GEOLOGY AND LANDFORMS OF MANITOBA

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The geological history of Manitoba spans more than 3.5 billion years. By studying the rocks of the province, geologists can deduce what the landscape of Manitoba was like millions, or hundreds of millions, of years ago. At times seas covered the whole province; at other times the province was covered by up to 1.5 km of ice. There were volcanic islands in the area that is now Flin Flon, and two continents collided in the Thompson area. Rocks can reveal whether it was warm or cold and indicate when our province was close to the equator. Also, by studying fossils we can even deduce something about the animals that lived here long before there were people.

Geologists partition the history of the earth in the same way that historians subdivide and name different periods of human history, such as the Bronze Age and the Renaissance. In the earth's history, the two major time divisions, termed *eons*, are the Precambrian (the time when there was little living) and the Phanerozoic (the time when evidence suggests life was abundant). Each of these eons was hundreds of millions of years long, so they are further divided into *eras:* the Precambrian is divided into the Archean and Proterozoic, and the Phanerozoic is divided into the Paleozoic (the time when early forms of life existed in the seas and then spread onto the land); the Mesozoic (often called "the age of reptiles"); and the Cenozoic (the time when warm-blooded animals — mammals — became dominant) (Table 2.1). The Phanerozoic eras are further subdivided into *periods*. Manitoba's geological history is so rich that much of the geological time scale is represented in our rocks.

The rocks and minerals that formed at different times in the past occur in different places throughout the province (Figure 2.1). The oldest rocks in Manitoba were formed during the Precambrian eon, and are exposed in the Precambrian Shield that stretches from southeastern Manitoba northwestward to Saskatchewan and the Northwest Territories. Younger sedimentary rocks of the Phanerozoic eon are found in the southwest of the province and in the Hudson Bay Lowlands, in the northeast.

In south-central Manitoba, rocks deposited in shallow seas during several periods of the Paleozoic are found; these periods are, from oldest to youngest, the Ordovician, Silurian, Devonian, and Mississippian. For the Mesozoic era, we have rocks deposited during the Jurassic and Cretaceous periods, and in some locations these are overlain by Cenozoic rocks from the Tertiary period. Of most recent origin are glacial sediments from the Quaternary period that cover much of the province.

HISTORY IN THE ROCK RECORD

Precambrian

Rocks in the Precambrian Shield are predominantly igneous in origin but include areas of metamorphosed volcanic and sedimentary rocks called *greenstone belts*. Broad areas of igneous rocks were formed by the cooling and crystallization of extremely hot melted rock material called *magma*. After the old rocks of the Precambrian Shield were formed, they were buried deeply in the earth and changed by heat and pressure to metamorphic rocks. However, this explanation is oversimplified; the rocks are able to tell us more about the distant past. They tell of continents colliding, volcanoes erupting, and great wandering rivers in mountains that may have been as majestic as the Rockies today. At times the area that is now Manitoba was even in a different global position from that which it occupies today.

Archean

The rock record of Manitoba starts in the Precambrian eon about 3.5 billion years ago. In the eastern part of the Precambrian Shield, in the area known as the Superior Geologic Province, rocks were formed during the Archean era and are more than 2.5 billion years old. Early in the Archean, from about 2.7 to 3 billion years ago, there was no large continent as there is today. At that time ocean basins existed with black pillowed basalts[1] being formed along ocean ridges, much like mid-ocean spreading ridges found in the Atlantic and Pacific today. Also, chains of volcanic islands known as island arcs were being formed. Remnants of rocks formed during these times are preserved in the greenstone belts. Very old areas of continental granites are preserved, indicating that some continental land masses must also have existed in the early Archean era. Very slowly, the forces that move continents today were at work moving the various segments of the crust together to form the Superior Craton (Continent) by about 2.7 billion years ago.

Geological forces are imperceptibly slow but never idle, and 2.7 billion years ago a major geological event called an *orogeny* began. During the next 60 million years high mountains were thrust up and great rivers ran through deep valleys. Gravel and sand deposited by these rivers are preserved in some of the greenstone belts. Also during this period of mountain building, called the Kenoran Orogeny, many of the granitic rocks of the Superior Geologic Province were formed, and tremendous heat and pressure metamorphosed the rocks beneath the high mountains.

Table 2.1 Geological Formations of Manitoba

AGE*	ERA	PERIOD	EPOCH	FORMATION	MEMBER	MAX THICK (m)	BASIC LITHOLOGY
	CENOZOIC	QUATERNARY	RECENT				Top soil, dune sands
			PLEISTOCENE	GLACIAL DRIFT		140	Clay, sand, gravel, boulders, peat
50		TERTIARY	PLIOCENE MIOCENE OLIGOCENE EOCENE				
65			PALEOCENE	TURTLE MTN.		120	Shale, clay and sand. Lignite beds — located only in Turtle Mountain
	MESOZOIC	CRETACEOUS	UPPER CRETACEOUS	BOISSEVAIN		30	Sand and sandstone, greenish grey — located only in Turtle Mountain
				RIDING MTN.	COULTER ODANAH MILLWOOD	310	Grey shale — non-calcareous, local ironstone, bentonite near base, gas found
				VERMILION RIVER	PEMBINA	155	Shale, dark grey carbonaceous non-calcareous; bentonite bands
					BOYNE		Shale, grey speckled calcarous, bentonitic; slightly petroliferous
					MORDEN		Shale, dark grey non-calcareous, concretions, local sand and silt
				FAVEL		40	Grey shale with heavy calcereous specks, bands of limestone and bentonite
100			LOWER CRETACEOUS	ASHVILLE ASHVILLE SAND		115	Shale, dark grey non-calcareous, silty quartz sand or sandstone
				SWAN RIVER		75	Sandstone and quartz sand, pyritic shale — grey non-calcareous
		JURASSIC	UPPER JURASSIC	WASKADA		200	Banded green shale and calcareous sandstone
150				MELITA			Bands of limestone, vari-coloured shale
			MIDDLE JURASSIC	RESTON		45	Limestone, buff, and shales, grey
				AMARANTH	UPPER EVAPORITE	45	White anhydrite and/or gypsum and banded dolomite and shale
200					LOWER RED BEDS	40	Red shale to siltstone, dolomitic, oil producing
250		TRIASSIC PERMIAN PENNSYLVANIAN		ST. MARTIN COMPLEX		300	Carbonate breccia, trachyandesite (crypto-explosion structure) Permian-Triassic (?)
300		MISSISSIPPIAN		MADISON GROUP: CHARLES		20	Massive anhydrite and dolomite
				MADISON GROUP: MISSION CANYON		120	Limestone, light buff, oolitic, fossiliferous fragmental, cherty, bands of shale and anhydrite, oil producing
				MADISON GROUP: LODGEPOLE		185	Limestone and argilaceous limestone, light brown and redish mottled. Zones of shaly, oolitic, crinoidal and cherty limestone Oil producing
				BAKKEN		20	Two black shale zones separated by siltstone. Oil show
350	PALEOZOIC	DEVONIAN		QU'APPELLE GROUP: LYLETON		35	Red siltstone and shale, dolomitic
				SASK GROUP: NISKU		40	Limestone & dolomite, yellow-grey fossiliferous, porous, some anhydrite
				SASK GROUP: DUPEROW		170	Limestone and dolomite, argilaceous and anhydritic in places
				MAN GROUP: SOURIS RIVER (1st RED)		120	Cyclical shale, limestone and dolomite, anhydrite
				MAN GROUP: DAWSON BAY (2nd RED)		65	Limestone and dolomite, porous, anhydrite — local shale red & green
				ELK POINT GROUP: PRAIRIE EVAP.		120	Salt, potash and anhydrite, dolomite interbedded
				ELK POINT GROUP: WINNIPEGOSIS		75	Dolomite, light yellowish brown, reefy
				ELK POINT GROUP: ELM POINT			Limestone, fossiliferous high-calcium
400				ELK POINT GROUP: ASHERN		12	Dolomite and shale, brick red
		SILURIAN		INTERLAKE GROUP		135	Dolomite, yellowish-orange to greyish-yellow, fossiliferous silty zones
		ORDOVICIAN		STONEWALL		15	Dolomite, greyish-yellow, bedded
				STONY MOUNTAIN	WILLIAMS GUNTON	30	Dolomite, yellowish-grey; shaly
					PENITENTIARY		Dolomite, dusky yellow, fossiliferous
					GUNN	20	Shale, red-green, fossiliferous, limestone bands
450				RED RIVER	FORT GARRY SELKIRK CAT HEAD DOG HEAD	170	Dolomitic limestone, mottled, and dolomite
				WINNIPEG		60	Shale, green, waxy; sandstone interbedded
							Sand and sandstone, quartzose
500		CAMBRIAN		DEADWOOD		60	Glauconitic sandstone and siltstone, and shale; green-grey to black; very edge of S.W. Manitoba only
550							
	PRECAMBRIAN (EON)						Acid and basic crystalline and metamorphic rocks.

*millions of years before present

Source: *Geological Highway Map of Manitoba 1994*, 2nd ed. (Winnipeg: Manitoba Minerals Division, 1994).

Thus, by the end of the Archean, 2.5 billion years ago, the Superior Province of Manitoba had changed from oceanic basin and islands in some unnamed sea — similar to the East Indies of today — into a continent with mountains along the western edge, near where Thompson is now located.

Proterozoic

The Proterozoic era started some 2.5 billion years ago. There is evidence that a portion of the western margin of the Superior Geologic Province was rifted away westward about 2.2 billion years ago, creating an oceanic basin in the same fashion that the Atlantic Ocean has opened and spread to separate the Americas from Africa and Europe. Within this new ocean the cycle of ocean floor spreading, island arc de-

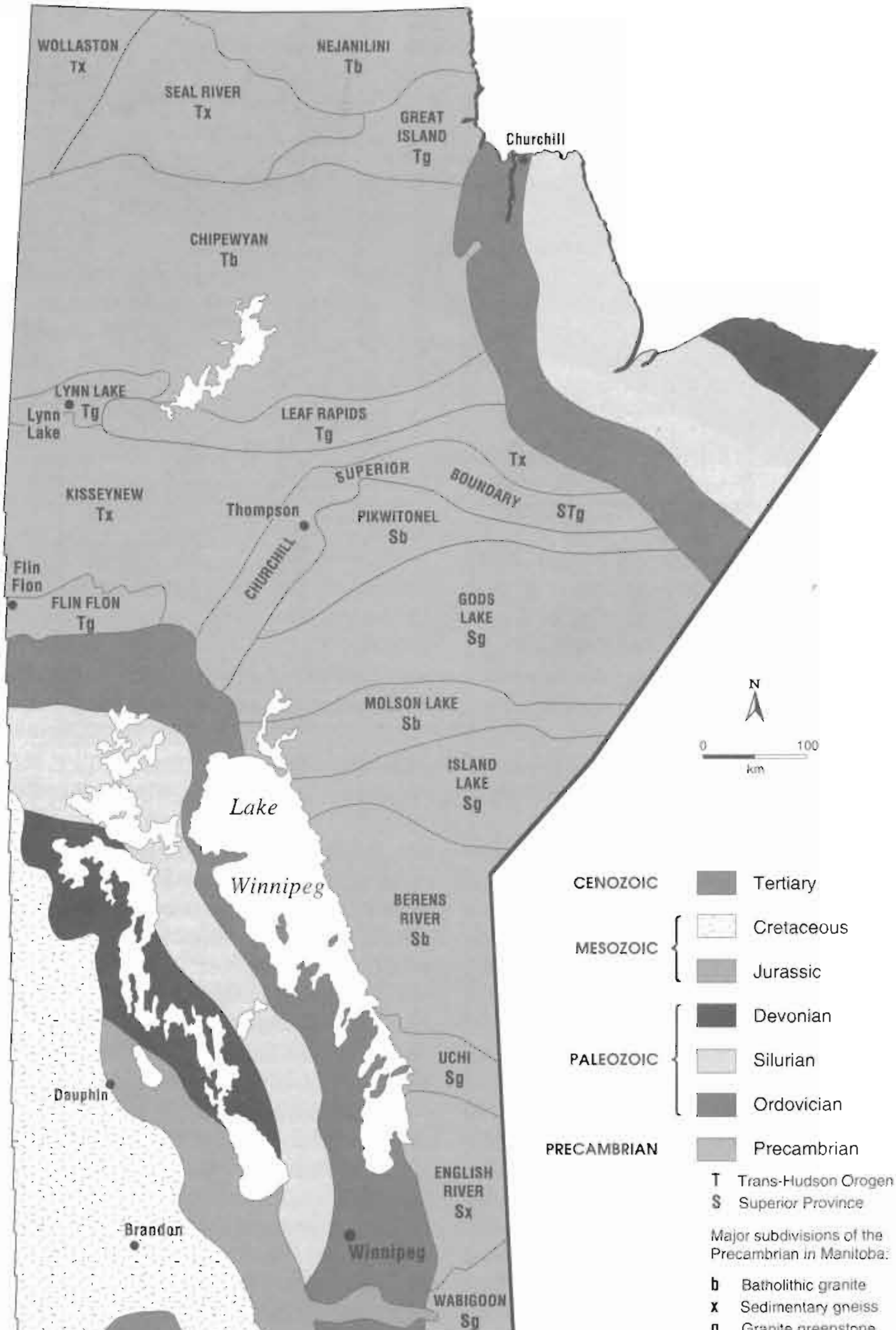

Figure 2.1 Generalized Geology of Manitoba (Source: Modified from Geological Highway Map of Manitoba 1994, *2nd ed. [Winnipeg: Manitoba Minerals Division, 1994])*

velopment, and sedimentation began again.

The famous Thompson Nickel Belt was forming along the west coast of the Superior Continent. The sands of the day were sitting on the granites and gneisses of the worn-down mountains from the Kenoran time about 600 million years before. Out in the seas to the west, deposits of mud and sand were building up on the bottom, and new chains of volcanic islands were being formed in the basin. During this time the Flin Flon, Lynn Lake, and Thompson ore deposits were formed.

As in the Archean, pressures built up and another old Archean continent to the northwest drifted towards the Superior Craton. In the same way that India ran into Asia and pushed up the Himalayas, the Hearne-Rae Craton squeezed the sediments, volcanics, and ore deposits formed during the Proterozoic and created a chain of mountains. Again the rocks were melted and metamorphosed during another mountain-building event, called the Trans-Hudson Orogeny, which closed the Precambrian eon in Manitoba.

The geological cycle of continental rifting and ocean floor spreading, closure of the ocean basin by subduction of the oceanic plate, and continental collision concurrent with a mountain-building event has been repeated many times throughout geological history. It has now come to be known as the Wilson Cycle, after the famous Canadian geologist J. Tuzo Wilson, whose pioneering work led to the theory of plate tectonics.

Phanerozoic

By the beginning of the Phanerozoic eon, the area that is now Manitoba had been eroded down to a relatively flat to undulating peneplain (almost a plain) located in the centre of the continent. Sediments deposited since then have not been disturbed except by periods of erosion when the land was above sea level, because Manitoba, unlike the mountainous areas of Alberta and British Columbia, has not been disturbed by a more recent orogeny. This has resulted in the preservation of abundant fossils and sedimentary features in the rocks of the Paleozoic era.

All the younger (Phanerozoic) rocks in Manitoba are sedimentary. There are two types of sedimentary rocks: clastic rocks and chemical rocks. A clastic rock is formed when an older rock is (1) broken into fragments, (2) transported by water or air, (3) deposited to form a sediment such as a beach sand, and then (4) lithified (made into a solid rock), typically by cementation. Clastic rocks are widespread in southwestern Manitoba.

A chemical rock forms by precipitation of atoms or molecules from a solution within an ocean or lake. This can occur when organisms such as coral or clams make their shells; alternatively, if too much of a certain substance is dissolved in the solution, it precipitates to form a rock. Chemical rocks are abundant in the Manitoba Lowlands of south-central Manitoba and in the

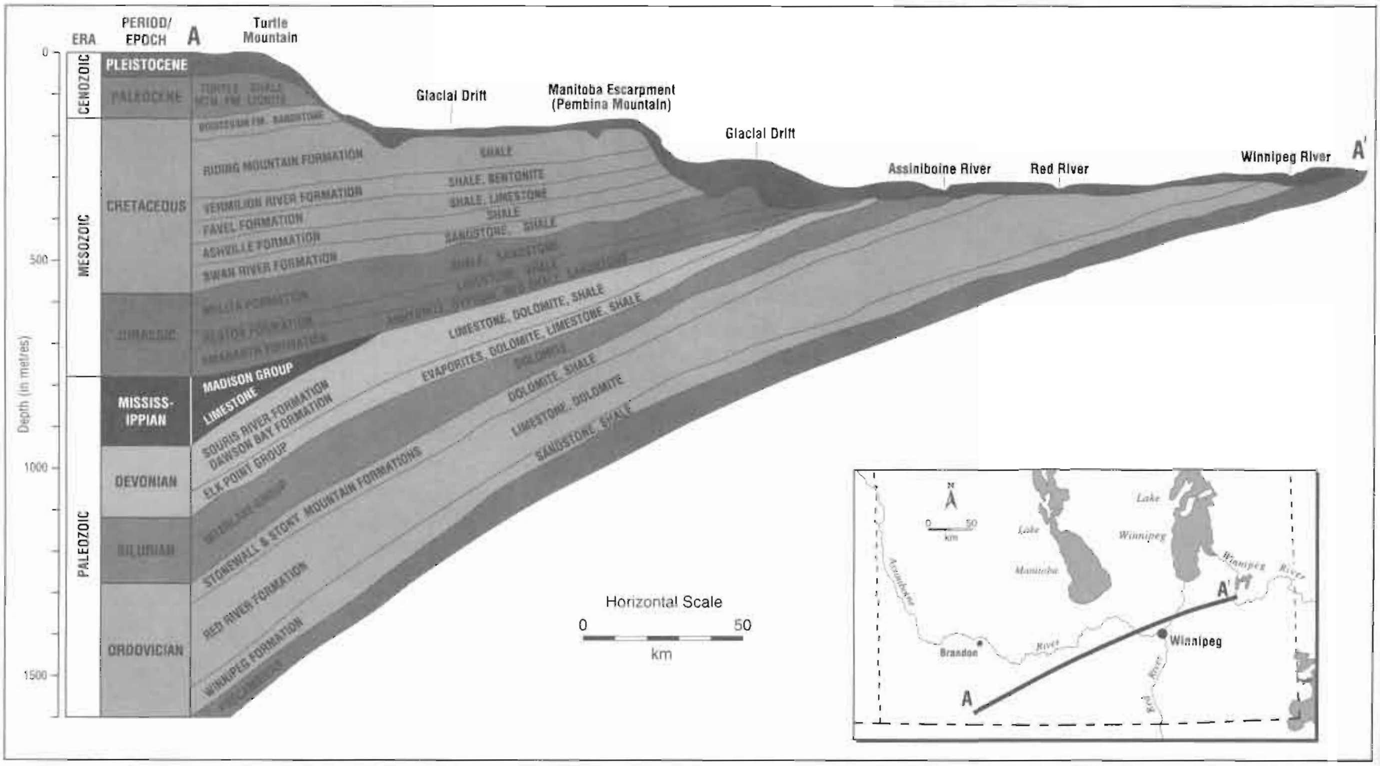

Figure 2.2 Geological Cross-section of Southern Manitoba (Source: Modified from Geological Highway Map of Manitoba 1994*, 2nd ed. [Winnipeg: Manitoba Minerals Division, 1994])*

Hudson Bay Lowlands.

Manitoba has rocks from most periods in the Phanerozoic eon (Figure 2.2), but there are some gaps. For instance, there are no rocks from the Pennsylvanian, Permian, or Triassic periods, nor are there any from the Upper Jurassic. During these times all of Manitoba was above sea level as it is today, and as now, the rocks that were deposited during the previous periods were eroded by river and wind activity. Thus during these times, not only were no new sedimentary rocks deposited in our geological record but we were actually losing pieces of the record. When a new shallow cratonic sea again covered the central part of North America during the Jurassic period, the sedimentary record resumed, with the sediments being deposited on the eroded surface of the older Paleozoic strata. This type of contact is called an *unconformity* (Figure 2.2).

Paleozoic

Paleozoic sedimentary rocks cover the Precambrian Shield in the Hudson Bay Lowlands and in southwestern Manitoba. These rocks accumulated in depressed areas in the earth's crust known as sedimentary basins, two of which influenced sedimentation in Manitoba: the Hudson Bay Basin, centred in Hudson Bay, and the Williston Basin, centred in northwestern North Dakota.

The Williston Basin developed from the south as the seas advanced over the slowly subsiding Precambrian Shield. This advance of the sea, termed a *transgression,* left deposits of sandstone (dominated by the quartz-rich sandstone of the Winnipeg Formation) as it flooded northward (Table 2.1). As the Precambrian Shield continued to subside, sediments accumulated on the shallow bottom of the ancient sea at a rate that kept pace with the sinking of the crust below. These sediments formed the dolomites, limestones, and interbedded shales of the Red River Formation. The rocks dip gently towards the centre of the basin in North Dakota, where subsidence was greatest (Figure 2.2). The Paleozoic rocks of the Williston Basin contribute to Manitoba's mineral industry through products such as silica sand, dolomitic limestone for building stone, dolomite, and high-calcium limestone for cement; subsurface deposits of salt and potash are potential products (Chapter 16). In addition, some of the rocks serve as reservoirs for petroleum.

At this time Manitoba was at a tropical latitude, covered by warm, shallow seas that teemed with newly developing life. As a result, numerous fossils such as corals, trilobites, and brachiopods are found in Paleozoic rocks. It was during this era that an explosion of life forms occurred. However, this does not indicate that life began in the early Paleozoic, but rather that a wide array of animals evolved hard parts that could be preserved as fossils. It is an unanswered question why the sudden explosion of these life forms occurred at this time.

Paleozoic rocks in Manitoba contain representatives of all the major phyla of the animal kingdom (Table 2.2). A partial list of fossils from the Stony Mountain Formation (Ordovician) includes several kinds of coral, snails, brachiopods, crinoids, sponges, trilobites, nautiloid cephalopods, and even some of the earliest armoured fishes.

Table 2.2 Major Phyla of the Animal Kingdom

Phylum	Animals Included
Porifera	Sponges
Coelenterata	Corals, sea anemones
Mollusca	Clams, snails, squid
Annelida	Worms of all shapes and sizes
Arthropoda	Trilobites (extinct), crustaceans (crabs, crayfish, shrimp, barnacles), insects, chelicerates (spiders, scorpions, ticks, mites)
Echinodermata	Starfish, sea cucumbers, sand dollars, sea urchins, crinoids
Chordata	Almost all animals with a backbone (fish, amphibians, dinosaurs, reptiles, birds, mammals)

Mesozoic

At the conclusion of the Paleozoic era, the marine sedimentary rocks were raised above sea level and eroded. This erosional surface was characterized by the development of sinkholes and caves in limestone, and by the development of hills and valleys. Later, downward movement of the earth's crust led to a return of shallow seas and to the accumulation of Mesozoic sediments on the erosional surface. The contact between the eroded Paleozoic rocks and the base of the Mesozoic rocks is another example of an unconformity. Mesozoic sediments, which formed red siltstones, sandstones, shales, and gypsum, were deposited in ancient seas that covered Manitoba from about 64 to 225 million years ago. Distant volcanic activity, probably in western North America, spread volcanic ash, which was later altered to beds of bentonite, across Manitoba. Gypsum, bentonite, brick clay, and shale are important mineral products from the rock formations of the Mesozoic era (Chapter 16).

With the return of the shallow seas, most of the species that had previously lived in the region returned, with some noteworthy exceptions; for example, trilobites and graptolites, which would have done well in a similar environment, were extinct by this time. However, fossils of large marine vertebrates, such as mosasaurs and plesiosaurs, are found in Mesozoic strata. This was the age of reptiles, and although fossils of dinosaurs have not been found in the predominantly marine strata in Manitoba, the rocks of equivalent age to the west have abundant dinosaur remains. There is still a possibility of finding fossil dinosaurs in Manitoba, in the eastern margins of the deltaic systems of rivers flowing from the mountains to the west.

Cenozoic

Only a small portion of Manitoba contains rocks of early Cenozoic time, which began about 64 million years ago. Paleocene strata of the Turtle Mountain Formation are limited to a relatively small isolated area capping the topographic high of Turtle Mountain, in southwestern Manitoba. These strata, consisting primarily of fine sandy and silty shales, rest directly on Mesozoic rocks.

The past 55 million years has been a time of relative geological stability in central North America. The region was uplifted from the sea and became a flat plain. There was little sedimentation, and erosional patterns began to develop on the plains. Animal life became diverse and abundant; paleontological digs in 10-million-year-old sediments in the central plains of the United States indicate that dozens of hoofed species, similar to those found in the African plains of today, were present. Grazing animals such as horses, pronghorns, and camels occupied the grasslands, which they shared with varieties of elephant, rhinoceros, and tapir. The presence of fossil tortoises and alligators, which could not survive extended periods of cold weather, indicates a warm climate. Carnivores such as sabre-toothed cats, bears, dogs, and small weasels found no lack of food on these grassy plains. Even an unusual sabre-toothed deer found a niche in the environment.

As the climate changed with approach of the Ice Age, so did the animal life. Woolly mammoth, bison, and other cold-tolerant species took the place of the savanna-dwelling populations. Possibly the latter were finally driven to extinction as colder winters and dry conditions reduced their range.

PREGLACIAL TOPOGRAPHY AND DRAINAGE

The land was uplifted about 50 million years ago, and the Mesozoic seas retreated from Manitoba; even Hudson Bay may have been elevated above sea level. This newly exposed, generally flat former seafloor was subjected to erosion by rivers. Erosional patterns that persist today began to develop on the thick Cretaceous shales that covered most of southern Manitoba 55 million years ago. The land then, as now, sloped away to the east from the Rocky Mountains, and rivers flowed eastward across the Prairies, down this gentle slope towards the Canadian Shield (Figure 2.3). Some were diverted northward into the Mackenzie watershed, others south to the Mississippi watershed, and possibly some flowed across the

Shield to drain to the area where Hudson Bay is today.

It is difficult to locate these ancient river and stream valleys because they have been deeply buried beneath glacial deposits, but they had 50 million years to erode the Mesozoic shales that may have extended as far east as the Ontario border.[2] Before the onset of glaciation, the shales were eroded back to the Manitoba Escarpment, and the eastward-flowing streams carved deep valleys, producing the embayments in the escarpment that are now occupied by the Assiniboine, the Valley River, and the Swan River.

The Manitoba Escarpment is, then, a preglacial feature. It was not significantly eroded by glaciation because of the erosion-resistant nature of the overlying hard gray Odanah shale. This shale, with its high silica content derived from volcanic ash and the remains of siliceous microorganisms, formed a resistant caprock to the Manitoba Escarpment and prevented it from being reduced to the level of central and eastern Manitoba. The escarpment generally forms the easternmost edge of Cretaceous rocks in the province.

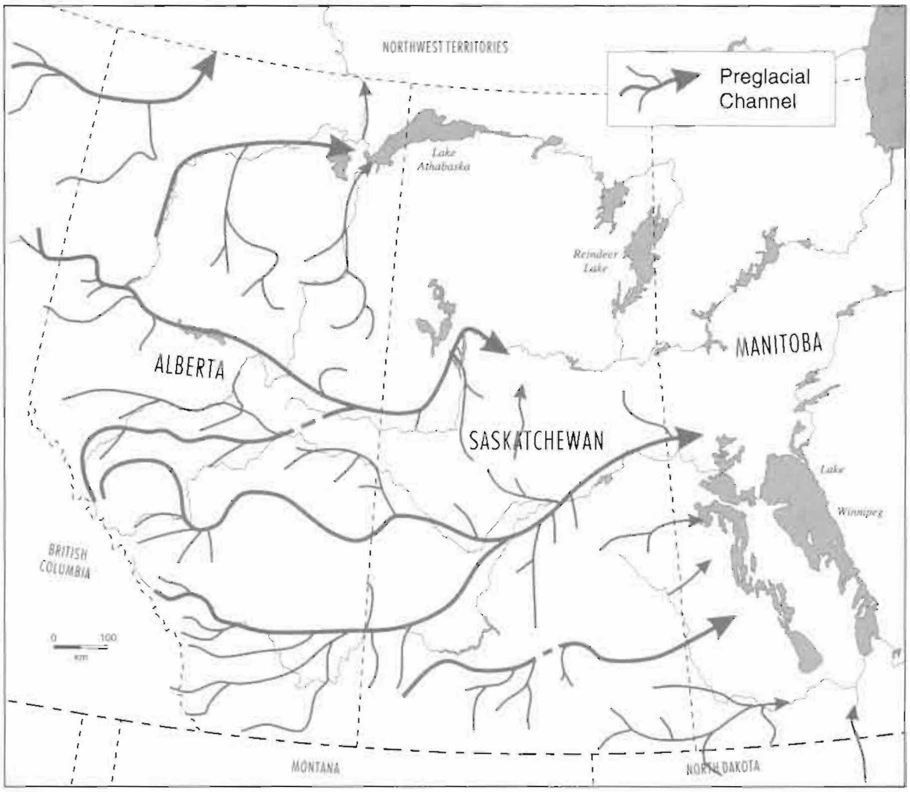

Figure 2.3 Preglacial Drainage of the Prairies (Source: Modified from J.B. Bird, The Natural Landscapes of Canada *[Toronto: Wiley Publishers of Canada, 1972], 117)*

GLACIATION

Glacial Periods

Periods of glaciation are not restricted to the time we call the Ice Age. During the 4.5-billion-year history of the earth, global climatic conditions have changed many times; indeed, major fluctuations are the norm rather than the exception. While Manitoba was basking in the sunny conditions and warm seas of the Paleozoic era, other continents, such as Africa and South America, experienced repeated glacial periods. This reflects the global position of the continents as they were moved by plate tectonics during these times. However, proximity to the earth's polar regions did not always mean ice and cold; there is evidence of great forests similar to those on the west coast of Canada near the North Pole during Mesozoic times, indicating a global warm spell.

During a glaciation, climatic conditions are so cold that continental glaciers expand thousands of kilometres from high latitudes, and alpine glaciers build up and flow down from the mountains. This happens when the annual addition of winter snow is greater than the melting or sublimation in the summer. Even small amounts of annual addition of snow, which turns to ice, will build up over thousands of years. The resulting ice, which in our area is estimated to have been as much as 3 km thick over Hudson Bay and possibly 2 km thick over Winnipeg, will try to form a level surface just as water seeks the lowest point as gravity pulls it downward. Thus, as the ice thickens by annual addition of snow, the margins are pushed from behind and the ice advances as the glacier flows to reach an equilibrium.

As well as spreading out over the land surface, the immense weight of ice depresses the earth's crust; as the density of ice is about one-third that of the rocks, it is estimated that 3 m of ice will depress the earth about 1 m. So in the region of Hudson Bay, the earth's crust may have been depressed by as much as 1,000 m. When the climate changes again and warms enough so that the winter addition of ice is less than the summer reduction, the glacier slowly stops advancing and the edges melt away faster than the ice can flow.

At this point the glacier is said to be receding; as the weight of the glacier is removed, the lands rise back to their equilibrium position by a process called *isostatic rebound.* This rebound is fast at first and then slows. It is not complete even today, and in the area of Churchill the rate of rise is still about 70 cm per century.

As the ice advances over the ground, it picks up loose gravel and soil, which are then frozen into its base, producing an effective abrasive as the moving ice erodes and reshapes the land below. Glacially polished outcrops with straight grooves called striations or crescent-shaped fractures called chatter marks are one result of the movement of the debris-laden ice over the rocks.

Eroded material that is picked up by the glacier is transported and later deposited as *till,* an unsorted, unlayered mass of debris. Water from the melting glacier also deposits sediments known as outwash deposits, and still other materials are deposited along the shores and on the floors of glacially dammed lakes.

During the last several million years of the Pleistocene epoch, Europe, Asia, North America, and Antarctica have been in a relatively cold period — often so cold that vast areas were covered by repeated advances of the continental ice sheets. Studies indicate that there have been numerous periods of glaciation, each lasting thousands of years, the most recent of which, termed the Wisconsinan, began about 75,000 years ago and ended about 8,000 years ago.

Ice sheets did not continuously cover all of Canada during this time but fluctuated north to the Arctic and south into the United States as the climate varied. Ice from the last glaciation receded about 7,000–8,000 years ago, after a 15,000-year period of continually moving glacial ice. The erosion and deposition from these episodes of glaciation and the significant sedimentary deposits formed by meltwater as the glaciers continued their slow 3,500-year process of melting and retreat are responsible for most of Manitoba's present-day landscape.

Results of Glaciation

The effects of the glaciation of Manitoba can be grouped under four headings: glacial erosion, glacial deposition, creation of glacial lakes and the alteration of the drainage system, and the results of isostatic depression and rebound.

Glacial Erosion

The preglacial topography of Manitoba was devoid of high mountains and deep valleys; consequently, the potential for alpine glaciation producing spectacular landforms such as in the mountains of Alberta and British Columbia did not exist. Nevertheless, glacial erosion played a role in the evolution of the landscape of Manitoba, particularly of the north. Here the ice scraped off the surface materials, leaving behind extensive exposures of bedrock once the ice melted. Glacial scouring and etching took the form of striations and gouges on a small scale, and the larger north-south and northwest-southeast flutings in the Westlake and Interlake regions. Over the rest of southern Manitoba, evidence of glacial erosion is largely absent, or at least hidden by glacial deposition. However, at one stage ice flowing from the Hudson Bay region may have been blocked by the Manitoba Escarpment.[3] As this ice was channelled to the southeast, it may have scoured the edge of the escarpment.

Glacial Deposition

Much of Manitoba is covered by glacial, glaciofluvial, and glaciolacustrine deposits, although especially in the southeast, east, and parts of the north, bedrock is exposed at the surface. Till and glaciofluvial deposits are widespread, as are many of the landforms commonly associated with deposition by a major ice sheet. Hummocky stagnation moraine[4] (ground moraine) covers large parts of Turtle Mountain, Riding Mountain, Duck Mountain, and the Porcupine Hills. In the area between Deloraine and Waskada in the southwest, this ground moraine has a distinctive circular ridge pattern, whereas further east, particulary northwest of Killarney, low till ridges 1.5–6 m high trend northeast to southwest.

Classic "inverted-spoon-shaped" drumlins are not common in southern Manitoba, but rock-cored streamline hills have been mapped in the Holland/Treherne/Notre Dame de Lourdes area,[5] and drumlins and drumlinlike ridges have been mapped in the area between Binscarth and Russell.[6] Similar features are widespread throughout northern Manitoba.

Eskers and kame complexes are also abundant in both the north and the south. Numerous small eskers were mapped by Elson[7] in the area south and west of Baldur and in the area between Cartwright and Crystal City, and by Klassen[8] east of the Assiniboine River southwest of Birtle. The Arrow Hills, a prominent landform rising 50 m above the surrounding landscape northwest of Oak Lake, are probably an esker. A prominent esker also marks the eastern end of the Brandon Hills.[9] But perhaps the best known esker is that at Birds Hill, 16 km northeast of Winnipeg. Here a high, narrow ridge of sand and gravel extends 6.5 km east from Birds Hill and then merges into a delta-shaped plateau that extends over a broad area underlying Birds Hill Park. The esker is the main source of aggregate material for the city of Winnipeg.

End moraines are thought to have been deposited at the edge of ice sheets when forward motion balanced wastage. No fewer than 17 have been mapped throughout the province, although the best known are in southern Manitoba.[10] The Darlingford moraine extends from north of Brandon through the Brandon Hills to the Tiger Hills and east to Pembina Mountain. Further north, The Pas moraine extends south from near The Pas, then eastward between Cedar Lake and Lake Winnipegosis, and on to form Long Point in Lake Winnipeg (Figure 2.4).

Glaciofluvial outwash sediments deposited by glacial meltwater are also extensive. They give rise to flat terrain on which former outwash stream courses can often be seen in air photographs, such as in the area between Pilot Mound and Crystal City.

Glacial Lakes

Some of the most distinctive scenery of Manitoba results from the fact that glacial lakes existed in the area at the end of the Wisconsinan. Evidence for the existence of these lakes takes four forms: strandlines, which mark former lakeshores; spillways, which carried water from one glacial lake to another; deltas, where rivers entered the lakes and deposited sediments; and lake bottom sediments, deposited beyond the immediate shores of the lakes.

Lake Agassiz, the largest of the lakes, probably came into existence about 13,000 B.P. as the result of the merging of a number of smaller lakes (Figure 2.5).[11] It owed its existence to ice damming the northward-flowing, preglacial drainage. With various advances and retreats of the ice, the lake rose and fell so that at different times it emptied south into the Mississippi system, east into the Great Lakes system, and northwest into the Mackenzie system.[12] Finally the present outlet to the north along the Nelson River became available, leaving Lakes Winnipeg, Winnipegosis, and Manitoba as remnants of the former glacial lake (Figure 1.1.1 on page 6). Other named glacial lakes were Lake Souris and Lake Hind in southwestern Manitoba.

When it was at its highest, Lake Agassiz extended far into the Assiniboine embayment, and strandlines were formed along the Manitoba Escarpment. Beaches of this stage, known as the Herman, are found along the east side of Pembina Mountain and Riding Mountain. At a later date the lake stood at the Upper Campbell level, during which time a prominent beach was formed that extends from the United States border northwest along the Manitoba Escarpment to the Saskatchewan border. Known as the Arden Ridge in the Neepawa area, it determines the southeast-northwest direction of Highway 352 in this area, and is also followed by Highway 10 further north.

The steep-sided, flat-floored spillways are a second piece of evidence for the former existence of glacial lakes. They are occupied by rivers that are misfits, flowing in valleys far too large for the present discharge. The Assiniboine Valley west of Brandon is one example, as is the Qu'Appelle Valley, which joins the Assiniboine near St. Lazare. These valleys provide a startling contrast to the general flatness of the surrounding prairies. They were created, possibly in a very short period, by glacial meltwater flowing from one glacial lake to another.[13] In the south, the Souris and Pembina rivers occupy spillways for much of their length.

Deltas were deposited into the glacial lakes. Elson lists 33 deltas deposited into Lake Agassiz, the largest of which is the massive Assiniboine Delta.[14] A broad preglacial embayment in the Manitoba Escarpment was invaded by glacial Lake Agassiz, and here a delta, with its apex near what is now Brandon, was deposited. The delta extends eastward almost to Portage la Prairie, a distance of approximately 120 km, and has a maximum width from north to south of 75 km. The bulk of the sediments in the delta entered Lake Agassiz by way of the Assiniboine/Qu'Appelle system.[15]

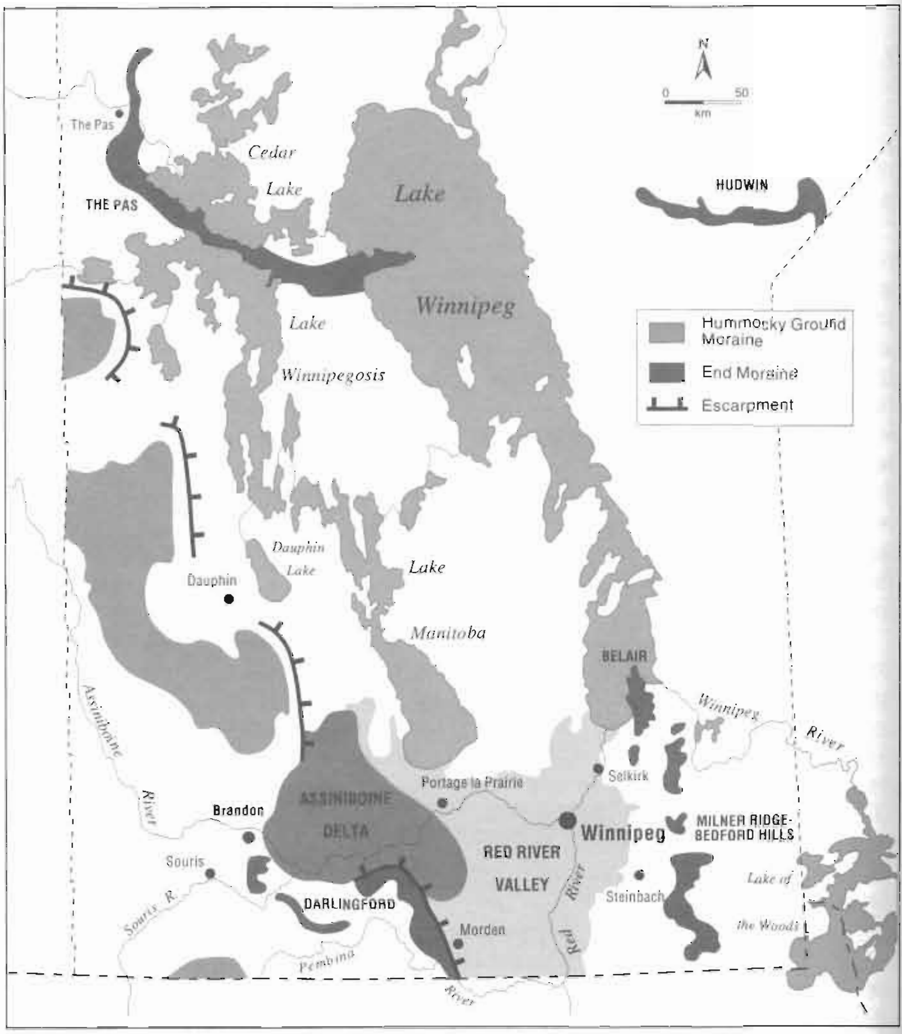

Figure 2.4 Major Glacial Depositional Features of Southern Manitoba (Source: Modified from Geological Highway Map of Manitoba 1994, *2nd ed. [Winnipeg: Manitoba Minerals Division, 1994])*

The final piece of evidence for the glacial lakes is the existence of lake-floor sediments, principally fine sand, silt, and clay, which cover parts of Manitoba and give rise to flat terrain. Deposition into Lake Agassiz produced the excessively flat land around Winnipeg, north of Portage la Prairie, and around Dauphin and Swan River. Much of the sedimentation is in the form of varved clays, sediments displaying regular alternations of thin laminations and somewhat thicker layers. The alternations may represent seasonal deposition, with the coarse-grained layers being deposited in summer, when the lake was open, and the fine-grained layers accumulating in quiet conditions during the winter, when the lake was frozen.

Isostatic Depression and Rebound

The weight of the ice caused depression of the earth's crust, which rebounded towards its former position once the ice melted. Depression and subsequent rebound was greatest where the ice was thickest. In northern Manitoba the Hudson Bay Lowlands were depressed relative to sea level, resulting in a transgression of the sea (called the Tyrrell Sea) as far inland as 200 km from the present shore of Hudson Bay.

Strandlines formed along the shore and have since been elevated to heights as much as 183 m above

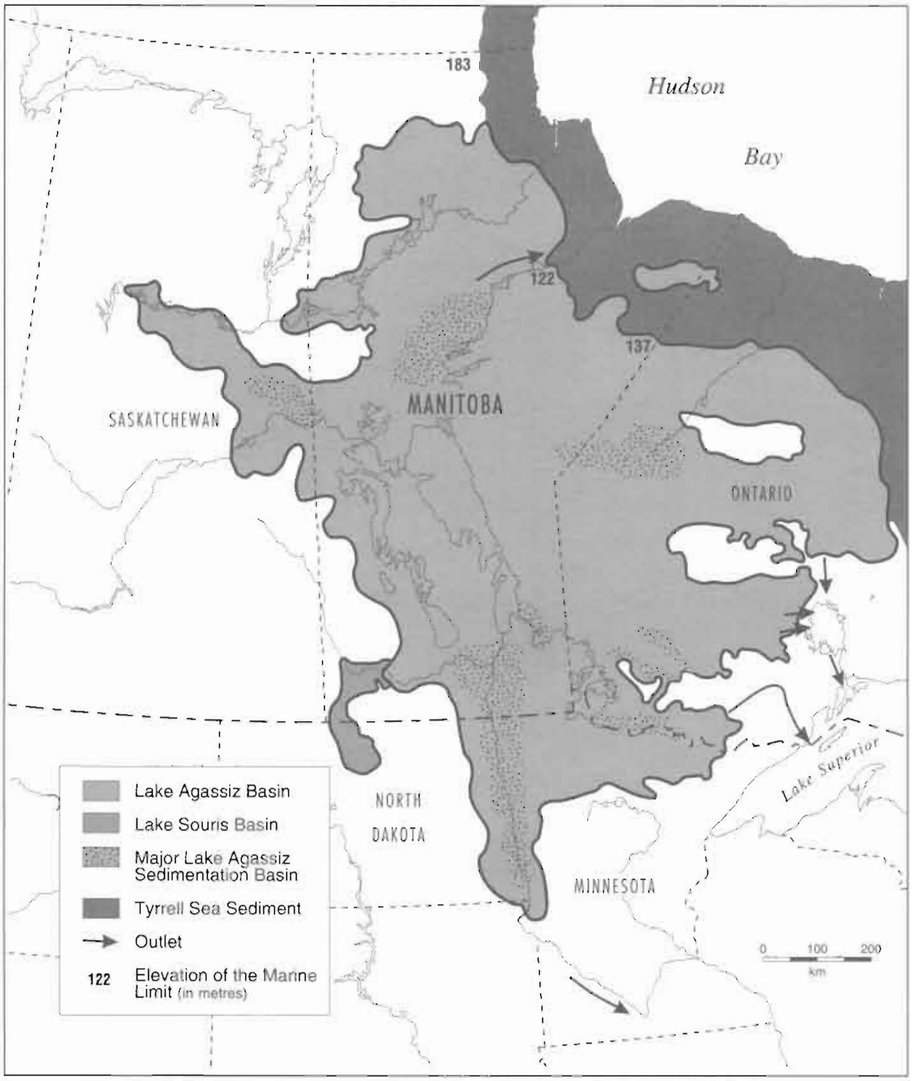

Figure 2.5 The Extent of Glacial Lake Agassiz (Source: E. Nielsen et al. Surficial Geological Map of Manitoba *[Winnipeg: Province of Manitoba, Department of Energy and Mines, 1981])*

sea level on the Manitoba–Northwest Territories border.[16] Further south, the Agassiz strandlines were tilted up to the north; for example, Herman beaches are found at elevations of 389 m above sea level west of Morden but rise to 410 m above sea level west of Neepawa.[17] Also, the upper Assiniboine Delta slopes down to the south as a result of isostatic rebound, so that the modern Assiniboine flows along its southern edge.

HOLOCENE DEVELOPMENT

With the northward retreat of the ice front, the drainage pattern of Manitoba gradually evolved to the present situation, in which the main flow is to the north via the Nelson River into Hudson Bay. Several rivers of southern Manitoba have changed course during postglacial time. Perhaps the most remarkable is the Souris, which once flowed southeast in the direction now followed by the Pembina, but which now takes a sharp turn to the northeast to join the Assiniboine (Figure 2.6). The bend is explained as an elbow of capture, the former Souris having been captured by a tributary of the Assiniboine. Below the elbow, the Souris flows in a series of incised meanders best seen at the village of Wawanesa (Figure 2.7).

In addition, the misfit rivers of southern Manitoba — the Assiniboine, the Souris, and the Pembina — have adopted a meandering form on the floor of the spillways that they occupy. Meander development and abandonment is rapid; the Assiniboine has created 26 cutoffs in the area between the Shellmouth Dam and Portage la Prairie in the hundred years since the first maps of the area were made.

Another Holocene development has been the dissection of the Manitoba Escarpment by small creeks draining to the Manitoba Lowlands. In the Riding Mountain area, "the escarpment slope region is . . . characterized by deeply incised intermittent streams. Stream incisions of between 30 m and 60 m are common."[18] At the base of the escarpment, deposition of eroded shale has produced a series of low-angle alluvial fans. Fans of similar origin occur where small streams flowing from Pembina Mountain reach the lowlands between Morden and Rathwell.

A prominent feature of the landscape of southern Manitoba are sand dunes developed on lake-deposited sediments and on outwash. Most marked are those on the sands of the Assiniboine Delta, which, north of the Assiniboine River, have been blown into dunes of various types. Some, southwest of Epinette Creek, are long, seif-like dunes that trend northwest-southeast. These are now stabilized by a discontinuous cover of vegetation, but in the Bald Head Hills is an area of active dunes with arcuate plans, steep southeast faces, and gentle northwest slopes[19] (Figure 4.1.2 on page 57). Although the area of active dunes has decreased during the past 20 years, it has been calculated that the dunes are moving southeastward at a rate of 20 cm a year.[20] Other, less well-known dune areas are the Lauder Sand Hills on sands deposited into Lake Hind, and an area west of St. Lazare developed on glaciofluvial sands.

PRESENT-DAY TOPOGRAPHY

Manitoba can be divided into four physiographic regions (Figure 2.8), each of which shows the effects of Pleistocene glaciation.

Hudson Bay Lowlands

The Hudson Bay Lowlands consist

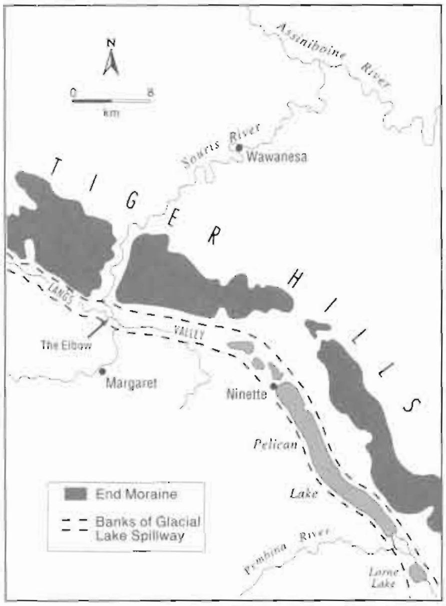

Figure 2.6 The Souris Elbow of Capture

Figure 2.7 Incised Meander and an Abandoned Meander of the Souris River at Wawanesa (Photograph: National Air Photo Library [NAPL] A16404-15)

of an undulating plain of low elevation. South of the Churchill River, limestone till covers Paleozoic strata, whereas in the north of the region it overlies the Precambrian. The whole area is overlain by marine clays. In this region of little relief, the major elements of relief are strandlines, former positions of the Tyrrell Sea shore. Additional relief features are the valleys of the Churchill and Nelson rivers, both of which have cut through the till and into bedrock. Erosion by the continental ice sheet deranged the drainage, resulting in a maze of swamps, lakes, and streams. The region is still rising because of isostatic rebound. On 1 July 1757, Samuel Hearne, a Hudson's Bay Company explorer, carved his name and the year into quartzites while sitting by a mooring ring on the shore of Hudson Bay. Today this ring is several metres above the highest tide levels.

Precambrian Shield

The Precambrian Shield is the largest physiographic region, an area of uneven or hummocky terrain. The central part of the Shield is occupied by the Nelson depression or trough, which slopes towards Hudson Bay and is drained by the Churchill, Nelson, and Hayes rivers. Local relief is created by lakes and rivers that are generally entrenched by 15 to 30 m. In northwestern Manitoba the surface of the Precambrian Shield is hilly, with rock outcrops and numerous glacial landforms such as eskers and moraine ridges. The region is covered by the great expanse of boreal forest and thousands of lakes and rivers.

Manitoba Lowlands

The Manitoba Lowlands are the flattest part of the province, relief being generally less than 8 m. The lowlands are located southwest of the Precambrian Shield and are bounded on the west by the Manitoba Escarpment (Figure 2.9). The region is developed primarily on gently dipping Paleozoic limestone and dolomite strata, and has been modified by glacial erosion and mantled by glacial deposits. It is drained by the Saskatchewan, Red, and lower Assiniboine rivers, which cut across the structure of the underlying strata.

Of note in this region are Lakes Winnipeg, Winnipegosis, and Manitoba, all remnants of Lake Agassiz (Case Study 1.1 on page 6). South of Manitoba's Great Lakes, bedrock is deeply buried beneath the silty clays of Lake Agassiz that form one of the flattest and most prosperous farming areas in Canada. In the Interlake region to the north, topography is more bedrock-controlled, with limestone outcrops forming plateaus, rarely more than 30 m high, often covered by a thin layer of glacial deposits. Here the lowland is forested and has extensive areas of muskeg and string bogs.

Throughout most of the region, there are scattered moraines as well as beach ridges of former Lake Agassiz. The Assiniboine River has cut a channel through the sands of the Assiniboine Delta, and is one of many entrenched streams that dissect the region. The top of the Assiniboine Delta has been windblown to form extensive sand dunes that are partially fixed by vegetation (Case Study 4.1 on page 56). In the extreme southeast, towards

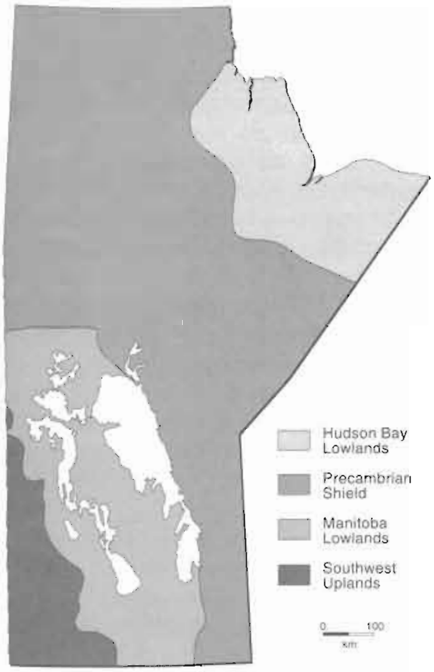

Figure 2.8 Physiographic Regions of Manitoba

Lake of the Woods, sandy morainic deposits impart variable relief and drainage, and large areas are peat bogs and swamp.

Southwest Uplands

The Southwest Uplands form the western edge of the Saskatchewan Plains and are underlain by gently westward-dipping Mesozoic strata. The region is characterized by the Porcupine Hills, Duck Mountain, Riding Mountain, and Pembina Mountain, whose western margins form the Manitoba Escarpment. Between the "mountains" are broad valleys, formed by the work of preglacial rivers much larger than the present misfit streams. The surface of these mountains, which at their highest rise 500 m above the Manitoba Lowlands, is a relatively flat plateau. Bedrock is exposed along the escarpment face, but on the plateaus it is covered by great thicknesses of glacial deposits, reaching 250 m on Duck Mountain.[21]

In the south, Turtle Mountain (757 m above sea level) is an erosional remnant, a topographic feature that remained after erosion had reduced the surrounding area. It is capped by rocks of Paleocene age that are covered by thick (up to 150 m) glacial drift.[22]

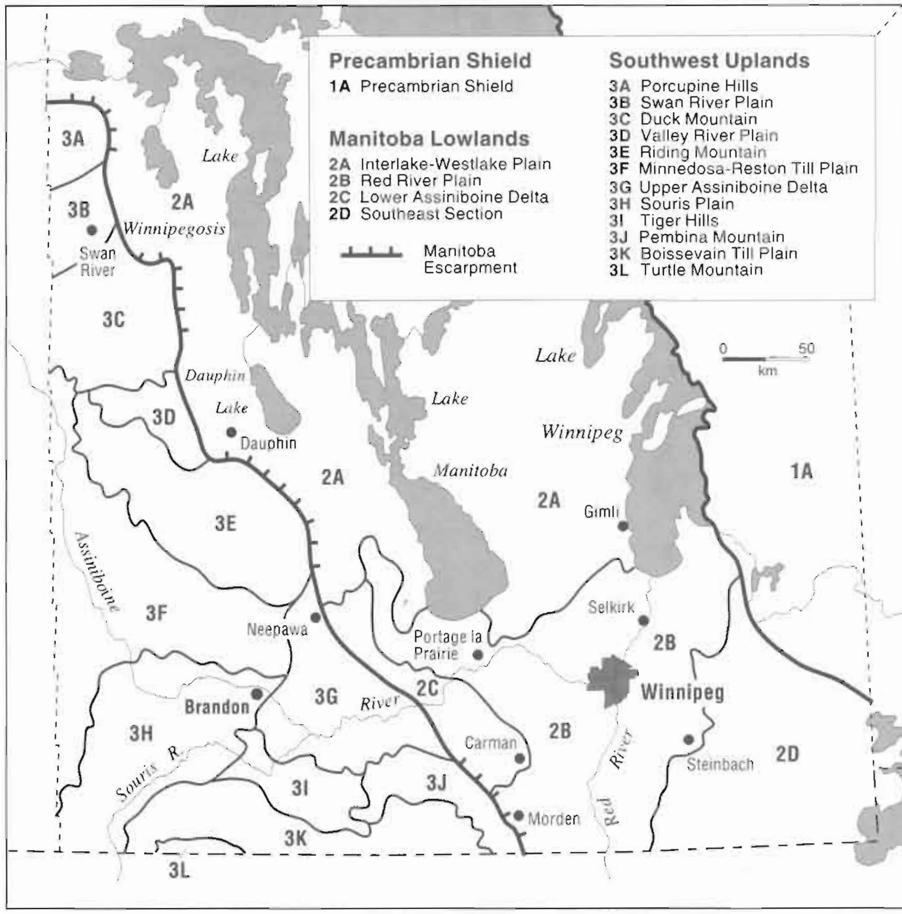

Figure 2.9 Physiographic Regions of Southern Manitoba (Source: After T.R. Weir, ed., Economic Atlas of Manitoba *[Winnipeg: Province of Manitoba, Department of Industry and Commerce, 1960])*

CONCLUSION

The present physiography of Manitoba has been shaped by 3.5 billion years of geological history. Geological activity continued from the early Precambrian volcanism and mountain-building events for a billion years to grind the Precambrian Shield flat, so that the shallow seas of the Paleozoic and Mesozoic could lay down the limestones of the Manitoba Lowlands and the shales of the Southwest Uplands. More recently, glacial periods left a mantle of deposits over much of the province and depressed the land to allow the rivers to run across the Shield to Hudson Bay.

Each event has left its fingerprint on the land. The Precambrian produced early volcanism, left as greenstone belts that have provided areas of mineral wealth. Then the major Kenoran Orogeny about 2.7 billion years ago produced the extensive regions of granite and gneiss that form the bulk of the Superior Province. The cycle was repeated 1.7–1.8 billion years ago, forming the rocks of the Trans-Hudson Orogen in northwestern Manitoba. There followed a long period of general quiescence during which the Precambrian Shield was eroded down to a relatively flat plain that extends far to the west, deep beneath the Rockies.

Throughout the Paleozoic and Mesozoic eras, continental drift placed Manitoba near the equator. At this time the Williston Basin slowly subsided and was filled with carbonate rocks, and newly evolving life forms filled the seas. During the late Mississippian period the sea receded, the waters became brackish and dissolved salts killed off the animal life, and evaporites and the last of the Paleozoic dolomites were deposited. Then the land emerged again from the waters to be partially eroded away. Later in the Mesozoic the seas returned, bringing more sediments and new life forms in the waters, and land animals appeared in areas at the western edge of the province.

By the end of the Cretaceous and early Tertiary, the land was once again emerging from the seas. The continent of North America slowly drifted northward to its present location. Land animals, many of them mammals, occupied the land, and the stage was set for the Ice Age, during which the details of Manitoba's landscape were produced. Glacial erosion and deposition have produced a variety of landforms. Also, damming of the preglacial drainage by the ice resulted in a number of glacial lakes, which in turn have left behind their own distinctive assemblage of landforms.

The period since the Ice Age is but an instant in geological time. Nevertheless, some details have been added to the physiographic map, such as alterations in river courses, formation of sand dunes, and uplift of glacially depressed areas. The last, at least, continues.

NOTES

1. When lava flows are expelled (extruded) under water, the outer surface of the lava cools quickly, forming a thin crust. Liquid parent lava breaks through the crust to form a series of pillowlike masses. Continuation of the process produces a series of interconnected pillows. The significance of pillow lavas is that they indicate underwater formation.
2. B.B. Bannatyne and J.T. Teller, "Geology of Manitoba before the Ice Age," in *Natural Heritage of Manitoba: Legacy of the Ice Age,* ed. J.T. Teller (Winnipeg: Manitoba Museum of Man and Nature, 1984), 7–21.
3. E. Nielsen et al., *Surficial Geological Map of Manitoba, Map 81-1* (Winnipeg: Province of Manitoba, Department of Energy and Mines, 1981).
4. When the ice sheets were no longer being replenished by snowfall, the ice disappeared by stagnation and downwasting. Sediments contained within the ice were deposited on the land below, resulting in an irregular topography of hills and depressions referred to as *hummocky ground moraine* or *hummocky stagnation moraine.*
5. J.A. Elson, "Surficial geology, Brandon west of principal meridian, Manitoba, Map 1067A," in E.C. Halstead, *Ground Water Resources of the Brandon Map-Area, Manitoba,* Memoir 300 (Ottawa: Geological Survey of Canada, 1960).
6. R.W. Klassen, *Pleistocene Geology and Geomorphology of the Riding Mountain and Duck Mountain Areas, Manitoba-Saskatchewan,* Memoir 396 (Ottawa: Geological Survey of Canada, 1979).
7. Elson, "Surficial geology."
8. Klassen, *Pleistocene Geology.*
9. J. Welsted and H. Young, "Geology and origin of the Brandon Hills, southwest Manitoba," *Canadian Journal of Earth Sciences* 17(1980):942–51.
10. These are mapped and named in Nielsen et al., *Surficial Geological Map of Manitoba.*
11. Ibid.
12. T.G. Fisher and D.G. Smith, "Northwest outlet of glacial Lake Agassiz: the Clearwater–Lake Athabaska spillway valleys," Abstract in *Programme with Abstracts, Third International Geomorphology Conference* (Hamilton, ON: McMaster University, 1993), 139.
13. A.E. Kehow and L. Clayton, "Late Wisconsinan floods and development of the Souris-Pembina spillway system in Saskatchewan, North Dakota and Manitoba," in J.T. Teller and L. Clayton, eds., *Glacial Lake Agassiz,* Special Paper 26 (St. John's, NF: Geological Association of Canada, 1983), 187–209.
14. J.A. Elson, "Geology of glacial Lake Agassiz," in W.J. Mayer-Oakes, ed., *Life, Land and Water* (Winnipeg: University of Manitoba Press, 1967), 37–95.
15. Klassen, *Pleistocene Geology.*
16. Nielsen et al., *Surficial Geological Map of Manitoba.*
17. Ibid.
18. R.A. McGinn, "A general description of the eastern slopes of Riding Mountain" (unpublished manuscript, Brandon University, 1983).
19. W.J. Brown, "Geomorphology Field Trip to Southwest Manitoba," in *Department of Geography, University of Manitoba Field Guide for the Canadian Association of Geographers Annual Meeting, June 1970* (Winnipeg: University of Manitoba, Department of Geography, 1970), 43–71.
20. M.H. Ward, "Vegetative Colonization and Succession and the Impacts of Trampling in the Carberry Sand Hills, Manitoba" (M.Sc. thesis, University of Manitoba, 1980).
21. Nielsen et al., *Surficial Geological Map of Manitoba.*
22. Ibid.

Case Study 2.1
Karst in Manitoba
Geraldine Sweet

"Karst" is a term used to describe landscapes developed both on the surface and underground in regions of soluble rock. Typical features include pavements, depressions, caves, and springs. In Manitoba, throughout the southern Interlake region (the area between Lake Winnipeg and Lakes Manitoba and Winnipegosis) and along the Hudson Bay coast are extensive areas of limestone, dolomitized limestone, and dolostone, all of which are soluble to some degree in acid-rich, terrestrial water. These rocks occur at the surface or are covered by a variable layer of glacial debris. Anhydrite (gypsum),[1] one of the most soluble of all rocks, is exposed around Gypsumville. Although there are probably karst features wherever these rocks occur (Figure 2.1.1), they are masked in the south and in the far north by the glacial overburden. There is evidence of large sinks in the bedrock below the city of Winnipeg, and large infilled cavities have been encountered in cores from the Devonian rocks west of Lake Manitoba.

Surficial karst features are clearly defined, and cave passages reach the surface and can be explored in three regions in the province.

(1) Near Lake St. Martin (Figure 2.1.1), exposures of gypsum result in a well-developed landscape of sinkholes, trenches,[2] and shallow caves. Because gypsum dissolves easily in water, this kind of karst is usually quickly formed and relatively short-lived. The present landscape is thought to be postglacial, the rock being so fragile that the ice would probably have destroyed any surface features. However, in some of the caves there is evidence of intense folding of the bedrock that may have been glacially induced.

Because the rock is so malleable, the caves vary considerably in form, but the most common are long, narrow phreatic tubes,[3] which formed below the piezometric surface (water table)[4] but which are now dry because of a lowering of the local water table. In fact, the longest cave yet found in Manitoba, Labyrinth Cave near Gypsumville, which measures over 180 m, is of this type. Often the tubes intersect, creating small chambers at the intersections. The land surface in the Lake St. Martin area resembles the classic cockpit karst of tropical regions, with many well-developed sinks coalescing, creating a densely pitted surface. The reason for the density of sinks — an indicator of advanced development — is the extremely soluble nature of the rock.

(2) There is some surface expression of karst in the southern part of the Interlake, where the now-famous snake dens at Narcisse are examples of collapse sinks. Water below the surface has dissolved the rock, creating cavities whose roofs have subsequently collapsed. There are much larger depressions of this nature in places like Broad Valley, and farmers throughout the area tell tales of pits and trenches they have filled with rocks.

At Inwood, Stony Mountain, and Garson, the limestone has been excavated for building material, exposing extensive enlarged joint systems in the walls of the quarries, but the main area of cave development is near Dallas, where a number of explorable caves have been discovered. Some are simply long trenches, widened by running water just below ground level, probably during the immediate postglacial period, when running water was more abundant. Some are easily accessible through breaks in the roof. Others are more difficult to find; entrances are typically a small hole, followed by a short drop into the cave proper. St. George's Bat Cave is of this type: it opens out into a sizable cavity about 5 m high and 165 m long. It even has a side passage and some stalactites, formed by secondary precipitation.[5] Altogether eight small caves have been found in this area, and exploration by the Speleological Society of Manitoba is continuing.

(3) The most extensive area of both surface and underground features is between Grand Rapids and William Lake, in the northern

Figure 2.1.1 Location of Karst Areas in Manitoba

Interlake (Figure 2.1.2). Here the bedrock is exposed over hundreds of square kilometres, with only a thin till cover in the lower areas. The result is a region of well-developed karst pavements, so named because the surface resembles paving stones. In places, blocks have subsided or have been dissolved to produce shallow bedrock sinks. In others, deep trenches, or zanjones, are the result of joint enlargement by both chemical and physical processes.

An escarpment marking the boundary between the Silurian and Ordovician outcrops has a series of springs along the base indicating the underground drains of many of the lakes on top of the escarpment. There are numerous collapse features similar to those at Narcisse, and many small, bell-shaped cavities. Caves were first discovered in the northern Interlake by hunters and trappers, but in the last 10 years a plan of exploration by Manitoba cavers has yielded many new cavities, and more are being found each year. Most are found within the top 20 m of the bedrock and range considerably in shape and size, although they are all small by world standards.

There seems to be a pattern to the development of the caves. In most cases the main excavation has occurred in the relatively soft and vuggy dolostone of the Atikameg unit,[6] part of the Silurian, usually found 1–3 m below the surface and overlain by thinly layered, fine-grained rock. The Atikameg dolostone is easily dissolved and cavities have formed. Later the roof collapsed, and in many cases the cave was enlarged along one or several fractures.

In Dale's Cave, passages are phreatic, having formed below the piezometric surface. Most of the caves are still actively forming, as there is often much water available during spring melt when it is particularly aggressive, and therefore solution is rapid. In early spring Moosearm Pit (Figure 2.1.3) has over a metre of meltwater sitting in it, until ice in the floor melts and the water disappears rapidly, suggesting well-developed drains in the bedrock below. Few of the caves have stalactites, probably because cave formation is still active, but there is some secondary precipitation in the form of the aptly named cave popcorn and dogtooth spar.

Almost all the caves show evidence of physical weathering — frost action — and the bedrock is generally shattered to a depth of at least 30 m. This is the result of postglacial pressure release and may account for the lack of an integrated cave system, as water can move easily almost anywhere in the rock. In the 1960s Manitoba Hydro decided to build a dam on the Saskatchewan River at Grand Rapids (Chapter 18). More than a third of the cost was devoted to grouting the rock in the forebay, to prevent water from escaping underground. Photographs taken at the time show long, wide trenches in the bedrock.

At Steep Rock, on the east side of Lake Manitoba, there are a whole series of "sea" caves. Also, along the shore of Lake Winnipeg, lake water has eroded the carbonate cliffs to create deep undercuts, cavities, arches, and stacks, a type of development found to a greater or lesser extent on the shores of a number of lakes. In addition there are several locations in Grass River Provincial Park and on Clearwater Lake, northeast of The Pas, where large sections of cliff have collapsed, forming cavelike passages. The latter are not really caves, despite the names given them by the Department of Natural Resources, but the collapse has occurred as a result of solutional widening of the natural joints of the rock.

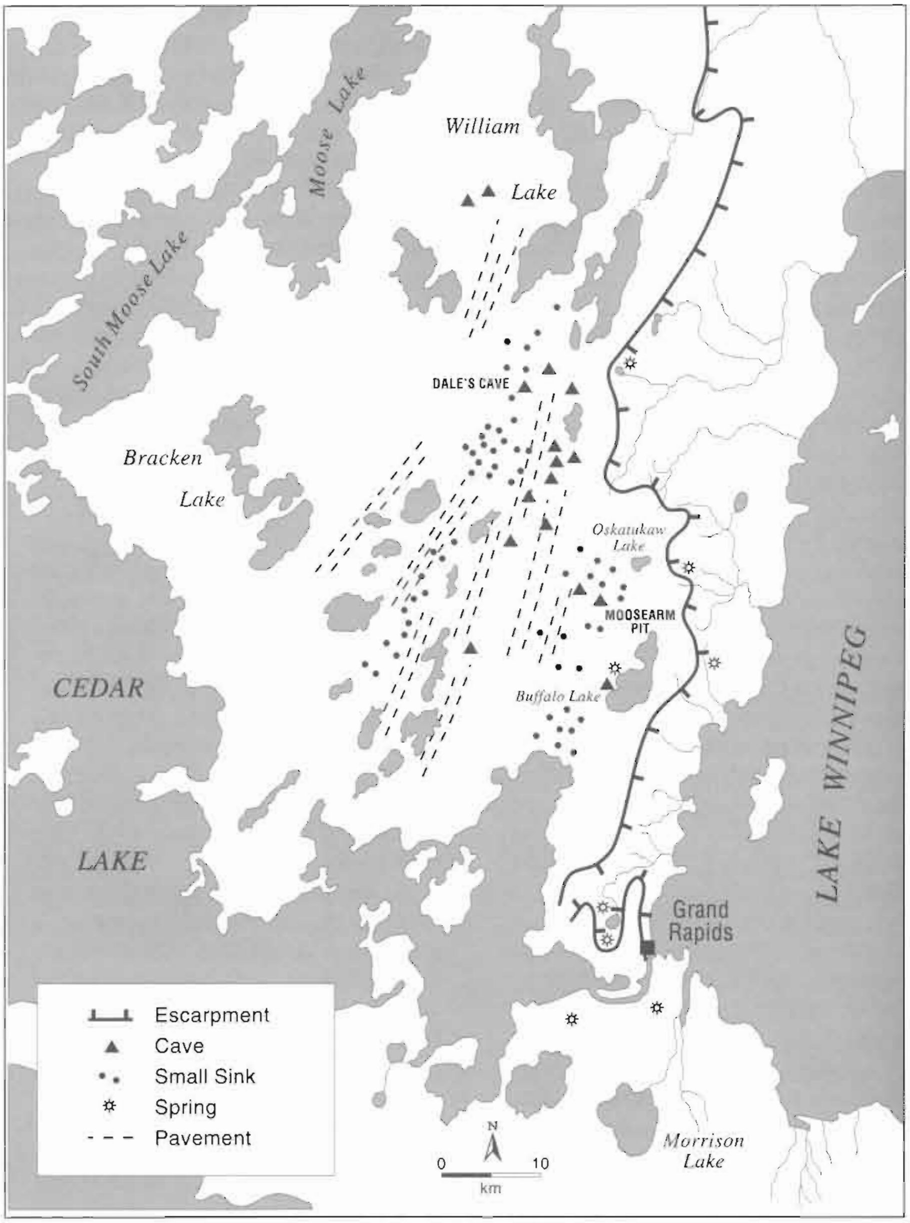

Figure 2.1.2 Karst Features of the Grand Rapids–William Lake Area

Although the caves in Manitoba are quite small, they are geologically, hydrologically, and biologically interesting. So far no evidence of human occupation has been found, other than the odd beer bottle or tin can, but many of them are occupied by colonies of Little Brown Bats (*Myotis lucifus*). Caves have an ambient temperature close to the annual mean of the area, between -2°C and +1°C, so in winter they are warmer than the air; in summer, colder. In many caves the roof is higher than the entrance, so "warm" air is trapped. The bats take advantage of this and hibernate rather than migrate south. Some species of moth do the same. Larger mammals, such as porcupines and bears, sometimes use the caves as dens.

Over a hundred individual caves have been found in the province. Perhaps in the future something larger will be found, as the environment is certainly conducive to karst development. In the meantime, Manitoba's caves provide a second, almost unknown landscape, underground.

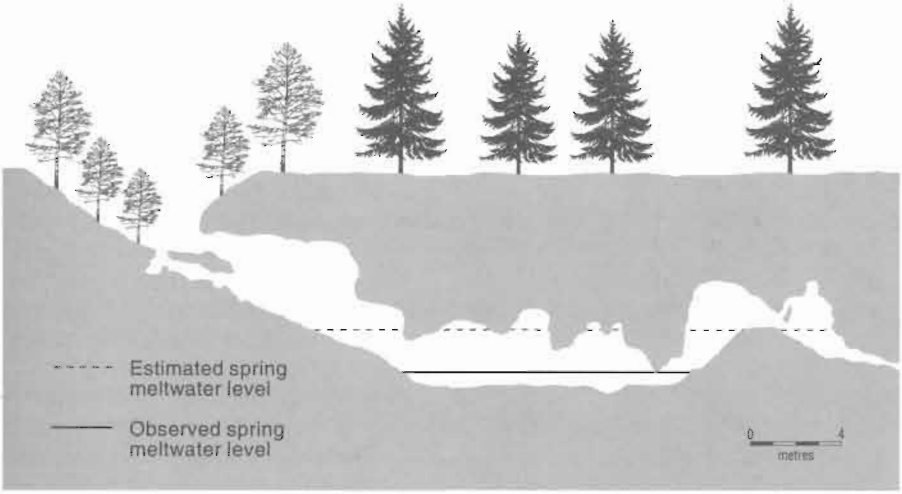

Figure 2.1.3 Cross-profile of Moosearm Pit, in the Grand Rapids–William Lake Area (Source: From a survey by P. Voitovici, G. Sweet, et al.)

NOTES

1. Gypsum is the hydrous form ($CaSO_4.2H_2O$) of anhydrite, a mineral sometimes found in large enough masses to form a rock. It will dissolve in any liquid.
2. Some of these may simply be enlargement of joints. In tropical environments the term "zanjone" is common, and refers to major enlargement by solution and subsequent collapse. Some of the trenches in the northern Interlake exhibit similar characteristics.
3. The terms "phreatic" and "vadose" refer to the location of cavities in relation to the piezometric surface (water table), and hence their method of formation. Vadose cavities are formed when freely flowing water comes in contact with soluble rock; the emphasis is on downcutting, and the upper part of the cavity is frequently above the water. Phreatic cavities form below the water table; the entire surface will therefore undergo solution at the same time, creating round tubes that follow the dip of the rock.
4. A glossary of technical terms in included at the end of this case study.
5. "Speleothem" is the collective name for all forms of secondary precipitation in caves. Speleothems are formed when calcium sulphate-rich waters enter open caves and the pressure release causes deposition that clings to the cave wall in much the same way as the "fur" in a kettle.
6. Different modes of formation produce different fabrics or textures in the rock. Much of the carbonate found in Manitoba was formed in warm, shallow seas, where sediment was trapped in algal mats. The resulting rock is crumbly and full of spaces, or vugs.

GLOSSARY

Zanjone — An enlarged fracture, generally associated with solution of carbonate rocks in the tropics.

Cockpit karst — An area of closely linked depressions with remnant hills between them.

Piezometric surface — The interface between rock containing freely moving water and the saturated stratum (also called the water table).

Cave popcorn — Small growths of calcium carbonate on cave walls and ceilings; a form of stalactite.

Dogtooth spar — Secondary deposition of pure or nearly pure calcium, shaped like teeth.

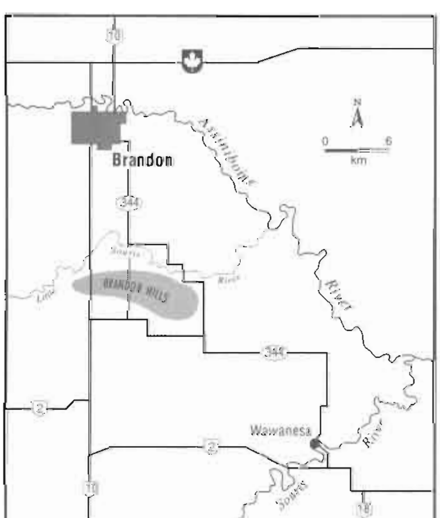

Figure 2.2.1 Location of the Brandon Hills

Case Study 2.2
The Brandon Hills

John Welsted and Harvey R. Young

In an area better known for its flatness than for hills, the Brandon Hills come as a surprise to the outsider. Located approximately 20 km south of Brandon, they rise prominently above the surrounding landscape (Figure 2.2.1). They must "have been a welcome sight for a party of settlers led by the Reverend George Roddick from Pictou County, Nova Scotia, who in May 1879 crossed the Assiniboine at Grand Valley three miles downstream from the present-day Brandon and saw an island of woodland set amidst a sea of waving grasses."[1] Although the surrounding land was soon prepared for agriculture, the hills offered little agricultural potential and have remained an island of natural vegetation surrounded by cultivated land.

Description

The hills run for approximately 12 km in a generally east-west direction, and are about 5 km across from north to south. In places they rise 90 m above the surrounding landscape and reach altitudes of over 480 m above sea level (Figure 2.2.2). Despite their limited area, they show considerable variation in topography, leading us to divide them into four physiographic regions: (1) the main body of the hills, an area of irregular topography with some definite ridges; (2) the eastern ridge, a large, sinuous, generally north-south-trending ridge; (3) the eastern complex, an area of mainly north-south-trending ridges and troughs east of, and adjacent to, the eastern ridge; and (4) the southern ridge, a northwest-southeast-trending ridge.[2]

The main body of the hills consists of a series of subparallel ridges that

trend northwest-southeast in the west, more nearly west-east in the centre, and swing around to become almost north-south in the east. These are mainly wooded (poplar, scrub oak, and Manitoba maple), but some of the more prominent ones have only a sparse grass cover. A profile drawn across them along the hydro road reveals that the topography is hummocky, with the south side of the hills being steeper than the north side (Figure 2.2.3). Glacial till is exposed in the road cuts along this minor highway.

The eastern ridge is quite different. It has been described as looking "as if an enormous dump truck has moved along depositing piles of dirt every few hundred metres."[3] Many do not recognize it as a ridge because most people see it while travelling on Highway 344, from which its steep eastern side is clearly visible, although there is no indication of an equally steep western side. Even the National Topographic Series 1:50,000 map does not show it, which is surprising because it reaches a maximum elevation of 477 m above sea level and is 90 m above the flat land to the east.[4] The view from the top is spectacular, stretching to Brandon in the north, beyond Shilo to the east, and across an old lake floor beyond the small hamlet of Rounthwaite to Wawanesa in the southeast.

The ridge is symmetrical in cross-profile, with slope angles of over 30° (Figure 2.2.4). Slow downhill soil creep has produced small terracettes, clearly visible only when the light is in the right direction. "Draws" or minor gullies on the ridge sides give a scalloped appearance when seen from above (Figure 2.2.5). Gravel pits at each end reveal that it is underlain by well-sorted and layered sands and gravels (glaciofluvial deposits), and borings made into the ridge crest indicate patches of till deposited directly from ice. Large boulders — "erratics" — are found along the ridge crest and sides. They are composed of rocks foreign to the area and can be grouped into two types: granitic boulders, generally spherical and usually covered by dark green lichens; and dolostone boulders, typically slablike and usually covered by bright orange lichens.

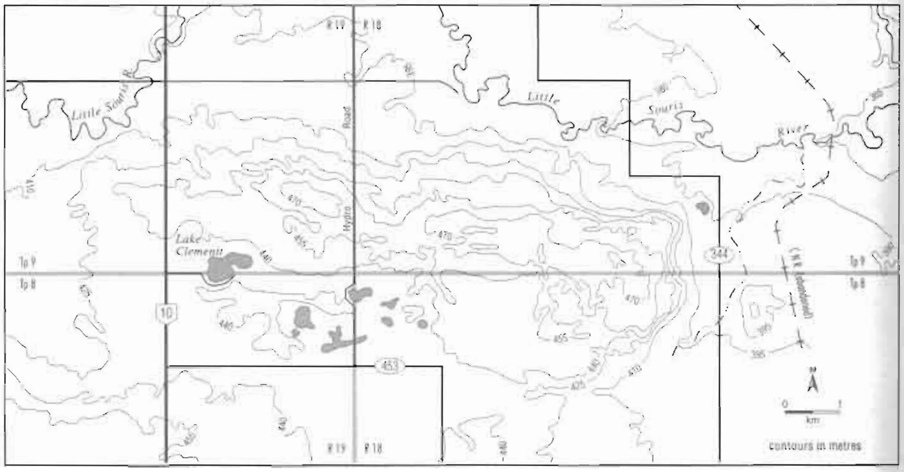

Figure 2.2.2 Topography of the Brandon Hills

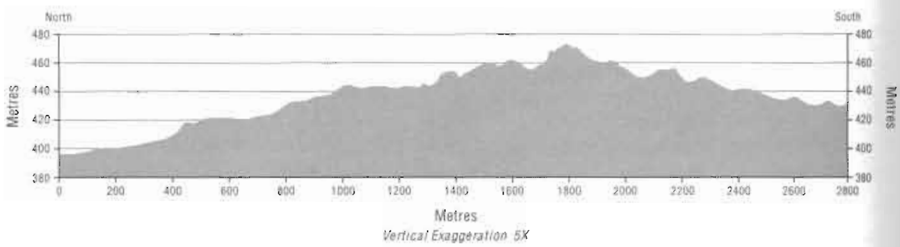

Figure 2.2.3 Topographic Profile along the Hydro Road

The ridge provides marginal conditions for plant growth. It is exposed to wind from all directions, and the permeable nature of the underlying sands and gravels militates against tree growth. Vegetation at the crest is limited to a sparse grass cover that is easily disturbed. However, small, scrubby trees can be found in the "draws" on the flanks, where there is more water and shelter from the wind.

The eastern complex is similar to the eastern ridge in consisting of a series of north-south-trending ridges. These are more obvious on air photographs than on the ground (Figure 2.2.5). They also have grass-covered crests, with trees growing in the intervening troughs. Erratics are common, including the largest we have found in the Brandon Hills, a giant slab of dolostone 3 m long and 1.5 m wide.

The southern ridge is also similar — both on the ground and on air photographs — to the eastern ridge. Erratics are of the same type and occur in the same ratio as on the eastern ridge. However, this ridge is lower (approximately 30 m) and less steep (maximum angles about 20°). It is also much straighter. The southwest (drier) side is grass-covered, whereas the northeast (wetter) side is wooded.

Origin

The Brandon Hills were formed during the last ice age, probably towards the end of the Wisconsinan glacial period. On surficial geology maps of southern and southwestern Manitoba, they are shown as end moraine, part of a system extending from north of Brandon through the Brandon Hills and the Tiger Hills to Pembina Mountain, a system usually referred to as the Darlingford Moraine. The designation "end moraine" suggests that they are composed of sediment deposited at the edge of an ice sheet when it was stationary, forward movement of the ice being balanced by melting. While this interpretation may be generally correct, the single term "end moraine" does not describe all the features of the Brandon Hills.

The main body of the hills is most accurately described as end moraine, but even here there are uncertainties. Beneath the area, the layered and sorted deposits are clearly of glaciofluvial origin; that is, they were deposited by water in association with ice. These are overlain by till, a true glacial deposit. Initially we believed that the ridges of the main body of the hills resulted from the irregular deposition of till as the ice front receded, but we now believe that they are of glaciofluvial origin and that the overlying till was deposited on preexisting ridges.

Both the eastern ridge and the southern ridge have many of the characteristics of an esker — a landform thought to originate by deposition in tunnels in a glacier or an ice sheet, the deposits being left behind in a ridgelike form when the ice melts. Because the sediments were deposited by running water, they are layered and sorted. The till patches and the scattered erratics on the ridges would have been deposited by the overlying ice as it melted. Both the eastern ridge and the southern ridge can be categorized as eskers, although the eastern ridge in particular is much higher than any other esker mapped in southern Manitoba.[5] The eastern complex is sufficiently similar in both composition and topography to the eastern and southern ridges to suggest that it has a similar origin.

The description of the Brandon Hills as an end moraine can be regarded as the "traditional" explanation. However, an alternative is provided by Aber, who claims that the hills are glaciotectonic in origin. He explains the ridges of the main body as being due to ice thrusting, with great slabs of previously deposited glacial sediment, or bedrock, being pushed forward by the advancing ice. Despite this explanation for the main body, he still regards the eastern and southern ridges as eskers.[6]

Whatever the origin of the Brandon Hills, they are a largely unspoiled landform that has maintained its natural vegetation and that offers a variety of opportunities for the outdoors person.

Figure 2.2.4 The Steep East-facing Side of the Eastern Ridge of the Brandon Hills (Photograph: John Welsted)

Figure 2.2.5 The Eastern Part of the Brandon Hills. The grass-covered eastern ridge (light-toned) crosses the area from north (at the top of the photograph) to south; the eastern complex is located east of the ridge and highway 344 is east of that. (Photograph: NAPL A16408-9)

NOTES

1. J. Welsted and H. Young, "The Blue Hills of Brandon," *Manitoba Nature* (Autumn 1972):32.
2. J. Welsted and H. Young, "Geology and origin of the Brandon Hills, Southwest Manitoba," *Canadian Journal of Earth Sciences* 17(1980):942–51.
3. J. Welsted and H. Young, "The Blue Hills of Brandon," 35.
4. The relevant map is 62G/12 Wawanesa. A survey point located near the centre of the ridge has the exact height 1566.3 feet (477.4 m).
5. Eskers in the Baldur, Notre Dame de Lourdes, and Bruxelles area to the east of the Brandon Hills are commonly in the order of 10 m in height.
6. J.S. Aber, "Spectrum of Constructional Landforms," in *Genetic Classification of Glaciogenic Deposits*, ed. R.P. Goldthwait and C.L. Matsch (Rotterdam: A.A. Balkema, 1989), 281–92; Figure 4.

Case Study 2.3 Evolution of the Lower Assiniboine River

W.F. Rannie

The "Forks" at the confluence of the Assiniboine and Red rivers has become one of Winnipeg's best-known features, the focus of major redevelopment and a source of international acclaim (Case Study 10.1 on page 150). Less well known is the fact that The Forks has not always been at its present location; indeed, there has not always even been a Forks. About 3,000 years ago, The Forks was at St. Norbert, 14 km to the south, where the La Salle River joins the Red, and for several thousand years before that the Assiniboine did not join the Red at all but flowed north from Portage la Prairie into Lake Manitoba. These and other routes of the Assiniboine River are shown schematically in Figure 2.3.1. The cause of these dramatic changes lies with the Portage la Prairie alluvial fan, an unusual feature that, although barely noticeable on the ground, has produced an evolution of the Assiniboine River with few, if any, counterparts elsewhere in the world.

Most alluvial fans are small, steep features composed of coarse materials deposited by multichannel streams with "flashy" (frequently ephemeral) flow regimes in dry climates. The fan constructed by the Assiniboine has none of these characteristics. The river itself is perennial, carries a modest sediment load, and has a strongly meandering single-channel pattern. The fan it has produced has a very low gradient, is composed of relatively fine materials, and is an order of magnitude larger than most other contemporary fans. Only in two crucial respects does it resemble other fans: the radial configuration of channels, and its location at the point where the Assiniboine emerges from its confining valley onto the Lake Agassiz Plain (Chapter 2).

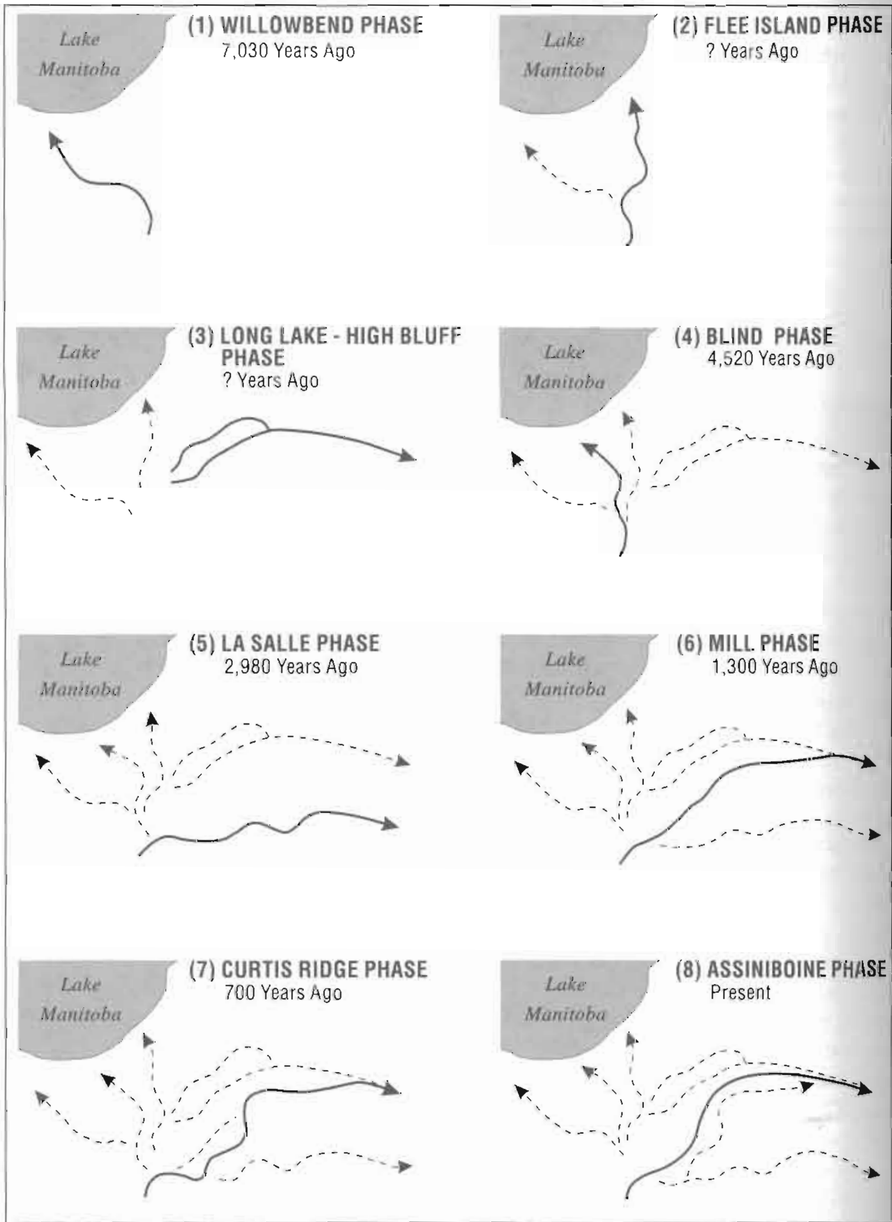

Figure 2.3.1 Evolution of the Lower Assiniboine River

The Portage la Prairie fan was produced by processes normally associated with floodplain formation by a laterally mobile meandering stream. Deposition in and near the river channel repeatedly elevated the river on an alluvial ridge. As it grew higher above the surrounding

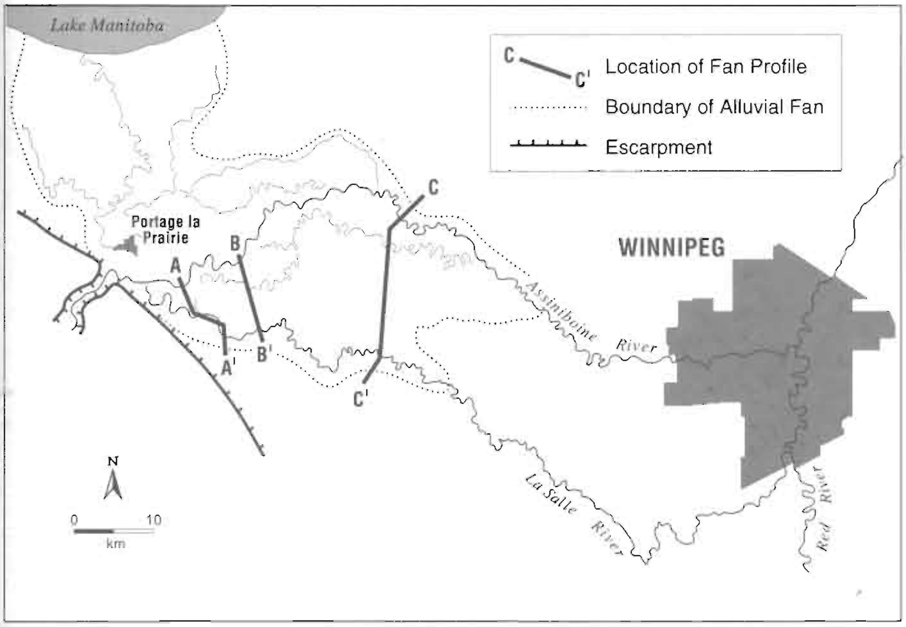

Figure 2.3.2 Paleochannels of the Lower Assiniboine River, Showing the Location of Profiles in Figure 2.3.3

terrain, it became increasingly unstable and was eventually abandoned in favour of a new lower course, a process called *avulsion*. Each of these episodes left an abandoned ridge-channel system, or paleochannel (Figures 2.3.2 and 2.3.3), with features such as scroll bars that show clearly on aerial photographs (Figure 2.3.4).

The initial courses of the river were northward to Lake Manitoba. The oldest paleochannel, Willowbend, was active before 7000 B.P., or shortly after the recession of Lake Agassiz water from the region. Drainage into Lake Manitoba shifted to the Flee Island channel and finally, by 4500 B.P., to Blind channel, which remained active at least until 3400 B.P. As the region between present-day Portage la Prairie and Lake Manitoba became "filled" with sediments and paleochannels, further avulsion exploited lower terrain and steeper gradients to the east, diverting the ancestral Assiniboine away from Lake Manitoba and towards the Red River.

The first eastward route was established by about 3000 B.P. along the channel now occupied by the La Salle River, joining the Red in present-day St. Norbert. By about 1,300 years ago (in the Mill Phase), the lower Assiniboine had shifted northward to join the Red at its present location at The Forks, but differed from its modern course on the fan. The upper fan section of the river was altered again by 700 B.P. in the Curtis Ridge Phase. Thus, the modern route of the Assiniboine from Portage la Prairie to Winnipeg is somewhat less than 700 years old.[1]

Interestingly, maps of the soils in the Portage la Prairie area reflect this evolution. Soils adjacent to the northward channels, being older, display mature chernozemic A horizons (Chapter 4), whereas those south of the present Assiniboine have immature, thin, organic layers, as would be expected in much younger sediments. The shift in outlet from Lake Manitoba to the Red River about 3,000 years ago coincided with a sharp reduction in sedimentation in Lake Manitoba and increased the sediment and water inflow to the Red. Although the sedimentation history of Lake Winnipeg is not known, an increase in the last 3,000 years would be expected.

Until recently, alluvial ridge formation continued to elevate the modern Assiniboine channel on the fan, producing a potential for future catastrophic channel abandonment during large flood events. This potential was greatly reduced in 1970, however, by the opening of the Portage Diversion (Case Study 18.2 on page 283). Located just west of Portage la Prairie, this large artificial channel enables water to be diverted from the Assiniboine to Lake Manitoba to reduce flow through Winnipeg during major floods (and incidentally to reduce flooding on the alluvial fan).

This diversion was possible only because of the elevation of the river provided by the fan near Portage la Prairie. Its value was demonstrated during truly exceptional floods in 1974 and 1976, when much of the alluvial fan and lower terrain would otherwise have been inundated. More importantly perhaps, given the elevated state of the Assiniboine, these floods might have triggered avulsive channel abandonment, which would have required expensive remedial works. Thus, human modification of the flood regime has probably ended the period of active fan formation.

NOTES

1. For more details, see W.F. Rannie, L.H. Thorleifson, and J.T. Teller, "Holocene Evolution of the Assiniboine River Paleochannels and Portage la Prairie Alluvial Fans," *Canadian Journal of Earth Sciences* 26(1989):1834–41; and W.F. Rannie, "The Portage la Prairie `Floodplain Fan'," in *Alluvial Fans: A Field Approach*, ed. A.H. Rachocki and M. Church (Chichester, England: John Wiley and Sons, 1990), 179–93.

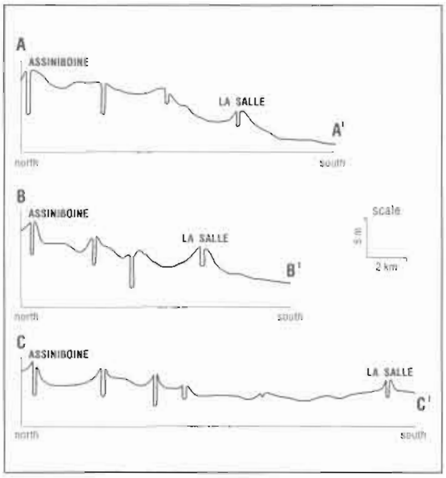

Figure 2.3.3 Cross-profiles of the Assiniboine Fan South of the Assiniboine River, Showing Major Alluvial Ridges

Figure 2.3.4 Paleochannels South of the Assiniboine River. The Trans-Canada Highway crosses the area in the north at the top of the photograph. (Photograph: Manitoba Air Photo Library [MAPL] MB 89021-176)