, or even a beach deposit (Feldmann, 1972).

Turtle Mountain Formation

Textural parameter plots of the Goodlands sand samples (Fig. 17 and 18) do not indicate a specific depositional environment. Lignite seams, relatively abundant in the Goodlands Member (Fig. 19), are discontinuous laterally and vary in position vertically (Figs. 20 A-F) showing that plant growth existed in a fluctuating depositional environment. Fossil plants that have been

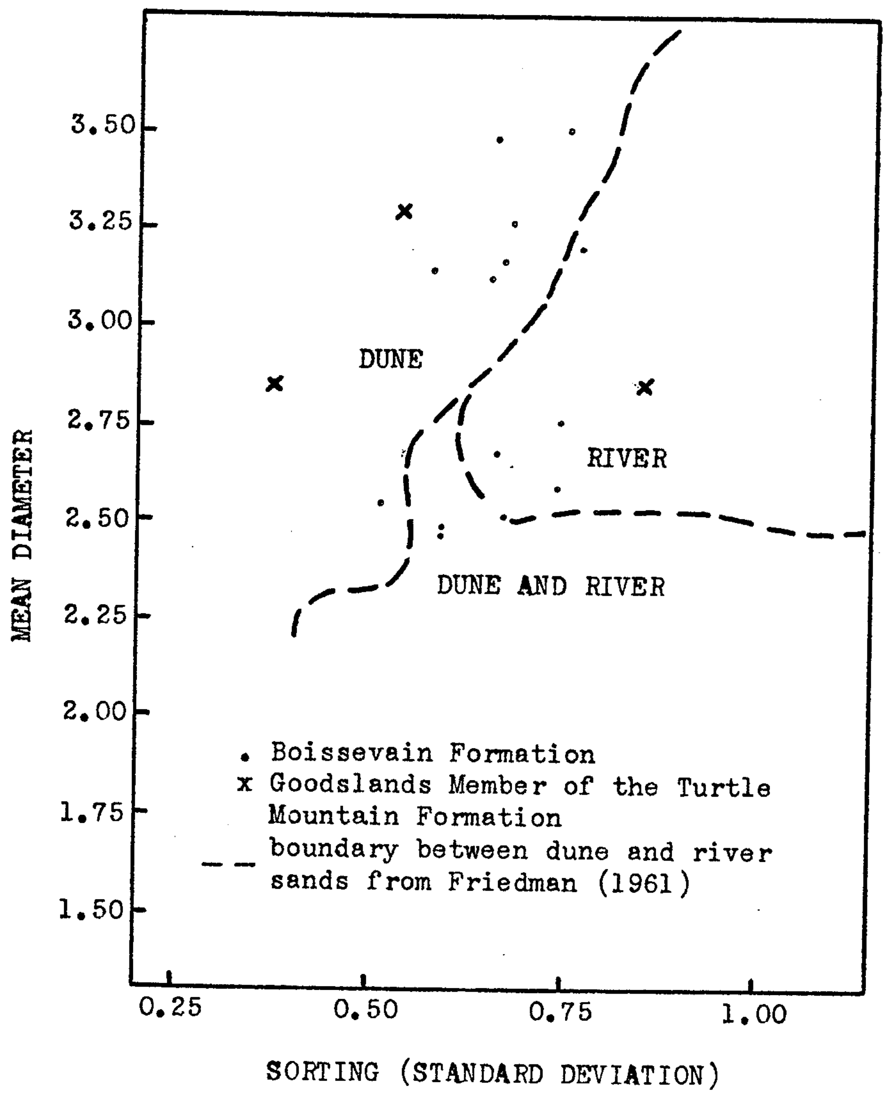
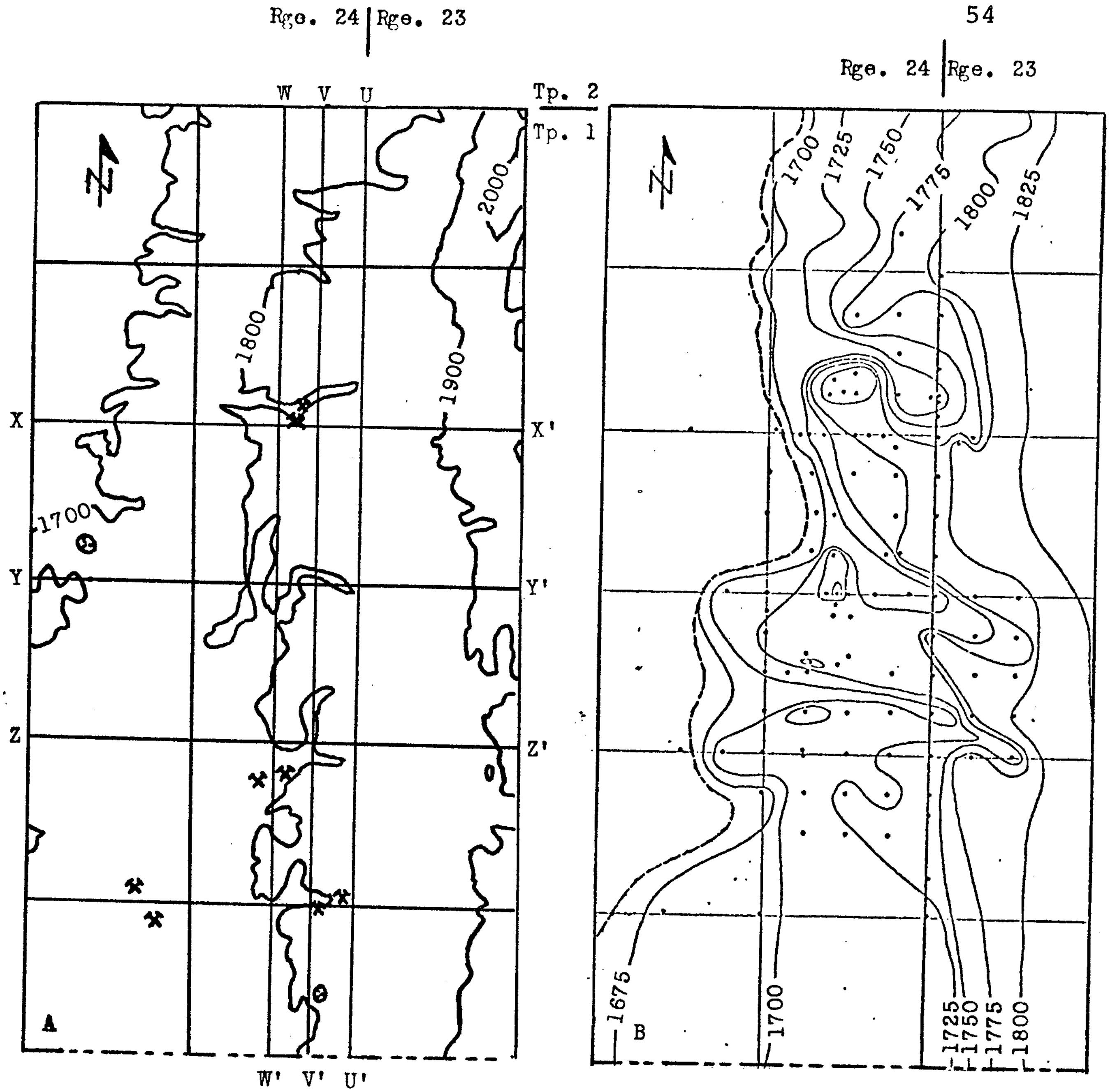


Figure 18. Plot of mean diameter and sorting using Ø scale for samples from the Boissevain Formation and the Goodlands Member of the Turtle Mountain Formation.



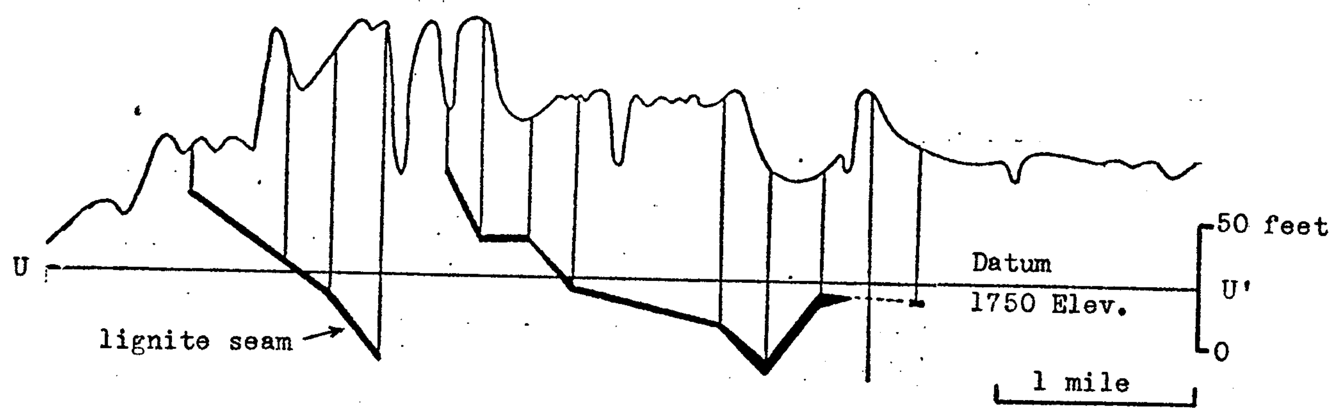
Topographic contour interval 100 feet.

Structure contour interval 25 feet.

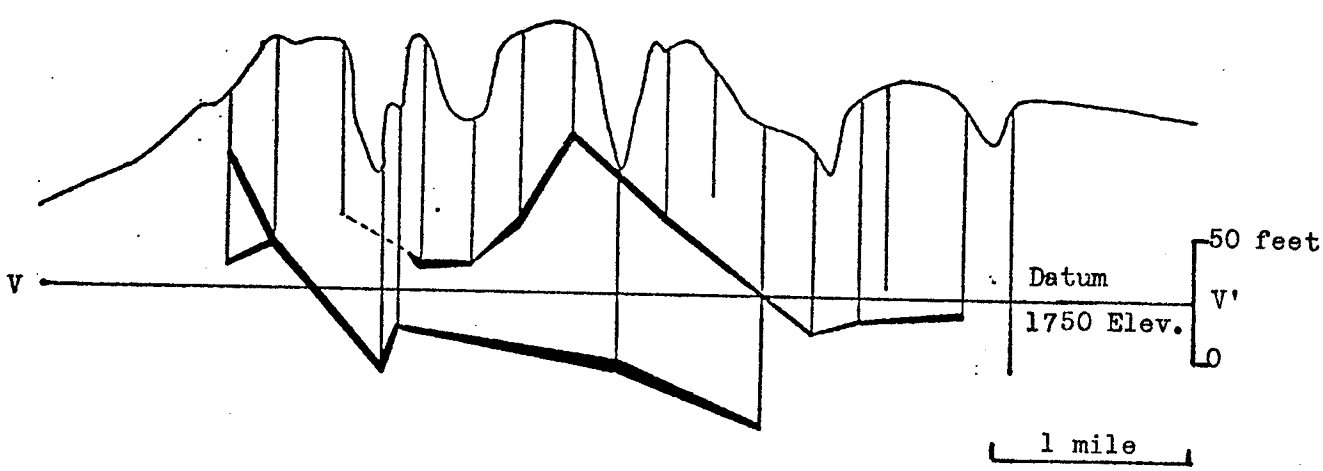
1 mile

⚒ Site of abandoned lignite mine.
Z-Z' Lines of cross-section.
• Control point, drill hole.
--- Limit of lignite seams.

Figure 19. A, surface topographic map showing type area of the Goodlands Member of the Turtle Mountain Formation, lines of cross-section (see figure 20), and locations of abandoned lignite mines. B, structure contour map on upper surface of lignite deposits in type area, located on west side of Turtle Mountain.

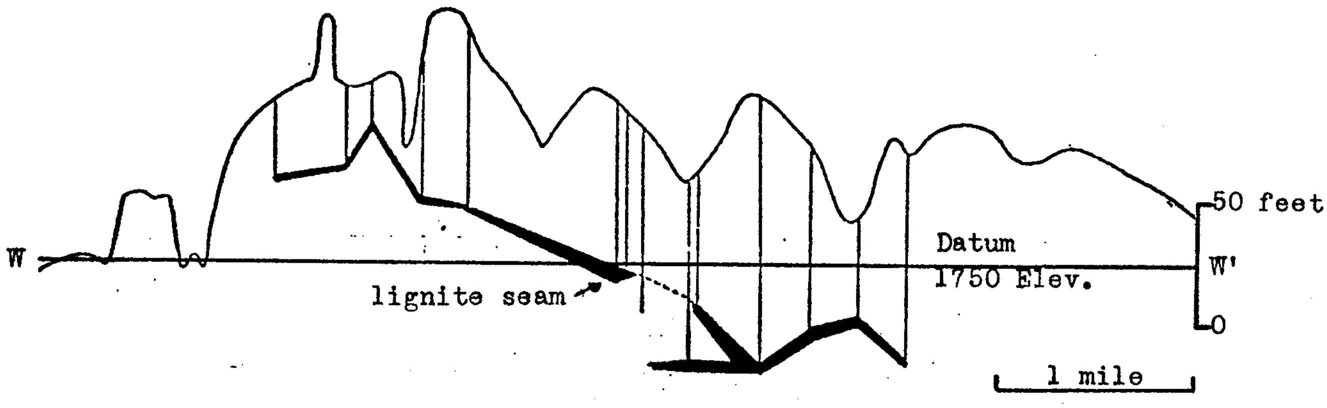


A1. Section U-U'

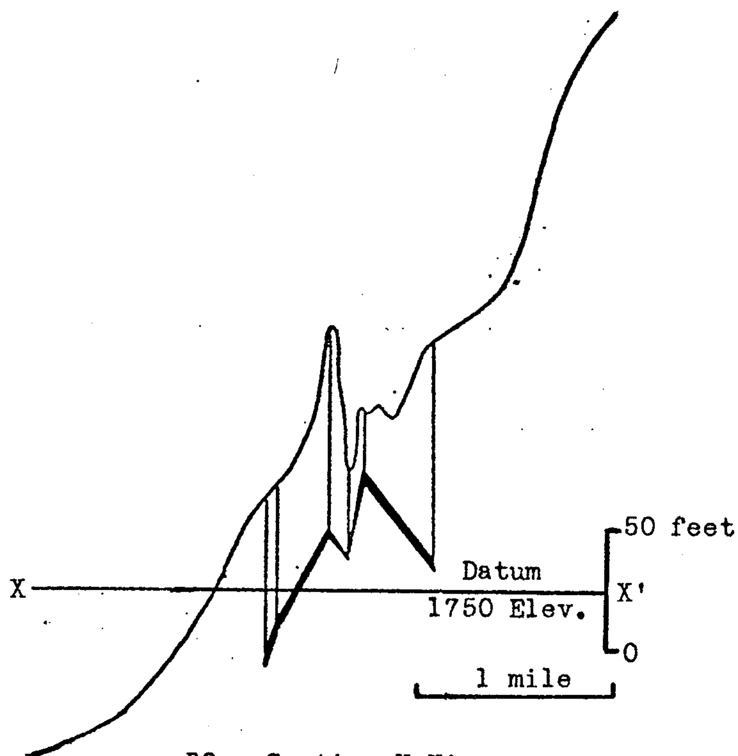


A2. Section V-V'

Figure 20A. Geologic cross-sections U-U' and V-V' of lignite seams in the Goodlands Member of the Turtle Mountain Formation. See figure 19 for lines of cross-section. Vertical scale greatly exaggerated.

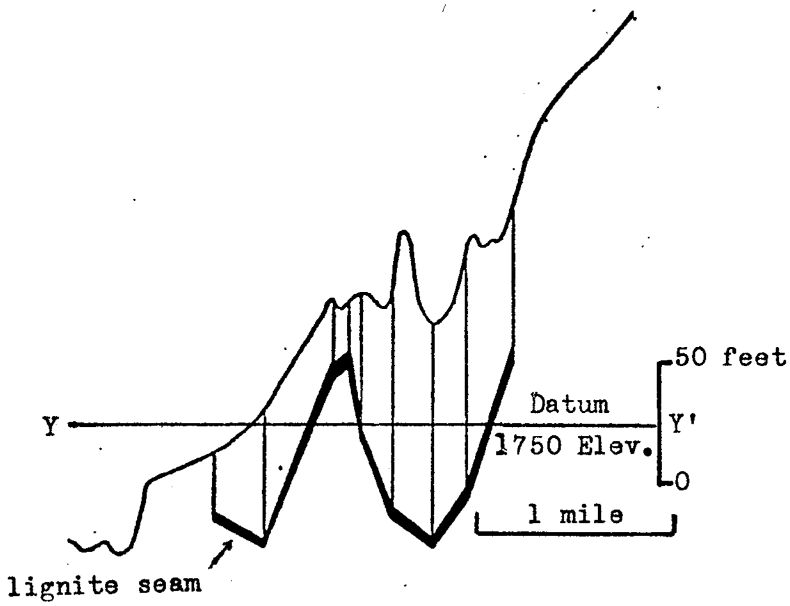


B1. Section W-W'

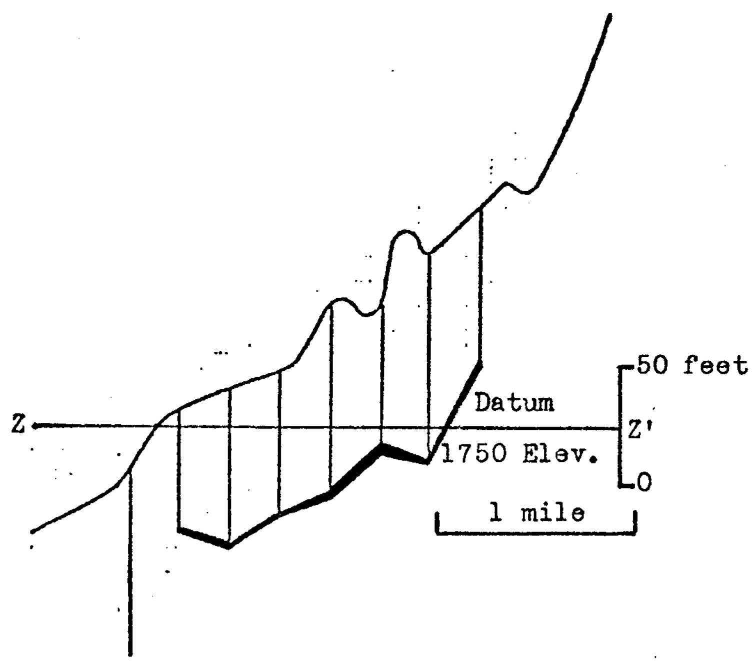


B2. Section X-X'

Figure 20B. Geologic cross-sections W-W' and X-X' of lignite seams in the Goodlands Member of the Turtle Mountain Formation. See figure 19 for lines of cross-section. Vertical scale greatly exaggerated.



C1. Section Y-Y'



C2. Section Z-Z'

Figure 20C. Geologic cross-sections Y-Y' and Z-Z' of lignite seams in the Goodlands Member of the Turtle Mountain Formation. See figure 19 for lines of cross-section. Vertical scale greatly exaggerated.

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 170 feet in drill hole #16. The numerous lignite seams, organic rich sediment, and at least one marine fauna suggests that circulation was poor and shallow water conditions existed. Krumbein and Sloss (1963, p. 258) state 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 (Fig. 7) according to Frye (1969) is a complex of lagoonal, brackish water, fresh water, and flood plain deposits. However, the Frenchman Formation (Fig. 7) is a non-marine alluvial flood plain deposit (Byers, 1969), which may indicate a gradual change from 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 communication, 1972 and 1973):

Drill hole	
#16, 18, 19, 21, 28	various foraminifera (see page 35)

Drill hole	
#21	Ostracoda: from 10'10" - 38'9" (?) Orthonotocythere sp. (molt) Fragments of specimens similar to above. Echinodermata: from 10'10" - 38'9" (?) Plates of asteroids
#28	Few diatoms and seed cases 6' - 31' Few diatoms, spores, and fragmental ostracods 75' - 100'

Shallow water conditions are indicated by the unusually small size, poor preservation, and sparseness of the foraminifera. Beds equivalent to the Peace Garden Member (Fig. 7) 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 (Fig. 7) was deposited in an alluvial flood plain environment. The above interpretations indicate that, in addition to an upward change from marine to non-marine conditions, a similar change took place gradually from east to west during Paleocene time.

CHAPTER VI

LATE CRETACEOUS AND PALEOCENE HISTORY

The Turtle Mountain area is situated on the northeastern rim of the Williston Basin, a negative structure on the craton. The Late Cretaceous and Paleocene geologic history of the North Dakota and Saskatchewan portions of the Williston Basin have been described by Gill and Cobban (1966, p. A43) and by Caldwell (1968, p. 3), 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, p. A43) the Western Interior region of North America during the Late Cretaceous was the site of an epicontinental sea. The Millwood, Odanah, and Coulter Members of the Riding Mountain Formation were deposited in this sea. The maximum probable extent of the sea is shown in figure 21A. The nature and position of the northeastern shoreline is uncertain. With local and continental uplift, the sea gradually withdrew southward (Fig. 21B) 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 study area.

As the seas withdrew, continental plant growth

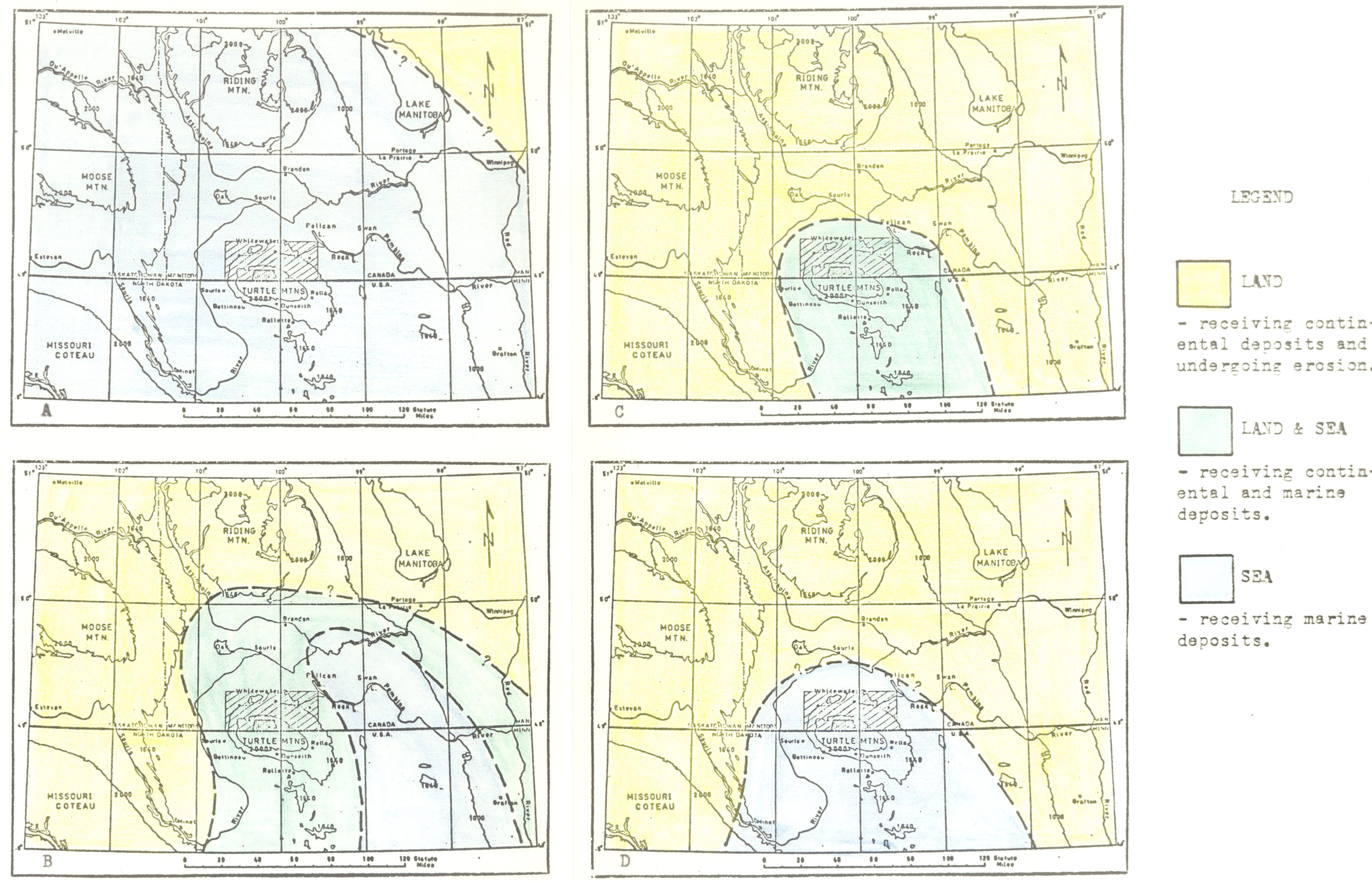


Figure 21. Late Cretaceous and Paleocene History of the Turtle Mountain area and immediate vicinity. Configuration of land and sea during deposition of: A, Millwood and Odanah Member; B, Coulter Member and Boissevain Formation; C, Goodlands Member; and D, Peace Garden Member.

became established, marking the beginning of the Paleocene in the study area (Fig. 21C). The plants later formed the lignite seams, fossil plants, and carbonaceous sediments of the Goodlands Member of the Turtle Mountain Formation. 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 over the transitional and continental deposits. The Peace Garden Member of the Turtle Mountain Formation was deposited during the transgression and subsequent regression (Fig. 21D). 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, p. 31).

The intertongued relationships of sediments deposited in North Dakota, Saskatchewan, and the study area during the Late Cretaceous and Paleocene are shown in figure 22. Also indicated in the figure are the depositional environments of the sediments.

In post-Paleocene time uplift resulted in a high base level and Turtle Mountain was left as an erosional remnant, an outlier of the Missouri Coteau (Fig. 23).

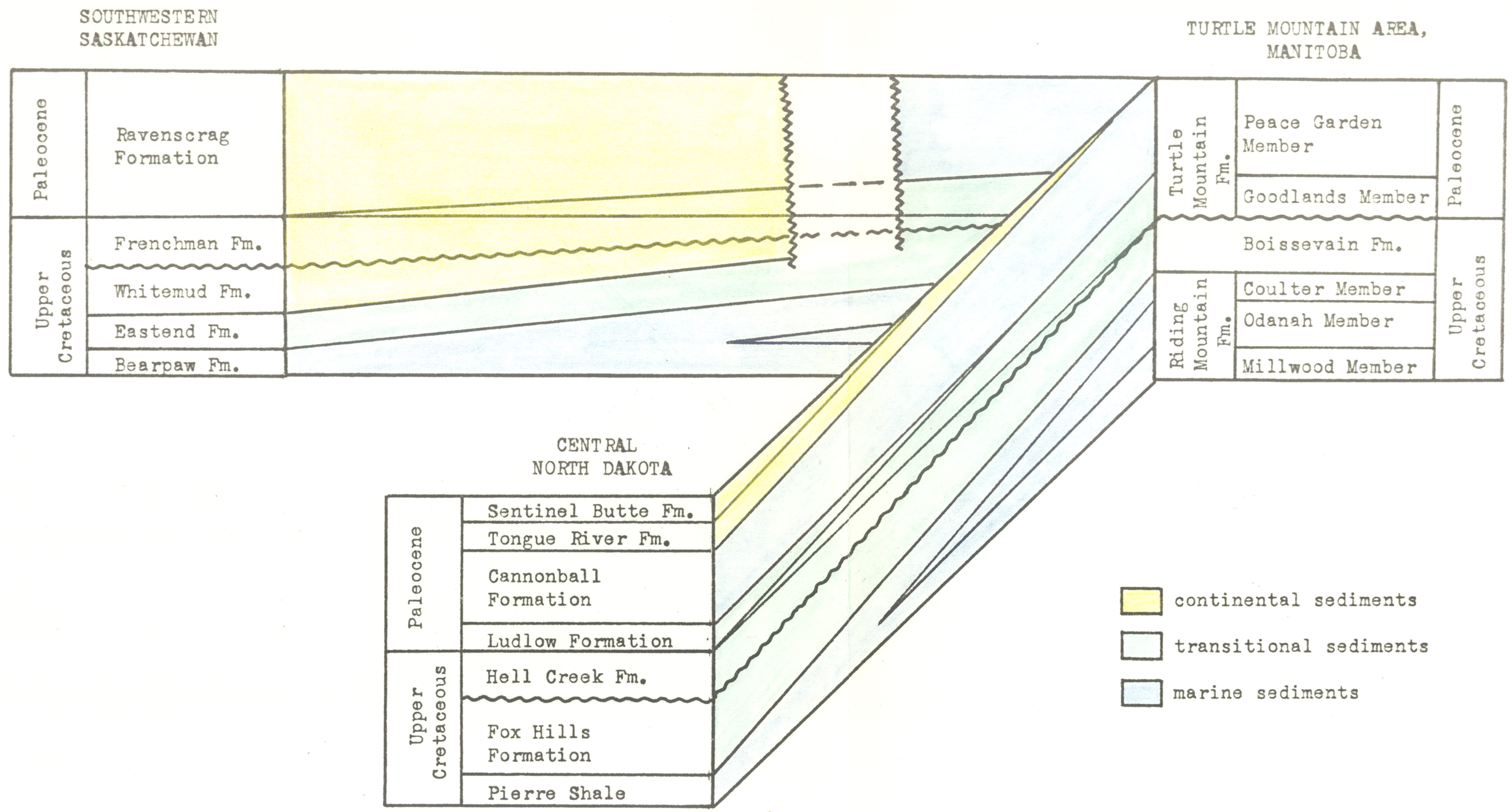


Figure 22. Reconstructed simplified geologic cross-sections of Upper Cretaceous and Paleocene (continental, transitional, and marine) sediments showing their intertongued relationships.

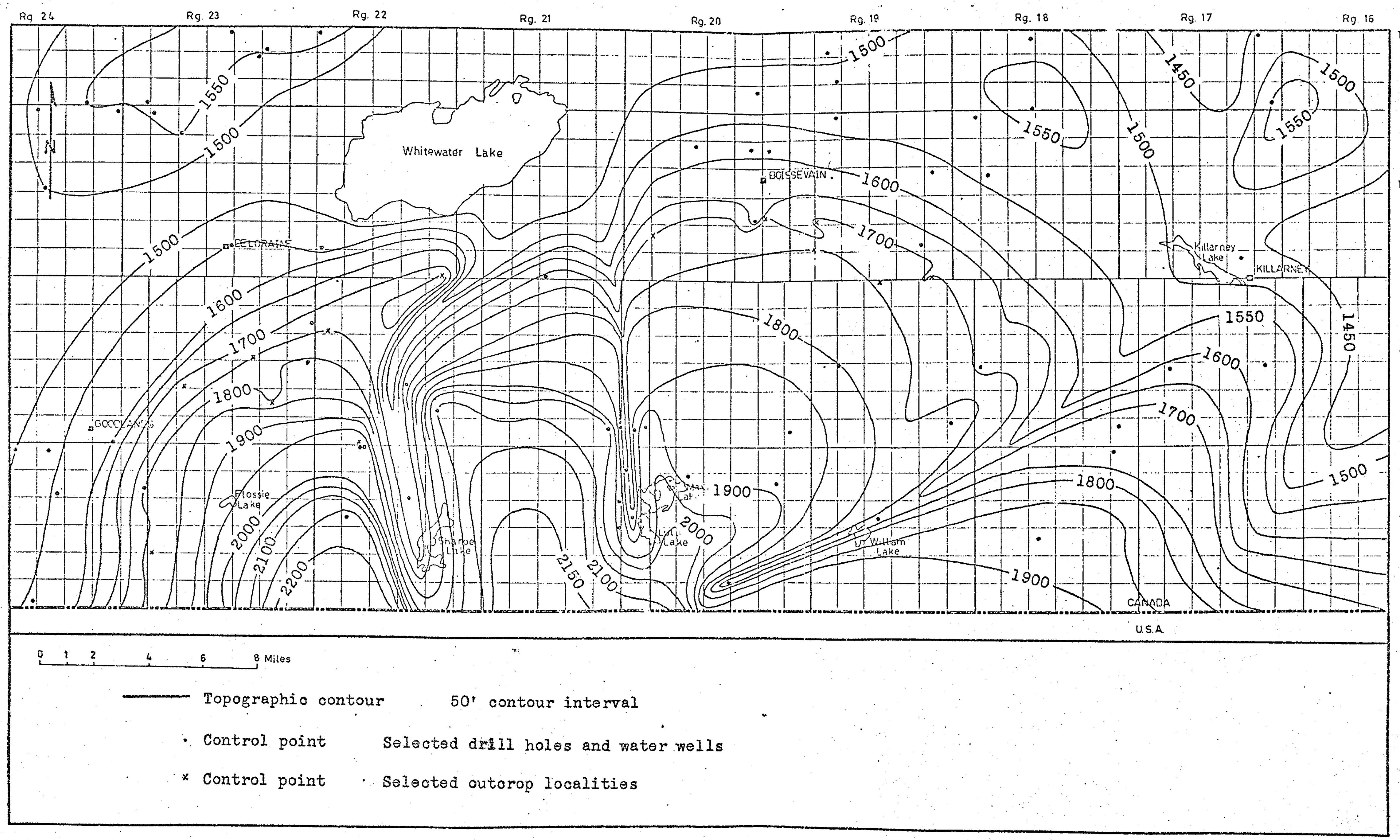


Figure 23. Bedrock topography map of the Turtle Mountain area.

CHAPTER VII

STRUCTURE

STRUCTURAL SETTING

The Turtle Mountain area is located on the east limb of a shallow syncline which plunges gently toward the centre of the Williston Basin. The approximate dip of the upper surface of the Millwood Member is 6 feet per mile; of the Coulter Member, 3 feet per mile; and of the Boissevain Formation, 2 feet per mile. In Saskatchewan and North Dakota, on the west limb of the syncline, the equivalent strata dip southeast (Hansen, 1967). Fraser et al (1935) stated that superimposed upon the regional synclinal structure are irregular minor structures which include abrupt steepening or flattening of the dips, small faults, and minor undulations.

STRUCTURAL DEFORMATION

Possible causes of structural deformation which may have produced the irregular minor structures seen in figures 24-28 are tectonism, salt solution, differential compaction, ice-thrusting, and slumping. The increased control in the SW¼, Tp. 3, Rge. 21 and the W½, Tp. 1, Rge. 21 may account for the contrast between the steep dips within these areas and the gentle regional dip.

The strata between drill holes #17 and #4 are folded

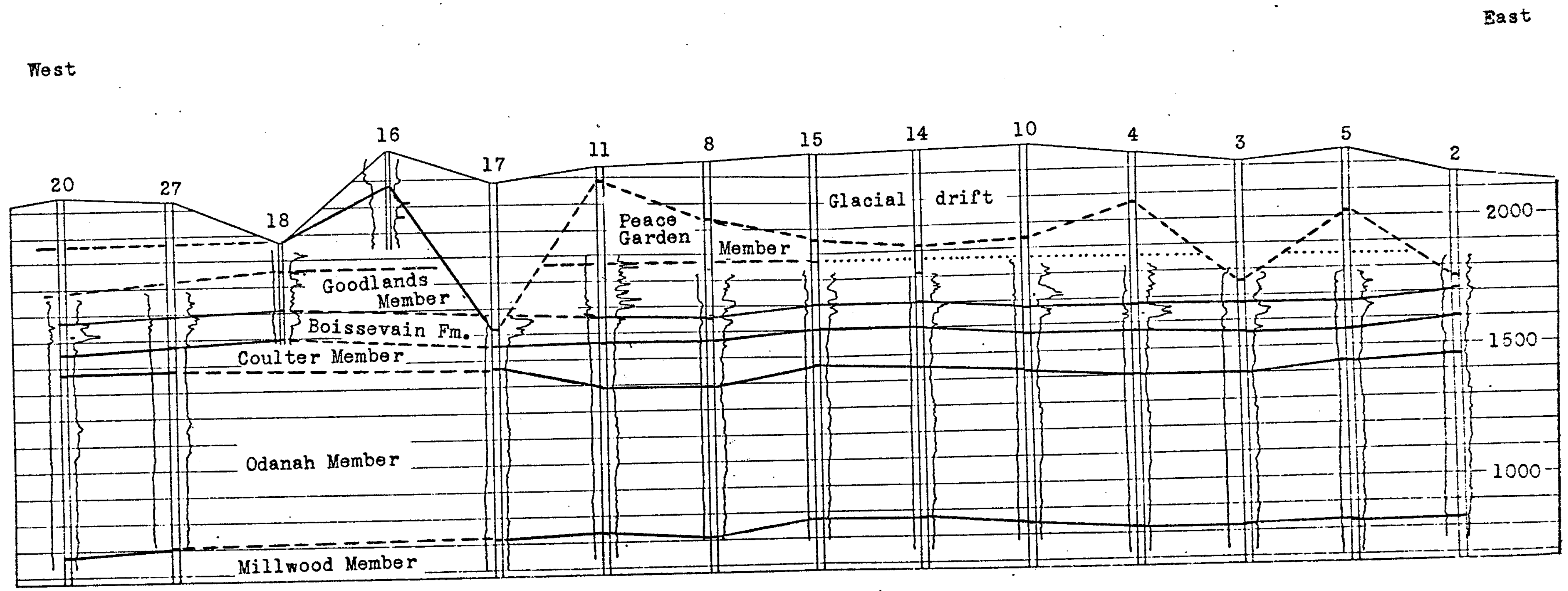


Figure 24. Structural-stratigraphic correlations in the Turtle Mountain area.

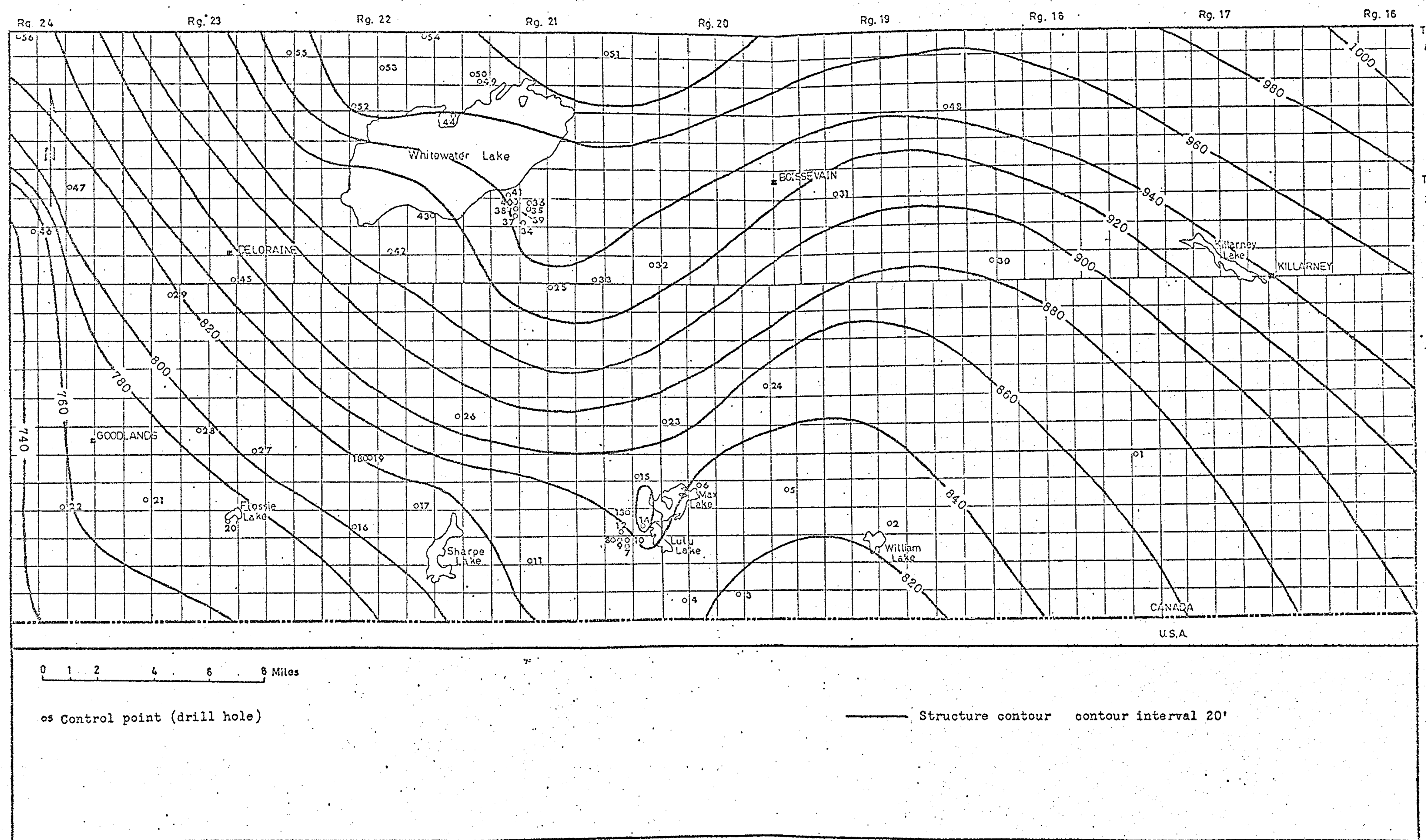


Figure 25. Structure contour map on top of the Upper Cretaceous Millwood Member of the Riding Mountain Formation.

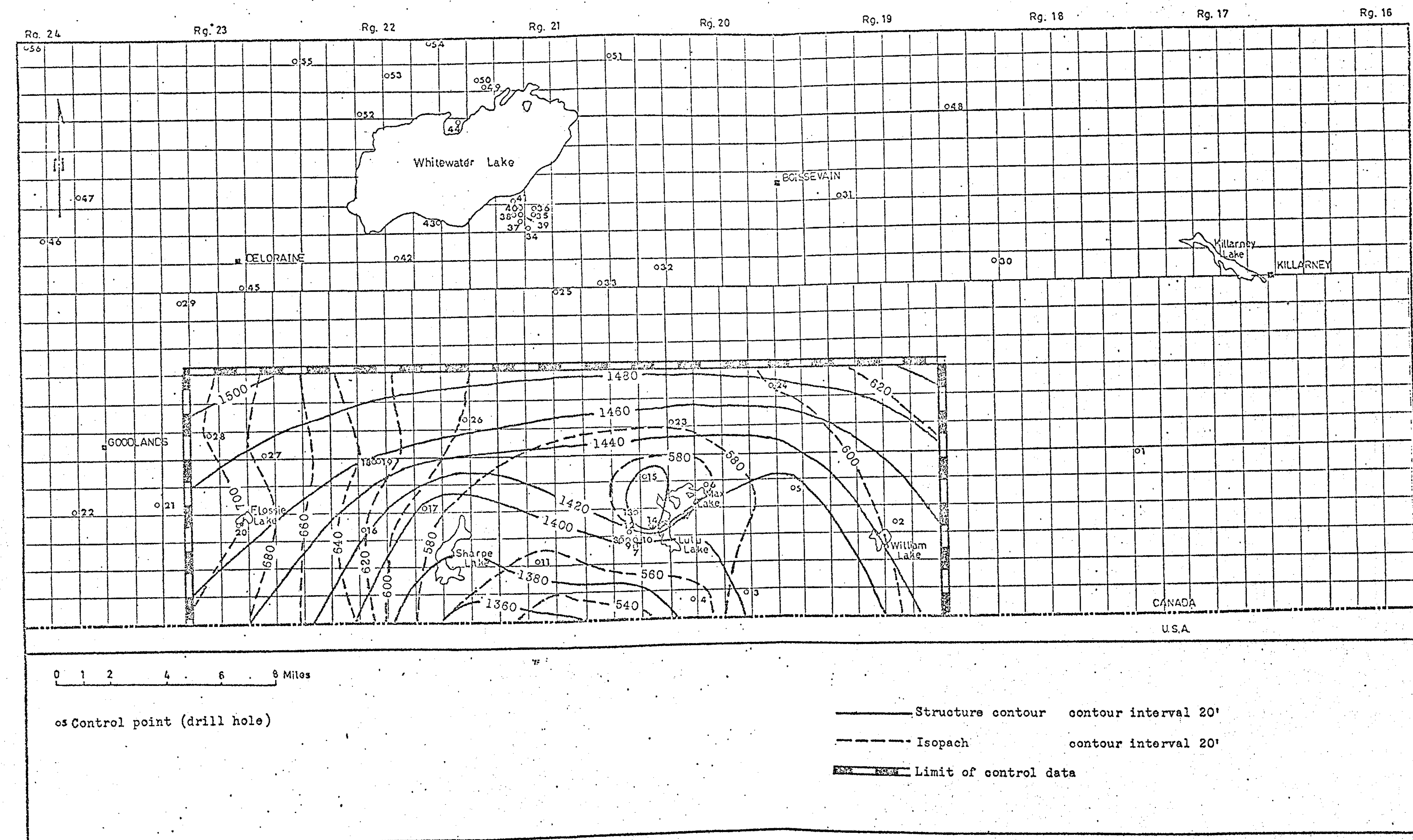


Figure 26. Structure contour and isopach map on top of the Upper Cretaceous Odanah Member of the Riding Mountain Formation.

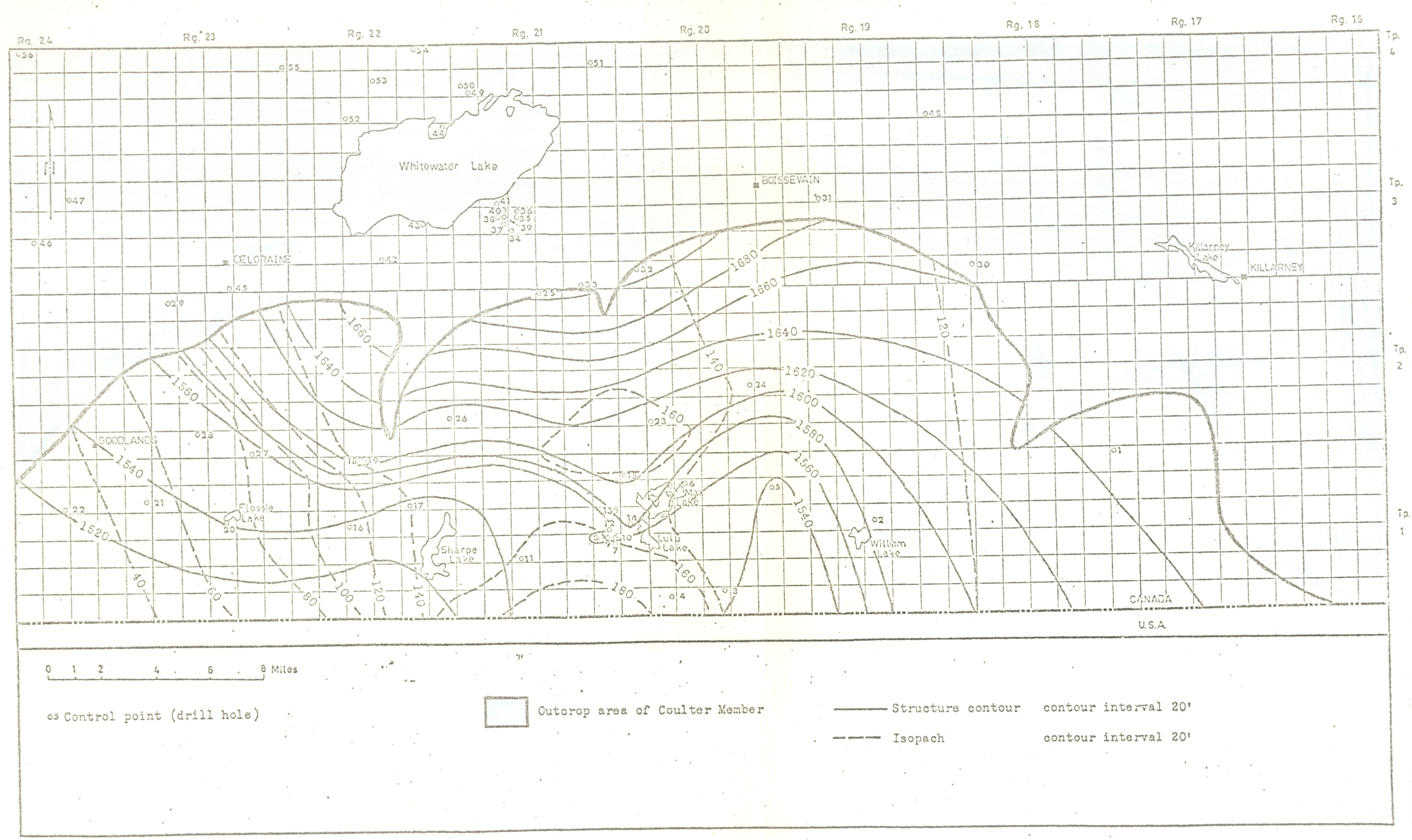


Figure 27. Structure contour and isopach map on top of the Upper Cretaceous Coulter Member of the Riding Mountain Formation.

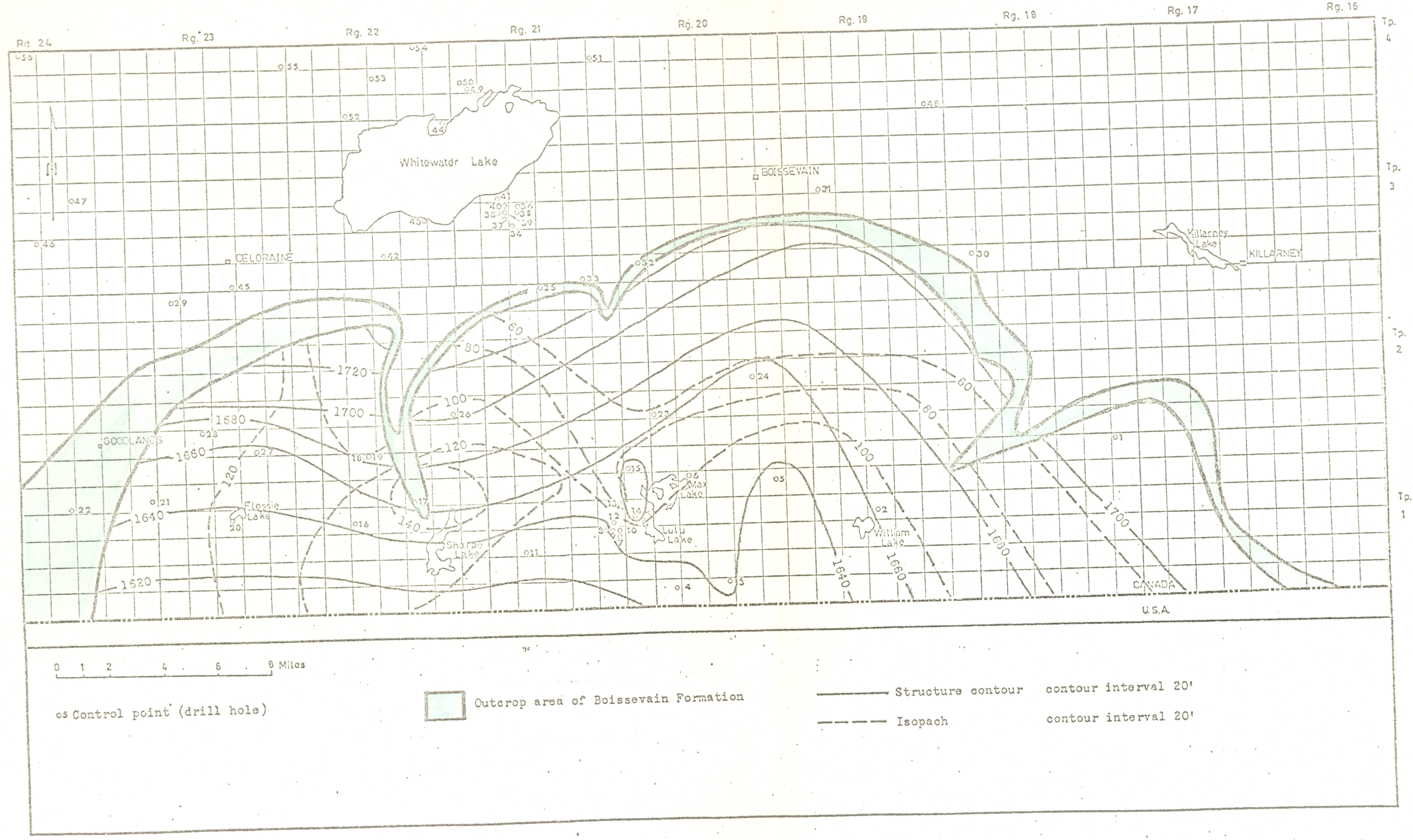


Figure 28. Contour map of the Upper Cretaceous Boissevain Formation erosion surface and thickness remaining.

into a syncline-anticline pair with a structural relief of approximately 50 feet (Fig. 24). Tectonic deformation in the Precambrian basement may account for this gentle flexure. Laird (1964) placed the junction of the Churchill, Peace River, and Superior Precambrian Provinces on the west side of the study area. Movements along their boundaries could have resulted in structural deformation of the overlying sediments.

Solution of salt beds underlying the study area is another possible cause of structural deformation. The Devonian Prairie Evaporite is believed to have once underlain the study area before it was dissolved (H. R. McCabe and B. B. Bannatyne, Manitoba Mines Branch, personal communication, 1973). Slow collapse would have produced deformation of the overlying strata.

A third cause may be the differential compaction of sediments underlying the study area. A total of 3000 feet of shale and sandstone were deposited upon the Paleozoic carbonate sequence of sediments (McCabe, 1963) and since the end of the Paleocene some compaction would have occurred.

Several ice sheets overrode this area (Halstead, 1959) and their weight may have added to the differential compaction.

Any or all of the above causes may have produced the syncline-anticline pair. A complete study of the Paleozoic to Cenozoic sequence of strata should be made to determine which cause predominated.

Disturbed bedrock outcrops 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 in figure 27. Also, in drill hole #28, the sediments of the Turtle Mountain Formation lack bedding planes and instead have fractures at 45 to 60 degree to the horizontal. Faulting, ice-thrusting, and/or slumping can usually account for these irregular structures.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

The following is a brief summary which contains conclusions reached as a result of the present work on the strata of the Turtle Mountain study area.

1. The Riding Mountain Formation, not exposed in situ within the study 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 paper for the clayey silt beds formerly included in the upper part of the Odanah Member.

2. A Late Cretaceous age is assigned to the Riding Mountain Formation on the basis of 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.

3. Only the upper half of the Boissevain Formation outcrops within the northern and central portions of the study area. The lower beds of this half of the Boissevain Formation are exposed on both sides of Highway No. 3, four miles southeast of Boissevain. The upper beds are exposed five miles south of Deloraine.

4. The Boissevain Formation is correlated with the Fox Hills Formation of North Dakota and with the Eastend, Whitemud, and Battle Formation 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 Late Cretaceous, also.

5. 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.

6. 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, (W. G. E. Caldwell, University of Saskatchewan, personal communication, 1971 and 1972), who identified diagnostic foraminifera in drill core from the same formation in the study area.

7. The average sediment-size of the Riding Mountain Formation varies from a silty clay in the Millwood Member to a clay-shale in the Odanah Member to a clayey silt in the Coulter Member. The medium to fine-grained Boissevain sands are generally coarser than those of the Goodlands Member of the Turtle Mountain Formation. Silty clays are the dominant

sediment-size of the Peace Garden Member of the Turtle Mountain Formation.

8. The mineralogy and grain size of the sand units in the Boissevain and Turtle Mountain Formations are similar and probably indicate the same provenance area for these sediments. This, together with the general eastward direction of sediment transport as indicated by crossbedding in the Boissevain Formation, suggests an igneous and metamorphic source area located in Montana.

9. Lignite seams in the Goodlands Member are thin, discontinuous, and irregularly distributed. Only the upper beds of this member have been investigated by lignite exploration companies and additional lignite seams of economic value may underlie the depths at which drilling stopped.

10. The Upper Cretaceous and Paleocene sediments of North Dakota, Saskatchewan, and the Turtle Mountain study area are time-transgressive, becoming gradually younger eastward. Thus, the basal beds of the Goodlands Member may be Late Cretaceous, as are the equivalent beds in North Dakota and Saskatchewan.

11. 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 rivers which emptied into the seaway, formed the margins of the sea during its regression. The basal sediments of the Goodlands Member of the Turtle Mountain Formation, deposited in a 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 study area. The sediments of the Peace Garden Member of the Turtle Mountain Formation were deposited in a shallow water environment during a 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.

12. Structural deformation of Upper Cretaceous and Paleocene sediments in the study area, as shown by a syncline-anticline pair, may have been produced by tectonism, salt solution, differential compaction, ice-thrusting, slumping, or any combination of these causes. A complete study of the Paleozoic to Cenozoic sequence of strata should be made to determine which cause predominated.

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APPENDIXES

APPENDIX A

LIST OF OUTCROP LOCALITIES

Outcrop Locality #	LOCATION L. S.	Sec.	Tp.	Rge.
1	13	6	3	18
2	4	1	3	19
3	14	35	2	19
4	13	35	2	19
5	1	2	3	19
6	16	34	2	19
7	15	34	2	19
8	3	2	3	19
9	4	34	2	19
10	14	34	2	19
11	1	3	3	19
12	2	3	3	19
13	15	33	2	19
14	14	33	2	19
15	4	3	3	19
16	16	32	2	19
17	5	5	3	19
18	1	17	3	19
19	9	7	3	19
20	13	7	3	19
21	13	18	3	19
22	14	12	3	20
23	5	13	3	20
24	13	11	3	20

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

APPENDIX B

SELECTED OUTCROP DESCRIPTIONS

1. Colour descriptions are those of moist sediments.
2. For outcrop locations see figure 3, page 5.

Locality # 2

NE$\frac{1}{4}$ of L.S. 14, Sec. 35, Tp. 2, Rge. 19 WPM, stream cut along drainage ditch on south side of Hwy. 3, about 1$\frac{1}{2}$ miles east of locality #4 . Elev. of top 1730 feet above sea level. (TYPE SECTION FOR BOISSEVAIN FORMATION)

	Thickness (ft)	Sample JB-
BOISSEVAIN FORMATION		
24. Brown fine grained sand	0.8	72
23. Yellow clay	0.1	71
22. Brown fine-grained sand	0.5	70
21. Yellow clay	0.2	69
20. Brown fine-grained sand with minor sandstone	1.0	67 - 68
19. Yellow clay	0.1	
18. Brown massive sand	2.4	66
17. Clay	0.3	65
16. Brown fine-grained sand	0.3	64
15. Orange-brown ironstone concretion layer	0.5	63
14. Brown silty sand	3.7	61 - 62
13. Compacted hard silt, laminated	6.0	59 - 60
12. Brown compacted hard sand, laminated	1.3	57 - 58
11. Orange-brown ironstone concretion layer	0.5	56
10. Brown fine-grained sand	0.5	55
9. Mixed silt and clay	0.5	54
8. Brown fine-grained sand	0.5	53
7. Clay	0.4	52
6. Brown fine-grained sand	1.2	51
5. Hard compacted sand	1.0	50
4. Crossbedded sand with indurated blocks and orange-brown ironstone concreation layers	6.0	43-49
3. Covered interval	3.0	
2. Crossbedded reddish-orange sand	1.2	38
1. Grey crossbedded sand	3.5	37 - 74
Total	35.5	

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 1728 feet above sea level.

	Thickness (ft)	Sample JB-
TURTLE MOUNTAIN FORMATION (GOODLANDS MEMBER)		
25. Light green thin bedded silt, slightly oxidized near top	1.0	130
24. Orange clay with $\frac{1}{4}$ inch ironstone concretion layer near base	0.8	131
23. Grey-buff clay with iron-stained fracture surfaces	2.8	132
22. Olive clay gradually becoming silty downwards	1.0	133
21. Olive clay and yellow silt interlayered, layers 2 inches thick	1.5	134
20. Orange-brown ironstone concretion layer.	0.3	135
19. Olive clay to silt downwards	1.4	136
18. Orange-brown ironstone concretion layer.	0.5	137
17. Yellow clay and tan silt interlayered ..	0.5	138
16. Dark olive clay with iron-stained fracture surfaces	0.6	139
15. Light olive clay with iron-stained fracture surfaces	0.5	140
14. Yellow silt and olive clay interlayered, beds $\frac{1}{4}$ to $\frac{1}{2}$ inch	1.7	141
13. Light and dark olive clay, thin bedded .	0.8	142
12. Orange-brown concretion layer	0.2	143
11. Dark olive clay with blocky iron-stained fracture surfaces and lignite fragments.	1.5	144
10. Olive sand, compacted with silt bands and lignite fragments	3.2	145
9. Olive clay and yellow silt interlayered.	0.8	146
8. Orange-brown ironstone concretion layer.	0.4	147
7. Olive clay and yellow silt interlayered.	1.0	148
6. Dark olive pink clay with plant and lignite fragments, and iron-stained fracture surfaces	1.8	149

	Thickness (ft)	Sample JB -
BOISSEVAIN FORMATION		
5. Olive silt gradational downward into fine-grained olive sand	1.3	150
4. Orange-brown ironstone concretion layer	0.2	151
3. Olive thin bedded silt and sand with minor clay	3.5	152
2. Blue-gray to brown, iron-stained sand with salt and pepper texture	1.0	153
1. Brown oxidized sand, crossbedded with minor sandstone	4.0	154 - 155
Total	32.3	

Locality #30

SE$\frac{1}{4}$ 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 1995 feet above sea level.

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

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, 30 feet west of Hwy. 21.

	Thickness (ft)	Sample JB -
TURTLE MOUNTAIN FORMATION (PEACE GARDEN MEMBER)		
4. Yellow weathering thin bedded to blocky silt with iron-stained fracture surfaces...	3.5	187
TURTLE MOUNTAIN FORMATION (GOODLANDS MEMBER)		
3. Grey iron-stained clay	0.5	188
2. Dark grey, laminated, crossbedded sand and silt, oxidized in part; contains 8" clay tongue	6.0	189 A - B
1. Dark grey carbonaceous clay	3.6	190
Total	13.6	

Locality #43

NE$\frac{1}{4}$ of L.S. 2, Sec. 25, Tp. 1, Rge. 24 WPM, on south side of stream cut about $\frac{1}{4}$ mile west of Hwy. 21 and locality #4 . (TYPE SECTION FOR GOODLANDS MEMBER)

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

APPENDIX C

DRILL HOLE DATA

1. Locations of drill holes are described as L. S. - Sec. - Tp. - Rge., and all are WPM. (Example: 13-36-1-18).

2. Numbers in vertical columns are elevations above sea level in feet and refer to the top of respective formations and members. (Example: Well No. 1, Turtle Mountain Formation, upper surface is 1739 feet above sea level).

Well No.	WELL NAME	Location	Kelley Bushing	Ground Level	Turtle Mountain	Goodlands	Boissevain	Coulter	Odanah	Millwood
1.	GREEN HILLS KILLARNEY	13-36-1-18	1837	1828	1739	-	-	-	-	868
2.	CLEARY CALSTAN PROV.	6-21-1-19	2154	2144	1743	-	1687	1584	1451	825
3.	AMERADA TURTLE MOUNTAIN PROV."M-A"	16-4-1-20	2211	2201	-	-	1661	1551	1401	817
4.	DOME CALSTAN LULU LAKE	9-6-1-20	2249	2238	-	-	1648	1553	1385	828
5.	HOMESTEAD et al TURTLE MTN. No.1	10-26-1-20	2247	2236	1890	-	1648	1538	1414	826
6.	CITIES SERVICE EAST MAX LAKE No.1	14-29-1-20	2233	2223	1893	-	1667	1567	1433	839
7.	ROYALITE TRIAD et al LULU LAKE	9-14-1-21	2260	2248	-	-	1673	1554	1393	830
8.	ROYALITE TRIAD et al LULU LAKE	14-14-1-21	2288	2277	-	-	1662	1577	1407	833
9.	ROYALITE TRIAD et al LULU LAKE No.3	15-14-1-21	2271	2259	-	-	1670	1567	1401	831
10.	ROYALITE TRIAD et al LULU LAKE No.1	16-14-1-21	2296	2286	1915	-	1657	1568	1410	835
11.	NORTHERN NELLIE LAKE	3-17-1-21	2238	2226	-	-	1642	1554	1391	833
12.	ROYALITE TRIAD et al LULU LAKE	2-23-1-21	2283	2271	-	-	1668	1560	1407	839
13.	GEOG. CHAGOS LULU LAKE	16-23-1-21	2336	2323	1885	1823	1674	1599	1445	850
14.	ROYALITE TRIAD LULU LAKE	6-24-1-21	2288	2279	1809	-	1686	1597	1442	866
15.	ROYALITE TRIAD et al MAX LAKE No.1	4-36-1-21	2287	2278	1828	-	1696	1601	1450	856
16.	GEOL. SURV. CAN. 68-33	5-20-1-22	-	2310	2185	-	-	-	-	-
17.	BAYSEL CALSTAN SHARPE LAKE	3-27-1-22	2183	2170	-	-	1612	1528	1396	803
18.	MINES AND NATURAL RESOURCES No.1	15-32-1-22	-	1970	1967	1854	1702	1602	-	-
19.	MANITOBA MINES BRANCH M-3-71	15-32-1-22	-	1968	1964	-	-	-	-	-
20.	CLEARY FLOSSIE LAKE	10-21-1-23	2151	2141	-	-	1657	1540	1469	768
21.	MANITOBA MINES BRANCH M-11-70	8-25-1-24	-	1820	1820	1781	-	-	-	-
22.	PLAZA SOUTH GOODLANDS	1-28-1-24	1635	1624	-	-	-	-	-	759
23.	CHEVRON MAX LAKE	4-7-2-20	2114	2102	-	-	-	-	1447	870
24.	JUMPING POUND-PROSPECT-HIGH CREST et al HORTON	8-15-2-20	1913	1903	-	-	-	-	-	853
25.	MANITOBA MINES BRANCH M-1-71	13-33-2-21	-	1768	-	-	1768	-	-	-
26.	OWEN No.1	8-11-2-22	2124	2118	-	-	-	1615	1465	868
27.	MIDWEST IMPERIAL LIEGE	2-3-2-23	2129	2118	-	-	1675	1558	1478	808
28.	MANITOBA MINES BRANCH M-2-71	15-5-2-23	-	1873	1873	1833	-	-	-	-
29.	CALSTON DELORAINE	10-31-2-23	1646	1634	-	-	-	-	-	815
30.	CALSTON SOUTH NINGA	9-6-3-18	1710	1699	-	-	-	-	-	884
31.	BAYSEL CALSTAN BOISSEVAIN	3-20-3-19	1689	1675	-	-	-	-	-	912
32.	SAMEDAN HAMAL BOISSEVAIN	10-6-3-20	1765	1744	-	-	-	-	-	935
33.	DOME NACO SOUTH WHITEWATER	2-2-3-21	1788	1779	-	-	-	-	-	938
34.	MADISON WHITEWATER	4-16-3-21	1668	1656	-	-	-	-	-	958
35.	CALSTAN WHITEWATER	11-16-3-21	1661	1652	-	-	-	-	-	965
36.	SWEET GRASS WHITEWATER	14-16-3-21	1649	1638	-	-	-	-	-	959
37.	CALSTON WHITEWATER	8-17-3-21	1653	1644	-	-	-	-	-	956
38.	CALSTAN WHITEWATER	9-17-3-21	1658	1649	-	-	-	-	-	957
39.	CALSTAN WHITEWATER	10-17-3-21	1647	1638	-	-	-	-	-	946
40.	CALSTAN WHITEWATER	16-17-3-21	1645	1636	-	-	-	-	-	951
41.	CALSTAN WHITEWATER	2-20-3-21	1638	1628	-	-	-	-	-	952
42.	J.P. OWENS ELLIS	3-10-3-22	1649	1644	-	-	-	-	-	908
43.	SAPPHIRE WEST WHITEWATER	8-14-3-22	1643	1632	-	-	-	-	-	909
44.	CALSTAN WHITEWATER	15-36-3-22	1638	1629	-	-	-	-	-	959
45.	DELORAINE WELL	1-3-3-23	-	1644	-	-	-	-	-	857
46.	CALSTAN IMPERIAL N.GOODLANDS	16-9-3-24	1554	1544	-	-	-	-	-	743
47.	DAKOTA LEIGHTON	5-23-3-24	1594	1582	-	-	-	-	-	812
48.	ORDOCO-BOISSEVAIN	3-1-4-19	1659	1649	-	-	-	-	-	944
49.	CALSTAN SOUTH REGENT	2-7-4-21	1640	1629	-	-	-	-	-	969
50.	CALSTAN SOUTH REGENT	6-7-4-21	1647	1636	-	-	-	-	-	973
51.	B.A.UNION CROLL	4-13-4-21	1646	1637	-	-	-	-	-	993
52.	DOME COX WHITEWATER LAKE	4-4-4-22	1653	1644	-	-	-	-	-	964
53.	IMPERIAL REGENT	12-10-4-22	1656	1645	-	-	-	-	-	971
54.	B.& F. SOUTH REGENT PROV.	15-14-4-22	1660	1648	-	-	-	-	-	977
55.	IMPERIAL DAND	1-13-4-23	1650	1639	-	-	-	-	-	949
56.	H.W. & L. MEDORA PROV.	14-16-4-24	1518	1505	-	-	-	-	-	825

APPENDIX D

SELECTED DRILL HOLE LOG DESCRIPTIONS

1. Colour descriptions are those of dry sediments. Colours of wet sediments follow immediately afterward and are enclosed in parantheses.

2. For drill hole locations see figure 3, page 5.

Drill Hole #16

L.S. 5, Sec. 20, Tp. 1, Rge. 22 WPM, Geological Survey of Canada borehole 68-33, surface elev. 2310 feet above sea level, first 125 feet is glacial drift. (UPPER PART OF COMPOSITE TYPE SECTION FOR THE PEACE GARDEN MEMBER)

Depth in feet

TURTLE MOUNTAIN FORMATION
Peace Garden Member

125-141	Sand, very fine grained, quartzose, micaceous, non-calcareous, iron-stained, olive, 2.5Y5.5/2 (4.2Y5/4).
141-157	Silt, fine grained, micaceous, grey, 2.5Y7/2.
158-180	Clay, silty, micaceous, light grey, 5Y7/2 (4.2Y4/2), foram Polymorphina sp. at 170 feet.
188-220	Sand, fine grained, iron-stained, olive, 5Y6/3 (5Y3/2) interbedded with clay, silty, olive, 2.5YN3/.
221-230	Clay, silty, kaolinitic, grey, 5Y6/1 (10YR2/1).
231-285	Sand, fine grained, micaceous, grey, 5Y6/1 (5Y3/1).
290-300	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	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 #18

L.S. 15, Sec. 32, Tp. 1, Rge. 22 WPM, Manitoba Mines and Natural Resources borehole #1, surface elev. 1970 feet above sea level. (LOWER PART OF COMPOSITE TYPE SECTION FOR THE PEACE GARDEN MEMBER)

Depth in feet	
	TURTLE MOUNTAIN FORMATION Peace Garden Member
3-19	Sand, silty, very fine to medium grained, micaceous, grey, 5Y6/1 (5Y3/2).
21-40	Silt, clayey, very fine grained, micaceous, grey, 5Y5/1 (5Y3/1).
45-80	Sand, fine grained, non-calcareous, grey, 5Y5.5/1 (5Y4/2.5).
81-95	Silt, clayey, very fine grained, grey 5Y5/1 (5Y2/1).
96-105	Clay, silty, grey, 5Y5/1 (5Y2/1).
197-111	Sand, very fine grained, grey, 5Y5.5/1.
	TURTLE MOUNTAIN FORMATION Goodlands Member
113-115	Clay, silty, grey, 5Y6/1 (5Y3/1), bentonitic at 114 feet.
117-125	Sand, very fine grained, grey, 5Y5/1 (5Y3/1).
126-140	Silt, very fine grained, grey, 5Y6/1 (5Y3/2).
141-180	Sand, very fine grained, upper part calcareous, grey, 5Y6/1 (5Y4/2), foram <u>Protelphidium</u> at 174 feet.
183-192	Silt, very fine grained, light grey, 5Y6/1 (3.2Y3/2).

195-201	Sand, very fine grained, grey, 5Y6/1 (3.2Y3/2).
203-230	Silt, very fine grained, light grey, 5Y6/1 (5Y3/1), carbonaceous and kaolinitic in places.
231-234	Clay, silty, carbonaceous, grey, 5Y2/1, minor pyrite.
234-235	Lignite, black 2.5YN2/0.
236	Silt, very fine grained, light grey, kaolinitic, 5Y7/1.
237-246	Sand, very fine grained, light grey, 5Y6/1 (5Y3.5/1).
249-252	Clay, silty, light grey, 5Y6/1 (5Y3.5/1).
253	Lignite, black, 2.5YN20.
255-258	Clay, silty, olive, 5Y4.5/1 (5Y2/1), with thin lignite fragments.
259-264	Silt, medium grained, olive, 5Y5/1 (5Y2/1.5).

BOISSEVAIN FORMATION

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

RIDING MOUNTAIN FORMATION
Coulter Member

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

Drill Hole #19

L. S. 15, Sec. 32, Tp. 1, Rge. 24 WPM, Manitoba Mines

Branch drill hole M-3-71, surface elev. 1964 feet above sea level.

Depth in feet

TURTLE MOUNTAIN FORMATION
Peace Garden Member

5.0-10.0	Clay, light grey.
10.0-20.0	Silt, fine grained, greenish-grey, minor clay.
20.0-43.3	Clay, greenish-grey, minor silt. (From 25-43 feet, forams Nodosaria sp. and Guttulina sp.).
43.4-77.9	Sand, medium grained, grey, minor clay.

Drill Hole #21

L. S. 8, Sec. 25, Tp. 1, Rge. 24 WPM, Manitoba Mines Branch drill hole M-11-70, surface elev. 1820 feet above sea level. Peace Garden - Goodlands contact.

Depth in feet

TURTLE MOUNTAIN FORMATION
Peace Garden Member

7.4-10.8	Silt, clayey, coarse grained and very fine grained, grey (olive), partly oxidized to yellow, lignite flecks, biotite flakes.
10.8-32.4	Clay, silty, becoming siltier downwards, grey (olive), very finely laminated, lignite fragments, muscovite flakes, micro-fossils: ostracods, forams, echinoderms, (From 10.8 to 38.75 feet, forams *Protelphidium* cf. *sublaeve*, *Anomalinoides* sp., *Haplophragmoides* sp., and *Ammodiscus* sp.).
32.4-38.75	Silt, greenish-grey (olive), finely laminated, lignite fragments, micro-fossils: ostracods, forams, echinoderms.

TURTLE MOUNTAIN FORMATION
Goodlands Member

38.75-45.0	Clay, buff becoming dark brown (dark olive) downwards, very finely laminated, large lignite fragments, (From 38.75 to 98.8 feet, forams *Haplophragmoides* sp. and *Saccammina* sp.).
45.0-45.8	Clay, silty, grey, very finely laminated.
45.8-46.3	Lignite, black, poorly developed thin laminations.

46.3-60.0	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	Silt and clay, interlayered, dark grey (black), carbonaceous, very finely laminated.
64.25-69.0	Sand, fine to medium grained, dark greyish-green (olive), muscovite fragments.
69.0-74.2	Silt, fine grained, dark greyish-green (olive).
74.2-74.4	Clay, dark grey (dark grey).
74.4-77.3	Silt, fine-grained, dark grey (olive), with irregular blebs of silt, medium grained, light grey.
77.3-87.0	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	Clay, minor silt, light grey (dark olive), manganese stains.
88.6-92.75	Lignite, black, finely laminated.
92.75-93.75	Sand (slump?), light grey (light olive).
93.75-96.3	Lignite, black, finely laminated.
96.3-97.0	Clay, silty, brownish-grey (light olive).
97.0-98.8	Sand, light grey (light olive), laminated.

Drill Hole #25

L. S. 13, Sec. 33, Tp. 2, Rge. 21 WPM, Manitoba Mines Branch drill hole M-1-71, surface elev. 1768 feet above sea level.

Depth in feet

BOISSEVAIN FORMATION

0.0-2.0	Sand, light grey (grey).
2.0-4.75	Clay, buff (yellow).
4.75-12.3	Silt, light buff (yellow) with minor two ironstone layers, brown.
12.3-26.0	Sand, cream-coloured, salt and pepper texture, minor clay, pyrite.
26.0-30.0	Clay (slumped?), buff (yellowish-green).
30.0-44.4	Sand, fine grained, light bluish-grey (blue), becoming clayey near base with minor thin brown layers.
44.5-52.0	Sand, medium grained, grey (blue) with minor sandstone fragments.
52.0-55.2	Clay, silty, dark greenish-brown.
55.2-57.3	Sand and clay, interlayered, buff.
57.3-62.0	Clay, buff (greyish-green).

Drill Hole #28

L. S. 15, Sec. 5, Tp. 2, Rge. 23 WPM, Manitoba Mines Branch drill hole M-2-71, surface elev. 1873 feet above sea level. Peace Garden - Goodlands contact.

Depth in feet

TURTLE MOUNTAIN FORMATION
Peace Garden Member

1.2-2.9	Siltstone, clayey, buff, oxidized, manganese stains, lignite fragments.
2.9-26.9	Clay and silt, interlayered, dark grey, finely laminated, mottled due to oxidation, abundant lignite and minor plant fragments. (From 6 to 31 feet micro-fossils: diatoms and seed cases).
26.9-31.0	Silt, minor clay, grey, partly oxidized to yellow, finely laminated.
31.0-34.0	Clay, silty, grey. (From 31 to 36 feet foram *Protelphidium* cf. *sublaevis*).
34.0-39.5	Silt, grey, oxidized to yellow in lower part, finely laminated.

TURTLE MOUNTAIN FORMATION
Goodlands Member

39.6-42.0	Clay, brownish-grey, finely laminated.
42.0-43.0	Clay, light grey.
43.0-43.3	Clay-shale lignitic.
43.3-52.9	Silt, clayey, dark grey, lignite fragments.
52.9-70.7	Silt and siltstone, grey, finely laminated.
70.7-73.9	Silt and clay, buff, oxidized.

73.9-77.0	Silt, grey, muscovite flakes. (From 75 to 100 feet, micro-fossil: diatoms, spores and fragmental ostracods).
77.0-80.0	Silt, dark grey, massive, lignite fragmehts.
80.0-82.0	Clay-shale, dark grey, fractured 60° to horizontal, bedding parallel to fractures.
82.0-83.9	Silt, dark grey, 60° fractures.
83.9-85.0	Sand (slump?), light grey.
85.0-87.9	Clay-shale, minor silt, grey, 60° fractures.
87.9-95.9	Silt, dark grey, massive.
95.9-99.5	Silt, clay, sand (slump?), light grey.
99.5-100.9	Silt, dark grey. (From 100 to 106 feet, foram Haplophragmoides spp.).
100.9-102.0	Clay, grey and sandstone fragments (slump?).
102.0-106.3	Silt, light grey, lignite fragments.
106.3-108.0	Clay, silty (slump?), light grey.
108.0-110.0	Silt, carbonaceous, horizontal, laminations.
110.0-111.0	Silt and sand, fine grained, interlayered, light grey.
111.0-112.3	Sand, dark grey and large siltstone fragments (slump?).
112.3-112.75	Clay, silty, light grey.
112.75-113.2	Lignite, dark black and oily residue?

APPENDIX E

COMPUTATION OF MEAN PREFERRED CROSSBEDDING ORIENTATIONS FROM LOCALITIES #3, #19, AND #24.

TABLE 1

COMPLITATION OF MEAN PREFERRED CROSS-BEDDING ORIENTATION BY RADIUS-VECTOR SUMMATION METHOD FOR OUTCROP AT NE$\frac{1}{4}$ L.S. 14, Sec. 35, Tp. 2, Rge. 19 WPM

Locality # 3

Azimuth Classes	Midpoint θ	n(θ)	sin θ	n(θ) sin θ	cos θ	n(θ) cos θ
15-45	30	5	.5000	2.5000	.8660	4.3300
45-75	60	1	.8660	.8660	.5000	.5000
75-105	90	1	1.0000	1.0000	.0000	
105-135	120	1	.8660	.8660	-.5000	-.5000
135-165	150					
165-195	180					
195-225	210					
225-255	240					
255-285	270					
285-315	300					
315-345	330	2	.5000	1.0000	.8660	1.7320
345-15	360	3	.0000		1.0000	3.0000
Total				5.2320		9.0620

$$\bar{x} = \arctan \frac{5.2320}{9.0620}$$

$$= \arctan 0.5774$$

$$= 030^\circ$$

TABLE 2

COMPLITATION OF MEAN PREFERRED CROSS BEDDING ORIENTATION BY RADIUS VECTOR SUMMATION METHOD FOR OUTCROPS
L.S. 9, Sec. 7, Tp. 3, Rge. 19 WPM to
NE$\frac{1}{4}$ L.S. 10, Sec. 7, Tp. 3, Rge. 19 WPM

Locality # 19

Azimuth Classes	Midpoint θ	n(θ)	sin θ	n(θ) sin θ	cos θ	n(θ) cos θ
15-45	30					
45-75	60	3	.8660	2.5980	.5000	1.5000
75-105	90	5	1.0000	5.0000	.0000	
105-135	120	2	.8660	1.7320	-.5000	-1.0000
135-165	150	4	.5000	2.0000	-.8660	-3.4640
165-195	180					
195-225	210	2	.5000	1.0000	-.8660	-1.7320
225-255	240					
255-285	270					
285-315	300					
315-345	330					
345-15	360					
Total				12.3300		-3.6960

$\overline{x} = -\arctan \frac{12.3300}{3.6960}$

$= -\arctan\ 3.3360$

$= -73^\circ$ and -253°

from 287° and 107° 107° selected

TABLE 3

COMPLITATION OF MEAN PREFERRED CROSS BEDDING ORIENTATION BY RADIUS VECTOR SUMMATION METHOD FOR OUTCROP AT SE$\frac{1}{4}$ L.S. 13, Sec. 11, Tp. 3, Rge. 20 WPM

Locality # 24

Azimuth Classes	Midpoint θ	n (θ)	sin θ	n(θ) sin θ	cos θ	n(θ) cos θ
15-45	30	2	.5000	1.0000	.8660	1.7320
45-75	60	2	.8660	1.7320	.5000	1.0000
75-105	90	1	1.0000	1.0000	.0000	
105-135	120	5	.8660	4.3300	-.5000	-2.5000
135-165	150					
165-195	180					
195-225	210					
225-255	240					
255-285	270					
285-315	300	1	-.8660	-.8660	.5000	.5000
315-345	330	2	-.5000	-1.0000	.8660	1.7320
345-15	360	2	.0000		1.0000	2.0000
Total				6.1960		4.4640

$$\overline{x} = \arctan \frac{6.1960}{4.4640}$$
$$= \arctan 1.3880$$
$$= 054^{\circ}$$