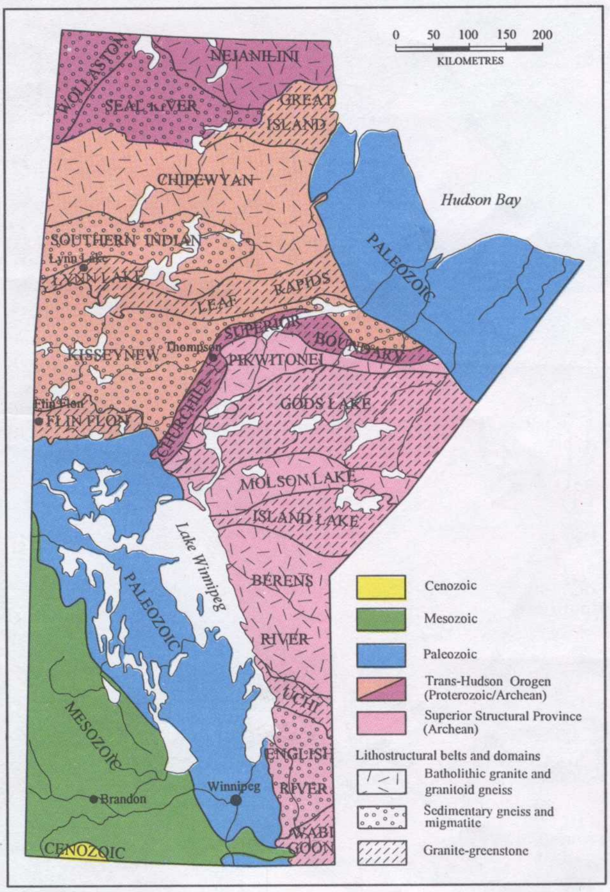
GEOLOGY OF MANITOBA

INTRODUCTION

The rocks of Manitoba fall naturally into three groups based on age and character. The most ancient group is Precambrian in age and consists of crystalline rocks of metamorphic and igneous origin. The Precambrian rocks are overlain by a younger group of sedimentary rocks deposited in seas during the Phanerozoic Eon. The Phanerozoic is subdivided further into the Paleozoic, Mesozoic and Cenozoic eras. The youngest Cenozoic deposits form the third natural group. These deposits are sedimentary; however, their origin is related to glaciers and glacial meltwater during Pleistocene times. The glacial deposits occur only at the surface and tend to cover the other two rock groups. The geologic time scale shown below will give the reader a more complete idea of the age relationships between these groups.

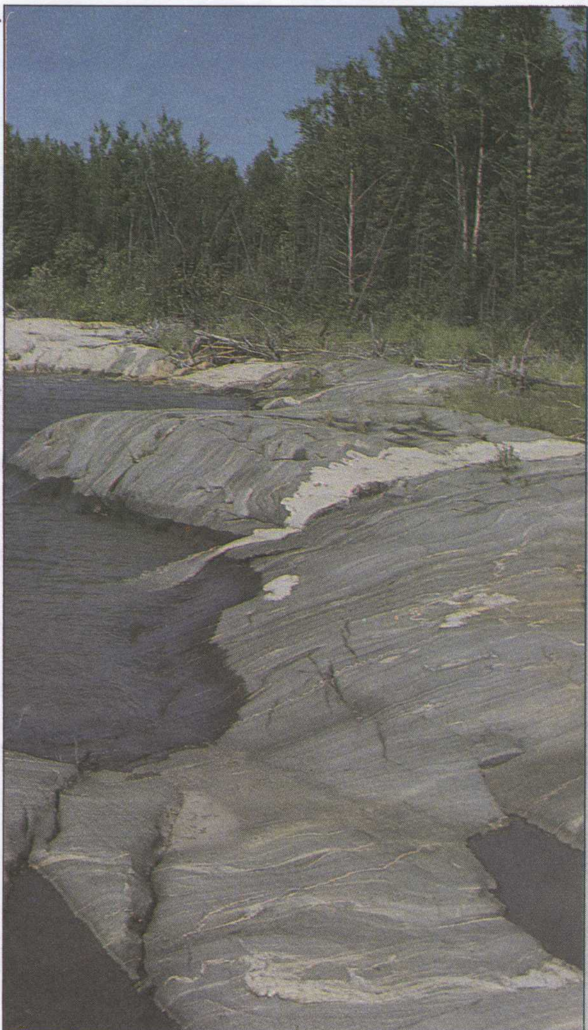
MAJOR GEOLOGICAL SUBDIVISIONS



PRECAMBRIAN

Precambrian rocks record some of the earliest events in the history of the earth. Additionally, they give geologist insight into processes that occur far below the earth's surface, at depths of 10 to 30 km. In Manitoba the Precambrian rocks can be divided into two geological provinces, largely on the basis of age. The Superior Province is roughly 3.0 to 2.5 billion years old, and the Churchill Province is younger, being about 2.8 to 1.7 billion years old. Both the Superior and Churchill provinces are further subdivided into various subprovinces, as the inset map illustrates. The Superior Province is dominated by granitic bodies which have intruded greenstone belts. Greenstone belts consist of metamorphosed volcanic and sedimentary rocks as shown by the panel on their formation. In Manitoba, the granitic-greenstone regions are the Gods Lake, Uchi and Wabigoon subprovinces. In addition to these subprovinces, the Superior Province also contains less extensive areas where the metamorphism has been so intense that the Precambrian rocks have been transformed into gneisses. These gneissic regions are called the

Archean pillowed basalt, Pipestone Lake



Proterozoic metamorphosed sediments, McCallum Lake

English River and Berens River subprovinces. Metamorphism, intrusion and deformation of the Precambrian rocks of the Superior Province terminated approximately 2.5 billion years ago.

The Churchill Province contains eight major geologic domains. The Flin Flon, Lynn Lake and Great Island domains are characterized by metavolcanic and minor metasedimentary rocks with abundant granitic intrusions, whereas the Seal River, Southern Indian and Kisseynew domains are complexes of metasedimentary and granitic rocks. The geologic characteristics and arrangements of these domains side by side suggest that they represent the roots of an ancient wide mountain system similar to that of present-day western North America. Within the Churchill Province, the last metamorphic, deformational and intrusive activity terminated about 1.6 billion years ago.

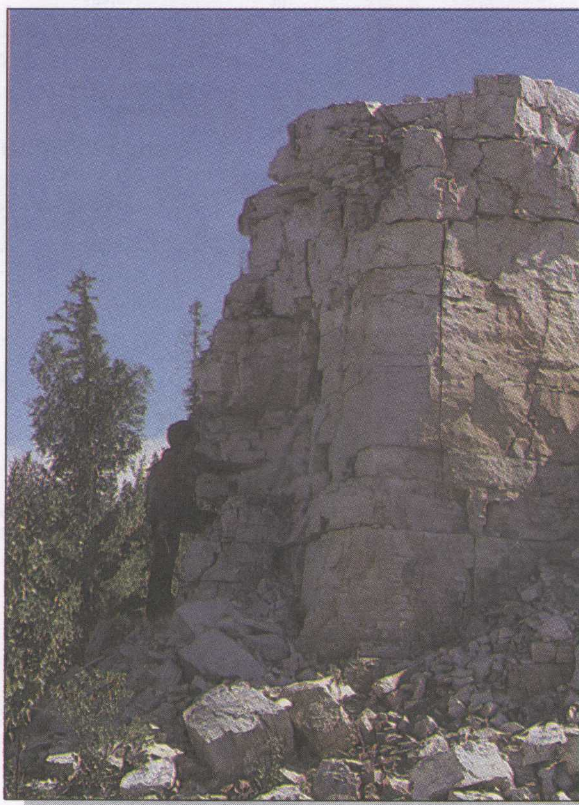
The greenstone belts of both the Superior and Churchill provinces have been important producers of copper, zinc and gold. The Churchill-Superior boundary zone marks the location of some of the world's largest nickel deposits; the best known is at Thompson.

PHANEROZOIC

PALEOZOIC

In Manitoba Paleozoic sedimentary rocks cover the Precambrian Shield in the Hudson Bay Lowland and in southwestern Manitoba. These rocks accumulated in depressed areas in the earth's crust known as sedimentary basins.

Two such sedimentary basins influenced sedimentation in Manitoba. These were the Hudson Bay Basin, centred in Hudson Bay, and the Williston Basin, centred in northwestern North Dakota. Within both of these areas the rocks dip gently towards the centre of the basin. The Paleozoic strata formed during a time span of about 570 million to 235 million years ago and comprise limestones, dolomites, shales, sandstones and some salt beds. All of these rocks were formed in ancient seas. The Paleozoic rocks of the Williston Basin contribute to Manitoba's mineral industry through mineral 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. In addition, some of the rocks serve as reservoirs for petroleum. Numerous fossils, such as corals, trilobites and brachiopods are found in Paleozoic rocks.



Paleozoic dolomite, Grand Rapids quarry

Mesozoic bentonite deposits, Morden-Miami area

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 the accumulation of Mesozoic sediments on the erosional surface. The contact between the eroded Paleozoic rocks and the base of the Mesozoic rocks is an example of an unconformity. Mesozoic sediments were deposited in ancient seas that covered Manitoba from about 225 million to 64 million years ago. These sediments include: red siltstones, sandstones, shales and gypsum. Distant volcanic activity, probably in western North America, spread volcanic ash across Manitoba; the ash was altered to beds of bentonite. Gypsum, bentonite, brick clay and shale are important mineral products from the rock formations of the Mesozoic Era. Large fossils of marine vertebrates such as mosasaurs and plesiosaurs are found in Mesozoic strata.

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 southern Manitoba. These strata, consisting primarily of fine sandy, silty shales, rest directly on Mesozoic rocks.

PLEISTOCENE

During the Pleistocene Epoch in late Cenozoic time, about 2 million years ago, the province was covered by repeated advances of the continental ice sheet, resulting in deposits which covered to various degrees all of the earlier rocks. The panels on glaciation highlight the nature of these deposits. Glacial material includes deposits laid down directly from the glacier, such as till, which is mixture of rock, sand and mineral particles that the glacier eroded from the various types of bedrock as it passed over the land. Glacial material also includes outwash deposits composed of sands and silts and lake deposits such as clays. These glacial deposits are economically important for Manitoba; sand and gravel is used in the construction industry and clay is used in the production of brick, tile and Portland cement.

RECENT

The main process of Recent time that is apparent to the traveller in Manitoba is erosion, primarily through the action of rivers and streams and along shorelines. Wind erosion also occurs where the vegetation cover is less established. The results of wind action can be seen in the sand dunes at Grand Beach and along the western edge of the Lake Agassiz plain in the Old Assiniboine Delta, where sand dunes are constantly shifting. Another important process in Manitoba is glacial rebound. Northern Manitoba is gradually rising to its pre-existing level prior to glaciation, at a rate of about 60 cm per century.

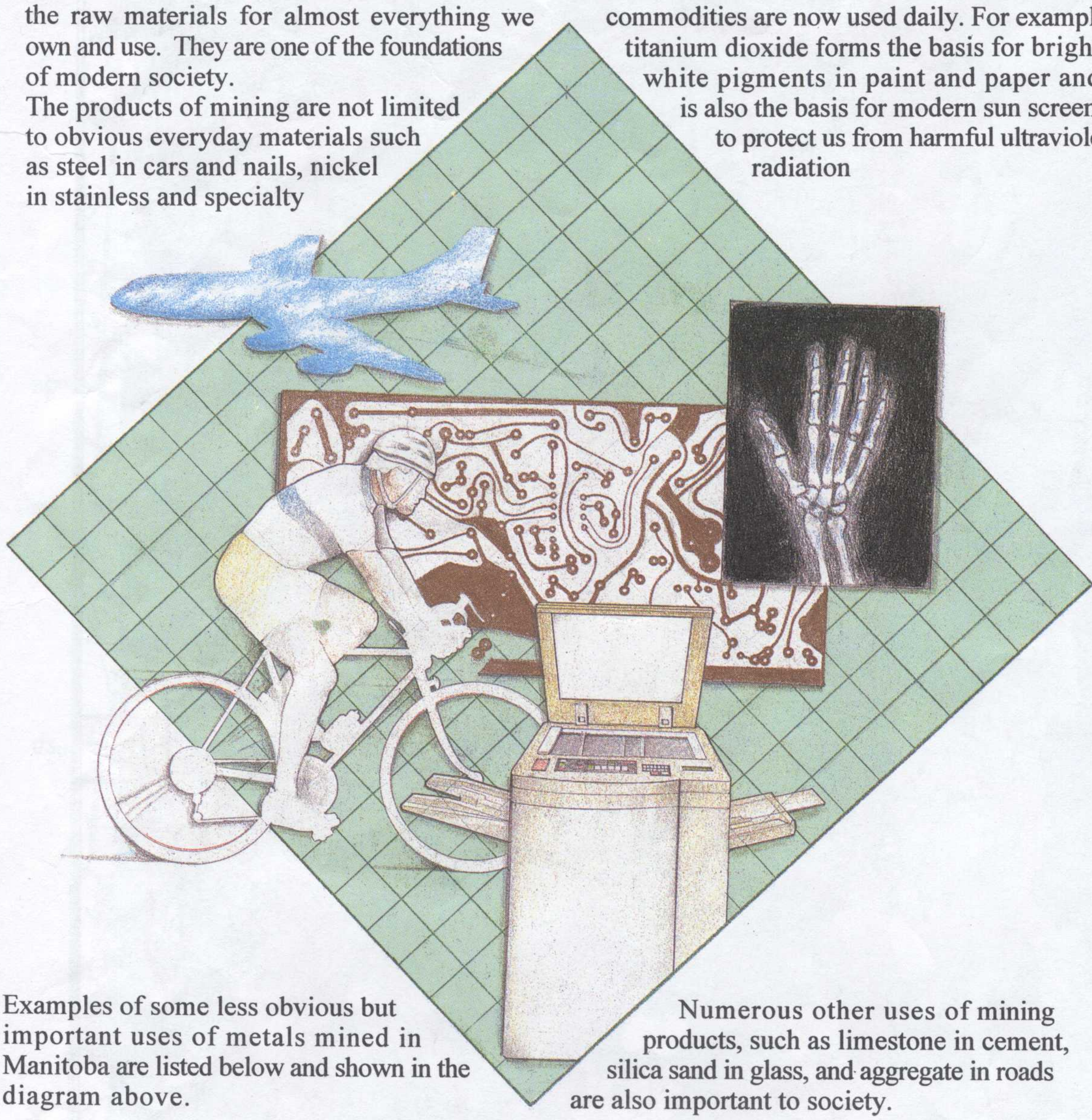
METEORITE IMPACT STRUCTURES

Manitoba has local, special structural features such as the West Hawk Lake crater, Poplar Bay crater, the Lake St. Martin crater, the High Rock Lake structure and the Denby structure. The Lake St. Martin structure is a cryptoexplosion crater, a descriptive term used to designate a roughly circular structure formed by the sudden release of energy, resulting in rock deformation with no relation to tectonic activity. The Lake St. Martin structure is probably a meteorite impact origin and is approximately Permian in age. The High Rock and Denby structures may also be the result of meteorite impact. Another crater structure is known in the Hartney area, 55 km southwest of Brandon; however, it is covered by Mesozoic sedimentary rocks.

MODERN SOCIETY AND THE MINERAL INDUSTRY

Minerals are indispensable in our daily lives and are often overlooked and underrated in public discussions of mining. They provide the raw materials for almost everything we own and use. They are one of the foundations of modern society.

The products of mining are not limited to obvious everyday materials such as steel in cars and nails, nickel in stainless and specialty steels, copper in plumbing and electrical wiring, and zinc in heating ducts and cans. More than 100 different minerals commodities are now used daily. For example titanium dioxide forms the basis for bright white pigments in paint and paper and is also the basis for modern sun screens to protect us from harmful ultraviolet radiation



Examples of some less obvious but important uses of metals mined in Manitoba are listed below and shown in the diagram above.

Numerous other uses of mining products, such as limestone in cement, silica sand in glass, and aggregate in roads are also important to society.

Cobalt: --------- jet engines, blue pigments for paints; a radioactive form is used as a tracer in radiation therapy
Chromium: ---- tanning leather, to fix dyes in fabric, in stainless steel
Lithium:-------- batteries, glass and ceramics and lubricants
Cadmium: ----- blue & green television screen phosphors, nicad batteries, yellow and red pigment in paints
Gold: ---------- printed circuits in electronics *i.e.* electronic games, computers, cameras; caps for teeth, medicine for arthritis
Zinc:----------- paint, rubber, cosmetics, soap, medicines, textiles, x-ray and television screens, galvanized coatings for other metals
Selenium:------ photovoltaic cells for converting sun to electricity, electronic equipment, photocopy machines
Spodumene: --- heat proof ceramic cookware (Corning Ware™)
Tantalum:------ surgical implants, glass for camera lenses, aircraft parts
Silver: --------- mirrors, jewellery, printed circuits, photography, batteries, and explosives

MANITOBA GEOLOGICAL HIGHLIGHTS

BIRDS HILL ESKER-DELTA COMPLEX

Locally, meltwater channels which cut into the glacier became filled with sand and gravel. These former ice-walled valleys are expressed today as winding ridges of sand and gravel called eskers. An extensive deposit of sand and gravel located at Birds Hill, 16 kilometres northeast of Winnipeg, is the main source of aggregate material for the city. The deposit consists of a high narrow ridge which extends eastward from the town of Birds Hill for 6.5 kilometres. The ridge merges into a delta-like plateau of sand and gravel which extends over a broad area including Birds Hill Park.

Quarrying Tyndall stone, Garson quarry

WEST HAWK LAKE

West Hawk Lake is believed to have formed as a result of meteorite impact because of its circular shape, the nature of the surrounding rocks and its great depth. Drilling results have shown that the rock below the lake is progressively less shattered and brecciated down to a depth of 600 m. Interesting outcrops of pillow lavas, a rock which is extruded onto a seafloor, occur throughout the area.

BIRDTAIL, QU'APPELLE, PEMBINA AND ASSINIBOINE VALLEYS

As the glaciers retreated from Manitoba, huge volumes of debris-charged meltwater, which drained directly from the glacier, carved large valleys on the landscape, such as the Birdtail, Qu'Appelle, Pembina and Assiniboine valleys. When the glaciers disappeared, the present rivers in Manitoba established channels on the outwash surface. These rivers are much smaller than the former meltwater rivers which originally shaped the valleys and are termed 'underfit streams'.

SETTEE MORAINE

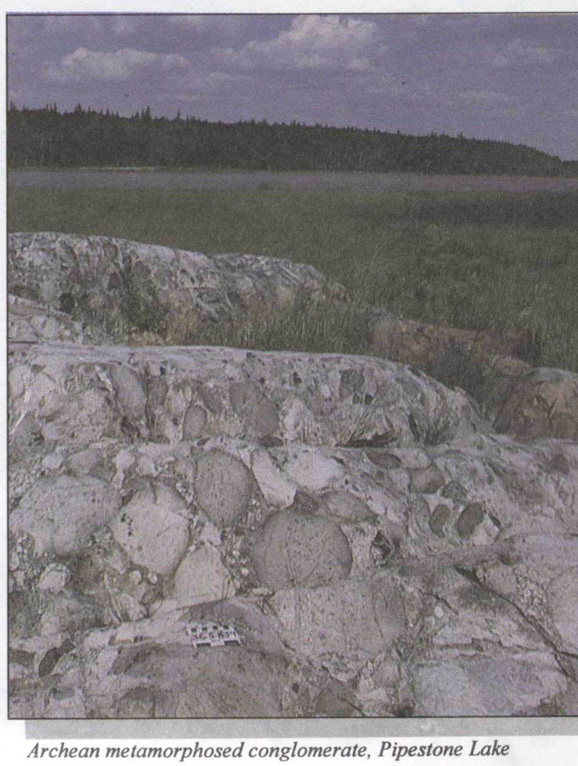
This moraine is located northwest of Thompson on Provincial Road 391 on the way to Nelson House. In the Leaf Rapids area the road travels upon an esker complex. These high, dry esker ridges from natural well drained roadbeds and trails.

SALT "MEADOW" WITH SALT SPRINGS

In the Dawson Bay area, along Pelican Rapids Road, and also along the roads on the southwest side of Lake Winnipegosis, large salt meadows with associated salt springs are abundant. They are believed to represent sites of Winnipegosis reefal structures where the overlying impervious Lower Dawson Bay rocks have been thinned or removed. Salt brines trapped within the reefs immediately below the surface are leaking out through salt springs.

MANITOBA ESCARPMENT

The Manitoba Escarpment is a preglacial feature and was not significantly eroded by glaciation due to the overlying deposits of hard grey Odanah shale. This shale, with its high silica content which was derived from volcanic activity, formed a resistant caprock of the Pembina and Riding mountains and the Manitoba Escarpment and prevented the escarpment from being eroded to the level of central and eastern Manitoba. The escarpment generally forms the easternmost edge of Cretaceous rocks in the province.



Archean metamorphosed conglomerate, Pipestone Lake

Abandoned beach ridges, Hudson Bay Lowland

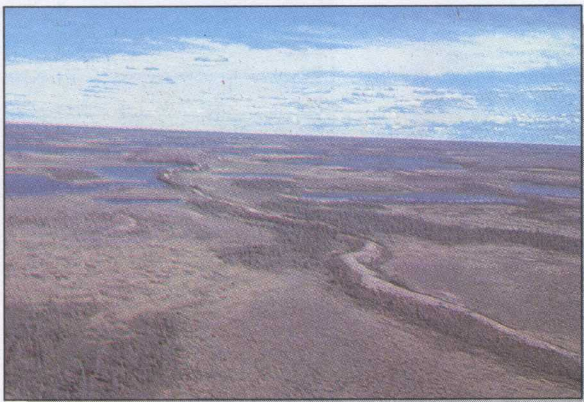
BELAIR, MILNER AND SANDILANDS MORAINES

Belair interlobate moraine forms a series of ridges extending north from Beausejour to Lake Winnipeg, composed of till overlain by stratified clean sand and gravel derived from ice lobes on either side of the ridges. East of Winnipeg there is a complex series of sand end-moraine ridges which stretch from near Victoria Beach and Milner Ridge south through Sandilands Provincial Forest. Partly because of erosion by waves of Lake Agassiz, many parts of this once extensive end moraine are now low-lying hills. The original western edge of this end moraine system can be seen along the Trans-Canada Highway about 5 kilometres east of Ste. Anne turn-off (Highway 12). From there the road rises from the flat plain of the Red River valley onto the irregular topography of the old Sandilands end moraine. A similar gentle rise occurs west of Anola and at St. Malo. Areas where a more abrupt front of the eroded end moraine can be seen are east of the Rat River along Highway 12 and north of Winnipeg along Highway 59 near the Gull Lake turn-off.

Paleozoic/Precambrian unconformity, Churchill River

DAWSON BAY, HIGHWAY 10

Along the Pelican Rapids Road, Dawson Bay area, undulating bedding-plane surfaces of Lower Dawson Bay strata reflect closely the configuration of underlying Winnipegosis reef complexes. Dawson Bay strata are draped over these reefs as a result of solution of Devonian Prairie Evaporite salt beds and subsequent collapse of strata. Highway 10 north of Red Deer River has a roadcut through the structural-topographic dome of Lower Dawson Bay strata which is draped over an underlying Winnipegosis reef. The reef top is within 5 to 10 metres of the surface.



Esker,Nejanilini Lake area

RED RIVER PLAIN

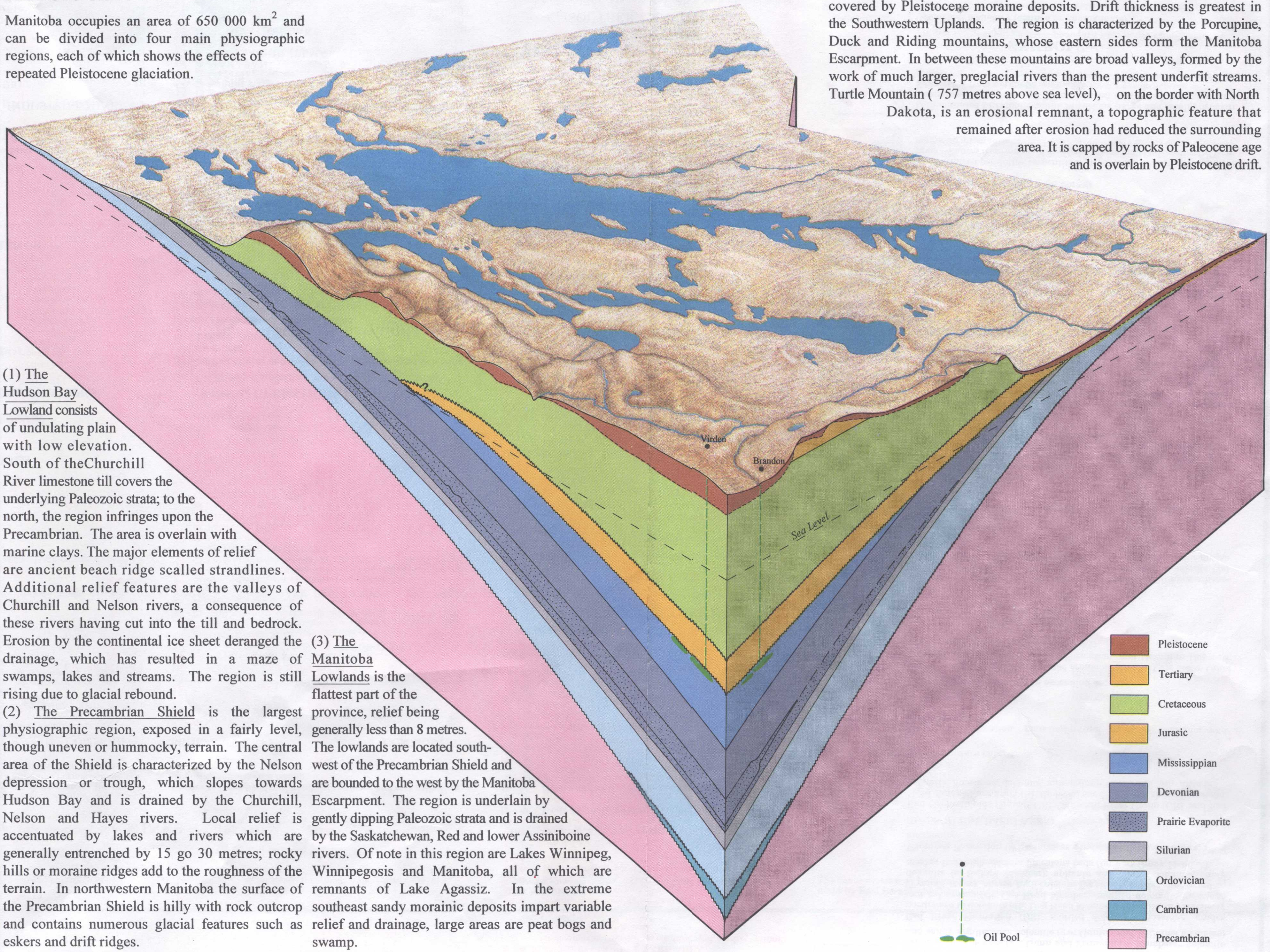
The Red River Plain, one the flattest regions in all of North America, formed as a result of glaciation and subsequent sedimentation in Lake Agassiz. Deposits of silt and clay settled onto the lake bottom. Such absence of surface relief in south-central Manitoba has led to extensive meandering of the Assiniboine and Red rivers and their tributaries.

CAMPBELL AND ARDEN BEACHES

The Campbell and Arden beaches, ancient beaches of Lake Agassiz, form prominent topographic features in Manitoba. Ridges of sand and gravel deposits were formed by reworking of material along the shores of Lake Agassiz. Wave action resulted in erosion of headlands and winnowing out of clay and fine sands, while coarse sand and gravel were spread along the shore to form beaches. These beach ridges served as natural routes of travel for the early Indians and explorers. Many cemeteries were also located on these ridges because of their good drainage. They currently provide roadbeds for railroads and highways.

PHYSIOGRAPHY

Manitoba occupies an area of 650 000 km^2 and can be divided into four main physiographic regions, each of which shows the effects of repeated Pleistocene glaciation.



(1) The Hudson Bay Lowland consists of undulating plain with low elevation. South of theChurchill River limestone till covers the underlying Paleozoic strata; to the north, the region infringes upon the Precambrian. The area is overlain with marine clays. The major elements of relief are ancient beach ridge scalled strandlines. Additional relief features are the valleys of Churchill and Nelson rivers, a consequence of these rivers having cut into the till and bedrock. Erosion by the continental ice sheet deranged the drainage, which has resulted in a maze of swamps, lakes and streams. The region is still rising due to glacial rebound.

(2) The Precambrian Shield is the largest physiographic region, exposed in a fairly level, though uneven or hummocky, terrain. The central area of the Shield is characterized by the Nelson depression or trough, which slopes towards Hudson Bay and is drained by the Churchill, Nelson and Hayes rivers. Local relief is accentuated by lakes and rivers which are generally entrenched by 15 go 30 metres; rocky hills or moraine ridges add to the roughness of the terrain. In northwestern Manitoba the surface of the Precambrian Shield is hilly with rock outcrop and contains numerous glacial features such as eskers and drift ridges.

(3) The Manitoba Lowlands is the flattest part of the province, relief being generally less than 8 metres. The lowlands are located south-west of the Precambrian Shield and are bounded to the west by the Manitoba Escarpment. The region is underlain by gently dipping Paleozoic strata and is drained by the Saskatchewan, Red and lower Assiniboine rivers. Of note in this region are Lakes Winnipeg, Winnipegosis and Manitoba, all of which are remnants of Lake Agassiz. In the extreme southeast sandy morainic deposits impart variable relief and drainage, large areas are peat bogs and swamp.

(4) The Southwestern Uplands consist of gently dipping Mesozoic strata covered by Pleistocene moraine deposits. Drift thickness is greatest in the Southwestern Uplands. The region is characterized by the Porcupine, Duck and Riding mountains, whose eastern sides form the Manitoba Escarpment. In between these mountains are broad valleys, formed by the work of much larger, preglacial rivers than the present underfit streams. Turtle Mountain (757 metres above sea level), on the border with North Dakota, is an erosional remnant, a topographic feature that remained after erosion had reduced the surrounding area. It is capped by rocks of Paleocene age and is overlain by Pleistocene drift.

SUSTAINABLE DEVELOPMENT AND THE RESOURCE INDUSTRY

Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

A balance is required in which several criteria are met: the existing population and future generations can maintain a healthy quality of life (*The Health of Society*); an industrial, agricultural, and social system can produce the materials required to meet the needs of the people (*The Economy*); the ecosystems necessary for continued existence of life are maintained (*The Environment*).

medicine from these resources is currently irreplaceable.

In the production of minerals, decisions that minimize the impacts of developmental and operational disturbance are necessary. To reduce possible negative effects of projects, continuing advances in science and technology are applied in planning and monitoring all stages.

Since these operations have a finite quantity of useful material available they also have a finite time of operation. At the end of operation, they need to be restored to

Mining is a vital component of our economy. It provides significant employment opportunities and taxes to help pay for our health and social programs. It is the Province's second leading primary industry (after agriculture), representing approximately 30% of Manitoba's exports.

It has been said "if you didn't grow it you mined it." The importance of the mining and petroleum products to society's well being is unquestionable. For example, even if the use of oil or coal for energy production was stopped, the need for plastic, fertilizer and

acceptable state. As well, the skilled and flexible work force required must be ensured of minimal social disruption.

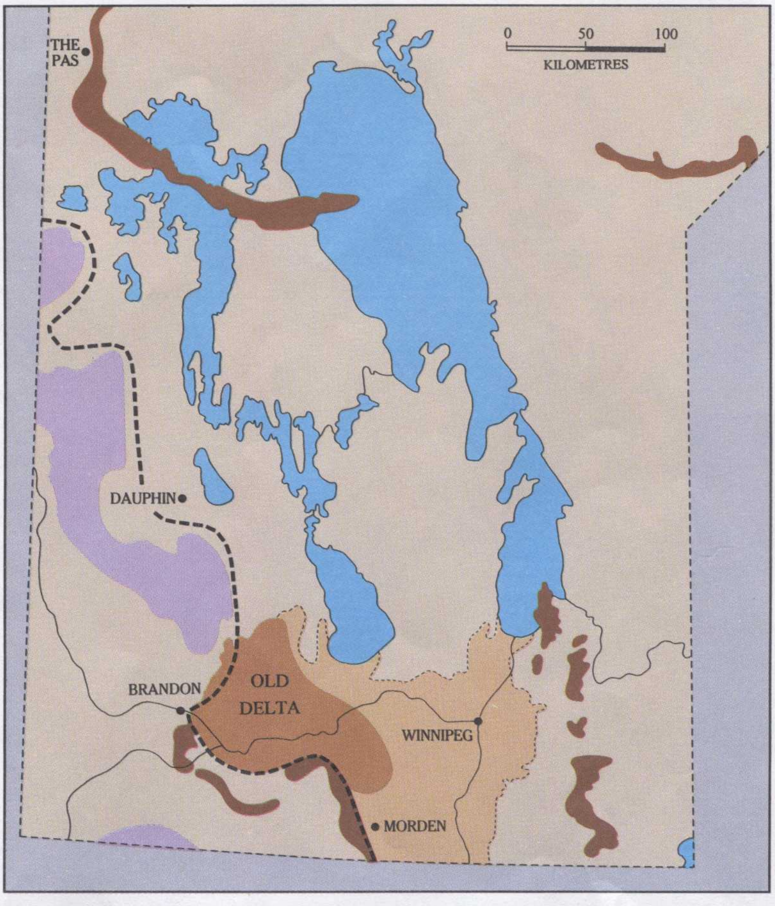
It would not serve society's needs to stop production of non-renewable natural resources that form the basis for a healthy society. The current population of the earth could not be maintained without the materials generated by these resources. It is equally important to preserve the well-being of the environment. Maintaining a balance will require better understanding of the impact of society on the natural system.

LATE PLEISTOCENE GLACIATION

The Pleistocene Epoch is often referred to as the Ice Age since continental ice sheets spread across Canada during this time. The effects of these glaciations profoundly influenced Manitoba's topography. Evidence suggests several major periods of glaciation during the two million years of the Pleistocene Epoch, each of which lasted for thousands of years. The maximum extent of glaciers during the Pleistocene is shown in the figure at the right.

The most recent glaciation, called the Wisconsinan, started approximately 75 000 years ago. The glaciers fluctuated back and forth between northern and southern regions during this time before they retreated about 8 000 years ago. The load of the ice resulted in crustal depression. Slow rebound of the crust followed the retreat of the glaciers and is still taking place in Manitoba. Though the climate began to warm about 16 000 years ago, it took almost 5 000 years before the ice melted to expose large parts of the land surface in southern Manitoba; the ice in northern Manitoba took another 3 500 years to melt away completely.

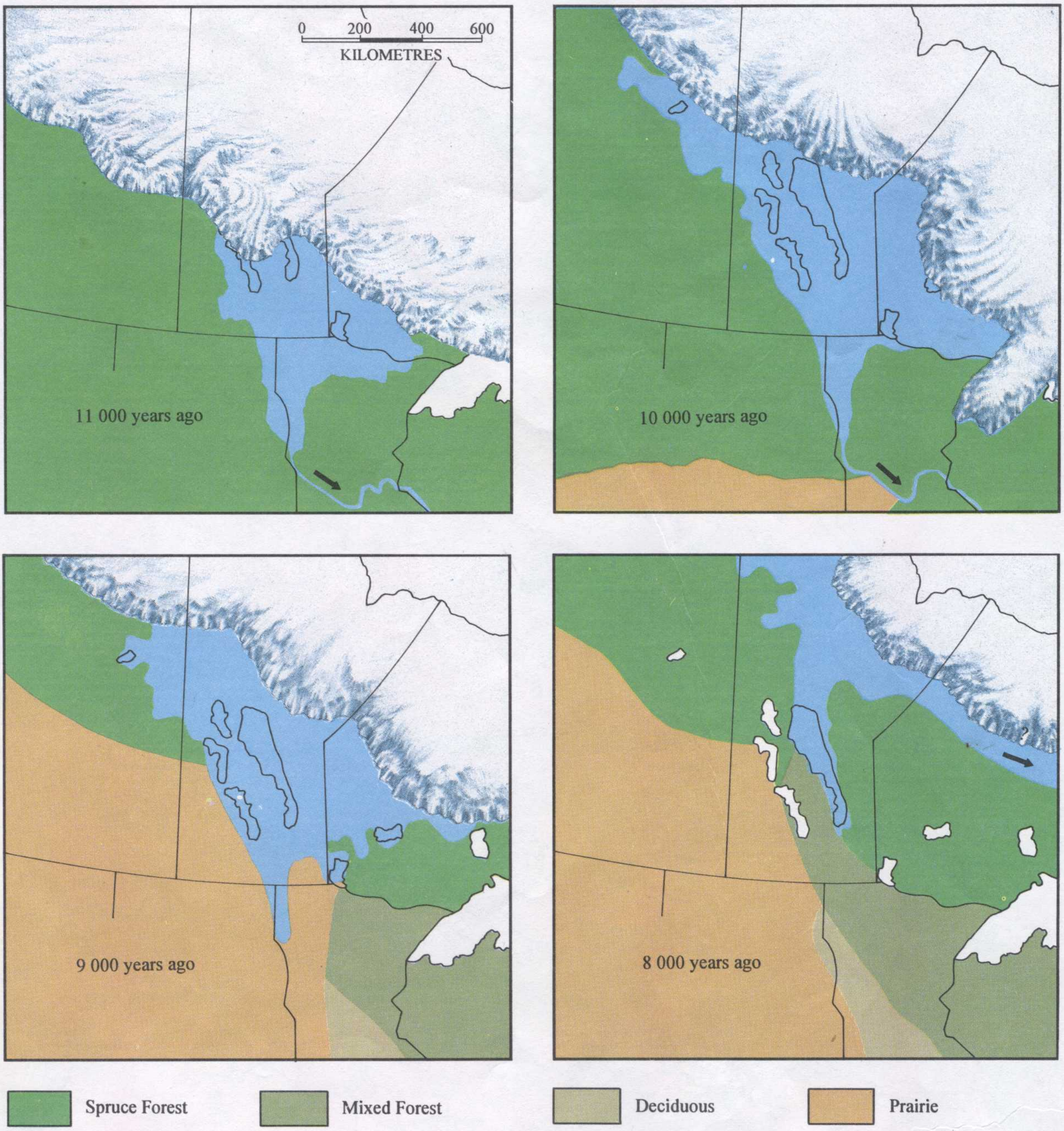
Manitoba's landscape currently bears the legacy of these late Pleistocene glaciations which eroded and reshaped the land surface. Esker complexes such as Birds Hill; moraines like The Pas, Sandilands and Tiger Hills; and the Pembina, Souris and Assiniboine valleys are just a few of the numerous consequences of glaciation. Meltwater Lakes, in particular Lake Agassiz, are another result of glaciation and have also influenced the shape of Manitoba's landscape.



GLACIAL DEPOSITS OF SOUTHERN MANITOBA

The Manitoba Escarpment is shown by the heavy dashed line, extending northwest to southeast. West of the escarpment, most of the surface deposits are composed of till, including hummocky "dead ice" moraine shown in light purple. The old delta of the Assiniboine River (east of Brandon) formed where the river entered glacial Lake Agassiz. The thick clay deposits of Lake Agassiz are found mainly east of the delta, in the Red River Valley (tan colour). Elsewhere, the surface is covered by a mixture of till, clay, sand, gravel and peat, with Precambrian bedrock exposed over large areas east of Lake Winnipeg. Major end moraines are the irregular rust-coloured areas.

EXTENT OF LAKE AGASSIZ DURING DEGLACIATION



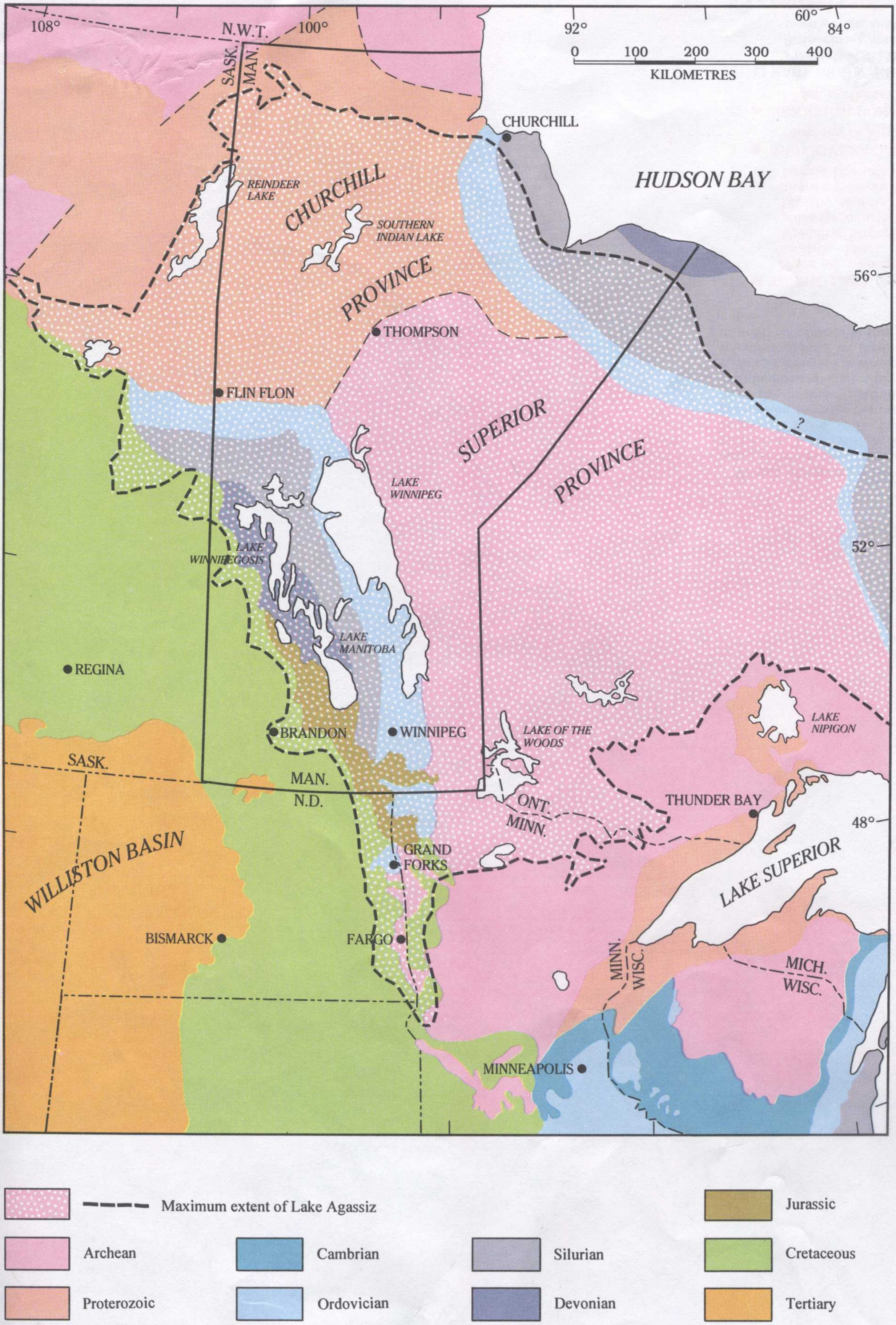
Glacial Lake Agassiz (in blue) formed in front of the glacier as it retreated northward through the Red River Valley and eventually became the largest of the glacial lakes.

Two stages, separated by an interval of low water, are recognized in the history of the lake. During the recessional stage several types of deposits were formed, such as outwash plains, deltas and beaches.

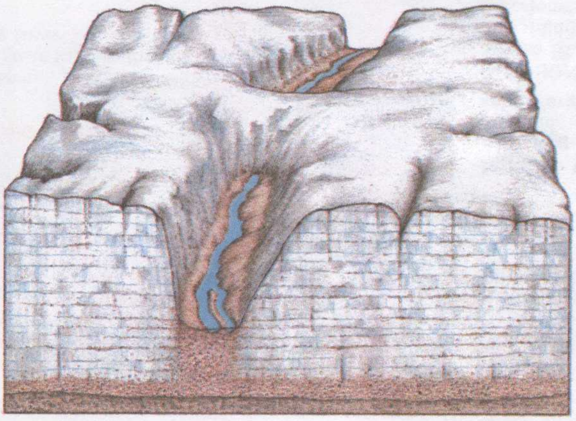
The ancient beaches of Lake Agassiz can be seen today as nearly parallel sandy ridges or as wave-cut cliffs along the Manitoba Escarpment. These beach ridges are higher to the north because of unequal glacial rebound.

About 10 000 years ago Lake Agassiz covered 350 000 km2. The water was more than 200 metres deep at Winnipeg. When the ice sheets had retreated as far north as the mouth of the Nelson River approximately 5 000 years ago, access to the open sea became available. This resulted in a sudden drainage of the remaining part of Lake Agassiz, which left behind the ancestral forms of Lakes Winnipeg, Manitoba and Winnipegosis. Deposits of silt and clay that were left on the lake bottom cover a large portion of the province today.

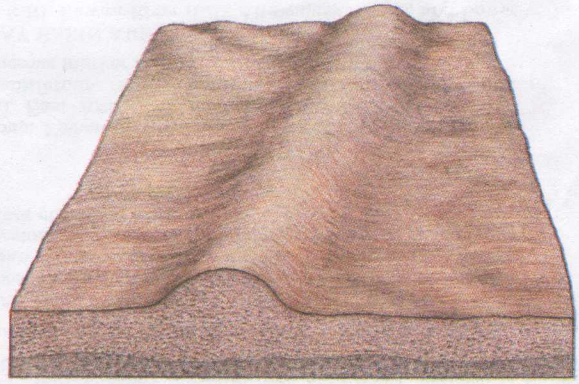
BEDROCK GEOLOGY OF GLACIAL LAKE AGASSIZ



ESKERS, END MORAINES AND HUMMOCKY TOPOGRAPHY



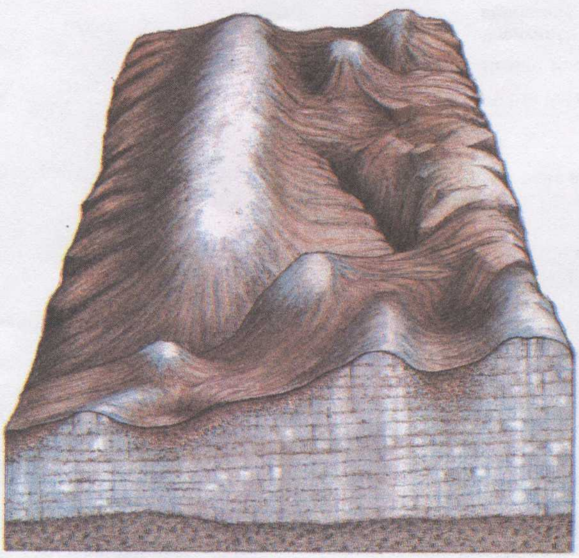
The diagrams show how an esker forms. In the left diagram, the river has cut its way down through the glacier and is depositing sand and gravel in its ice channel.



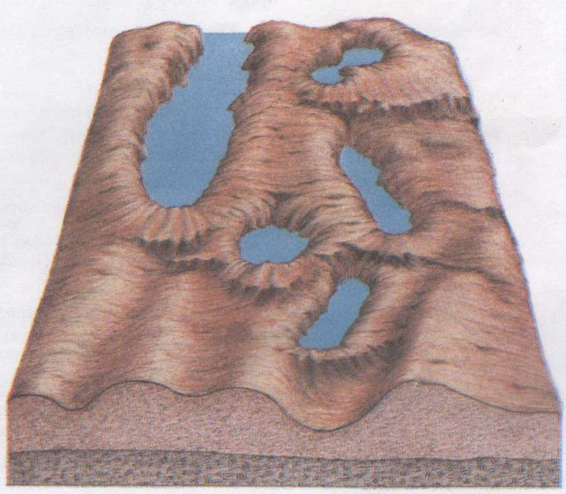
After the channel walls melt away, the river sediments are left as an esker ridge.

The diagrams show how end moraines form. In the left diagram, the rate of glacier melting equals the rate of glacier advance and a ridge of debris (till) is left along the margin.

Once the ice melts back, the ridge is left as an end moraine.



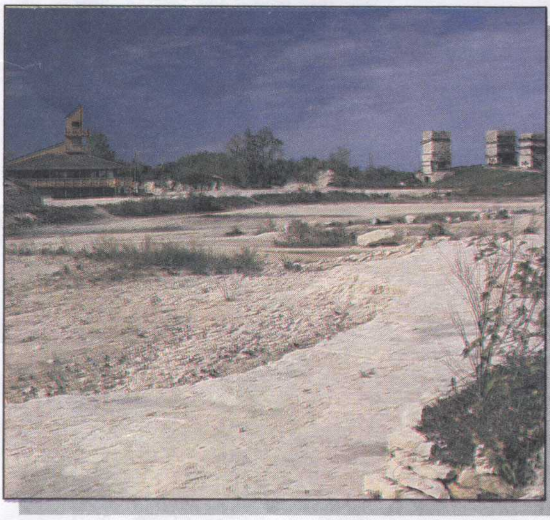
The diagrams show the development of hummocky topography in a stagnant (dead) ice area. In the left diagram, debris on the glacier's surface has slipped off the highest ridges and knobs into nearby low areas.



When the ice finally melts away those areas where the last glacier remnants existed will become depressions on the land's surface and may be filled with lakes and ponds.

FUTURE DEMANDS ON NON RENEWABLE RESOURCES

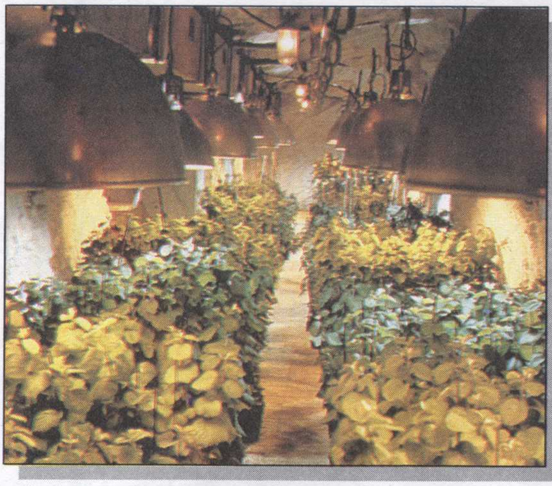
Demand for material things increases not only with population growth but also with development of Third World countries. One way to satisfy such demand is to increase production. However, materials from mining and petroleum are nonrenewable resources and as such are finite. Society is learning to change its consumption patterns, and to recycle, reuse and reduce in order to reduce waste and help meet the growing demand for minerals



Fort Whyte Centre for Environmental Education, Winnipeg

Many metals such as copper, zinc and iron in steel are not consumed or irreversibly changed, as gasoline is when burned for its energy content. The devices in which they are used simply become obsolete or irreparable. The metals can be removed and reworked into new products. This not only decreases the demand for new nonrenewable resources, it also conserves energy and reduces environmental impacts.

Even with recycling, the demand for new metal is increasing and the supply of raw material is dependent upon the growth in



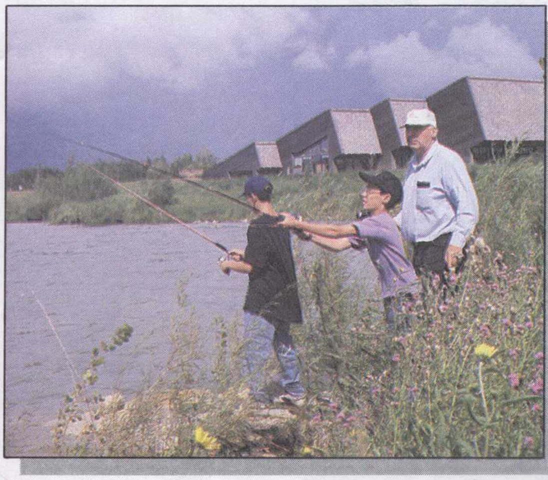
Underground garden in HBM&S Flin Flon mine

Steam venting from HBM&S zinc plant, Flin Flon

society's needs. Metals such as copper, lead and titanium will continue to be supplied by mining in the future.

The methods of extraction and production must continue to become more sustainable. For example, new technology in the Flin Flon smelter allows production of zinc in a way that eliminates sulphur dioxide as an air pollutant from the process. The only emission into the atmosphere is steam.

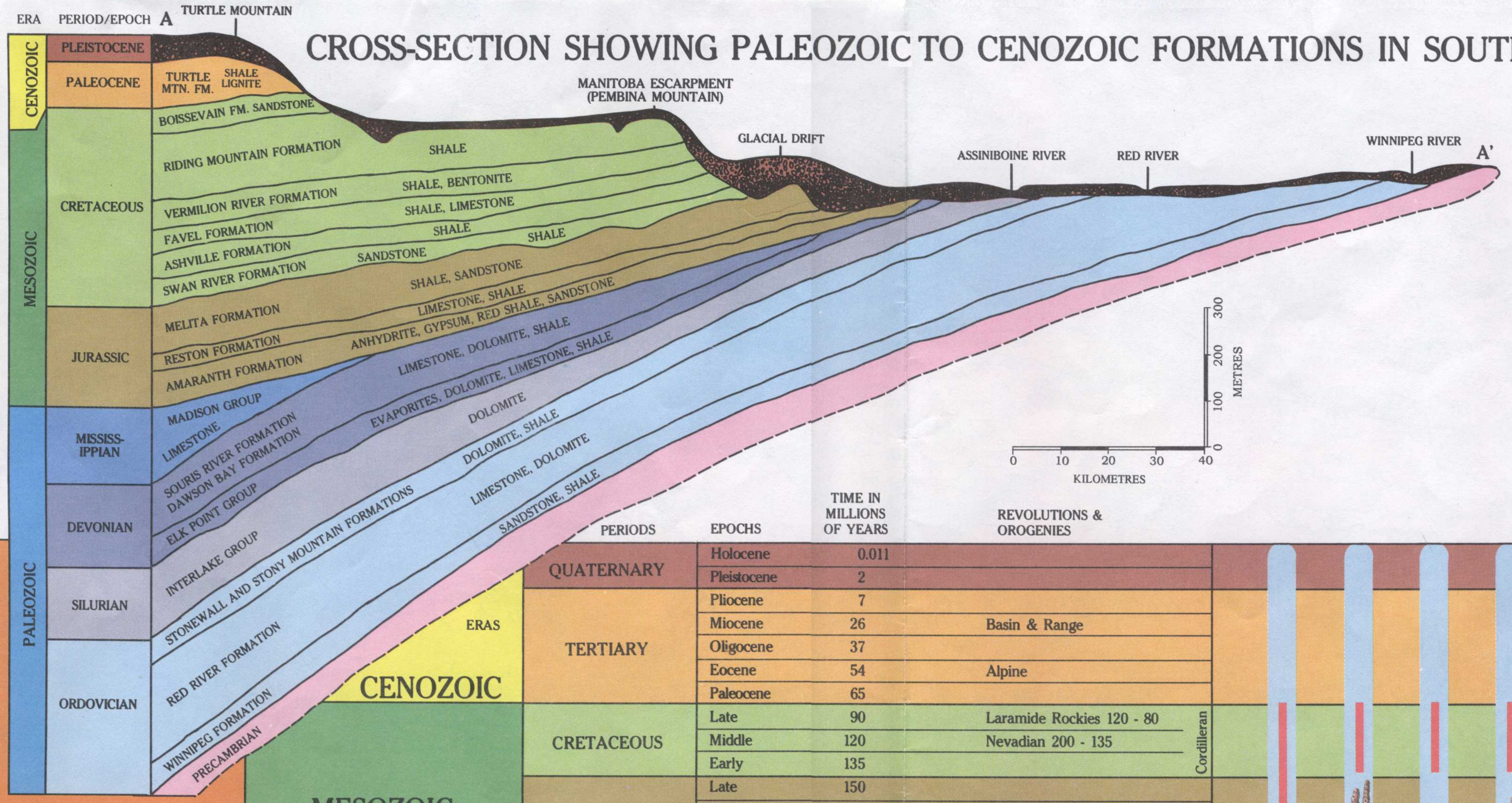
Mine sites such as Centennial Mine near Flin Flon have been reclaimed to a point that little evidence of mining remains today. The reclaimed quarry at Fort Whyte in Winnipeg



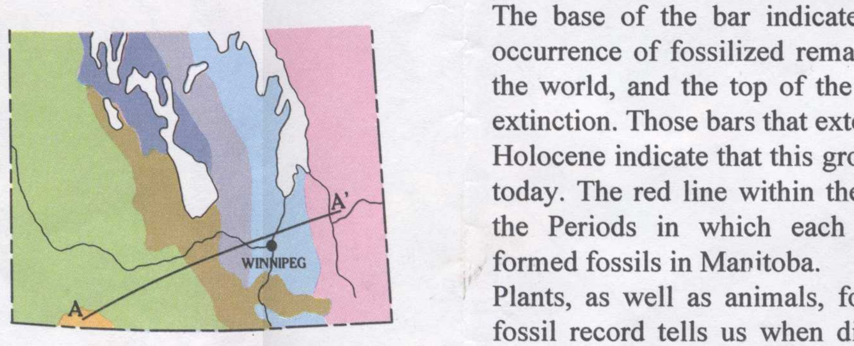
Stonewall Quarry Park, reclaimed limestone quarry, Stonewall

provides habitat for a variety of animals and is enjoyed by thousands of visitors to its park and nature centre. Lands that have been disturbed by mineral development shall be rehabilitated to a condition that is environmentally safe, ecologically sound, and valuable to society

CROSS-SECTION SHOWING PALEOZOIC TO CENOZOIC FORMATIONS IN SOUTHERN MANITOBA



FOSSIL LIFE FORMS IN MANITOBA



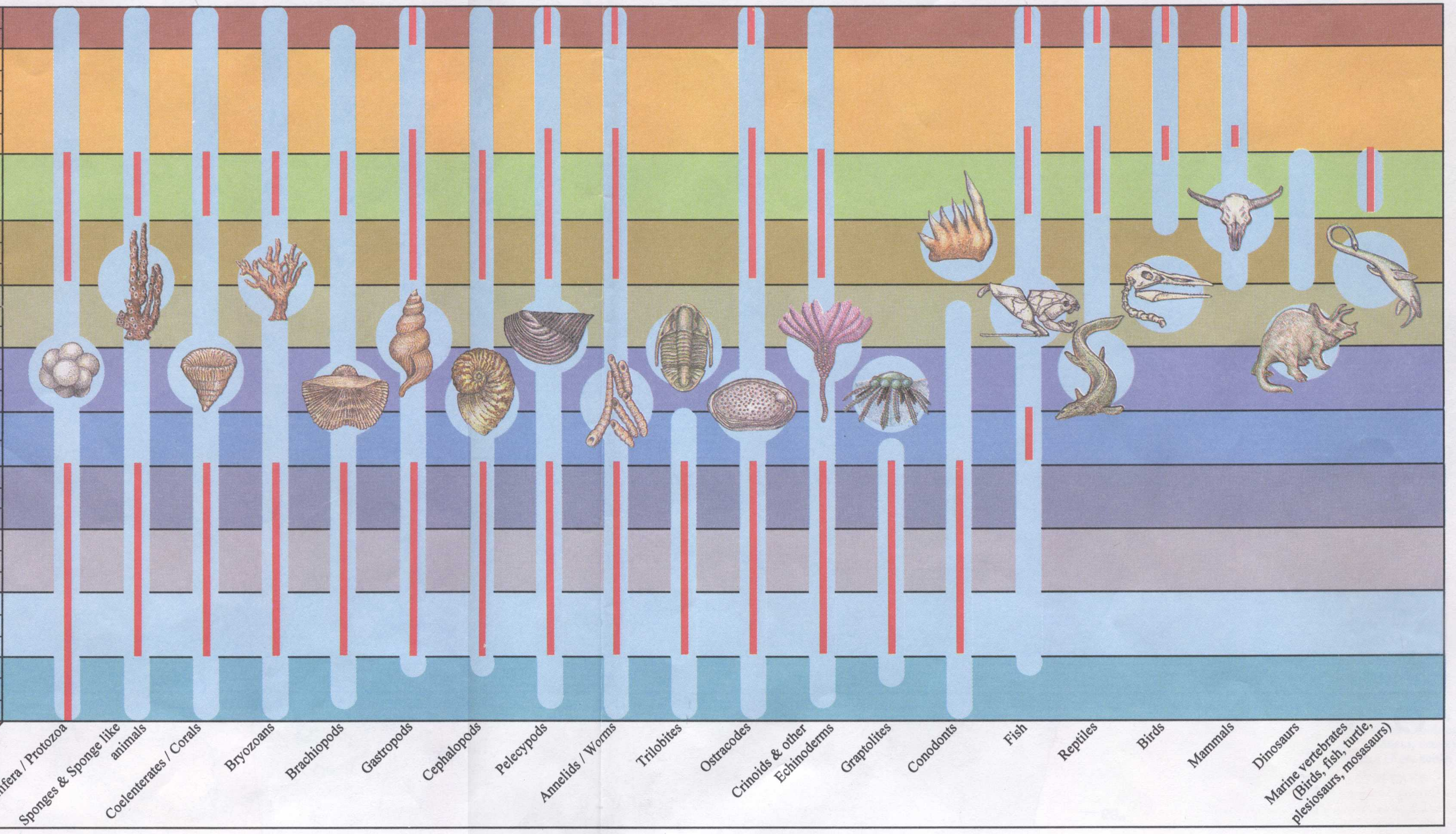
The chart below shows selected groups of animals that have formed fossils in rocks in Manitoba. The blue bar indicates the Periods in which each group of animals, depicted in the circle, lived. The base of the bar indicates the oldest know occurrence of fossilized remains of the group in the world, and the top of the bar the time of its extinction. Those bars that extend to the top of the Holocene indicate that this group of animals lives today. The red line within the blue bar indicates the Periods in which each group of animals formed fossils in Manitoba.

Plants, as well as animals, form fossils and the fossil record tells us when different varieties of plants evolved. The partial list below indicates important developments of some common plants.

- Archean - earliest known bacteria and algae
- Middle Silurian - first terrestrial plants
- Pennsylvanian - coal forming forests
- Late Permian - development of conifers
- Early Triassic - abundant cycads and conifers
- Late Cretaceous - first flowering plants
- Oligocene - abundant grasses

Note: Revolutions and Orogenies refer to mountain building or other large scale geological events. The geological ages in all of the illustrations are colour coded.

EONS	ERAS	PERIODS	EPOCHS	TIME IN MILLIONS OF YEARS	REVOLUTIONS & OROGENIES
PHANEROZOIC	CENOZOIC	QUATERNARY	Holocene	0.011	
			Pleistocene	2	
		TERTIARY	Pliocene	7	
			Miocene	26	Basin & Range
			Oligocene	37	
			Eocene	54	Alpine
			Paleocene	65	
	MESOZOIC	CRETACEOUS	Late	90	Laramide Rockies 120 - 80 (Cordilleran)
			Middle	120	Nevadian 200 - 135 (Cordilleran)
			Early	135	
		JURASSIC	Late	150	
			Middle	170	
			Early	190	
		TRIASSIC	Late	200	Palisades
			Middle		Rifting origin of Atlantic Ocean
			Early	225	
	PALEOZOIC	PERMIAN	Late	235	
			Middle	260	Allegheny 260 - 250
			Early	280	
		PENNSYLVANIAN CARBONIFEROUS		320	
		MISSISSIPPIAN		345	
		DEVONIAN	Late	365	
			Middle	390	
			Early	395	Acadian (Appalachians)
		SILURIAN	Late		
			Middle		
			Early	430	
		ORDOVICIAN	Late		Taconic
			Middle		
			Early	500	
		CAMBRIAN	Late	510	
			Middle	540	
			Early	570	
PRECAMBRIAN	PROTEROZOIC			1000±	Grenville
				2500±	
	ARCHEAN			3200±	
				3800±	Oldest rocks (S.W. Greenland)
				4600±	Evolution of core-mantle-crust



GEOLOGICAL FORMATIONS IN MANITOBA

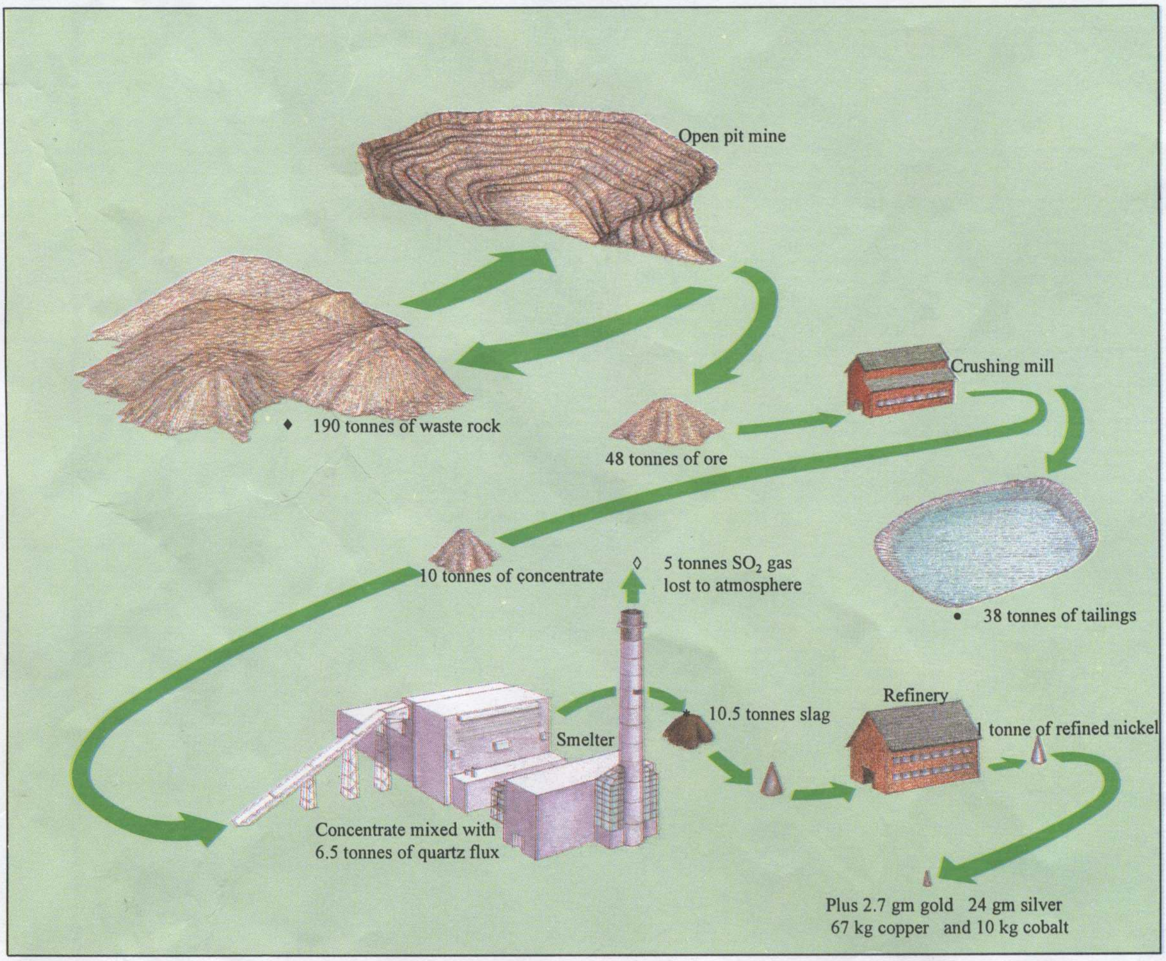
AGE *MYBP	ERA	PERIOD	EPOCH	FORMATION	MEMBER	MAX. THICK (m)	BASIC LITHOLOGY
	CENOZOIC	QUATERNARY	RECENT				Top soil, dune sands
			PLEISTOCENE	GLACIAL DRIFT		140	Clay, sand, gravel, boulders, peat
		TERTIARY	PLIOCENE				
			MIOCENE				
			OLIGOCENE				
50			EOCENE				
			PALEOCENE	TURTLE MTN.		120	Shale, clay and sand. Lignite Beds; located only in Turtle Mountain
65	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 calcareous, bentonitic; slightly petroliferous
					MORDEN		Shale, dark grey non-calcareous, concretions, local sand and silt
				FAVEL		40	Grey shale with heavy calcareous specks, bands of limestone and bentonite
100				ASHVILLE / ASHVILLE SAND		115	Shale, dark grey, non-calcareous, silty quartz sand or sandstone
			LOWER CRETACEOUS	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
					LOWER: RED BEDS	40	Red shale to siltstone, dolomitic, oil producing
200		TRIASSIC		ST. MARTIN COMPLEX		300	Carbonate breccia, trachyandesite (crypto-explosion structure) Permian-Triassic (?)
250	PALEOZOIC	PERMIAN					
300		PENNSYLVANIAN					
		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 argillaceous limestone, light brown and reddish mottled Zones of shaly, oolitic, crinoidal and cherty limestone Oil producing
				BAKKEN		20	Two black shale zones separated by siltstone. Oil show
350		DEVONIAN		QU'APPELLE GROUP: LYLETON		35	Red siltstone and shale, dolomitic
				SASK. GROUP: NISKU		40	Limestone and dolomite, yellow-grey fossiliferous, porous, some anhydrite
				SASK. GROUP: DUPEROW		170	Limestone and dolomite, argillaceous and anhydritic in places
				MAN. GROUP: SOURIS RIVER 1 ST RED		120	Cyclical shale, limestone and dolomite, anhydrite
				MAN. GROUP: DAWSON BAY 2 ND RED		65	Limestone and dolomite, porous, anhydrite — local shale red and 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
				ELK POINT GROUP: ASHERN		12	Dolomite and shale, brick red
400		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
450					GUNN	20	Shale, red-green; fossiliferous, limestone bands
				RED RIVER	FORT GARRY / SELKIRK / CAT HEAD / DOG HEAD	170	Dolomitic limestone, mottled, and dolomite
				WINNIPEG		60	Shale, green, waxy; sandstone interbedded
500							Sand and sandstone, quartzose
550		CAMBRIAN		DEADWOOD		60	Glauconitic sandstone and siltstone, and shale; green-grey to black; very edge of S.W. Manitoba only
	PRECAMBRIAN (EON)						Acid and basic crystalline and metamorphic rocks

*Millions of years before present

THE WORKINGS OF A MODERN MINE

Because recycling cannot replace the need for new production, the mining industry will continue to apply new technology to enhance production and reduce environmental impacts and waste. The diagram indicates the amount of material typically extracted in a nickel mining operation to produce one tonne of nickel.

Ever-expanding uses for materials that have typically been waste, as well as improved extraction technology, can increase the yield and products from an operation. Environmentally benign systems, such as the two stage pressure leach system of zinc extraction in Hudson Bay Mining and Smelting Co. Ltd.'s Flin Flon smelter, have resulted in cleaner production methods and thus reduced the emission of harmful waste into the ecosystem.



In Manitoba, nickel is mined by open pit and underground methods. The ore is taken to a crushing mill where metal bearing minerals are separated from waste rock. The concentrated ore is smelted with quartz flux. In this process iron and some sulphur impurities concentrate in slag and the remaining sulphur is vented up the stack. The nickel is then further refined electrolytically.

♦ Waste rock is used: to backfill underground mines, for road construction, as railway ballast and for dam construction.

• Tailings (waste portion separated from the ground ore) are empounded in tailings ponds with dams designed to be "maintenance free."

* Slag (solidified glassy waste separated from the metal in the furnace) is sold for a nominal fee for roofing materials (aggregate) and as a sand blasting medium.

◊ Half of the sulphur in the ore is fixed as pyrrhotite and in the slag. In the future, scrubbers will be added to the stacks to remove SO_2 from the hot gases being vented.

FORMATION OF A GREENSTONE BELT

Greenstone belts in the Precambrian Shield are elongate areas of metamorphosed volcanic and sedimentary rocks lying within broad areas of granite and gneiss. The hypothetical model for the formation of one such belt, in the Snow Lake area, typifies a possible mode of origin for these economically important areas.

A. During the early history of the earth, the crust was formed by upward separation of lighter rock material from the dense, mafic material in the layer below the crust, referred to as the mantle. This pre- existing crust contained many fractures or cracks. Mafic lavas poured out of the fractures onto the seafloor and solidified as black basalt. As this process continued, a thick platform of volcanic rocks built up gradually on the ocean floor.

B. As volcanic activity continued, the lavas underwent a change in chemical composition from mafic to more felsic lavas, such as andesites and rhyolites. The platform of accumulated volcanic rocks eventually built up to the surface of the ocean and individual volcanoes rose above sea level.

Subsequent erosion of these new land masses produced sediments called greywacke, a dark, coarse-grained sandstone derived by weathering of volcanic rocks. Continued volcanic activity produced fragmental material called volcaniclastics which, together with the greywacke, were deposited in basins flanking the volcanoes.

C. Gabbro, compositionally similar to basalt, intruded the volcanics. Large bulbous masses of felsic magma also intruded the volcanics and crystallized to form coarse-grained quartz-bearing granite plutons.

D. The granite plutons were eventually exposed by erosion of surrounding volcanics. Quartzose sandstone and impure sandstone, derived from both the volcanic and granite rocks, were deposited on top of the greywacke in basins that flanked the volcanic islands. Some of these basins were very large, extending hundreds of kilometres in which were deposited hundreds of metres of sediments.

A final mountain-building episode subjected the volcanic and sedimentary rocks to heat and pressure. These rocks were folded, and faulted, and intruded by masses of granite. The volcanic rocks were metamorphosed to "greenstones", which are fine-grained, typically dark green, altered volcanic rocks. Similarly, the sedimentary rocks were transformed into schists and massive quartzites.

After the close of the mountain-building events the metamorphosed sedimentary and volcanic rocks had been transformed into a solid, stable portion of the continental crust. Erosion continued uninterrupted for almost one billion years, reducing the landscape to the undulating surface of low relief that we observe today.

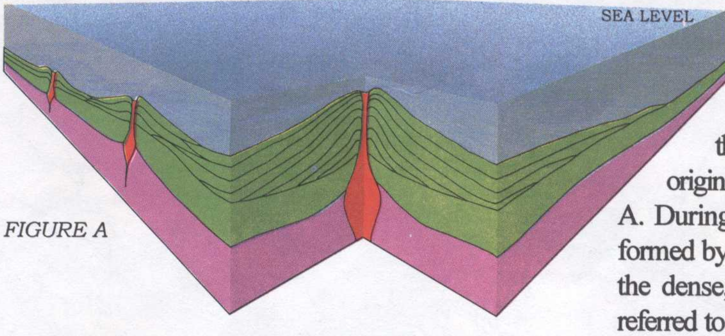


FIGURE A

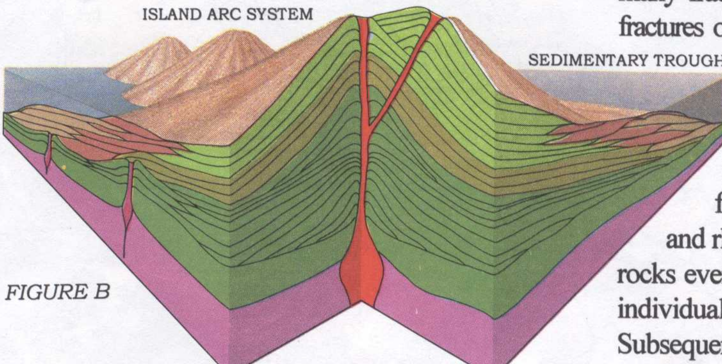


FIGURE B

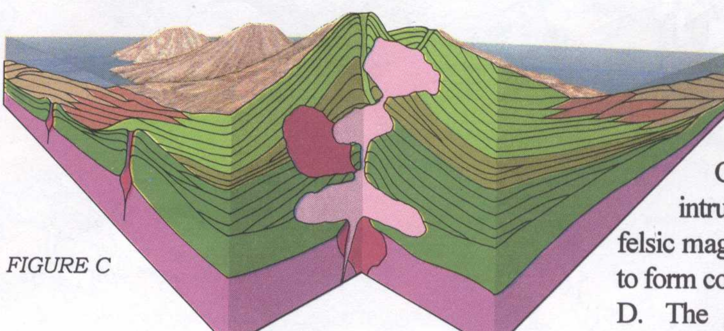


FIGURE C

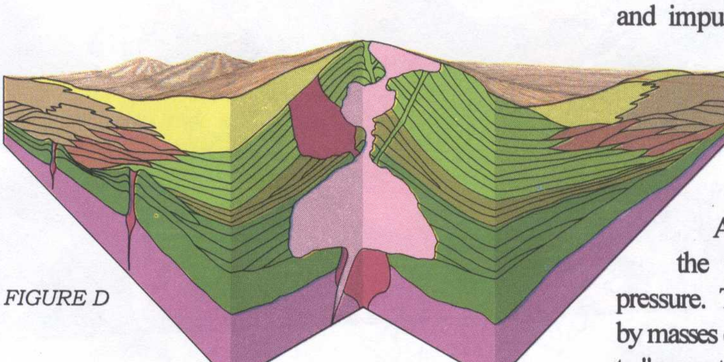
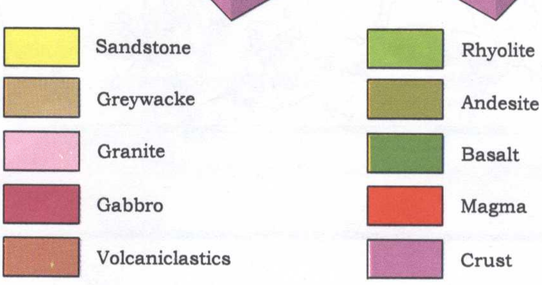


FIGURE D



SIMPLIFIED ROCK CYCLE AND GEOLOGICAL ENVIRONMENTS

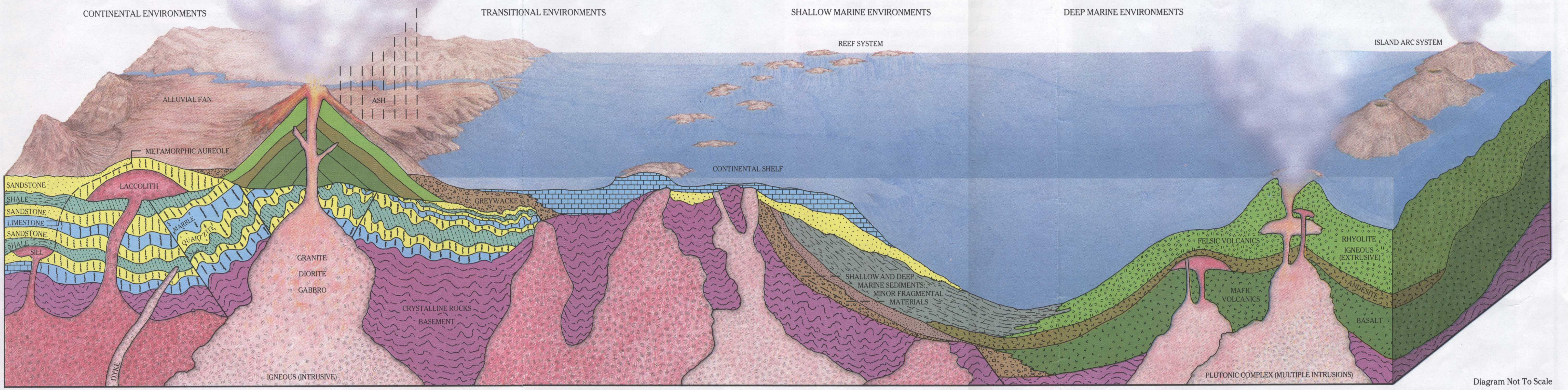
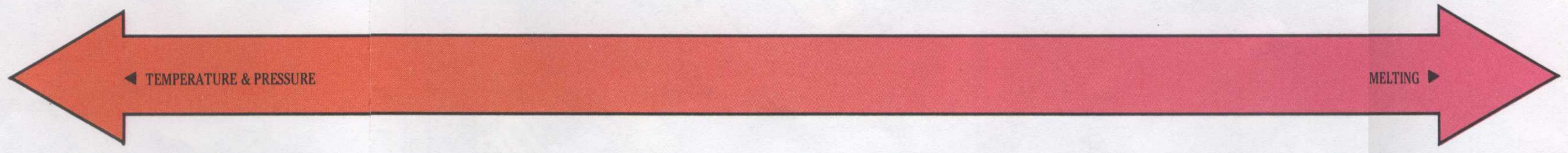
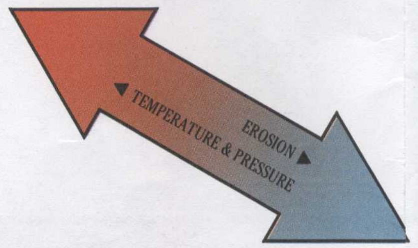


Diagram Not To Scale

METAMORPHIC ROCKS (FORMED BY ALTERATION)				
NON-FOLIATED	QUARTZITE	MARBLE	HORNFELS	AMPHIBOLITE
FOLIATED	SLATE	PHYLLITE	GNEISS SCHIST	MIGMATITE



IGNEOUS ROCKS (FORMED BY HEAT)								
GENERAL ROCK COLOUR	PALE (FELSIC)				INTERMEDIATE		DARK (MAFIC)	
FELDSPAR	MAINLY POTASSIC		SODIC AND POTASSIC		SODA LIME		LIME RICH	NONE
PLUTONIC (INTRUSIVE) ROCKS	GRANITE	SYENITE	GRANODIORITE AND QUARTZ MONZONITE	MONZONITE	TONALITE (QUARTZ DIORITE)	DIORITE	GABBRO	HORNBLENDITE PYROXENITE PERIDOTITE
VOLCANIC (EXTRUSIVE) ROCKS	RHYOLITE	TRACHYTE	QUARTZ LATITE	LATITE	DACITE	ANDESITE	BASALT	KOMATIITE



SEDIMENTARY ROCKS (FORMED FROM SEDIMENTS)							
CLASTIC (COMPOSED OF FRAGMENTS)	CONGLOM-ERATE	BRECCIA	SANDSTONE	ARKOSE ARENITE	GREYWACKE	SILTSTONE	SHALE BENTONITE MUDSTONE
ORGANIC AND CHEMICAL ORIGIN	LIMESTONE	DOLOMITE	PEAT	BITUMINOUS COAL LIGNITE	EVAPORITES ANHYDRITE GYPSUM	CHERT