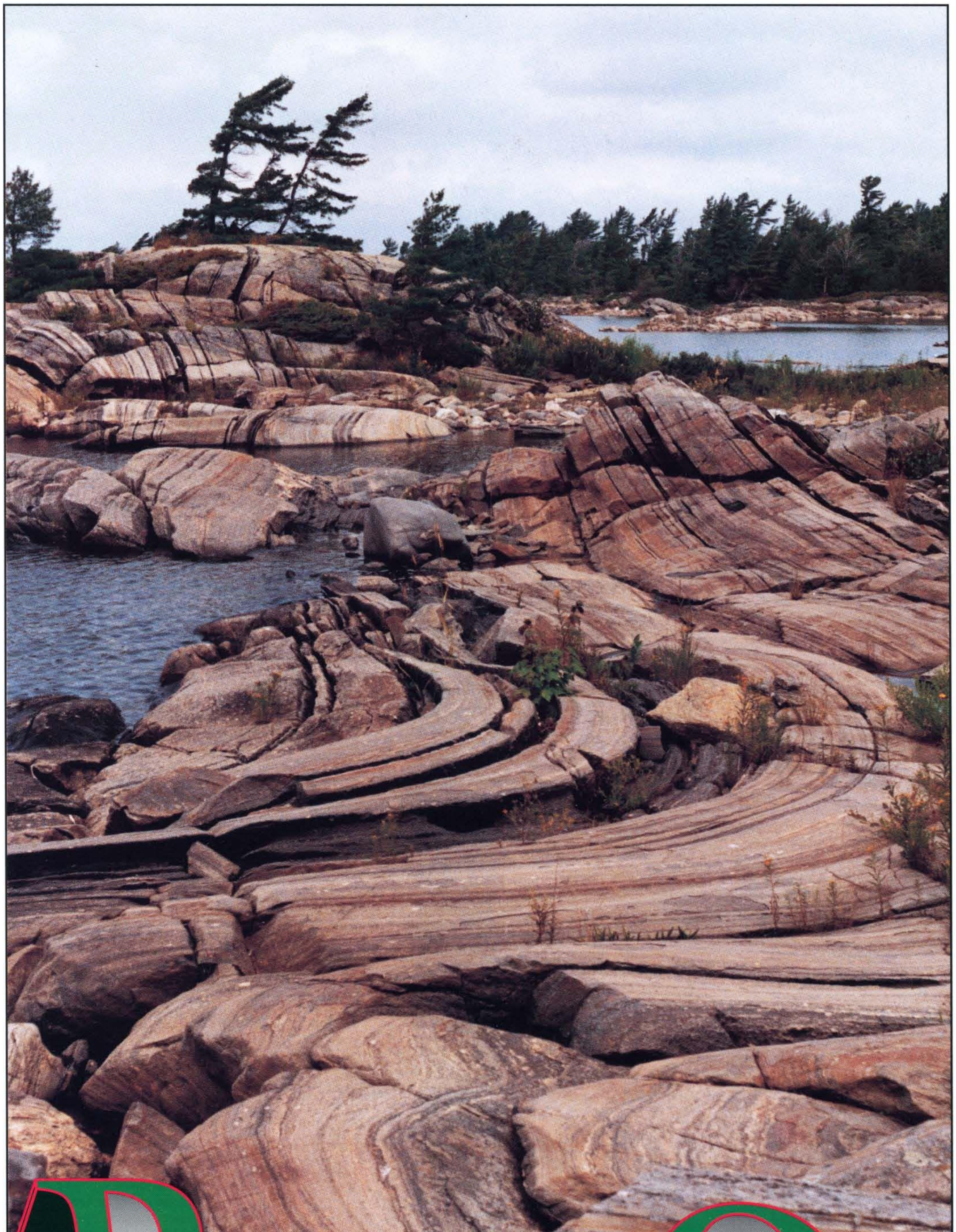

Ontario has a long and lively geological past which goes back to when the Earth was a very young planet. Since then, the province has been shaped by the movement of the ever-shifting plates that cover the surface of the earth.

ROCK ONtario

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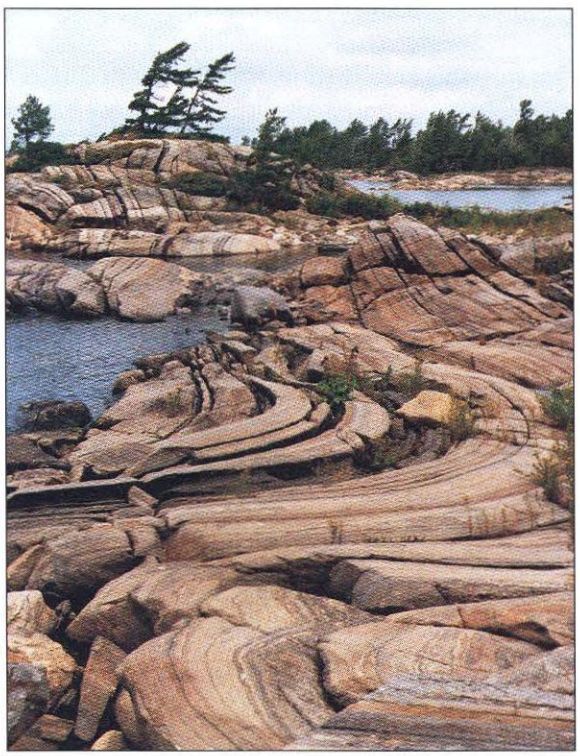
ROCK ONtario

ROCK ONtario tells the story of Ontario's rich and unique geology in terms the layman can understand. Lavishly illustrated with more than 100 photographs and drawings, it explains the development of Ontario's landforms through the ages. Subjects covered include plate tectonics, volcanoes, earthquakes, glaciation and the major geological areas of the province. It includes a description of the economic importance of geology, and tells how the minerals of the earth have contributed to the lifestyle we enjoy today.



Cover photograph:
Gaspar Island off the western side of Franklin Island on the eastern shore of Georgian Bay near Parry Sound. Photo taken by Ron Steenstra

Ontario

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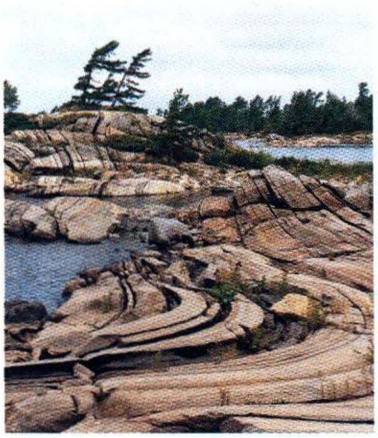
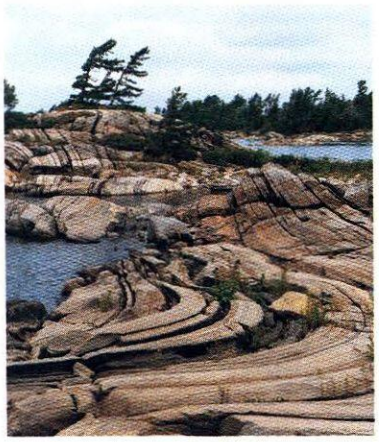
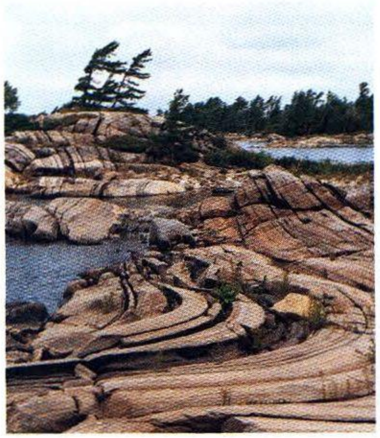
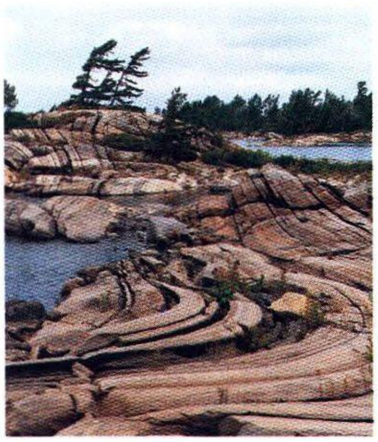
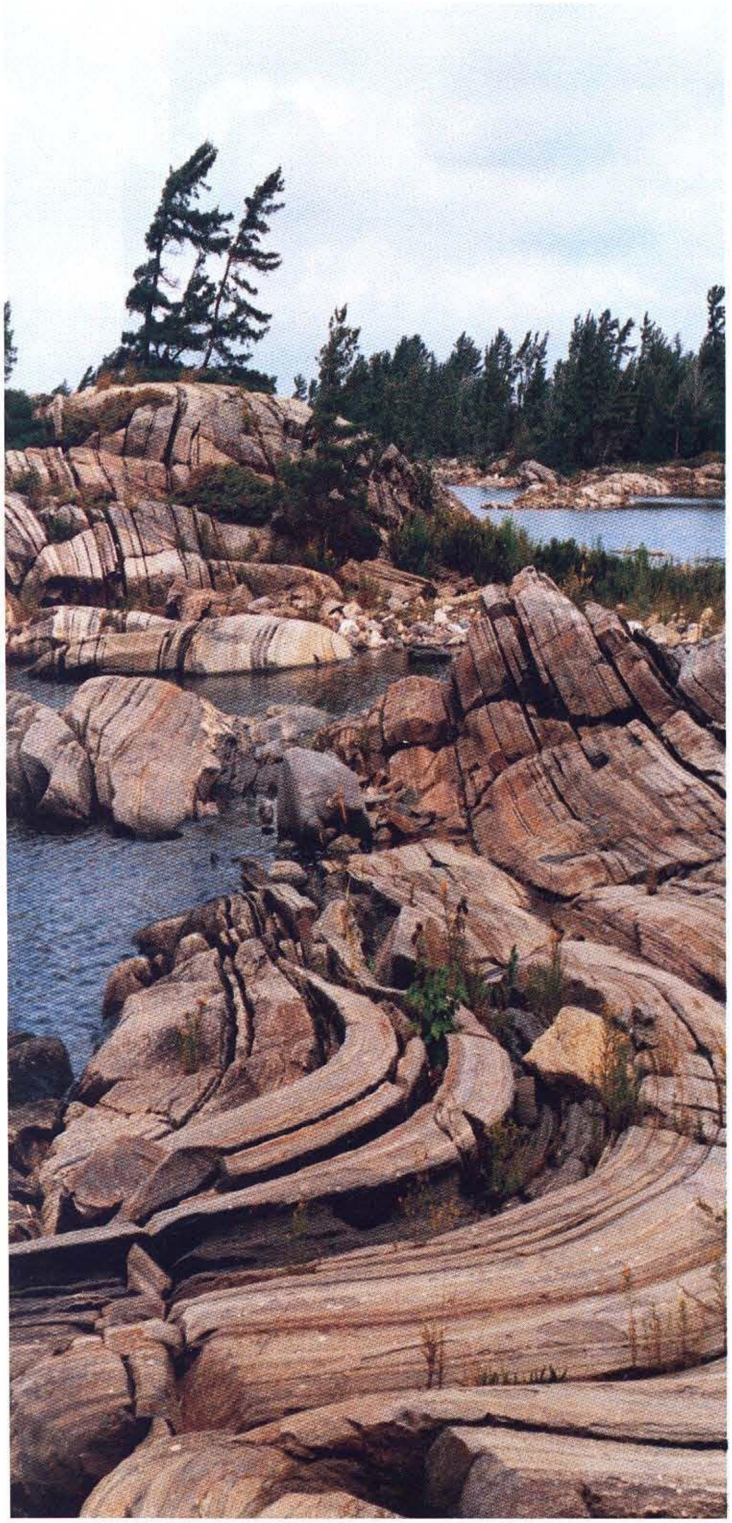










Gaspar Island, Georgian Bay

Ontario has a long and lively geological past which goes back to when the Earth was a very young planet. The first piece of crust that is now Ontario made its appearance more than three billion years ago. Since then, the province has been shaped by the movement of the ever-shifting plates that cover the surface of the Earth.

Ontario is a showcase of geological processes caused by these shifting plates, including volcanism, earthquakes and mountain building. Huge sheets of creeping ice, tropical coral reefs and even salt water lagoons are all part of our province's past.

These exciting events are all recorded in the rocks of the province.

What we know about the geology of Ontario today has taken patience, skill and a lot of detective work. This has been the job of geologists working with the provincial and federal governments, Ontario's universities, and the mining industry.

In **ROCK ONtario,** the story of Ontario's rich and unique geology is told. The book celebrates the province's geological heritage.

Moreover, this volume celebrates the 100th anniversary of the Ontario Geological Survey. The OGS had its start on May 4, 1891 as the Ontario Bureau of Mines. Today, the OGS is part of the Mines and Minerals Division of the Ontario Ministry of Northern Development and Mines.

Geologists have made important contributions to the mineral industry and the economy of the province. They have fanned out across Ontario to map its geology. They have discovered surface indications of ore which later became several of the province's producing mines.

Their basic geological maps show where the various types of rocks making up the province are found. Within the old rocks of the Canadian Shield, they found evidence that the plate tectonic activity which forms our earth today was also at work more than 2.5 billion years ago.

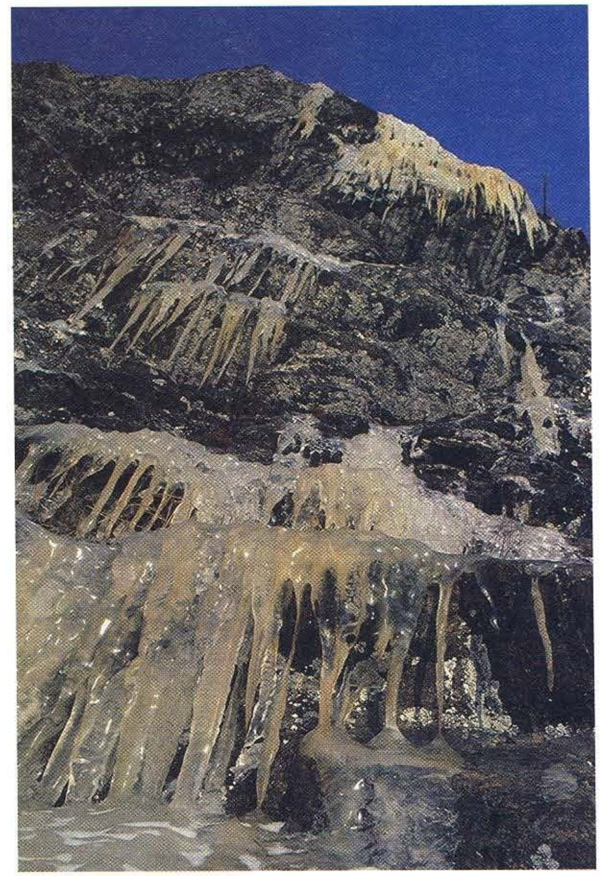
While this was not a new theory, the work of the OGS provided the first convincing, thorough demonstration that the forces of plate tectonics—which we will discuss in Chapter 2—were at work in the distant past.

This knowledge, along with the knowledge provided by other geologists, was recently compiled in ***The Geology of Ontario***, two volumes and a set of maps, that has revolutionized our understanding of Ontario's geology.

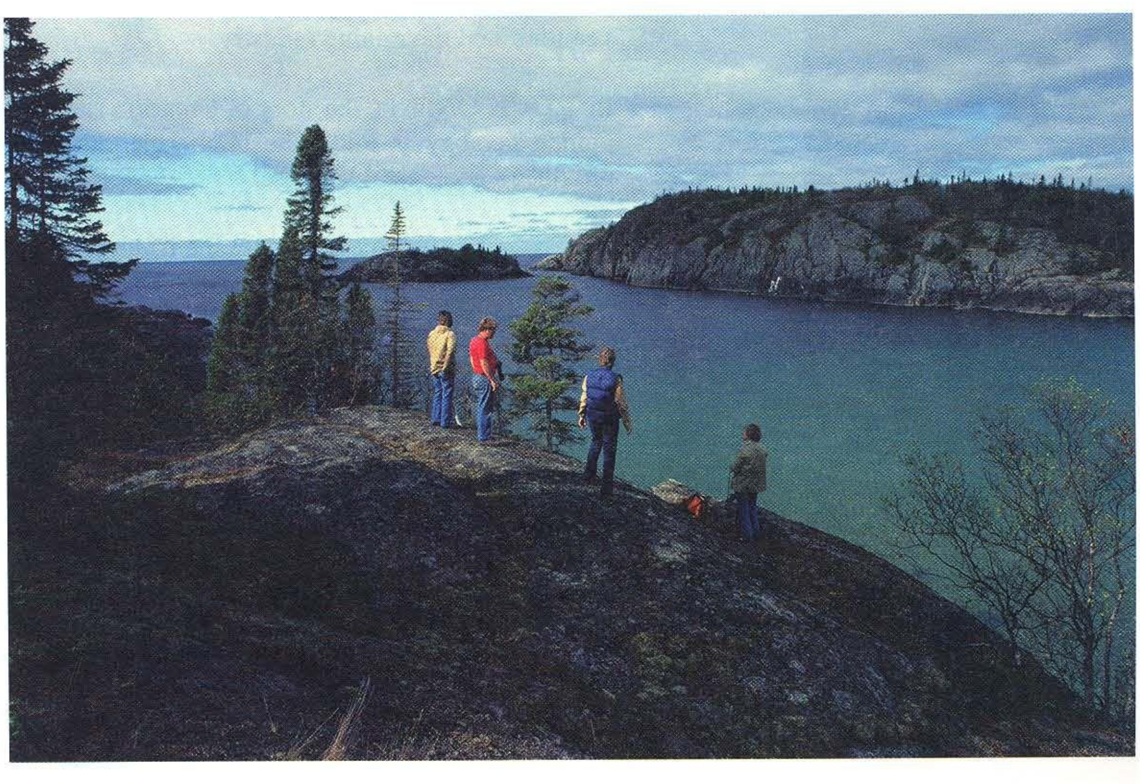
This book tries to bring some of that excitement to you.

As you will discover in the coming pages, geology is more than the study of rocks and minerals. It is the study of the whole planet Earth—the land we live on, the water we drink, the food we eat and the materials we use.

Geology is everywhere.



Winter near Lake Helen, Nipigon area

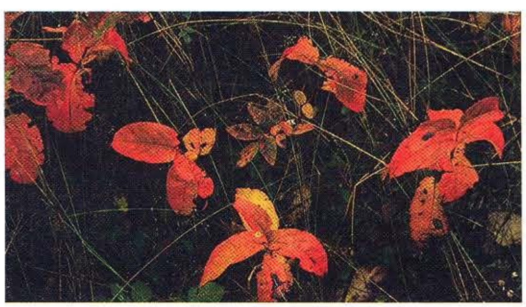


Pukaskwa National Park, north shore of Lake Superior

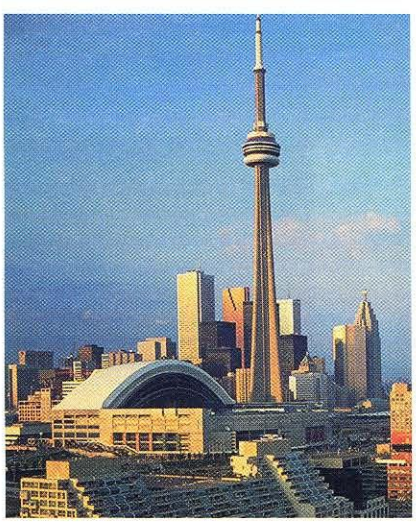
1 Geology is Everywhere

Geology: ***je ol' e je***
the study of the Earth: its origin, composition, and history, together with the processes that have led to its present state.

Highway road cuts are great places to look at rocks



Some plants only grow over certain types of rock



These Toronto landmarks exemplify geology in the city

Look around a classroom. Walk along a country lane. Drive through the city along a busy highway. Everything you see has to do with geology.

In the classroom, geology is the chalk, the pens, the pencils, the computer and even the tiles on the floor.

In the country, geology is the outcrops of granite along the path, the layers of soil in the farmer's field and the plants growing around the pond.

In the city, geology is the sand, gravel, cement and building stones that go into the skyscrapers and the roads, the location of the construction site and even the power lines that link us together.

When most people think of geology, they think of rocks and minerals. And they'd be right, but only partly so. Granite, limestone, marble and other rocks and minerals are the nuts and bolts of geology. But geology is much more.

As the definition at the top of the page says, geology is all about the living planet Earth: how it was made, what it is made of and the forces that shape it. It is the study of the land we live on, the air we breathe, the water we drink, the food we eat, the materials we use. It is the study of all those things, and how they are connected and related.

The Present is the Key to the Past

Geology is all about how our home planet works. It's about the forces that make and shape the Earth. These forces are powerful enough to push up towering mountains, change the course of mighty rivers and cause violent volcanic eruptions.

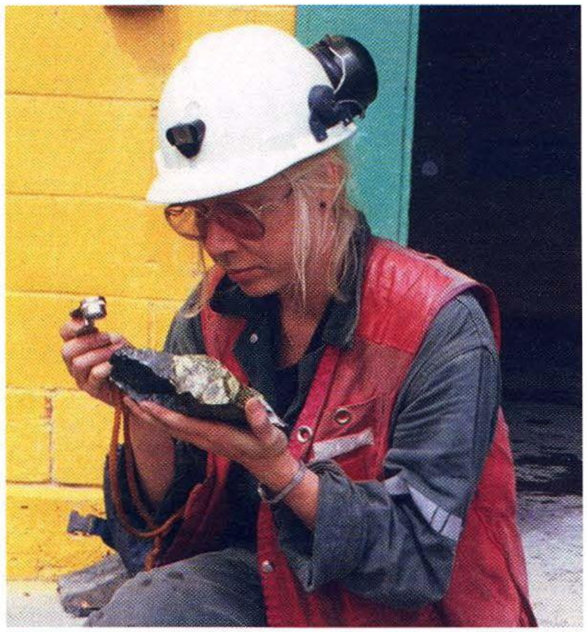
Believe it or not, these forces are working while you read this book. Right now, the continents are moving, glaciers are inching along, sediments are piling up in the sea, rocks are cracking, mountain ranges are rising up and land is shifting.

All around us, all the time, the planet is changing. The Earth we live on today is slightly different than it was 100 years ago or even yesterday. And it will be a little different tomorrow. And the next day.

Although the Earth is constantly changing, the geological forces which shape the planet do not change. These same forces that are at work right now—the building of mountains, the piling up of sediments and more—have always taken place and always will.

By looking at the geological forces taking place right now, a geologist can put together the history of the Earth. As geologists like to say, "the present is the key to the past."

The present also provides a key to what lies ahead. By studying the geological forces at work today, a geologist can reach forward and look at what the Earth may be like in the future.



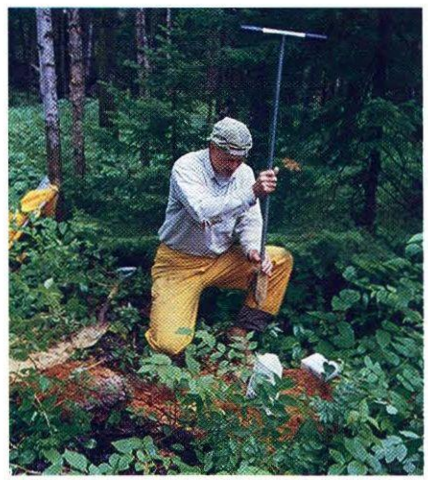
Geologists are scientists who study rocks

The Tools of the Trade

A geologist is an Earth scientist. He or she is like a skilled doctor who has the planet Earth as a patient. And like a doctor, a geologist examines the patient carefully.

Geologists need the knowledge of many other related sciences to do their job: physics, chemistry, botany, engineering, mathematics, oceanography, astronomy and more. It takes skill and patience to be a geologist. It also takes a sturdy pair of hiking boots.

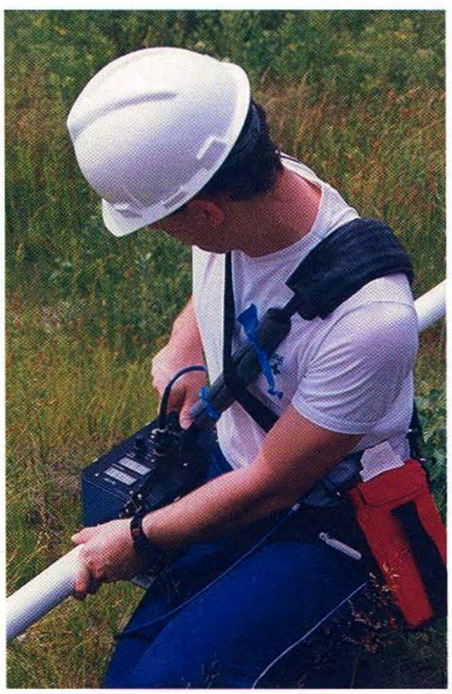
Helicopters are used to reach remote areas



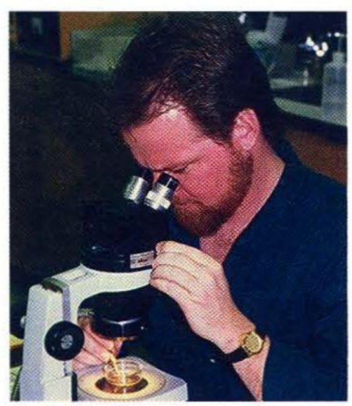
Soil samples can help find new mines

Geologists still tramp through the bush studying rocks and gathering new samples. They map rock formations, study rivers, measure layers of sediment and explore for gold, copper, sand and gravel, gypsum, salt, petroleum and others—all the minerals that are so essential to our modern life.

More and more, geologists rely on sophisticated equipment to help in their work. Exploration drills, satellites, remote sensing, airborne magnetic surveys, robot space probes, manned undersea vehicles, infrared photographs, computer-enhanced images—these have advanced the knowledge about our planet and the geological forces at work today.



Sophisticated instruments help find buried ore deposits

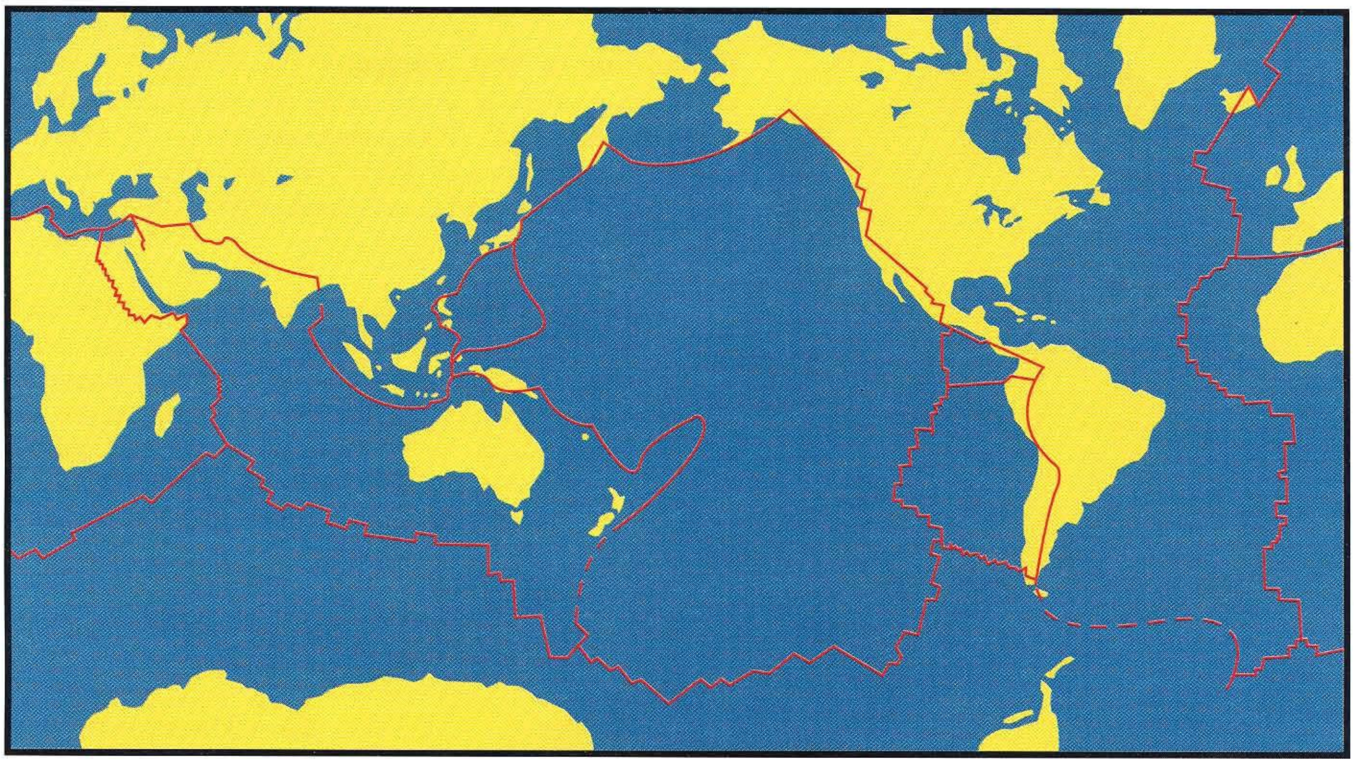


Tiny grains of certain minerals are used to tell us a rock's age

A New Way of Looking at the World

New technology has created a revolution in our knowledge about planet Earth. As you will discover in this book, one of the most exciting advances in geology has been the theory of **plate tectonics**. This theory is about the building of the Earth. Ontario geophysicist, John Tuzo Wilson, was important in developing this theory in the 1960s.

The theory is very simple. It says that the Earth's surface is divided into plates which are always moving. These ever-moving plates are thought to be the main cause of all geological change. Since the Earth was formed more than four billion years ago, they have opened and closed oceans, pushed up mountains and helped form deposits of valuable minerals and metals.



The plates of the Earth's crust

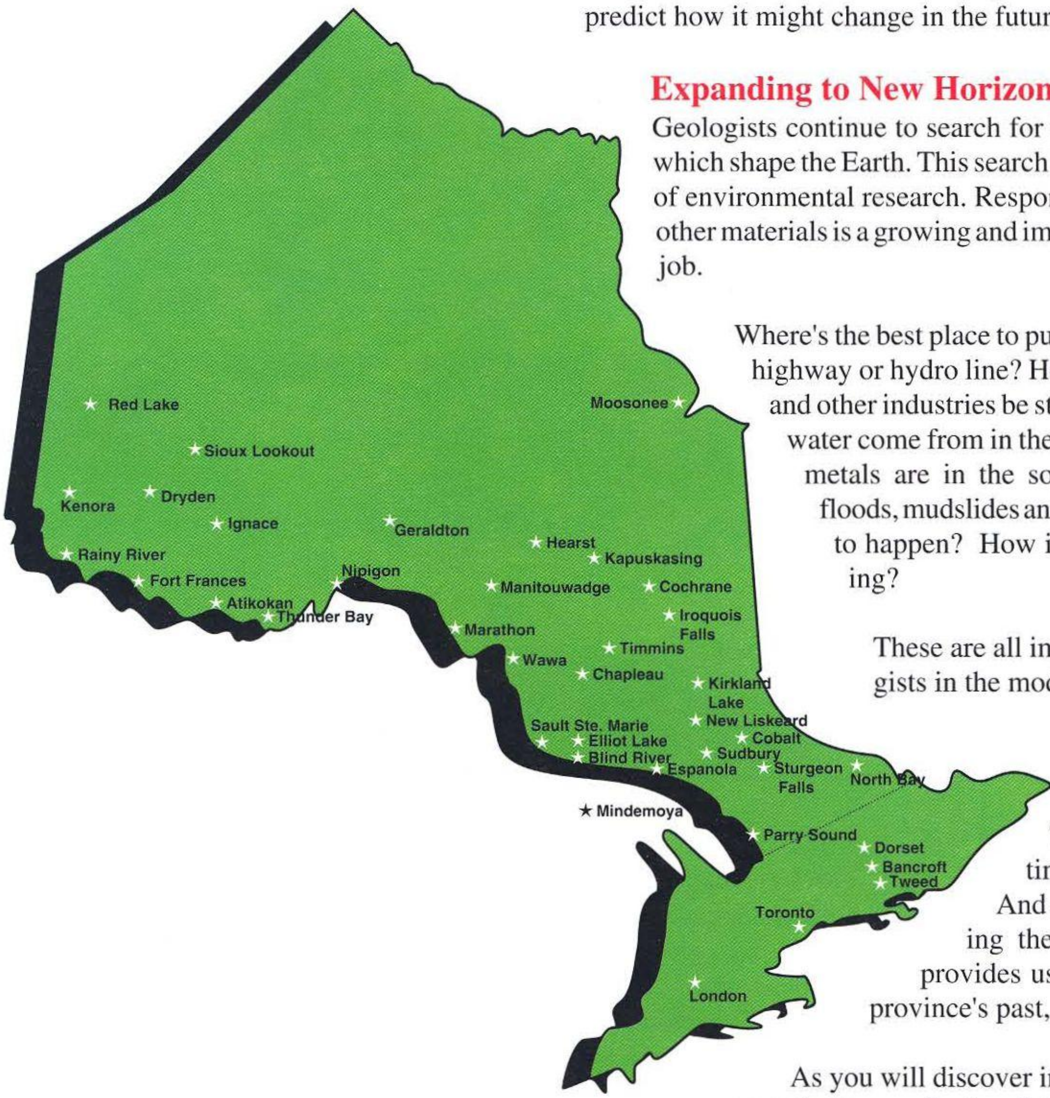
Rocks and Much More

Understanding where, when and how mineral deposits are formed remains an important job for the geologist. We turn to geologists to get the most up-to-date and accurate information about our natural resources. This information tells prospectors, mining companies and oil companies what is hidden deep within the Earth's **crust**. It helps pinpoint the exploration targets and **ore deposits** that are the source of our mineral wealth.

Geologists also try to find out how large our supplies of non-renewable resources such as oil, gas, coal and uranium are and what it will cost to develop them. They also look at the size of our reserves of metals such as nickel and copper, as well as other materials such as sand, gravel and building stone.

Geologists dive in specially equipped submersibles to the bottom of the ocean to find out more about how mineral deposits are formed. What they learn in the watery depths will help them in their search for valuable deposits on land. Geologists are even analyzing rocks from the moon in their quest for geological knowledge.

The work of geologists goes beyond the study of rocks. It has expanded to include how geological processes affect our daily lives. Even the weather has not escaped the attention of geologists. One important way geologists study the Earth's climate is by drilling cores of ice from **glaciers**. Air bubbles in these cores can show levels of carbon dioxide and other greenhouse gases in the atmosphere through the last several thousand years. This information helps geologists understand how the climate changed in the past, and helps them predict how it might change in the future.



Expanding to New Horizons

Geologists continue to search for the full picture of the forces which shape the Earth. This search has put them on the front line of environmental research. Responsible use of land, water and other materials is a growing and important part of the geologist's job.

Where's the best place to put a dam, park, bridge, tunnel, highway or hydro line? How should waste from mines and other industries be stored? Where will supplies of water come from in the future? What chemicals and metals are in the soil? Where are earthquakes, floods, mudslides and other natural disasters likely to happen? How is the world's climate changing?

These are all important questions for geologists in the modern world.

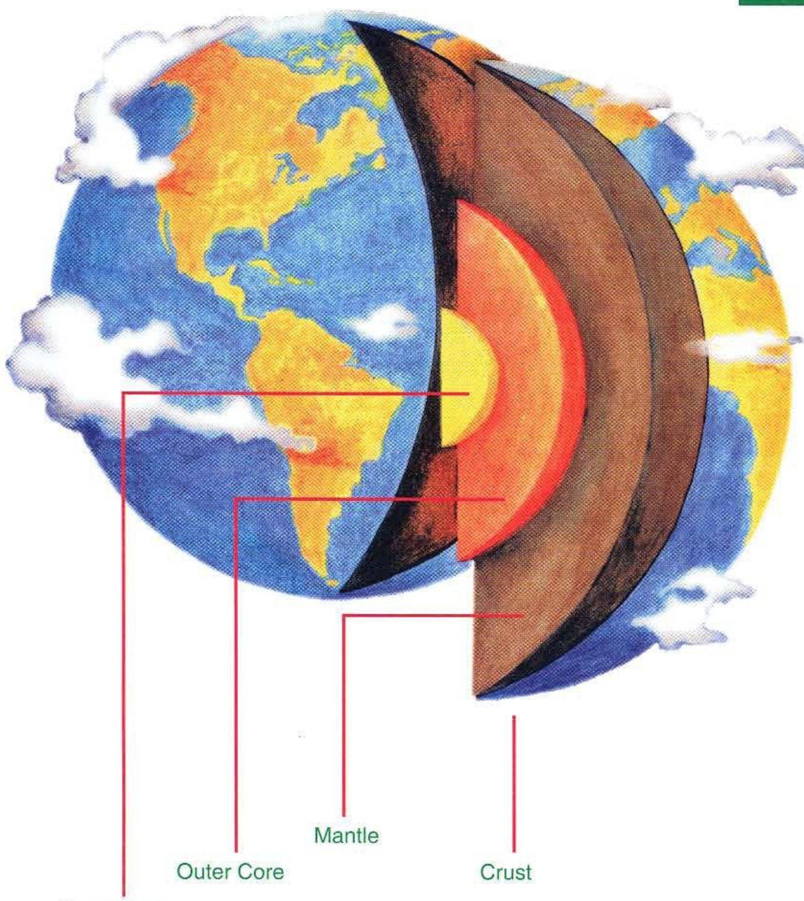
How Does Ontario Fit In?

The geology of Ontario is at times amazing and astonishing. And it is always exciting. Knowing the geological forces at work provides us with information about the province's past, present and future.

As you will discover in the next chapter, Ontario is part of a huge raft of rock floating on the surface of the Earth. This raft, or what geologists call a plate, is moving all the time, but it moves so slowly—two or three centimetres every year, or about as fast as your fingernail grows—that you can't feel it.

Read on in the next chapter to find out more about the plates and how their movements shape the Earth.

2 The Dynamic Earth



The interior of the Earth is layered

Layer	Thickness (km)	Temp. ° C
Oceanic Crust	8	0 - 700
Continental Crust	50	0 - 700
Mantle	2,870	700 - 3,000
Outer Core	2,240	3,000 - 4,000
Inner Core	2,440 (diameter)	4,000 - 4,200

We have barely scratched the Earth's surface. The total distance from the surface to its centre is 6,370 km. Yet, the world's deepest mine runs less than 4 km into the Earth's crust. And no drill has ever penetrated more than 12 km.

We often take the planet Earth for granted. Nothing really changes and it always looks the same. Right?

Wrong! The planet we live on is the result of billions of years of geological events involving tremendous heat and pressure, powerful volcanoes and earthquakes, and drifting continents. This chapter takes a close look at the Earth and the forces that shaped its past—and continue to shape its future.

Inside the Earth

Geologists think the Earth was formed about 4.5 billion years ago from a spinning cloud of hot gas and dust which shrank to a molten ball. As the planet cooled, the heavier pieces probably clumped together and sank, while the lighter pieces formed a thin crust on the surface. Over time, the Earth's three layers developed: the crust, the mantle and the core.

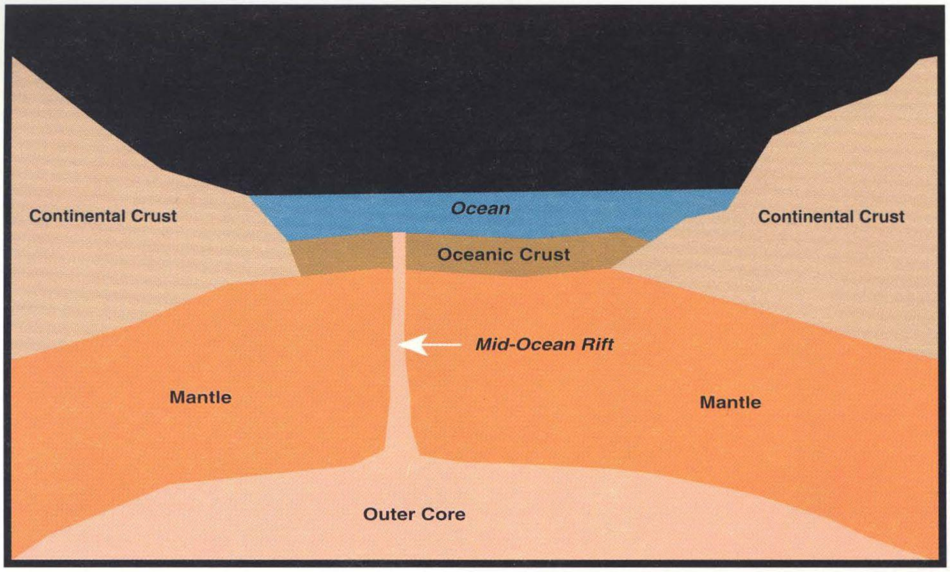
The **crust**, averaging 50 kilometres thick, ranges from 6 kilometres thick beneath the oceans to 90 kilometres thick under enormous mountain ranges.

Underneath this thin crust lies the **mantle**, a semi-solid 3,000 kilometre-thick layer of hot rock rich in the elements silicon, magnesium and iron.

At the centre lies the hottest part of the planet, the **core**. Geologists believe the outer part of the core is a hot liquid, rich in iron and nickel, while the inner part is a ball of mostly solid iron.

Two Crusts

The Earth's crust is a thin, hard layer of rock that floats on the mantle. There are two different types of crust: one that makes up the huge land masses or continents on which we live and another that lies beneath the oceans.



Cross-section through continental and oceanic crust

Continental crust is thicker, and consists of a mix of **granites** and other rocks that are more complex than those in **oceanic crust**. Rocks in the continental crust contain silica-rich minerals, such as **quartz** and **feldspar**, that are light in weight and colour. One big difference between continental and oceanic crust is age. Continental crust can be billions of years old, but oceanic crust is rarely more than 200 million years old. Geologists have often wondered why.

What is a Plate?

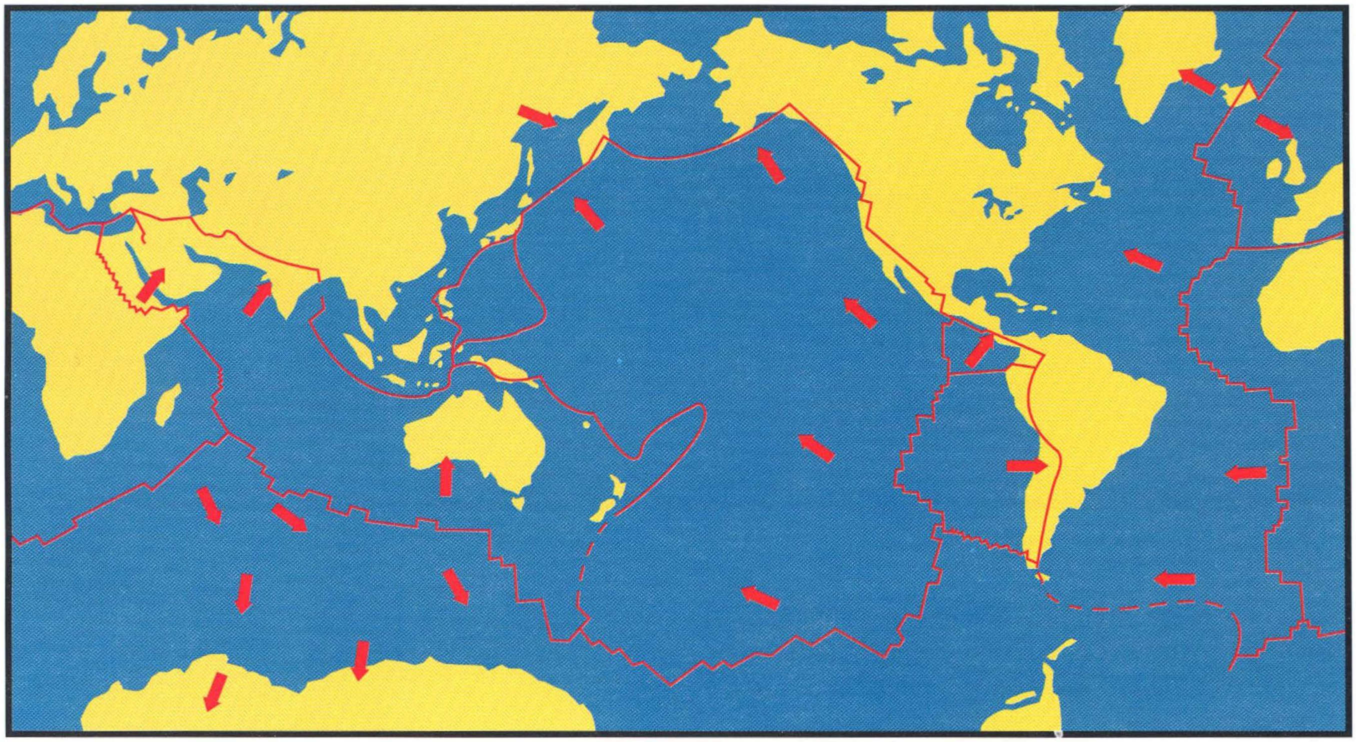
The crust of the Earth is split into a jigsaw of pieces like the cracked shell of a hard-boiled egg. These pieces are called plates. (See top of page 9).

Geologists believe that there are about 10 major plates of different shapes and sizes covering the surface of the Earth. Some carry an ocean, others carry both an ocean and a continent. There are also many smaller plates filling the spaces between the larger plates. The plates are up to 70 kilometres thick and float on the hot rocks of the mantle.

Some plates are enormous—measuring thousands of kilometres across. The largest is the Pacific Plate which is almost entirely covered by ocean. Ontario sits in the middle of the North American plate which includes much of the western part of the Atlantic Ocean and the North American continent.

Though the Earth's plates are always on the move, they wouldn't win any speed race. Most plates move less than three centimetres a year. Some move even slower.

The North American plate on which Ontario sits creeps westward about two centimetres or less in a year. At that rate, it would take this plate one million years to travel a distance of 25 kilometres.



The Earth's plates are constantly moving

How Plate Tectonics Works

The word *tectonics*, like the word architect, comes from the Greek word for *builder*. The theory of plate tectonics is about the building of the Earth.

The theory of plate tectonics is very simple. It says that the plates that make up the Earth's crust are always moving around the globe like slabs of ice after the first thaw on a lake in spring. It is this movement of the wandering plates that has shaped the world over the past thousands of millions of years and has given us the landforms and rocks we see today.

The theory of plate tectonics is a new way of looking at the world. It explains why earthquakes shake and volcanoes erupt in certain spots of the world, how mountains are built, why continents move and how oceans are formed. It also helps explain the pattern of where minerals and metals are found throughout the world.

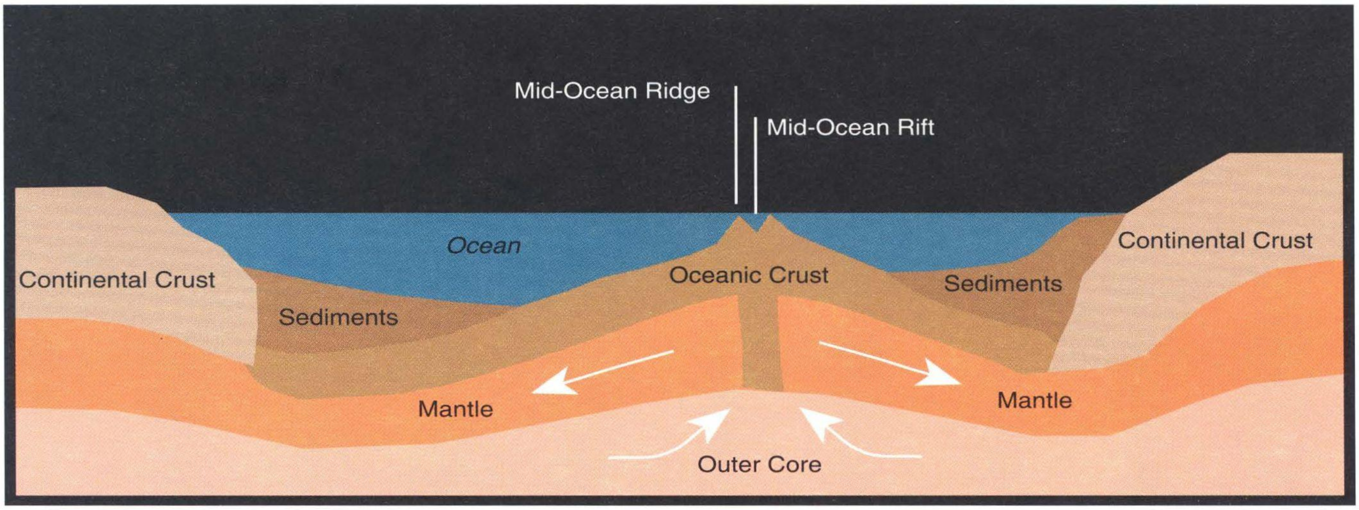
Sometimes two plates lock against each other and then move so suddenly that the results are dramatic and unforgettable. That's what happened on October 17, 1989, in San Francisco, California just when the third game of baseball's World Series was about to begin. There, the edges of two plates—the North American and Pacific—unlocked and slid past each other at their boundary line along the San Andreas Fault, shaking the area with a huge earthquake.

Why Plates Move

The plates float on the hot rocks of the mantle. Geologists aren't really sure what makes these plates move. Many think the plates are driven by the enormous heat that rises from deep inside the Earth. This heat makes the soft, hot mantle rocks bubble and churn up and swirl around. When these rocks cool, they become denser and sink back down. This up and down flow of mantle rock, known as convection, stirs up currents that move the Earth's plates.

Making New Crust

Geologists found the secret to plate tectonics under the sea. For centuries, they thought the ocean floor was a huge, flat plain. But then, they didn't have the tools to map the ocean floors.



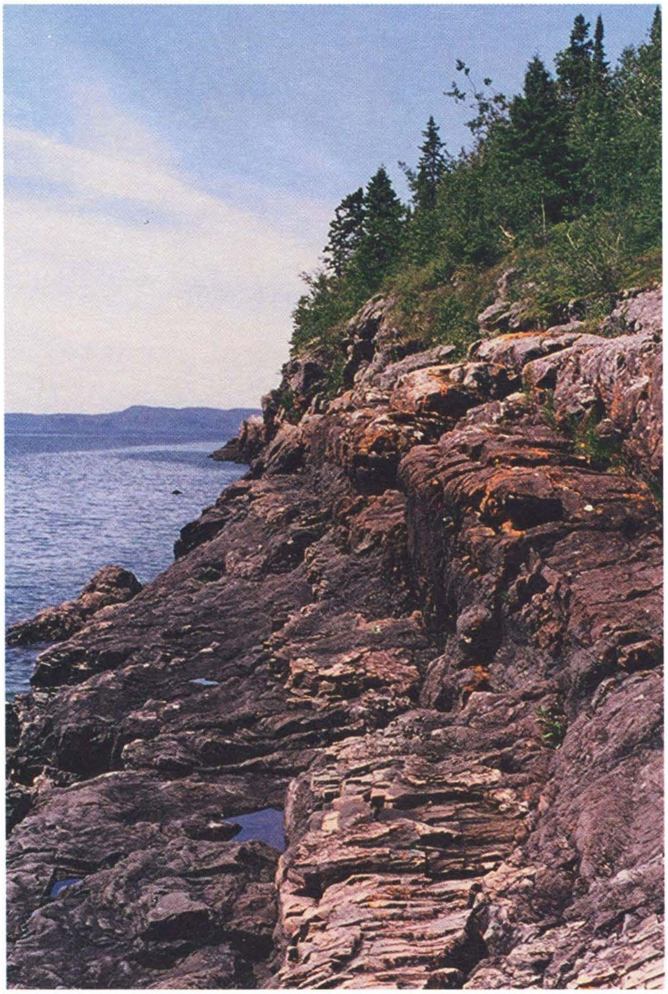
Cross-section through a mid-ocean ridge and rift

It was only in the late 1940s that geologists made a map of the ocean floor using echo sounders and deep sea cameras. The map revealed many amazing surprises. Yes, parts of the ocean floor were indeed flat, but in other parts there were trenches that were several kilometres deep.

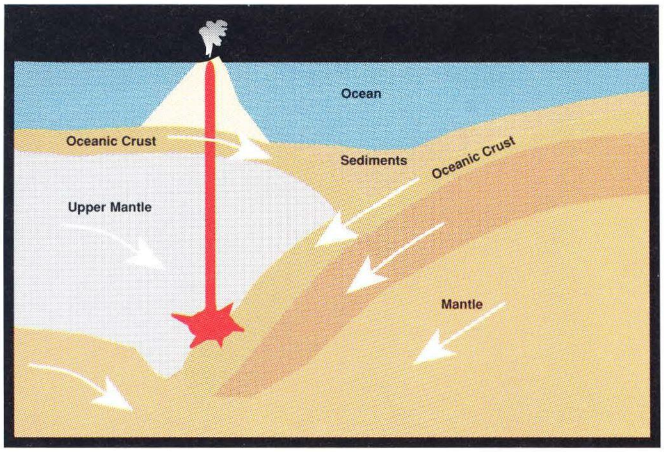
One of the most startling undersea finds was the discovery of the world's longest mountain chain, a **mid-ocean ridge**, winding 60,000 kilometres around the globe with some peaks towering more than 2,400 metres high. Geologists theorized that this was where the Earth made new crust.

Cracks along the crest of the underwater mountain system mark some of the boundaries of plates on the Earth's surface. Hot liquid rock, called **magma**, is constantly rising in the **convection currents** of the mantle and bumping the underside of the thin ocean crust. When the impact is strong enough to pierce the crust, magma pours out of the opening as **lava** that cools and hardens as new ocean floor. This enlarges the edges of the ocean plates and builds a mid-ocean ridge between them.

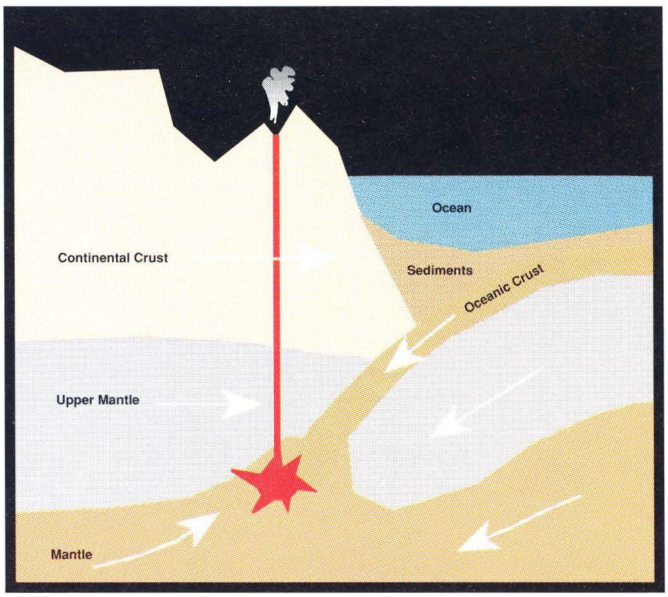
As the two plates continue to separate, the crack widens and magma fills it again. Adding new material to the edge of the plates at the mid-ocean ridge this way makes the plates grow in size and move apart. This cracking and filling process repeats many times over hundreds of millions of years. The older rock is pushed farther from the crest of the ridge by the newly-formed crust. During this time, the crust is gradually covered by layers of mud and other sediments deposited on the ocean bottom.



Rocks at Tee Harbour on the north shore of Lake Superior formed in a rift



Cross-section of oceanic crust sliding under other oceanic crust



Cross-section of oceanic crust sliding under continental crust

Disappearing Sea Floor

As new crust is made at a mid-ocean ridge, old oceanic crust disappears under another plate elsewhere on the sea floor in a process called **subduction**. The leading edge of one oceanic plate is pushed under another oceanic or continental plate, forming a trench. From here, it slowly slips back down into the mantle, where it melts and forms magma.

Plates Meeting Plates

When two plates meet, the results are usually dramatic. What's left behind, however, depends on what was on the plates.

A String of Volcanic Islands

When two oceanic plates collide, they leave behind a string of volcanic islands. This happens because one plate dives under the other, and starts to heat up and melt into magma. The melted crust is lighter than the mantle, it percolates up through cracks in the overlying plate. The hot magma may burst through these cracks and erupt as a series of underwater volcanoes.

These volcanoes grow and may rise above the surface of the sea to form an arc of volcanic islands. These are lines of volcanoes that form a curved string of islands. The Aleutian Islands and the Philippines are **island arcs** which were formed in this way.


The locations of the Earth's active volcanoes

Quakes, Volcanoes and Mountains

When an oceanic plate rams into a continent, the thin but heavier oceanic plate is dragged down beneath the lighter continent to form a deep underwater trench. The continental plate acts like a huge blade and scrapes off sediments and pieces of the sea floor from the sinking oceanic plate. The sediments pile up along the edge of the continent making the continent wider and thicker.

As the oceanic plate sinks deeper into the Earth, it starts to melt into magma which creeps up through the cracks in the continental crust and may even burst through to make a range of volcanic mountains. The Andes Mountains which run along the west coast of South America were formed when the Pacific Plate collided with the South American Plate.

More Mountains

When two plates carrying continents meet, the outcome is spectacular. Because continental crust is light, yet thick, neither plate sinks under the other into the Earth's mantle. Instead, the continents collide with such force that huge pieces of the crust are pushed up, and twisted and folded into an enormous mountain range.

Geologists believe that Mount Everest and the rest of the Himalayan Mountains which border India were formed about 50 million years ago when the Indian Plate collided with the Asian Plate.

Pieces of sea floor and overlying sediment may be caught between the colliding continents. These are also thrust up into the new mountains, resulting in fossils of ancient marine life ending up on the tops of some mountains, including Mount Everest, the highest mountain in the world.

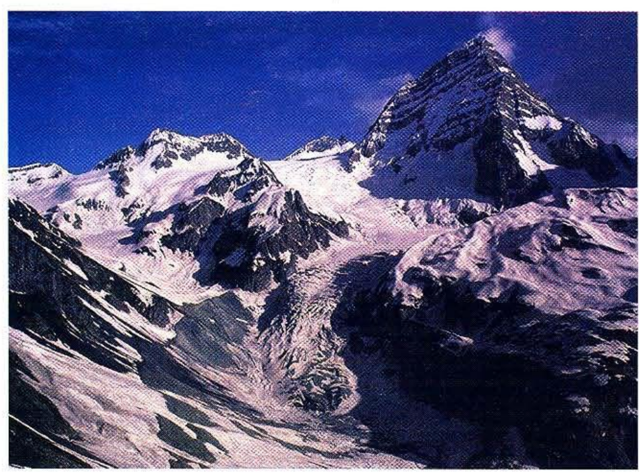
All Quiet

A plate carrying both a continent and an ocean is special. It has a quiet area where nothing happens from a geological point of view. There are no volcanoes, no earthquakes or no new mountains built. The area is found underwater along the very edge of the continent. This place is so quiet that geologists call it a '*passive margin*'.

The east coast of North America and South America are passive margins. So are most other land areas of Europe and Africa which border the Atlantic Ocean.

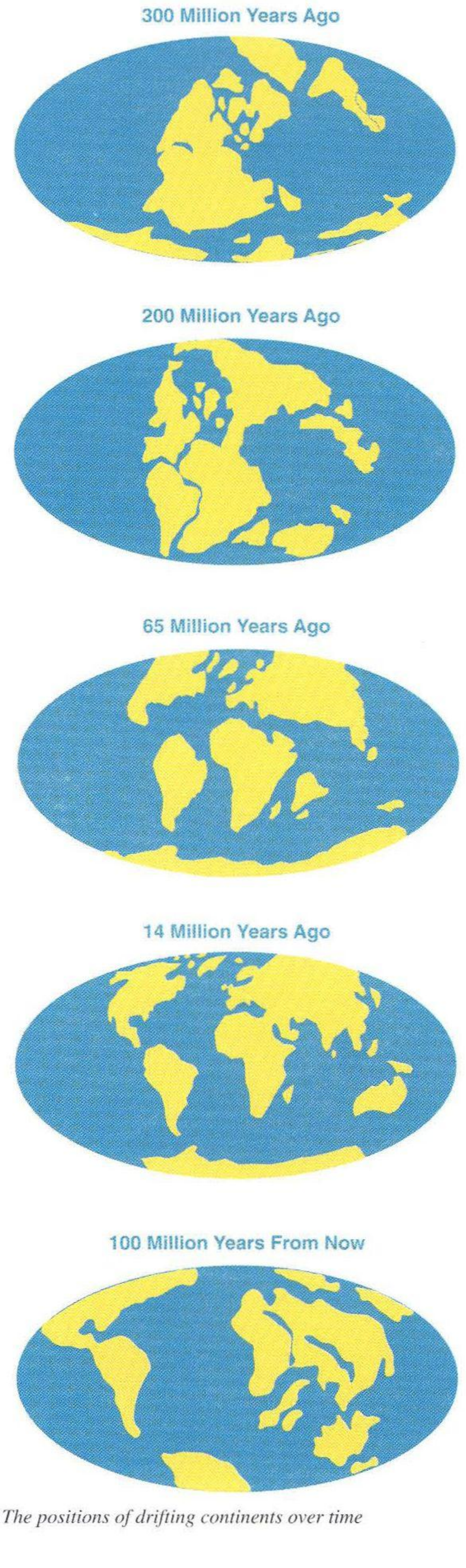
Mount St. Helens, like the volcanoes of the Andes, has violent eruptions

The 1980 eruption of Mount St. Helens in Washington State in the United States was the result of two plates—the Pacific and the North American—crashing into each other. When that happened, the edge of the Pacific Plate melted deep beneath the west coast of North America, and the new magma burst its way to the surface as an erupting volcano.



The majestic Himalayas are still growing

Today, the Himalayas, which measure about 5,000 metres above sea level, are still growing. That's because the two plates underneath the mountain chain continue to push against each other as they have done for the past 50 million years. As a result, Mount Everest sprouts five centimetres taller every year. But it's worn down just as quickly by wind and rain.



The positions of drifting continents over time

Drifting Continents

Long before the theory of plate tectonics, geologists suspected that the continents moved around the Earth's surface. The clues are many:

- The opposite coasts of the south Atlantic Ocean have similar shapes and seem to have once fitted together like pieces of a jigsaw puzzle.
- Rocks and fossils found on opposite sides of the northern Atlantic Ocean are remarkably similar and suggest that the two shores were once connected.
- Old mountain belts can be matched across the continents spanning the south Atlantic Ocean as if these continents were once joined together.

In the early 1900s, German scientist Albert Wegener pioneered the theory of **continental drift.** He believed there was once a single supercontinent called Pangaea, which broke apart about 300 million years ago.

The idea never really caught on at the time, because no one had a good explanation of what made the continents move. It was only when the theory of plate tectonics was developed that the mystery was solved. It was the drifting of the plates that moved the continents.

Today, geologists combine the concepts of continental drift and plate tectonics, and believe that continents come together in a supercontinent every few hundred million years or so, then drift apart, repeating the cycle over and over.

Growing Continents

Each continent has a geological centre, called a craton, that marks the spot where it first started to evolve. Geologists believe sediments and island arcs are swept against the edges of the cratons, building up larger and larger continents. Each new mountain chain or layer of sediment is welded to one formed earlier. These new blocks are called terranes. By looking at its terranes, geologists can read the history of a continent, much like one can examine the growth rings of a tree to determine its history.

Splitting Continents

Continents can also break apart. This occurs over hot spots beneath the Earth's crust where hot magma rises within the crust. If the crust opens, lava pours through the crack and it widens. Over time, the continent and its underlying plate divide into two pieces, forming a **rift valley**. As the plates separate, the rift valley becomes wider and the sea may flood in, transforming it into a small ocean. An example is the Great Rift Valley, where the African continent is being pulled apart. The north part of the rift, the Red Sea, is already a young ocean.

Where Does Ontario Fit In?

The biggest **craton** in the world is the Canadian Shield. It stretches from Alberta to Labrador and from the Arctic Ocean to the southern United States, an area of more than five and a half million square kilometres. This is the largest piece of ancient crust in the world.

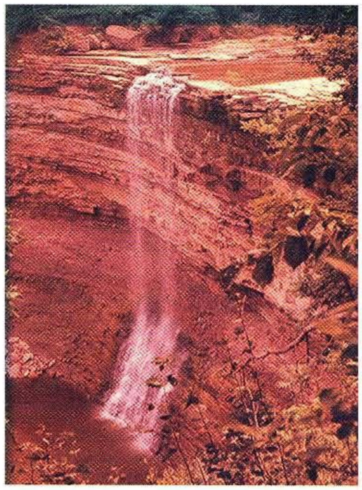
About half the Shield lies in Ontario, and it contains some of the oldest rocks in the world, dating back more than three billion years. Like most cratons, the Canadian Shield has been worn down by wind, ice and water, and surrounded by belts of rock which become younger and younger, the farther they are from the craton's rim.

In recent years, a number of earthquakes have rumbled beneath Ontario as the Earth's crust has shifted along cracks or faults. Though these earthquakes have not caused severe damage, they say in loud and clear language that the Earth is alive and active.

The Canadian Shield is the world's largest craton

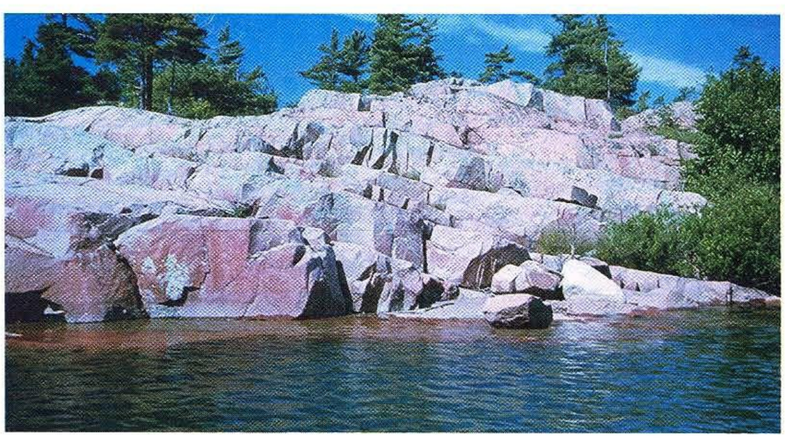
3

Reading the Rocks



Twenty Mile Creek tumbles over sedimentary rocks at Balls Falls, near St. Catharines

These creatures, called "trilobites", lived 425 million years ago



Granite, made up of quartz, feldspar, and other minerals, is an igneous rock

Rocks can tell scientists a great deal about the Earth's past—the forces that made it what it is today, the events that took place long before recorded history, and the plants and animals that lived here at that time.

Whether we hold a small rock with a shell-shaped fossil, or admire the beautiful colour and texture of marble and sandstone facades of historic buildings around us, rocks are the key to our past.

This chapter takes a close-up look at the three basic types of rock that exist and where you can find them in Ontario. It also explains the differences between **elements**, **minerals** and **rocks**.

Elements, Minerals and Rocks

Chemical elements make up everything; they occur naturally in the Earth. Some of the most common ones are oxygen, silicon, aluminum, iron, calcium, sodium, potassium, magnesium and carbon. These elements combine in different ways to form crystals.

Look at a rock through a magnifying glass and you will see it isn't completely smooth or uniform. Rocks are made up of crystals called minerals. There are several thousand minerals in the world but only about 20 or so common ones, such as **quartz**, **feldspar**, **mica**, and **pyrite**.

Some rocks are made of grains of just one mineral. Certain varieties of **sandstone**, for instance, contain only quartz. Other rocks have a mixture of several minerals. Granite is made up of quartz, two types of feldspar and other minerals, which can include mica or **hornblende**.

No matter how many minerals there are in the world, there are only three types of rock: **igneous**, **sedimentary** and **metamorphic**. All of them have a place in the endless **Rock Cycle**.

Igneous rocks are made when hot magma from deep within the Earth cools and hardens. Igneous comes from the Latin word *igne*, which means *fire*.

Sedimentary rocks are formed from pieces of other rocks washed away by water or blown by the wind in a process called **erosion** or **weathering**. These bits and pieces settle in layers on the bottom of oceans, lakes or rivers as sediment. Over millions of years, they are squeezed together and form new sedimentary rocks. The word sedimentary comes from the Latin word *sedere* which means to *sit*. They are also formed when sea water evaporates, and when shells, corals, and other forms of life die and leave behind their remains.

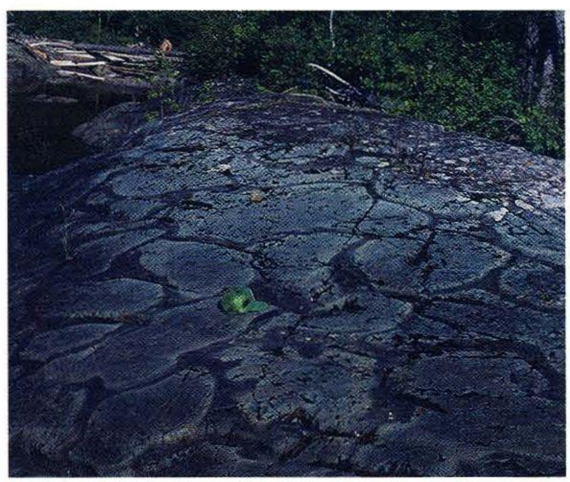
Blocks of sedimentary rock have traditionally been used as building stone

Metamorphic rocks are the result of incredible heat and pressure that change one type of rock into a new type during **metamorphism**. The name comes from the Greek words *meta* and *morphe*, which together mean *change of form*. Rocks that get in the way of hot magma or get wedged between two colliding plates change so much that they become a new kind of rock.

Fiery Igneous Rocks

When magma spews out of a volcano as lava and cools, it forms igneous rocks which go by the name of volcanic rocks.

There are many volcanic rocks scattered throughout Ontario. These rocks are leftovers from a series of huge volcanoes which erupted across the province several times during its long history. The eruptions started about three billion years ago, with the last volcano gushing out lava about one billion years ago. During this time, magma flowed out of volcanoes and covered part of the province with a massive lava blanket a record 30 kilometres thick.



Large lumps, or "pillows" are well preserved in this volcanic rock near Lake Nipigon

There are two major types of volcanoes. Some are very violent, literally blowing their top in an explosion of hot gases, small fragments of rock called ash, and large pieces of rock called bombs that can be as big as a house. Lava from violent volcanoes is rich in silica and flows sluggishly. The lava plugs up a volcano's opening until the only way the pressure can escape is through a huge explosion, as in the 1980 eruption of Mount St. Helens. Other volcanoes, like those in Hawaii, are less violent in their eruptions but their steady stream of lava can flow over long distances and cause serious damage.

Geologists believe that both types of volcanoes were active in Ontario billions of years ago, based on the variety of volcanic rock they have found.

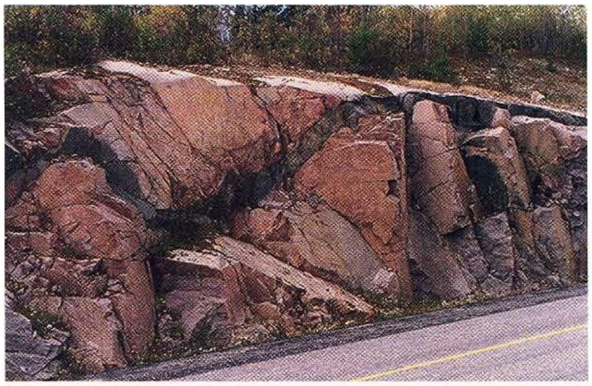
Basalt Pillows

The most common volcanic rock is **basalt**. This almost black, fine-grained rock makes up about 15 per cent of the **Canadian Shield**. You can see it in pillow-like formations in many areas including the Pickle Lake and Red Lake areas.

Sedimentary rock was used to build many of Ontario's prominent buildings. Sandstone from the Nepean area is found in many of Ottawa's buildings, including the Parliament Building.

Red sandstone from the Niagara Gorge adorns Ontario's Legislative Building, and Toronto's Old City Hall.

Pumice is a type of volcanic rock that's full of air bubbles



Granite can be seen in many of northern Ontario's roadcuts

Sedimentary and metamorphic rocks like those of the Legislative Building at Queen's Park are being joined by igneous rocks on Ontario's list of building stone products

Prized for their attractive colours and textures, and because they can be easily cut and polished, metamorphic rocks are widely used in buildings as dimension stone. The marble floors and walls inside Ottawa's Parliament Buildings and Toronto's Legislative Building came from quarries in Ontario.

Pillow basalt usually forms when a volcano erupts underwater. When observed on land, it is a sign that the site was once an underwater volcano.

Creamy Rock

Rhyolite is a grey or cream-coloured volcanic rock found near Kenora, Timmins and other parts of the Canadian Shield. Like basalt, it forms from lava which cooled quickly but it has more silica. Geologists believe that rhyolite comes from volcanoes that erupted with huge explosions.

Floating Rock

Pumice is a special type of volcanic rock. This light grey rock is full of holes like a honeycomb or sponge. If you think you have found a piece of pumice, here's a quick test. Toss it into a bucket of water. If it doesn't sink to the bottom, but bobs up to the top, it's pumice: the only rock in the world that can float on water.

The secret to this floating rock is its hundreds of holes. These holes were once gas bubbles in a stream of lava. When the frothy lava cooled and hardened, the gas disappeared but the holes remained.

"Pluto's" Rocks

Countless times in the Earth's history, hot magma has bubbled up towards the Earth's crust without reaching the surface. Instead, the magma collected and hardened in blobs or ponds in the crust. These intrusive rocks are called **plutonic** rocks after Pluto, the Greek god of the underworld.

Granite Everywhere

Granite is one of the most abundant plutonic rocks. You can see it anywhere from the shores of Lake Superior to the banks of the Ottawa River. More than half the Canadian Shield in Ontario is granite. There is still more in the province, but it is buried under a blanket of sedimentary rock.

The minerals in Ontario's granite give it light shades of red, pink, white or grey, speckled with dark flecks. It's easy to see the large mineral grains in granite, even without a magnifying glass, because it formed from magma which cooled slowly. The light colours come from silica-rich minerals, such as quartz, which is usually a grey or creamy colour, and feldspar, which is pink or white. The dark flecks are usually mica or hornblende. These minerals make granite very hard and almost weatherproof. This makes it an ideal stone for monuments and buildings. Stone used for building is often called **dimension stone**. Ontario is fast becoming an important supplier of dimension stone.

Dark Gabbro

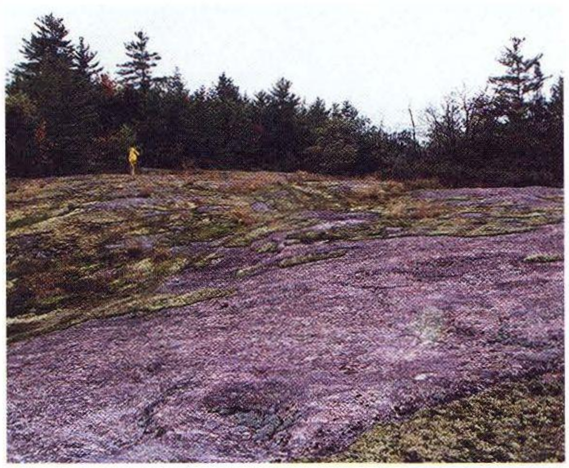
Gabbro is a dark grey plutonic rock common throughout Northern Ontario. Like granite, it formed from slow-cooling magma and contains big crystals. Gabbro contains less silica and more iron and magnesium, which explains the darker colour.

In addition to the fine- and coarse-grained rocks, there are also medium-grained rocks such as **diabase**. These cooled quickly in small pockets within the Earth's crust, near its surface.

Dikes and sills are common in the rocks of the Canadian Shield

Sills & Dikes

When magma squeezes into cracks between rock layers and hardens, it forms huge table-like sheets of igneous rock called **sills**. Some magma may cut up and down through the rock layers and form huge vertical walls of igneous rock called **dikes**. Several dikes side by side in the ground are called a swarm. There are countless swarms in Ontario. One of the biggest, the Matachewan-Hearst Swarm, is made up of hundreds of dikes. It is 500 kilometres long and 700 kilometres wide, and stretches south from Pickle Lake, almost reaching Sudbury.



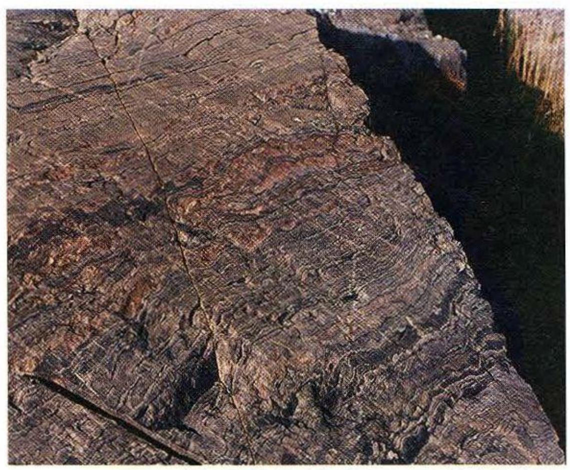
Huge areas can be underlain by one rock type

Batholith Blobs

Some masses of plutonic rock are as big as a mountain. Geologists call them **batholiths**, which means deep stone. Most are made up of granite. There are hundreds of batholiths in Ontario, some covering more than 20,000 square kilometres, an area 3.5 times the size of Prince Edward Island. One monstrous batholith is the Williams Lake Batholith, which stretches for more than 200 kilometres north of Red Lake all the way to Pickle Lake.

Layered Sedimentary Rocks

If you were to walk across Ontario, many of the rocks you would see—about 25 per cent—would be sedimentary. Through Ontario's long history, many parts of the province were covered by sea water. When this happened, layers of sediment collected on the sea floor. When the land rose or the sea level fell, sedimentary rocks were left behind. Often the same area was flooded by the sea over and over for long periods of time, so new layers of sedimentary rocks were laid on the top of older layers.

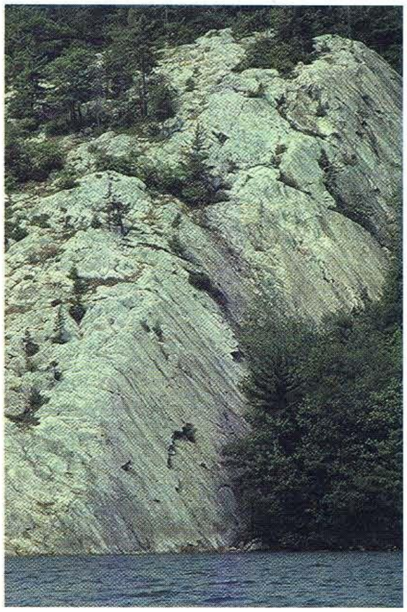


Sedimentary rocks are layered

A Rock Sandwich

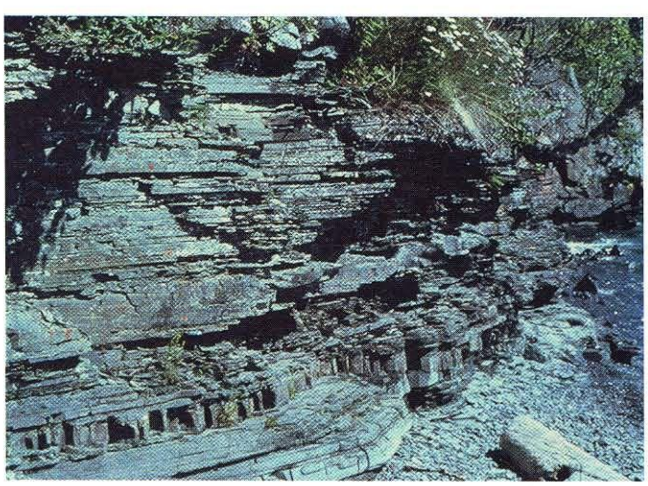
Sedimentary rocks are really layers of rock pressed together into a huge rock sandwich. These layers are called beds and they can be as thin as one millimetre or as thick as several metres.

Each bed is usually different from the one above and below it. Sometimes the differences are easy to spot, especially



These layers of quartzite near Killarney are standing on end

This conglomerate, packed with quartz pebbles, is found near Elliot Lake



Dirty-looking sandstones are called greywacke

when each bed's colours are different. Other times, it takes a magnifying glass to see a difference in grain size or in the type of minerals in neighbouring layers.

Usually these beds lie flat, like the layers of **shale** and **limestone** along the Kettle Point area of Lake Huron. They formed when sediment collected on flat or gently sloping sea floors.

The movement of the tectonic plates can easily fold the flat-lying layers of sedimentary rocks into mountains and valleys.

You can see layers of crumpled sedimentary rock in the Killarney area, north of Lake Huron, where sandstone and siltstone were folded into the rugged Penokean Hills. On the north shore of Cave Lake, also in the Killarney area, layers of sandstone and siltstone now stand straight up.

Dip and Strike

Geologists call the angle at which the rock beds tilt the **dip** of the beds. The amount of dip depends on how much the rock was folded. The direction in which the beds lie, or trend, is called the **strike**. Layers of crumpled sedimentary rock in the Killarney area have an east-west strike.

Lumpy Rocks

A special type of sedimentary rock, made of solidified gravel, is called conglomerate. Taken from the Latin for lumped together, conglomerates can contain stones ranging in size from small pebbles to large boulders.

A famous Ontario example of a **conglomerate** is found in the Elliot Lake area where just over two billion years ago, layers of gravel were laid down on the sea floor and later covered by layers of mud, sand, and silt. Today, these conglomerates are known for the uranium ore they contain.

Wacky Rock

Another common sedimentary rock is **greywacke** (pronounced grey wacky), a muddy grey-coloured rock. The Sleeping Giant, a famous landmark near Thunder Bay, contains layers of **shale** and greywacke topped off by a sill of diabase. Greywacke is actually a special kind of sandstone made from quartz, feldspar and pieces of rock cemented together in a fine mud mixture.

In some greywackes, the biggest grains are found at the bottom of the bed and the smallest at the top. This arrangement of big to small grains within one layer of rock is called graded bedding. Graded beds can be made by strong underwater currents called **turbidity currents** which carry a load of sediment quickly down an underwater slope. As the current slows, the heavy grains sink to the bottom of the seabed first and the lighter grains settle on top.

Zigzag Beds

Wind or water can shape layers of sedimentary rock into a zigzag pattern, like those seen in the sandstones along Highway 6 near Espanola. Here, each layer of sandstone is slanted at an angle to the layer above and below it. This layering pattern, called **cross-bedding**, is usually formed when water or strong winds sweep sand grains back and forth on steep ripples or dunes.

Bumpy Beds

Sedimentary rocks provide a record of the motion of the sea millions of years ago. Marks made by ancient waves are a common feature in the sandstone around Mica Bay, north of Sault Ste. Marie, and in Killarney Provincial Park.

Limey Rock

Limestone, one of the best-known sedimentary rocks, is made up of peculiar ingredients: grains of the mineral **calcite**, from which lime is made, and the shells of tiny sea creatures. When rocks containing calcite erode, the mineral is absorbed into streams and ground water, and eventually carried out to sea. Tiny sea creatures use the dissolved calcite to form their shells. When they die, these shells collect on the seabed, and form new layers of limestone. **Dolostone** is similar to limestone.

Baked and Squeezed Rocks

One of the best spots to find metamorphic rocks in Ontario is the area between Parry Sound, Sudbury, Pembroke and Cobalt, including Algonquin Provincial Park. Several kinds of metamorphic rocks can be found here, such as **gneiss**, **schist**, **marble** and **migmatite**.

Both igneous and sedimentary rocks can be baked and squeezed within the Earth so much that their appearance and mineral make-up change. A metamorphic rock can be changed two or three times into another metamorphic rock.

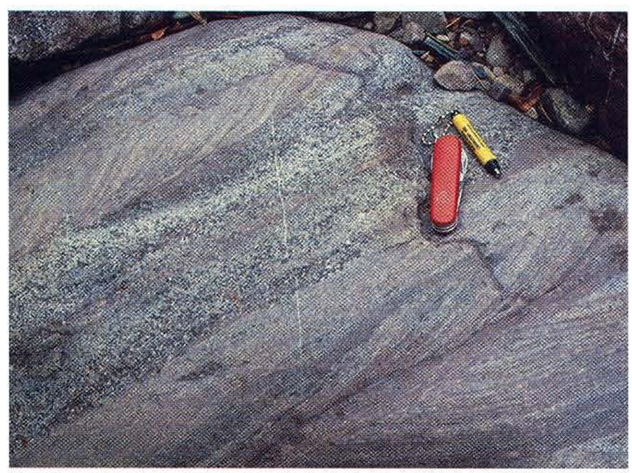
Most metamorphic rocks are found in the roots of ancient mountain belts. As the mountains formed, the rocks caught between the colliding plates were pressed into new rock through a process called **regional metamorphism**. This can affect huge areas, of land, up to several thousand square kilometres. Much of the Canadian Shield has been affected by regional metamorphism.

Home to Fossils

Sedimentary rock can be a treasure trove of fossils. Some of the oldest examples in Ontario are sandwiched between layers of dark red shale in road cuts along the Trans-Canada Highway near Schrieber. These include small cauliflower-shaped fossils of tiny algae which geologists believe were trapped between the layers about two billion years ago. Scientists made a similar find in the black shales at the base of Kakabeka Falls, just west of Thunder Bay.

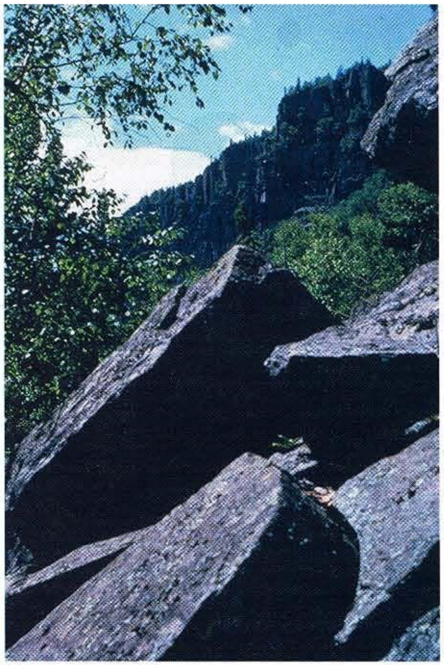
The black shales along the southern shores of Georgian Bay, sometimes called the Collingwood shales, are also good fossil-spotting grounds. Look for cephalopods (members of the squid family), brachiopods (shellfish), horn corals and bryozoans.

Fossils of tiny beetle-shaped sea creatures called trilobites are especially common in these 450 million-year-old rocks.

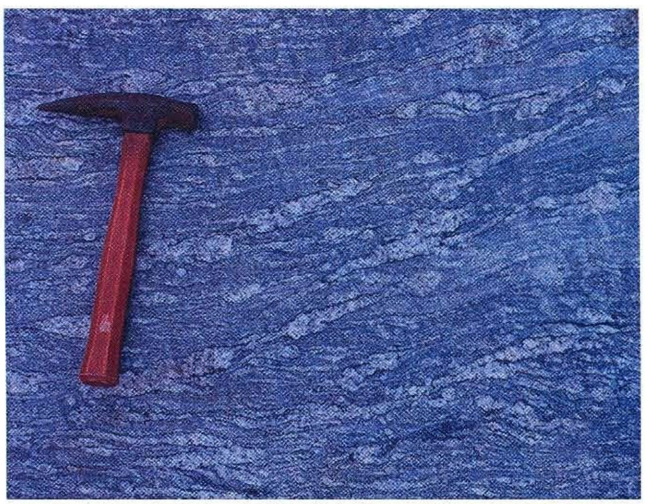


This rock's zigzag pattern tells us it was deposited by wind or flowing water

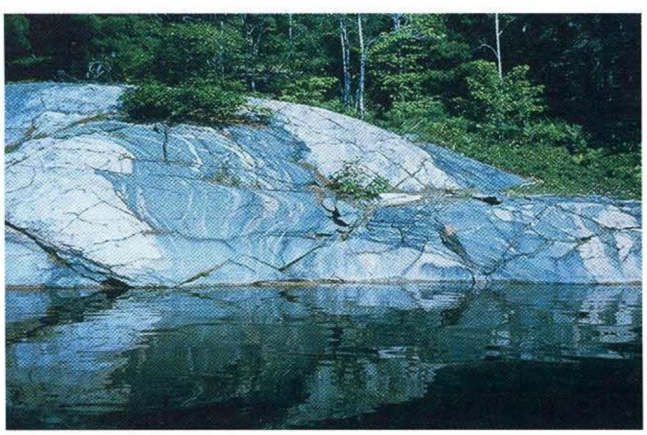
These tribolites lived 475 million years ago in Simcoe County



Contact metamorphism takes place along the edges of igneous intrusions



Migmatite is part metamorphic and part igneous rock



The rock found in much of Ontario's cottage country is gneiss

When magma collects in pockets inside the Earth's crust, it cooks the surrounding rock and creates a halo of metamorphic rock surrounding the batholith, dike or sill. This process is called **contact metamorphism**.

All in the Grade

Geologists grade metamorphic rocks depending on how much the rocks have been baked or squeezed.

In low-grade metamorphic rock, the original minerals have changed very little. Usually, they have grown a bit bigger or been squeezed more tightly together. Low-grade metamorphic rocks, such as slate, usually form near the Earth's surface.

High-grade metamorphic rocks have changed a great deal. They have formed deep within the Earth's crust where the temperatures and the pressures are greatest. Minerals in the original rock have been flattened and smeared, even melted. The minerals may have changed so much that geologists cannot determine what the original rock was.

Belts of Greenstone

When old-time prospectors searched for gold and other minerals in northern Ontario, they often came across fine-grained green rocks they called greenstones. These common metamorphic rocks in the Canadian Shield were once volcanic rocks but have been transformed by the pressures of colliding plates. Their green colour comes from the minerals chlorite and hornblende.

Mixed-Up Rock

Migmatite, from the Greek word *migma*, meaning a mixture, is part metamorphic and part igneous. Outcrops of migmatite can be seen in the White River area along Highway 17.

The two types of rock in migmatite probably met in one of two ways. As magma rose from deep within the Earth, metamorphic schist or gneiss in its way partially melted into liquid rock that cooled and formed igneous granite layers between the schist or gneiss. Or, granite magma may simply have squeezed its way into existing cracks in gneiss or schist.

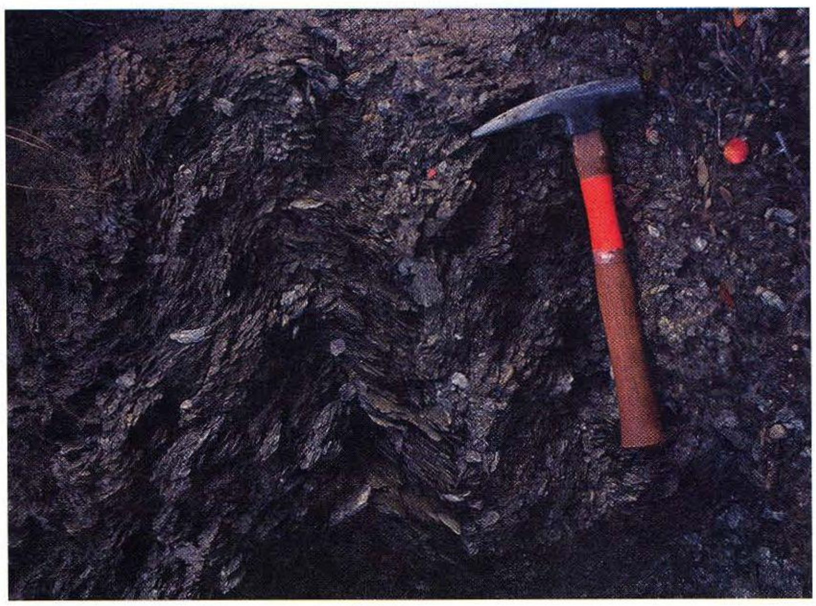
Nice Gneiss

One of the most common high-grade metamorphic rocks in Ontario is gneiss (pronounced 'nice'), which was once an igneous or sedimentary rock. Strong pressures squeezed the previous minerals into separate layers and folded the rocks, so that now the layers of minerals are twisted. No matter what rock it comes from, gneiss is usually easy to identify because of its light and dark streaks. Bands of pink and black gneiss can be seen along the east shore of Georgian Bay.

Splitting Schist

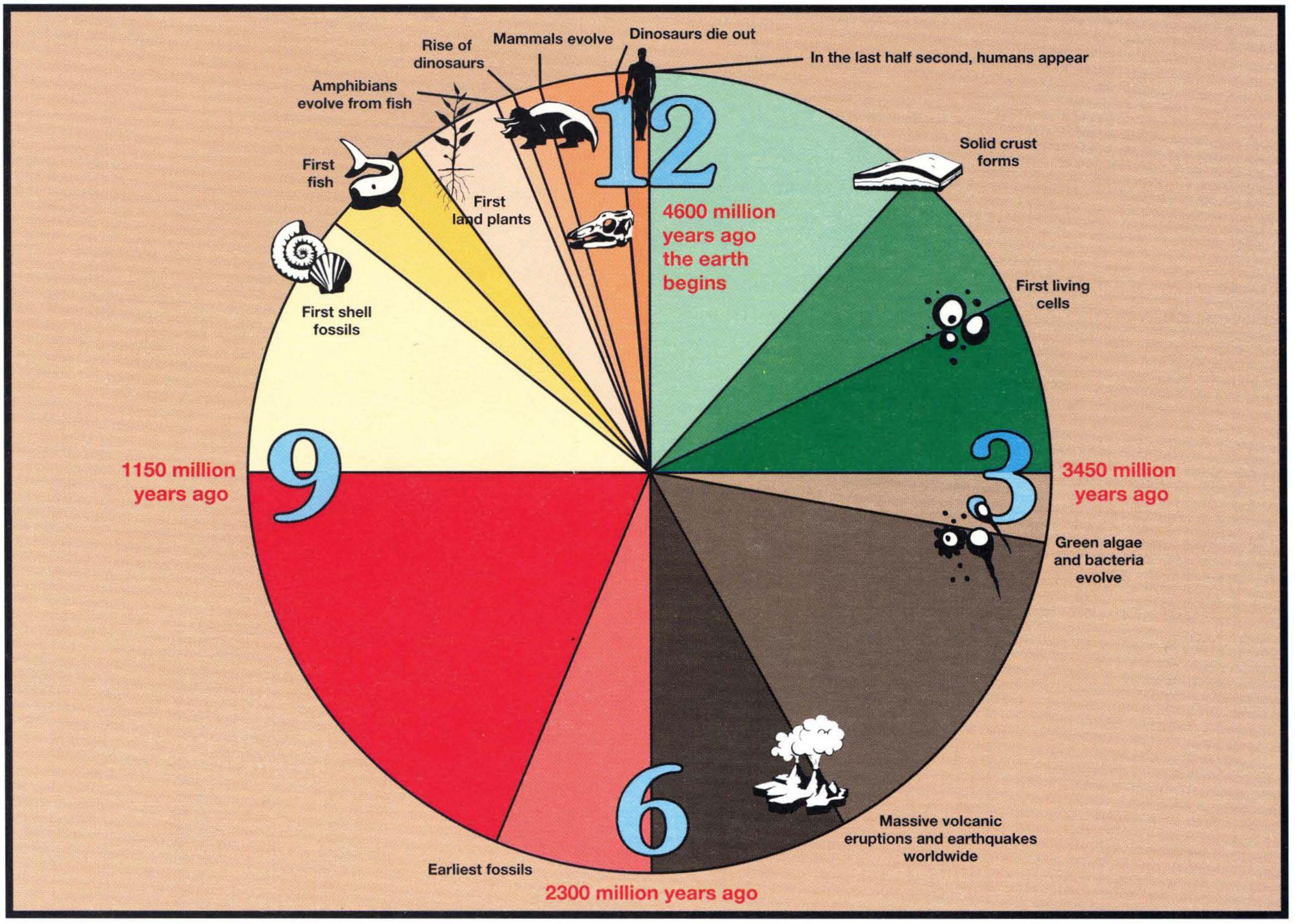
Another common metamorphic rock is schist. One of the first things you notice in a sample of this rock is its many thin, flat layers of minerals. Geologists call this unique arrangement of minerals foliation. When two tectonic plates meet, enormous pressure on the rock causes the minerals to form flat or nearly flat layers at right angles to the direction of the pressure. It's often easy to split foliated rock along these layers.

Gneiss typically has contorted layers of light and dark coloured rock



Metamorphic rocks with lots of flat minerals can be easily broken into layers

4 A Walk Through Time



The Earth has had a long, active history

We live in a fast-paced world where speed is everything. Hockey star Wayne Gretzky can score a goal in a split second. The world's fastest baseball pitcher can throw a ball across home plate at speeds of more than 160 kilometres per hour. We can munch on pizza only five minutes after placing our order at a fast-food restaurant. Your favourite television show lasts half an hour.

This chapter will explore how geologists measure time, and will look at the big picture of geological history.

For most of us, the difference between one million and 100 million years doesn't mean very much. But it does to a geologist.

In one million years, North America moves westward about 25 kilometres. In one hundred million years, the Atlantic Ocean can form, and wind, ice, and rain can wear down a mountain range as tall as the Rockies into something like the Appalachians..

Lop-Sided Day

If we could cram the Earth's entire past into 12 hours, we would have a very amazing day. Imagine that the Earth was formed at noon, and midnight marks where we are today. For the first few hours, things are very quiet. In fact, it isn't until almost 4 p.m. that the land that will be Ontario appears. Life as we know it didn't make an appearance until the last half hour before midnight. Then modern mammals, birds and insects flourish. A mere half-second before midnight, humans arrive on the scene.

Throughout these 12 hours, the continents are active. Geologists believe the continents clustered to form a supercontinent and drifted apart three times since the Earth was formed.

A Stack of Rocks

Geologists work like detectives, piecing together the story of the Earth from clues found in their study of rock structures, fossils and the age patterns of rocks.

Through research, geologists determined the order in which rocks formed. They compiled the rocks into the geological column, an imaginary stack of rocks with the oldest rocks on the bottom and the youngest on the top.

To help us read the history of the Earth, geologists have divided the geological column into chapters. Each chapter is called an eon and lasts hundreds of millions of years. The three eons are the **Archean**, **Proterozoic** and the current eon, **Phanerozoic**. The eons are further divided into shorter measures called eras and periods.

The Archean Eon

Often called The Ancient Age, the Archean Eon spans the first 2.50 billion years of the Earth's history. Some ancient rocks formed during this time have been found in Australia, Greenland and Ontario.

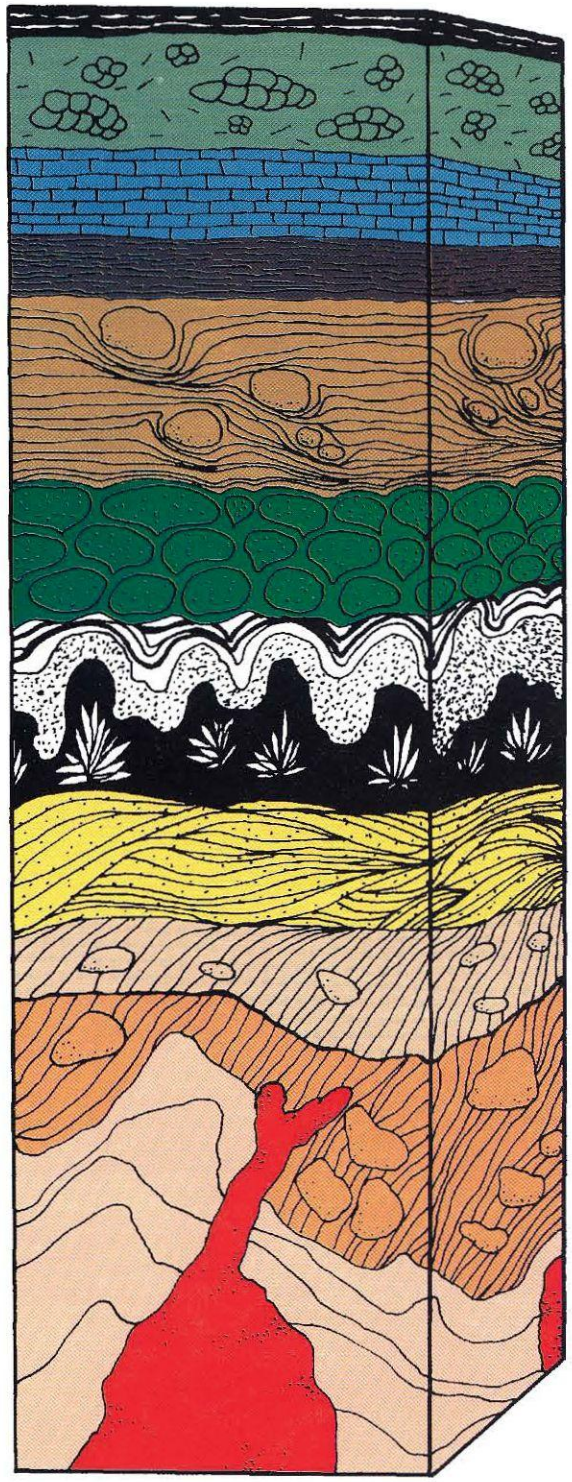
The Proterozoic Eon

The first real signs of life appeared on Earth during the Proterozoic Eon between 2.50 billion and 570 million years ago. For this reason, this eon is often called *The Age of Former Life.*

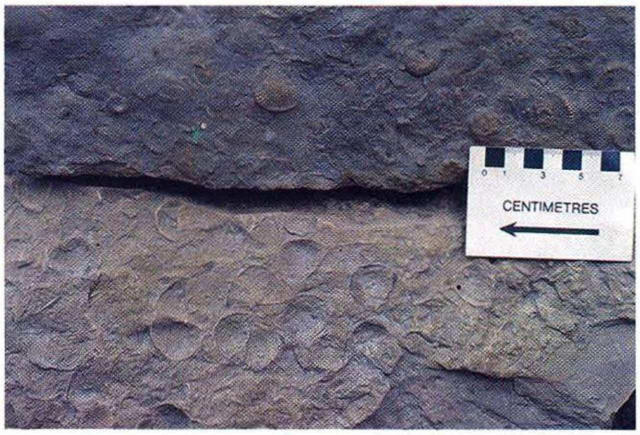
The plants and tiny creatures of this time did not have hard shells or skeletons and did not usually leave an imprint or fossil in the rocks.

But some life forms did leave their mark in northern Ontario. Small cauliflower-shaped fossils of tiny blue-green algae were trapped in layers of sedimentary rock about two billion years ago.

Geologists often combine the first two eons—the Archean and Proterozoic—and call this **Precambrian** time. Rocks formed during Precambrian time make

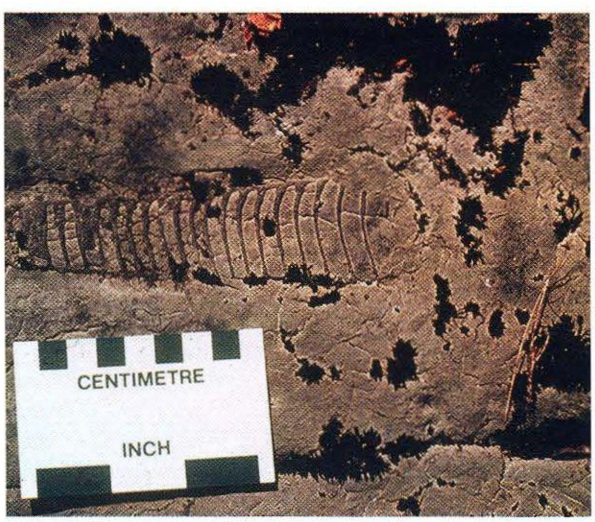


The geological history of an area can be shown by a cross-section like this



Each "thumbprint" in this rock from Georgian Bay is an ancient seashell called a brachiopod

These marks tell us that creatures burrowed in the mud on the sea floor 425 million years ago



This ancestor of squids, called a cephalopod, had a torpedo-shaped shell for protection

up most of our continents but lie hidden under layers of younger rocks.

The Phanerozoic Eon

We live in the Phanerozoic Eon covering the last 570 million years. This eon is divided into three eras: the **Paleozoic**, **Mesozoic** and **Cenozoic**.

The Paleozoic Era

At the beginning of this era, all plants and animals lived in the seas and oceans. By the end of it, they had moved onto land. The Paleozoic Era is subdivided into six periods: Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian.

Cambrian: (570–505 million years ago)

The Cambrian period marks the point when underwater creatures first developed skeletons that could be left behind as fossils. Fossils from this period show that the sea was home to such creatures as starfish, sponges and worms.

Ordovician: (505–438 million years ago)

Beetle-like sea creatures with hard shells, called **trilobites**, and giant sea scorpions roamed the waters.

Silurian: (438–408 million years ago)

Most life was still in the sea. Fossils from the Silurian period are found on most continents, and include corals, clams, sea snails and early fishes.

Devonian: (408–360 million years ago)

This period is sometimes called *The Age of Ferns and the Age of Fishes*. Many different kinds of plants, including ferns, started to grow on land during this period. In the seas, many new fish evolved, including the shark.

Carboniferous: (360–286 million years ago)

Swampy tropical forests covered the continents. When these forest plants died, many fell into the swampy water and over millions of years were squeezed together to form the coal we mine today.

Big is the word to describe life in this period. Giant tree ferns and horsetails grew in the forests. Dragonflies as large as dinner plates and other huge insects were common. Reptiles, such as the one-metre-long *Hylonomus*, arrived on the scene.

Permian: (286–245 million years ago)

Reptiles and insects flourished and the first coniferous trees started to grow. Many creatures and plants mysteriously became extinct at the end of this period and geologists aren't sure why.

The Mesozoic Era

This era started 245 million years ago and is subdivided into the Triassic, Jurassic and Cretaceous periods.

Triassic: (245–208 million years ago)

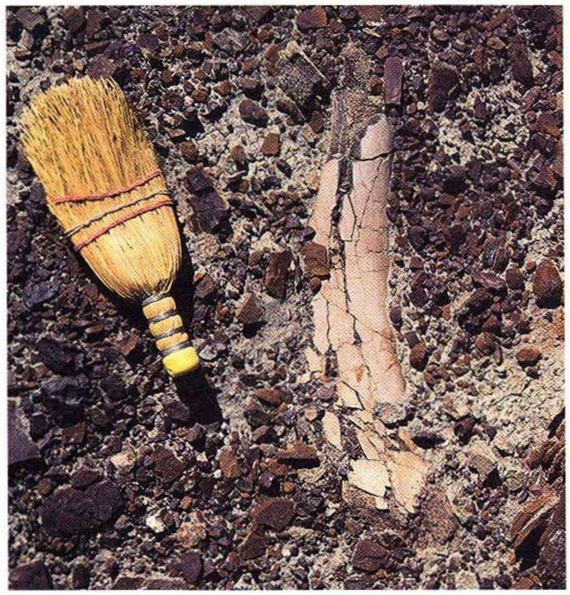
Ancestors of today's lizards and turtles, along with the first mammals, shared Earth with early dinosaurs including the eight-metre-long *Plateosaurus*.

Jurassic: (208–144 million years ago)

Dinosaur giants *Stegosaurus* and *Allosaurus* roamed the land. Pterosaurs flew overhead and icthyosaurs and plesiosaurs roamed the seas.

Cretaceous (144–66 million years ago)

Dinosaurs reached their peak during this period, including *Tyrannosaurus Rex*. By the end of the Cretaceous period, dinosaurs and many other creatures were suddenly and mysteriously wiped out.



Bones like this one from a duck-billed dinosaur can be found in rocks in several provinces

The Cenozoic Era

Also known as The Age of Recent Life, the Cenozoic era started 66 million years ago. It is made up of two periods, the Tertiary and the Quaternary.

Tertiary: (66–1.50 million years ago)

Birds and mammals replaced dinosaurs as rulers of the world.

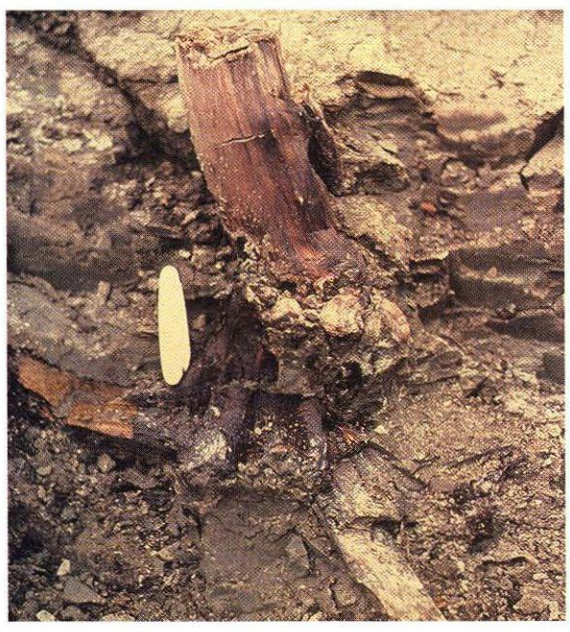
Quaternary: (1.50 million years ago—to the present)

Thick blankets of ice, the last of which melted 10,000 years ago, covered much of the northern world. Today's glaciers are remnants of this Ice Age. Huge furry mammals such as the woolly mammoth lived in North America, Europe and Asia, and woolly rhinos roamed Europe and Asia.

Many animals were larger than their relatives today. Giant deer and beavers lived in North America, while giant sloths and huge armadillos wandered South America. Australia was home to giant kangaroos. These giant animals disappeared about 8,000 years ago.

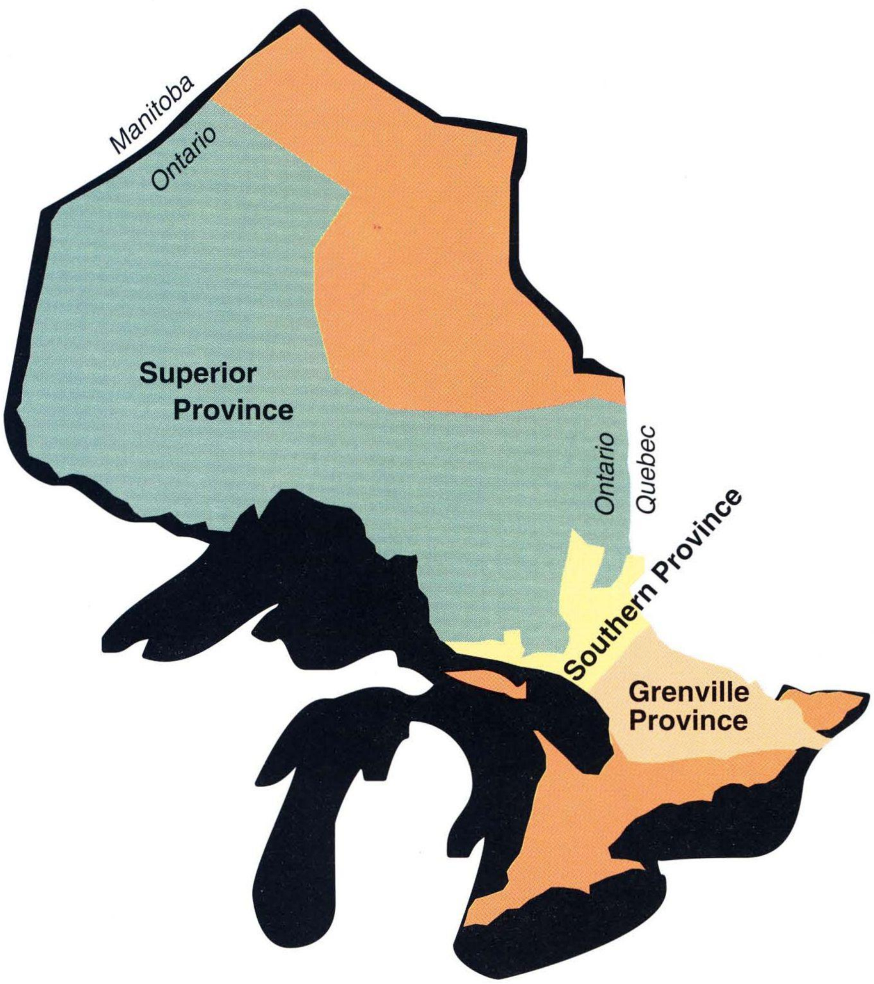
Early humans began evolving from an ape-like ancestor about 10 million years ago. By 40,000 years ago, modern humans arrived on the scene.

Dinosaur fossils haven't been found in Ontario yet. Although dinosaurs almost certainly roamed the province, evidence of their presence was lost when the rocks from the Mesozoic Era were eroded from all but a small area in the James Bay Lowlands.



This 135,000 year-old tree trunk was buried by mud during flooding

5 Geology in Action



The Superior, Southern, and Grenville Provinces make up Ontario's part of the Canadian Shield

The first piece of crust that is now Ontario made its appearance more than three billion years ago. Since then, Ontario has been a showcase of geological processes including volcanoes, earthquakes and mountain building, glaciers, erosion and more.

This chapter will explain how geologists organize the various regions across Ontario, and describe some of the differences between them.

Three Provinces in Ontario

Geologists divide Ontario into three geological areas called provinces. Each contains rocks of similar age and type, and corresponds to the geological time column illustrated in Chapter 4.

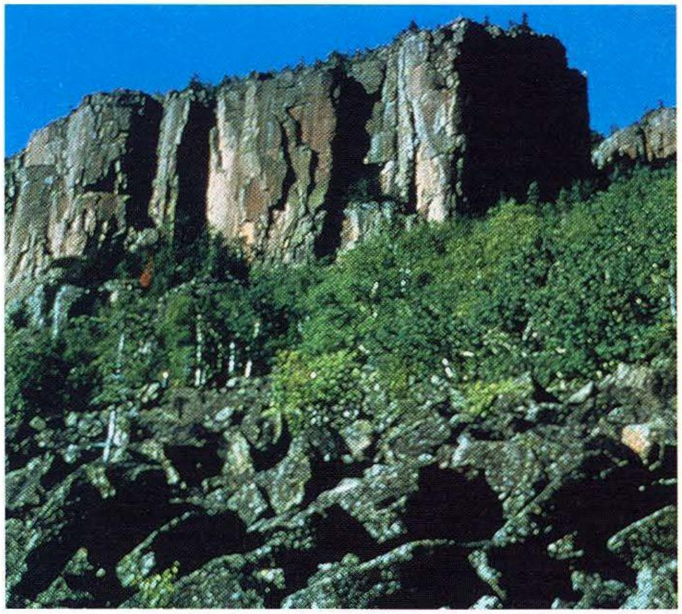
The geological provinces—Superior, Southern and Grenville—were formed at different times in Ontario's past. These three provinces are together called the Canadian Shield. The first to develop was the Superior Province, 4.50 to 2.49 billion years ago. As each province appeared, it attached itself to the older rocks. Together, they form the **bedrock** exposed throughout northern and central Ontario.

Superior Province

The Superior Province is the oldest part of the Canadian Shield and covers most of northern Ontario.It is divided into12 smaller subprovinces, based on rock type. Nine subprovinces are filled with greenstones (metamorphosed volcanic rocks) and two consist of sedimentary rocks, which have also been metamorphosed. The remaining one consists mainly of granite. There is also a lot of granite in and among both the greenstone and sedimentary subprovinces.

Southern Province

The Southern Province evolved between 2.49 billion and 570 million years ago. Only a small part of the Southern Province actually lies within Canada. Most of it occurs in the states of Michigan, Minnesota and Wisconsin.



Rocks of the Southern Province help create spectacular scenery along the north shores of Lake Huron and Lake Superior

In Ontario, a blanket of sedimentary rocks between 2.25 and 2.49 billion years old can be found in the Elliot Lake area. A second flat-lying blanket of 1.54 billion-year-old sedimentary rock covers the northern shore of Lake Huron, and some of the area west of Thunder Bay. Lightly-metamorphosed sedimentary and volcanic rock stretches from Lake Huron to Quebec. These are the remains of a 2.49 billion-year-old mountain range, called the Penokean Hills.

Layers of volcanic and sedimentary rocks fill a long trough which stretches from the middle of the United States through to the top of Lake Superior and on to about Windsor. This marks the mid-continent rift where the young North American continent tried to split apart a little more than one billion years ago.

Grenville Province

This is the youngest part of the Canadian Shield, only one billion to 570 million years old. Within Ontario, it stretches southeast from the area around Sudbury to the St. Lawrence River and includes Algonquin Park. The first gold discovery in Ontario was made in the Grenville Province in 1866.

The northern part of the Grenville Province is a vast sea of medium- to high-grade metamorphic rock, mainly gneiss. The southern part is full of sedimentary and volcanic rocks which have also been metamorphosed. There are also many granite plutons in the area.

The Paleozoic and Mesozoic Basins

During the time period 570 to 63 million years ago, basins developed in the lowlands of Ontario. In the north, the Hudson Bay and Moose River basins formed, while in the south the Michigan and St. Lawrence basins appeared. Thick layers of sedimentary rock such as limestone, shale and sandstone fill these basins on the edges of the Canadian Shield.

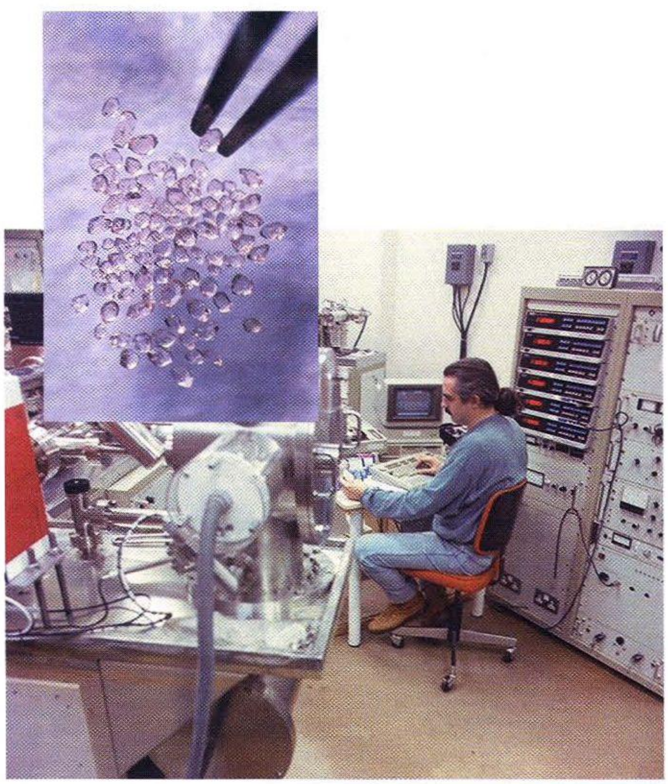
Quaternary Deposits

Deposits of sediments left throughout Ontario between 1.50 million years ago and the present are the youngest geological features of the province.

During this time, glaciers scoured the surface of Ontario. As these vast ice sheets melted, lakes and rivers covered most of Ontario. The glaciers not only scraped rock from the ground; they left behind many landforms including ancient lake bottoms, beaches and river banks. They also left huge hills and ridges made of till, a mixture of clay, gravel, boulders and other earth materials transported by the glaciers.

6 The Superior Province

Gold was discovered in the Archean rocks of the Red Lake area in 1926



Sophisticated techniques are used to free the secret of a rock's age from tiny grains of zircon

Three billion years ago, Ontario's Superior Province was a hot spot of geological activity. Tectonic plates jostled, volcanoes erupted, mountains and islands were formed, and sediments built up at the edges of the young province.

This chapter looks at the making of the Superior Province. First, it explores life in Archean time and early plate movements. Then, it looks at the rocks of northern Ontario.

Life in Archean Time

If you could visit the Earth three billion years ago, you would see a totally alien planet. It was covered by oceans. The continents we know today were just starting to form but were very small.

Volcanoes were erupting on land and under water, spewing lava, ash and gas. The air was unbreathable: there was too little oxygen and too much carbon dioxide and nitrogen oxide. The sun's ultraviolet light blasted down: the ozone layer, which filters out those rays, had not yet formed. The temperature was unbearably hot.

The small pieces of land were barren—no trees or grass, no animals. The only life was tiny algae and bacteria that lived in the sea.

Plate Action in Archean Time

The plates covering the Earth started to move approximately three billion years ago. They were thinner, smaller and moved much faster than they do today. Geologists also believe there were 20 major plates, compared with today's 10.

Most of the early plates were covered by ocean. Only a few carried tiny pieces of crust that became the cratons, or centres, of today's continents.

Superior Province: Up Close

By studying rocks, their ages and how they are grouped together, geologists have reconstructed the early history of Ontario. All the action centred around the Red Lake area, where the first piece of Ontario probably appeared. Rocks dating back almost 3.25 billion years have been found there.

Geologists believe this tiny piece of crust grew in several stages. First, volcanoes spread lava from east to west and made several arcs of volcanic islands. Over time, these volcanic islands collected on the edge of the young Ontario.

Gradually, the volcanic islands eroded and powerful currents swept the sediments into basins along Ontario's edge. This process repeated itself about three times.

The final stage occurred when pieces of crust—including the island arcs and the sedimentary basins—butted together into one large block of land with a force strong enough to create a mountain range as tall as the Rockies.

The impact of the colliding plates made huge balls of magma rise up, forming enormous granite batholiths beneath northern Ontario. It also baked and compressed the volcanic and sedimentary rocks, creating new metamorphic rocks.

Superior Province Rock Groups

Rottenfish, Pickle Crow and Catfish are names of rock groups. No, these groups do not have a lead singer or a guitar player. Instead, these groups are made of real rocks. Geologists call them **assemblages**, packages of rocks of the same age and type formed by the same geological process.

Rottenfish, Pickle Crow and Catfish, for instance, are all rock asemblages made up of volcanic rock. They were once part of a chain of volcanic islands which stretched from east to west across northern Ontario.

There are more than 200 rock assemblages across the Superior Province of Ontario. They are usually named after a nearby town, lake or river.

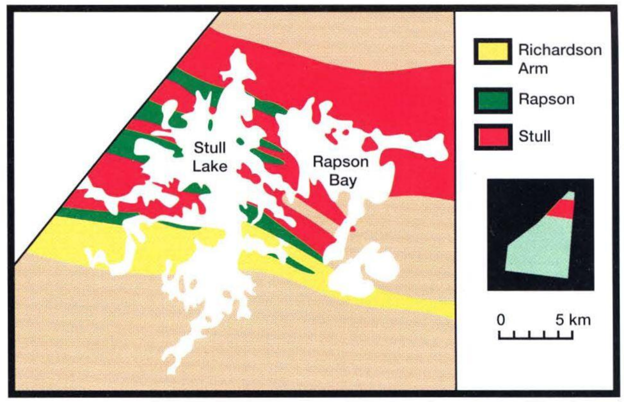
Most rock assemblages are hidden under layers of other rocks which were formed later. Sometimes, you can spot part of an assemblage in an outcrop along a highway or shore of a lake.

Geologists group rock assemblages made up of volcanic rock into larger groups called **greenstone belts**. These, in turn, are grouped into geological subprovinces.

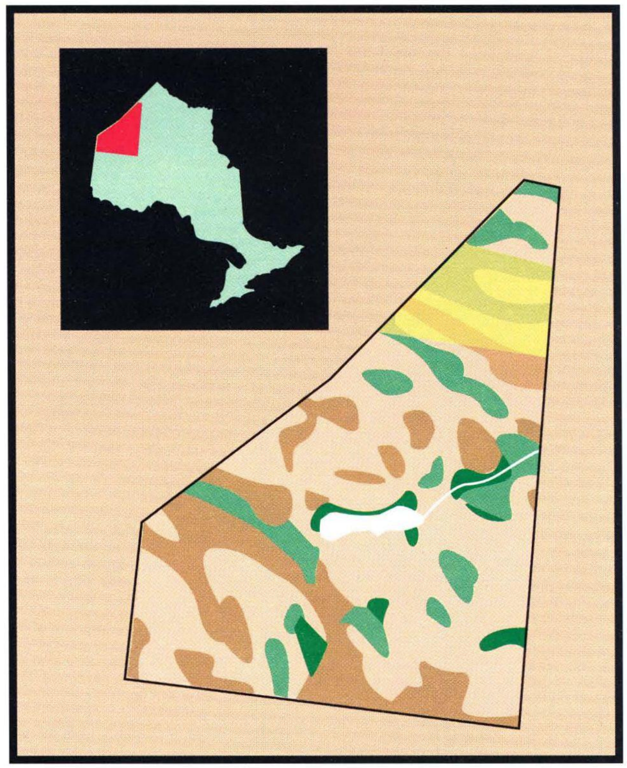
Subprovinces

The Superior Province has 12 geological subprovinces. There are nine granite-greenstone subprovinces; two sedimentary subprovinces and one subprovince made up of plutonic rock.

These subprovinces are separated from one another by faults or cracks in the Earth's crust. Here's a close-up look at each type of subprovince.



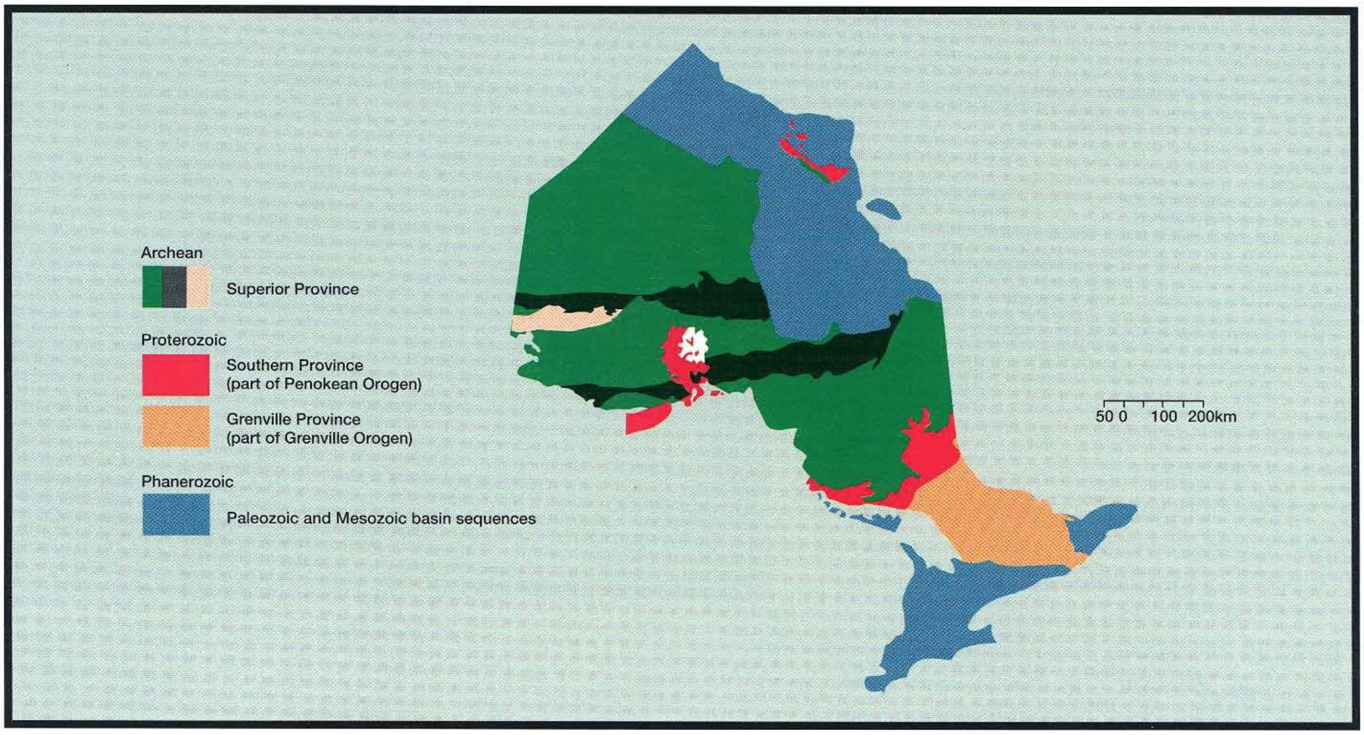
These three assemblages make up part of a greenstone belt in northwestern Ontario



Greenstone belts are shown in green on this geological map

Geologists have found original pieces of the Ontario crust south of Red Lake. They uncovered a rock which was an amazing 3.17 billion years old. But, they recently topped that with a rock north of Savant Lake in the Wabigoon subprovince.

Here, they found a single 3.30 billion-year-old grain of **zircon** in a piece of quartzite. Geologists aren't sure where it came from. All they can say for sure is this zircon grain was eroded from something 3.30 billion years old. But it still remains a mystery. Could it have been a very early piece of granite which formed from magma deep within the Earth's crust?



The subprovinces of the Superior Province are shown here in green (granite-greenstone), grey (sedimentary), and pink (plutonic)

This unusual texture, called spinifex, has earned rocks which have it the nickname "chicken track rock"

The Granite-Greenstone Subprovinces

The greenstones are long, narrow belts of volcanic rocks which were once island arcs. They are between 3.02 billion years and 2.70 billion years old.

The granite is found in huge dome-shaped batholiths nestled within the volcanic rock. Most of the granite is slightly younger than the surrounding greenstones.

There are nine granite-greenstone subprovinces: Winisk, Sachigo, Berens River, Uchi, Bird River, Wabigoon, Wawa, Opatica and Western Abitibi. They stretch from east to west and show the ancient path of the colliding plates. Some of these subprovinces touch each other. Others are separated by the sedimentary and plutonic subprovinces.

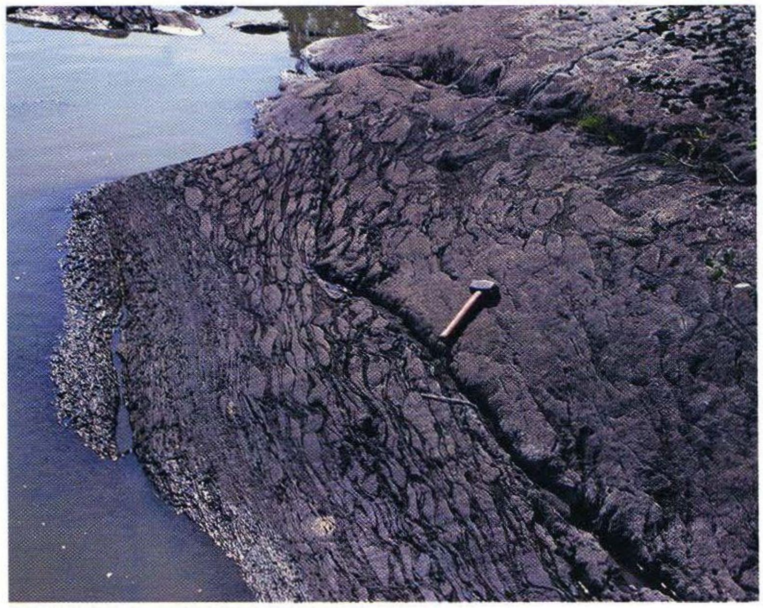
Rock Assemblages

There are four major types of rock assemblages in the granite-greenstone belts of the Superior Province: platform, arc, mafic plain and wrench basin.

Platform Assemblages

Platform assemblages have three layers: a quartzite-rich, sedimentary rock on the bottom; a middle layer of shale and a dark iron-rich sedimentary rock called iron formation; and a top layer of **komatiite**, a volcanic rock nicknamed "chicken track rock", because its crystals form a pattern which looks just like a chicken walked over it. Usually, the layers are folded like an accordion or even turned up on their end.

Platform assemblages formed between 2.99 and 2.85 billion years ago, when sediments settled in layers around the edges of Ontario, followed by lava from nearby volcanoes. Examples, such as the Steep Rock and Lumley Lake assemblages, are found in the Wabigoon subprovince.



These rocks from the shores of Sandy Lake formed during volcanic eruptions almost 3 billion years ago

Arc Assemblages

The bottom layer of an arc assemblage is a very thick layer of basalt. The top is a thin layer of volcanic ash, or other debris from a volcano including rhyolite **bombs** and **breccia**.

Breccia is rock made from fragments of other older rocks. It comes in sheets, layers, large pockets or dikes cutting though other types of rocks.

Quiet underwater volcanoes spilled out a steady flow of lava, which cooled into basalt. These were followed by violent underwater versions of Mt. St. Helens which exploded ash and rubble. The volcanoes erupted when two plates—an oceanic and a continental plate—collided.

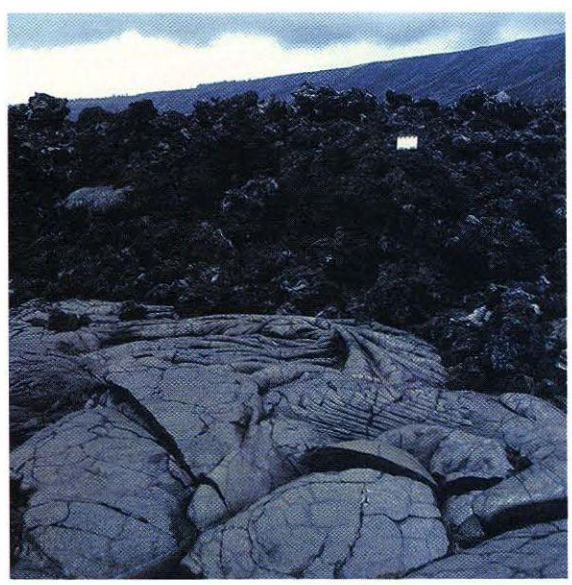
This is the most common rock assemblage in the Superior Province. It is found in most of the granite-greenstone subprovinces, and examples include the Rottenfish, the Catfish and the Pickle Crow assemblages. The oldest arc assemblage is the 3.02 billion-year-old North Spirit assemblage near Red Lake.

Mafic Plains

This is a very simple rock assemblage. In most cases, it is made up of basalt or komatiite, within beds of sedimentary rock such as black shale.

Mafic plains were formed between 2.77 billion and 2.70 billion years ago from lava which flowed from quiet underwater volcanoes, much like those that are still erupting today in the Hawaiian islands.

These rock assemblages are only found in a few spots in the Superior Province. One example is the Hawk assemblage near Wawa.



Lava in Hawaii forms smooth flows called pahoehoe, and rough, clinkery layers called a'a

These conglomerates form part of the wrench basin assemblage in the Shebandowan area just west of Thunder Bay

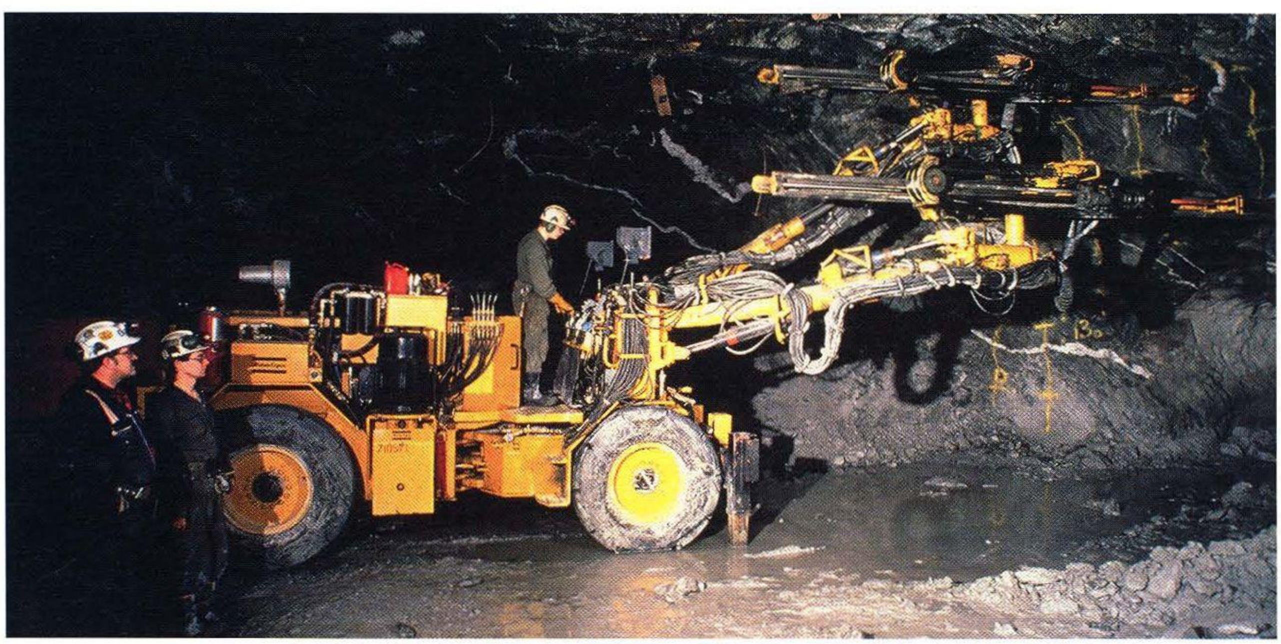
Wrench Basins

This is an unusual rock assemblage. It is a complicated arrangement of coarse sedimentary rocks and volcanic rocks found in a basin surrounded by active faults. The rocks of this assemblage lie on top of older rocks and very weathered greenstones.

Wrench basins are formed in the late stages of a collision between an island arc and an ocean plate. As the ocean plate slips below the island arc, sediments and pieces of the sea floor are scraped off. These sediments pile up against the island arc to form basins.

The collision also triggers volcanoes. These volcanoes end when the island arc and the sedimentary basin are jammed together. A fault marks the boundary where these two pieces of land have joined.

Wrench basins are a very important assemblage. Most of the gold in the Canadian Shield is found in or near the faults which mark their boundaries. Today, underground mines are found along these faults, especially around Timmins, Kirkland Lake, and in the Shebandowan area west of Thunder Bay.



Machines like this are used to drill holes for explosives in underground mines

The Sedimentary Subprovinces

These subprovinces are made up of sedimentary rock, mainly greywacke, but they may also contain conglomerate and siltstone.

There are two sedimentary subprovinces: the English River and the Quetico. They formed between 2.72 and 2.66 billion years ago, after the main volcanic action in the Superior Province.

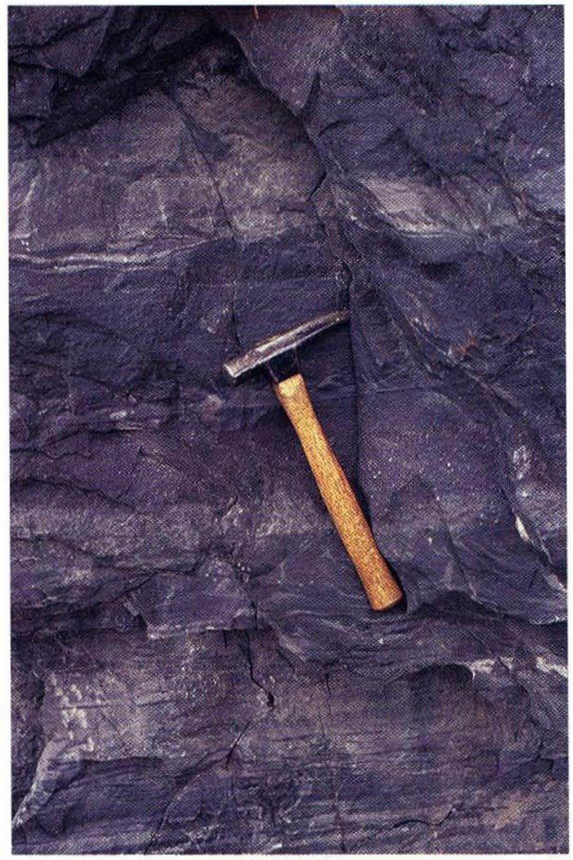
Each sedimentary subprovince is really one big rock assemblage. The layers of greywacke which make up each subprovince were deposited by strong underwater currents, called **turbidity currents**.

These currents are really underwater avalanches, sparked by colliding plates, that dumped huge loads of sediment, called prisms, into basins along the edges of the young Ontario.

One Plutonic Subprovince

There is only one plutonic subprovince, the Winnipeg River Subprovince. It is made up of plutonic rock, mainly granite.

Like the sedimentary subprovinces, this plutonic subprovince is also one big rock assemblage. In this case, however, it is made up of granite. This granite has been baked and squeezed by plate action, and was transformed into gneiss, a metamorphic rock, about 2.68 billion years ago.



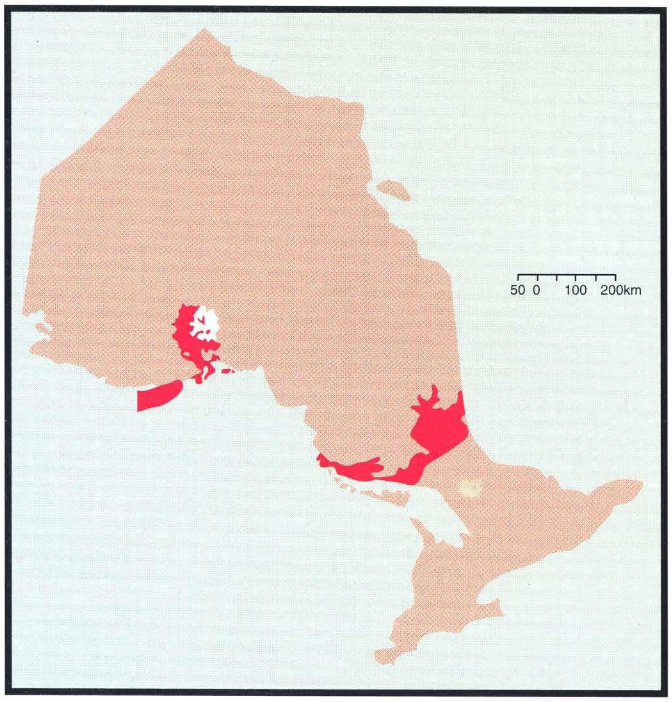
The grain size gradations in these layers of greywacke tell us they were deposited by turbidity currents

7 The Southern Province

About 2.49 billion years ago, the Earth was a very different place. The atmosphere could not support the life forms we have today. And there was rain—enough to erode whole mountain ranges!

Ontario was also very different. Nipigon, Black Bay Peninsula and Michipicoten Island were the sites of huge volcanoes that erupted when North America tried to split into two pieces. Shallow seas washed over Thunder Bay, Sault Ste. Marie, Elliot Lake and Espanola. And Sudbury, famous for its nickel and copper mines, might not even exist today had it not been for a gigantic **meteorite** which crashed into the Earth.

Welcome to the Southern Province. Read on to find out how this picturesque part of Ontario was made.



The Southern Province was once where the action was - geologically speaking

A Time of Beginnings

During the early years of the Proterozoic Eon, most of the continents around the world, except Australia, were covered by vast sheets of ice. Life in the Proterozoic Eon was in a time of change. The Earth's atmosphere was a mix of carbon dioxide and nitrogen. There was probably some oxygen but less than we have today.

However, there was plenty of water vapour. That meant rain—lots of it. As the heavy rains fell, mountain ranges made in Archean time eroded, and sediments were washed into the seas. Some sediments carried minerals which dissolved in the water and set the stage for early life forms.

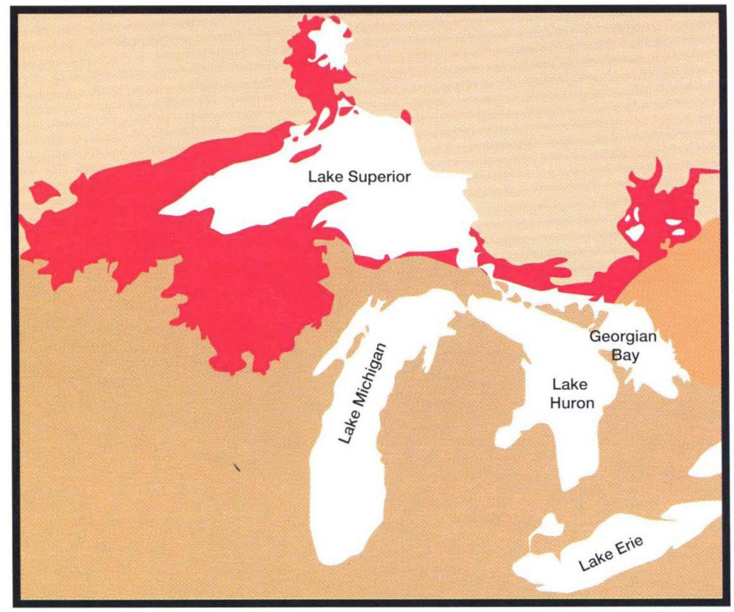
Tiny creatures, such as simple bacteria and blue-green algae, thrived in the shallow seas along the continents' shores. These first appeared in Archean time, but it was during the Proterozoic Eon that they started to evolve.

The blue-green algae lived in clusters, and were preserved as fossils called **stromatolites**. The algae used the sun's energy to make food in a process called **photosynthesis**.

Stromatolites like these are among the world's oldest fossils

They also pumped oxygen into the Earth's atmosphere. The oxygen slowly accumulated, and started to build the ozone layer that protects us from the sun's harmful ultraviolet rays.

Many geologists believe the major continents drifted together and formed a supercontinent for the first time during the Proterozoic Eon. This supercontinent likely formed about 1.75 billion years ago. It began to break apart about 1 billion years ago. There are signs of this breakup in North America today. A 2,000 kilometre-long rift valley—one of the longest and deepest in the world—now runs south from Lake Superior as far as central Kansas.



The Southern Province extends across the north shores of Lakes Superior and Huron

The Southern Province: Up Close

The making of the Southern Province—the second stage in Ontario's geological history—is an exciting and busy time. The action centred around Lake Huron and along the north shore of Lake Superior.

The Southern Province had its start with sediments that eroded from the Superior Province. These sediments were laid down from 2.49 billion to about 2.21 billion years ago.

The rocks formed from these sediments are mainly **conglomerate**, **sandstone**, **siltstone**, **mudstone** and **greywacke**. They are arranged in three **supergroups**. The oldest is the Huronian Supergroup, which as its name suggests, is around Lake Huron. The other supergroups—the Animikie and the Sibley—are along the north shore of Lake Superior.

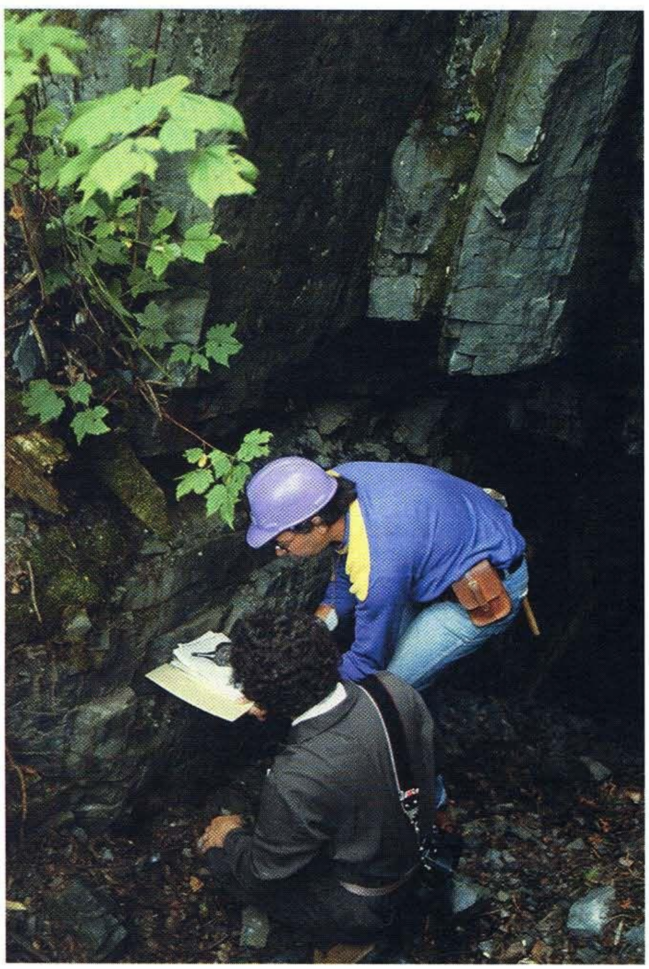
Next came a major mountain-building event called the Penokean **Orogeny**. This event was triggered when the young Ontario collided with another piece of crust located just off its southern edge. The result was a huge mountain range north of Lake Huron.

Rock-building reached a peak in the Southern Province about 1.11 billion years ago. The Earth's crust cracked. Volcanoes erupted. A long rift, or deep valley formed. Lava and sediments collected in the rift. Today, they make up the fourth supergroup of rocks in the Southern Province: the Keweenawan.

The mountain-building and the attempted breakup of the continent forced magma to flow up from the Earth's mantle. It collected and cooled in large pockets and sheets. Today, these form the igneous rocks which cut through the sedimentary rocks of the Huronian, Animikie, and Sibley Supergroups.

The Penokean Orogeny formed scenic ridges like this one north of Manitoulin Island

Gem Lake in Killarney Park was a subject for Group of Seven artists



The contact between Nipissing diabase (upper), and Cobalt Group rocks (lower) is the site of many of the silver deposits in the Cobalt area

The Sudbury Structure, known throughout the world for its nickel and copper, completes the rock picture of the Southern Province. As you will discover, the Sudbury rocks have a very special history.

The rest of this chapter looks at the rocks of the Southern Province in more detail.

The Huronian Supergroup

The Huronian Supergroup contains thick beds of sedimentary rock, mainly conglomerate, mudstone, siltstone and sandstone, which were later folded into mountains when they collided with an island arc about 1.80 billion years ago.

The sandstone around Lake Huron's North Channel, the steep escarpments around Elliot Lake and the quartzite of the LaCloche Mountains in Killarney Provincial Park are part of this supergroup.

The Huronian Supergroup is divided into four **groups** of rocks which lie one on top of each other like layers of a cake.

The Elliot Lake Group

The Elliot Lake Group is the oldest group. It is the only one to have volcanic rocks, both basalt and rhyolite. These rocks are from volcanoes which erupted when the Earth's crust started to pull apart near Sudbury 2.49 billion years ago. Sedimentary rocks, including quartz pebble conglomerate, cover the lavas. Mixed in with the conglomerate are grains of uranium-bearing minerals which eroded from the Superior Province.

The Other Groups

Glaciers travelled across Ontario three times between 2.45 and 2 .22 billion years ago. They laid down the sedimentary rocks of the Hough Lake, Quirke Lake and Cobalt groups. The ice sheets scratched and scoured the bedrock, and gouged out large boulders. Wave action left ripple marks, cross-beds and graded beds in these sedimentary rocks.

The Igneous Rocks

The Nipissing dikes and sills are huge sheets of igneous rock squeezed into the Huronian Supergroup's sedimentary rocks about 2.25 billion years ago. Some sheets are very large, measuring several hundred metres thick, and are mainly gabbro. They form the ridges that rise from the flat-lying sedimentary rocks of the Cobalt plain.

Pink granite of the Killarney Belt contrasts with white quartzite of the Huronian Supergroup in Killarney Provincial Park

The Killarney Belt is a pie-shaped wedge of land that separates the Huronian Supergroup from the Grenville Province. Geologists believe the Killarney Belt attached itself to the Superior Province southeast of Sudbury, about 1.74 billion years ago. It is made of enormous granite batholiths and volcanic rocks. Outcrops of bright pink and grey granite show along an 80 kilometre stretch in the Killarney Provincial Park area. They are related to rocks in a belt stretching from Wisconsin to Arizona.

The North Shore of Lake Superior

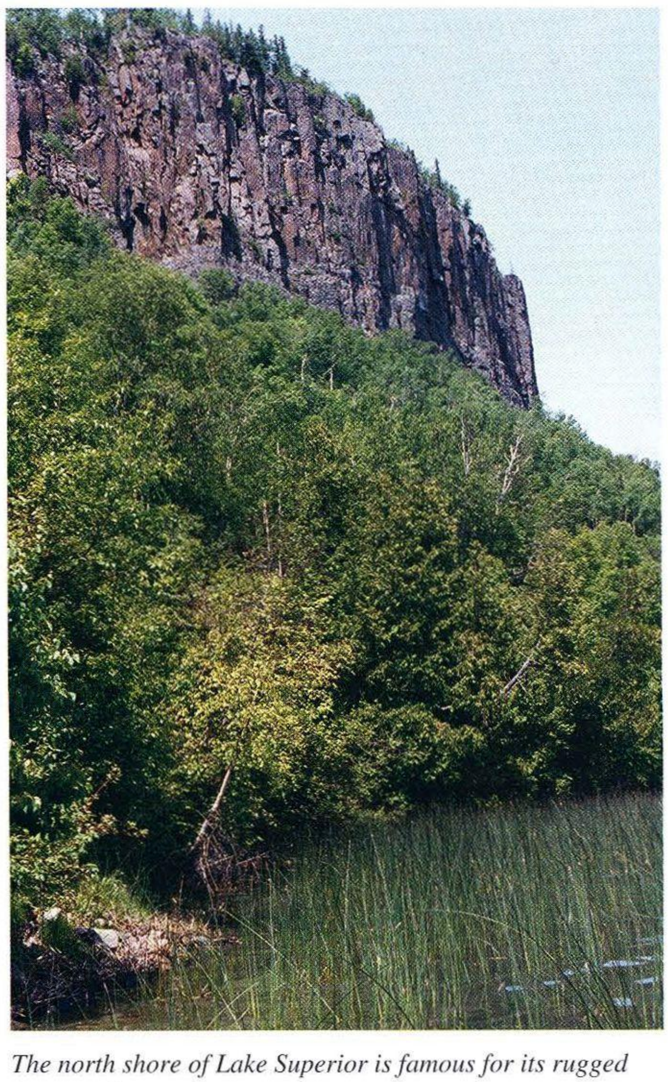
Sleeping Giant Mountain and the black shales of Kakabeka Falls, both near Thunder Bay, the cliffs along the Sibley Peninsula, the dark shales of the Pigeon River Gorge, the brilliant red hills around Nipigon, and the wave-washed headlands of basalt near Pancake Bay—all are found in the Southern Province, and are described below.

The Animikie Supergroup

The Animikie Supergroup is made of layers of **iron-stone**, sandstone, mudstone, shale and greywacke. These sediments eroded from the Superior Province between 2.10 and 1.85 billion years ago. They formed a sedimentary prism along its southwestern shoreline. The bottom of the Animikie Group is world-renowned for its spectacular fossil records of early life on Earth. These fossils are clusters of stromatolites which lived in shallow seas two billion years ago.

The Sibley Supergroup

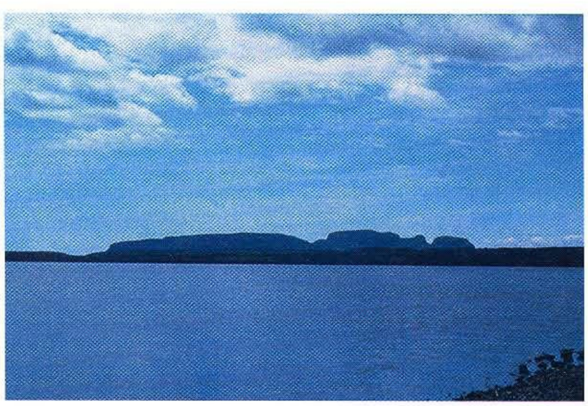
The Sibley Supergroup overlies the Animikie Supergroup. It contains layers of conglomerate, sandstone and shale. These sedimentary rocks, found between lakes Nipigon and Superior, formed when sediment eroded from the Superior Province about 1.54 billion years ago and washed into a shallow lake on top of the older rocks.



The north shore of Lake Superior is famous for its rugged topography

Iron causes the red colour of this sandstone from the Sibley Supergroup

Here, diabase sills have pushed their way between layers of sedimentary rock



The Sleeping Giant is a famous landmark near Thunder Bay

Travellers along the Trans-Canada Highway, especially around the Schreiber area, are treated to spectacular views of these rocks in roadcuts. The first thing you notice about the Sibley shales is their brilliant orange-red colour. The red colour tells geologists that oxygen was present in the atmosphere when these rocks formed.

How do they know? Stromatolites living at that time used the sun's energy to make food, and pumped oxygen into the air. Some Sibley rocks contain iron, which mixed with the oxygen and rusted into a red-hued mineral called **hematite** as the rock was forming. If oxygen had not been present, the iron would not have rusted.

The Igneous Rocks

The Sibley Supergroup is also home to a variety of igneous rocks. Sills and dikes of diabase cut through and between the layers of sedimentary rocks of the Animikie and Sibley supergroups. About 1.11 billion years ago, magma squeezed up from the mantle into the sedimentary rocks. The flow was triggered when North America tried to break into two pieces along a line centred beneath Lake Superior and stretching into the Lake Nipigon area. That line is now called the **Midcontinent Rift**.

The Sleeping Giant near Thunder Bay looks like the profile of a huge person having a nap. To geologists, this familiar land form is really a flat-topped hill called a **mesa**. The top of the mesa is a protective diabase sill which has withstood the attack of wind, ice and rain. The sedimentary rocks below have eroded to give the mesa its sloping sides beneath the steep diabase cliffs. Mount McKay, another familiar landmark in the Thunder Bay area, is also a mesa. A 60 metre-thick diabase sill covers many layers of shale and greywacke below.

In contrast, a **cuesta** has a gentle slope on one side where the sedimentary rocks have been eroded, while the other side is a steep escarpment. Red Rock Cuesta, just south of Nipigon, is a ridge which rises several hundred metres above the surrounding countryside. Its bright red shales stand out in contrast to the thick dark diabase sill on top.

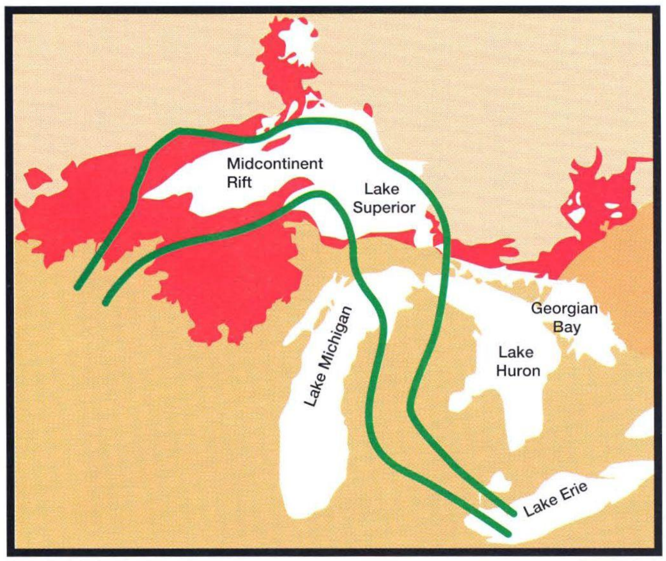
Another famous landmark in Sawyer Bay, near Thunder Bay, is a wedge-shaped rock formation just over seven metres tall. It rears out of the water and looks remarkably like a sea lion, but is really a diabase dike.

Geological forces have sculpted the Sea Lion from a diabase dike

The Keweenawan Supergroup

The bottom layers of the Keweenawan Supergroup are volcanic rock, mainly basalt and some rhyolite. The top layers are sedimentary rocks: conglomerate, shale and sandstone.

The Midcontinent Rift marks the spot where the young North American continent tried to split into two pieces about 1.11 billion years ago. As the plate beneath the crust split, it made a long and narrow **rift** or valley.



The Midcontinent Rift is filled with a 30 kilometre-thick sequence of rocks

Underwater volcanoes poured out lava which cooled into basalt. These rocks show up in Black Bay Peninsula, the St. Ignace Island area, Michipicoten Island and Mamainse Point. At Mamainse Point alone, geologists have found more than 300 basalt flows piled one on top of another. Fierce volcanoes on land spewed lava which cooled into rhyolite. Geologists traced some units of this cream-coloured rock up to 40 kilometres along the north shore of Lake Superior.

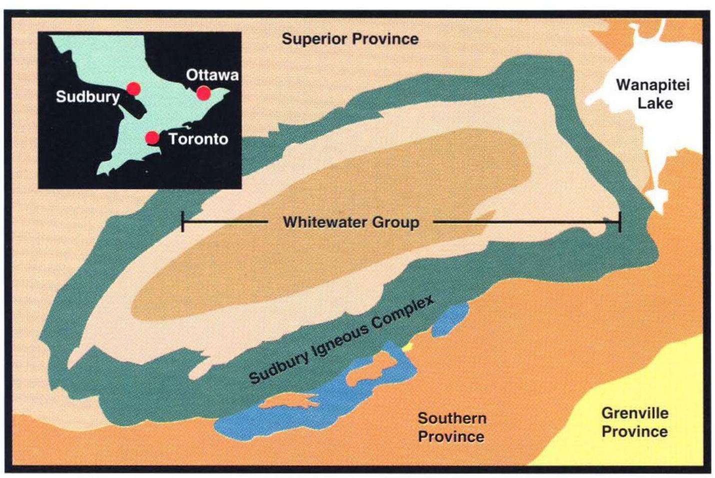
Eventually, the volcanic eruptions ended. The Earth's crust cracked, sagged and deepened the rift. Rivers and streams deposited sediments, outcrops of which can now be found in several places along the eastern end of Lake Superior. A 60-metre thick section of folded sandstone crops out in the Alona Bay-Mica Bay area near Mamainse Point, while other examples are found on the shores and islands of Black and Nipigon Bays. Sills and dikes of igneous rock, formed in the later stages of the rifting, cut through these sedimentary beds.

These conglomerates make up part of the Keweenawan Supergroup

The Inco smelter in Sudbury has recently had a $500 million upgrade

The Mysterious Sudbury Structure

The **Sudbury Structure** is world-famous for its nickel-copper ores which have been mined since 1883. But, it is also one of the most puzzling geological mysteries in the world. The Sudbury Structure is made up of two major parts: the Sudbury Basin, and the Sudbury Igneous Complex.



Geologists look around the outer rim of the Sudbury Igneous Complex to find ore

The **Sudbury Basin** is a huge oval-shaped bowl which measures 27 by 60 kilometres in size. It is also very deep, extending about 30 kilometres beneath the surface. The Basin is filled with the Whitewater Group of rocks, layers of breccia covered by sedimentary rocks, mainly mudstone, siltstone and greywacke.

The Basin is nestled in a thick bowl of igneous rock called the **Sudbury Igneous Complex**. The bowl is made up of rocks called **norite**, **gabbro** and **granophyre**.

For a long time, geologists believed the structure was made when a violent volcano near Sudbury erupted with a huge explosion. Magma welled up from the mantle, cooled and hardened within the crust and sediments later filled the volcanic crater.

Geologists have recently found evidence which makes many believe the structure is the crash site of a meteorite. They say a gigantic meteorite smashed into the Sudbury area about 1.85 billion years ago, when the area was under the sea. The crash triggered huge tidal waves and created a large crater; rocks shattered and the Earth cracked. When the meteorite hit the ground, it melted some older rocks of the Superior Province and forced magma up from the mantle.

The melted rock and magma were thrown out of the crater, only to be deposited back inside almost immediately along with fragments of the surrounding rock. Sediments eroded from the surrounding land filled the crater. Since then, it has been squeezed and tilted by mountain-building activity and later eroded.

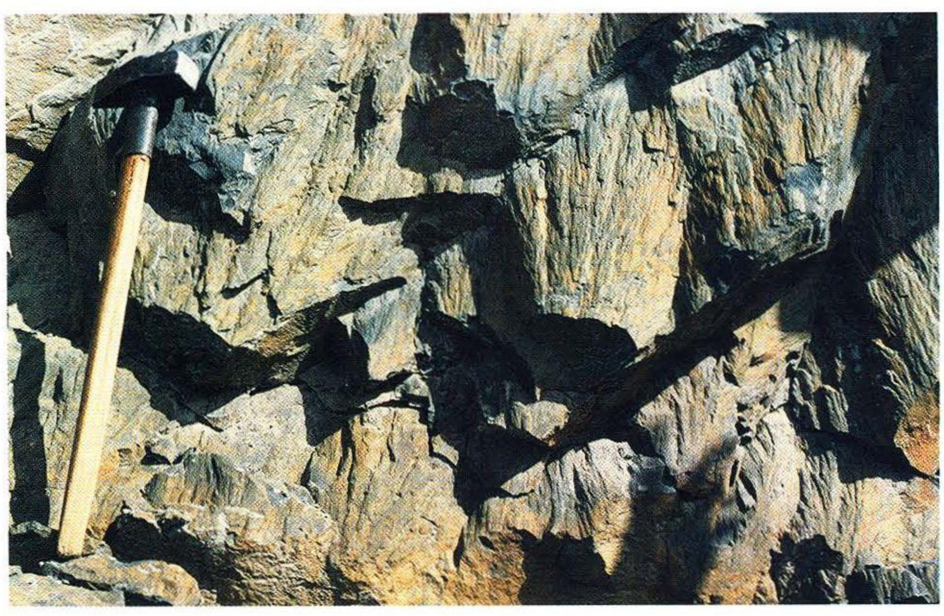
Two important pieces of evidence of the meteorite theory are breccia and shatter cones.

Three types of breccia, a rock made from fragments of older rocks, are associated with the Sudbury Structure; along the bottom of the Sudbury Igneous Complex, in the three lower layers of the Whitewater group, and scattered around the Structure up to 80 kilometres away.

The breccia in the three lower layers of the Whitewater Group is a puzzle. Some geologists say it is volcanic rock made by a violent volcanic eruption. Others say it is made of material which was blasted out of the impact crater of a meteorite, and then fell back down to earth.

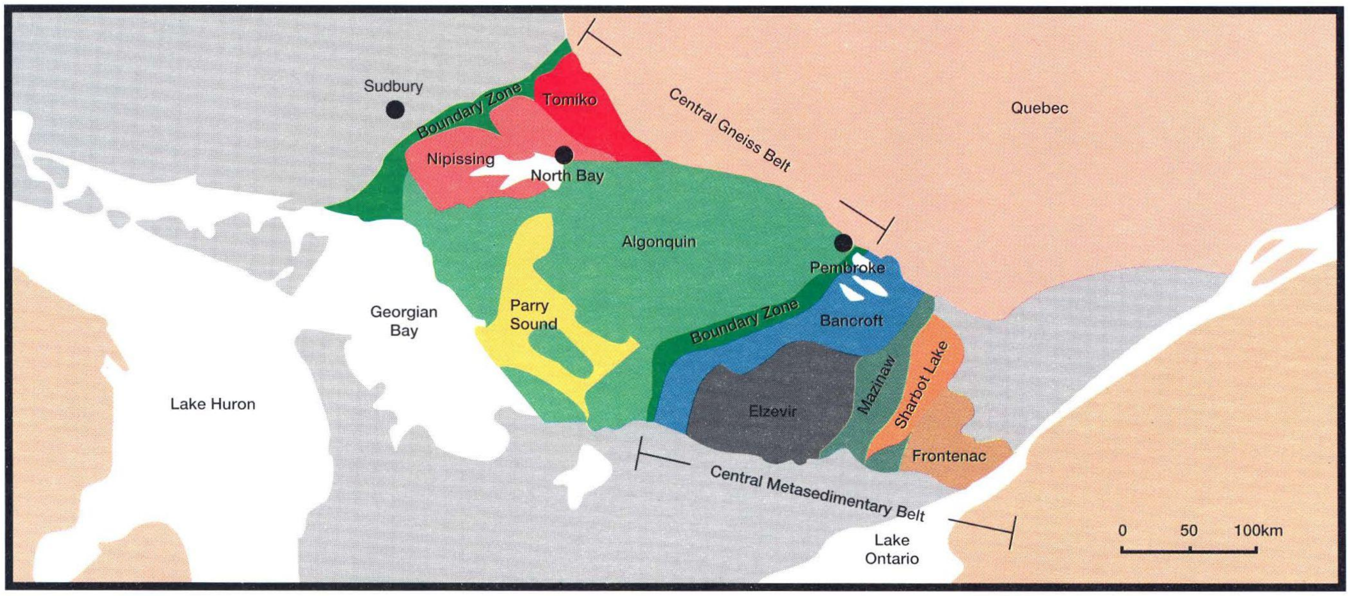
Shatter cones are cracks in rock which spread out from a centrepoint like petals of a flower. They vary in size, from just 10 centimetres in length to one or more metres long. Shatter cones are common sights in rock quarries where construction crews blast rock, and in craters made by meteorites. In the Sudbury area, they are found in rocks all around the Sudbury Igneous Complex, even as far as 17 kilometres from the Structure itself.

Breccia like this, found up to 80 kilometres from the Sudbury Structure, may have formed when a meteorite slammed into the Earth

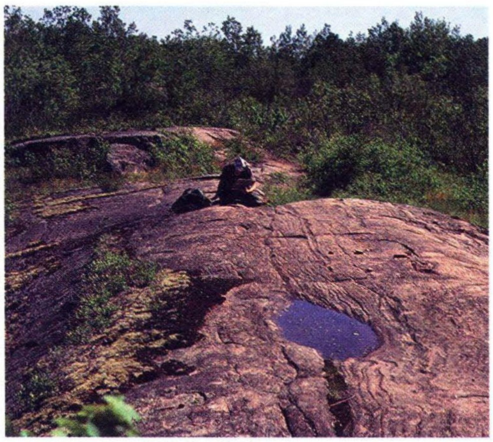


Some of the best shatter cones in the Sudbury area are just outside the office of the Ontario Geological Survey

8 The Grenville Province



The Grenville Province, a jigsaw puzzle of terranes, was pieced together over more than 500 million years



These gneisses near Minden are part of the Grenville's largest terrane - the Algonquin

Glacial activity stripped the soil from parts of the Grenville Province

Snug Harbour, Pointe au Baril, Port Loring—this scenic area of Ontario's cottage country was beneath a huge mountain range about 1.18 billion years ago.

The towns of Tweed and Apsley were once sites of powerful volcanoes.

That stretch of dark green rocks from Parry Sound to just east of Huntsville was formed about 1.45 billion years ago in another part of the world.

About 1.24 billion years ago, shallow tropical seas washed over the towns of Westport, Gananoque and Portland.

This is the Grenville Province of central and eastern Ontario, a patchwork of many different pieces of crust, or **terranes**. These terranes collided in a powerful mountain building event which thrust up a major mountain range.

Today, the ancient mountain range has been eroded by wind, rain and ice. Rocks that were once deeply buried within the Earth's crust are now uncovered as the rocks of the Grenville Province.

The Grenville Province: Up Close

The making of the Grenville Province is the third stage in the formation of Ontario. Built from about 1.76 billion to about 1.00 billion years ago, it is the youngest part of the Canadian Shield.

The rocks of the Grenville Province were baked, squeezed, stretched and twisted into metamorphic rocks by a series of powerful and long mountain-building events between 1.18 billion and 1.00 billion years ago.

The Grenville's Two Belts

The Grenville Province in Ontario is divided into two major sections: the Central Gneiss Belt and the Central Metasedimentary Belt, each with a unique geological history.

Each of these belts, in turn, is subdivided into smaller units called terranes.

"Suspect" Terranes

Terranes which are thought to have travelled along the Earth's plate tectonic conveyer belt are called **suspect terranes**.

There is one suspect terrane in the Central Gneiss Belt—the Parry Sound Terrane. Geologists think it was part of an ancient volcanic island arc which formed at some unknown location thousands of kilometres away from Ontario.

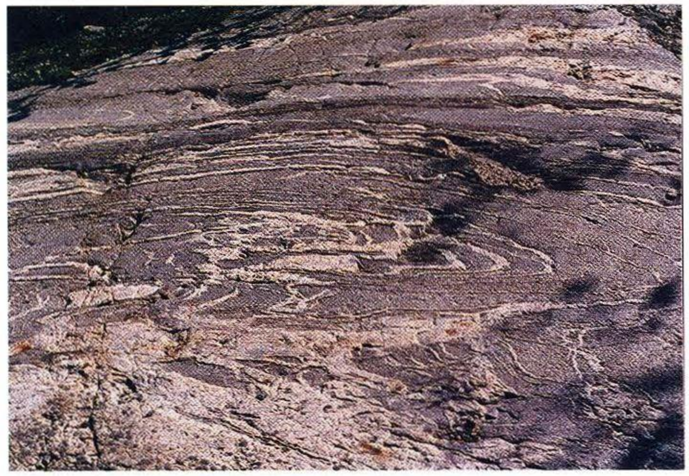
All the terranes in the Central Metasedimentary Belt are suspect terranes.

Geologists are still unravelling the complex Grenville story. Here's a look at what they have found so far.

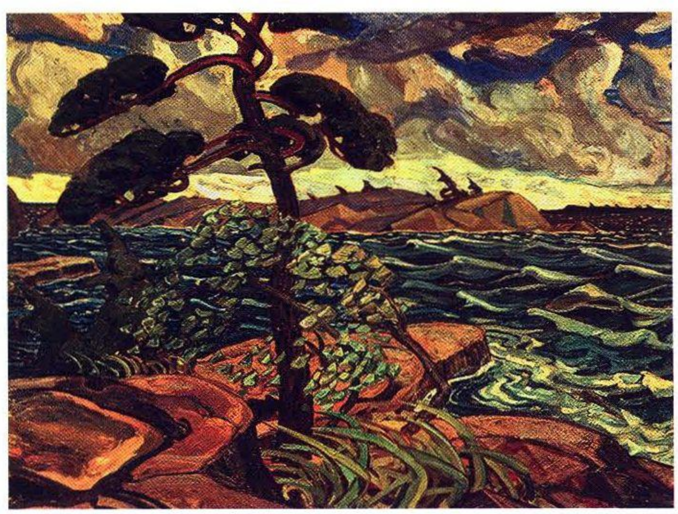
The Central Gneiss Belt Terranes

The Central Gneiss Belt is the oldest part of the Grenville Province. Its oldest terrane is the Nipissing Terrane, which is 2.73 to 1.45 billion years old.

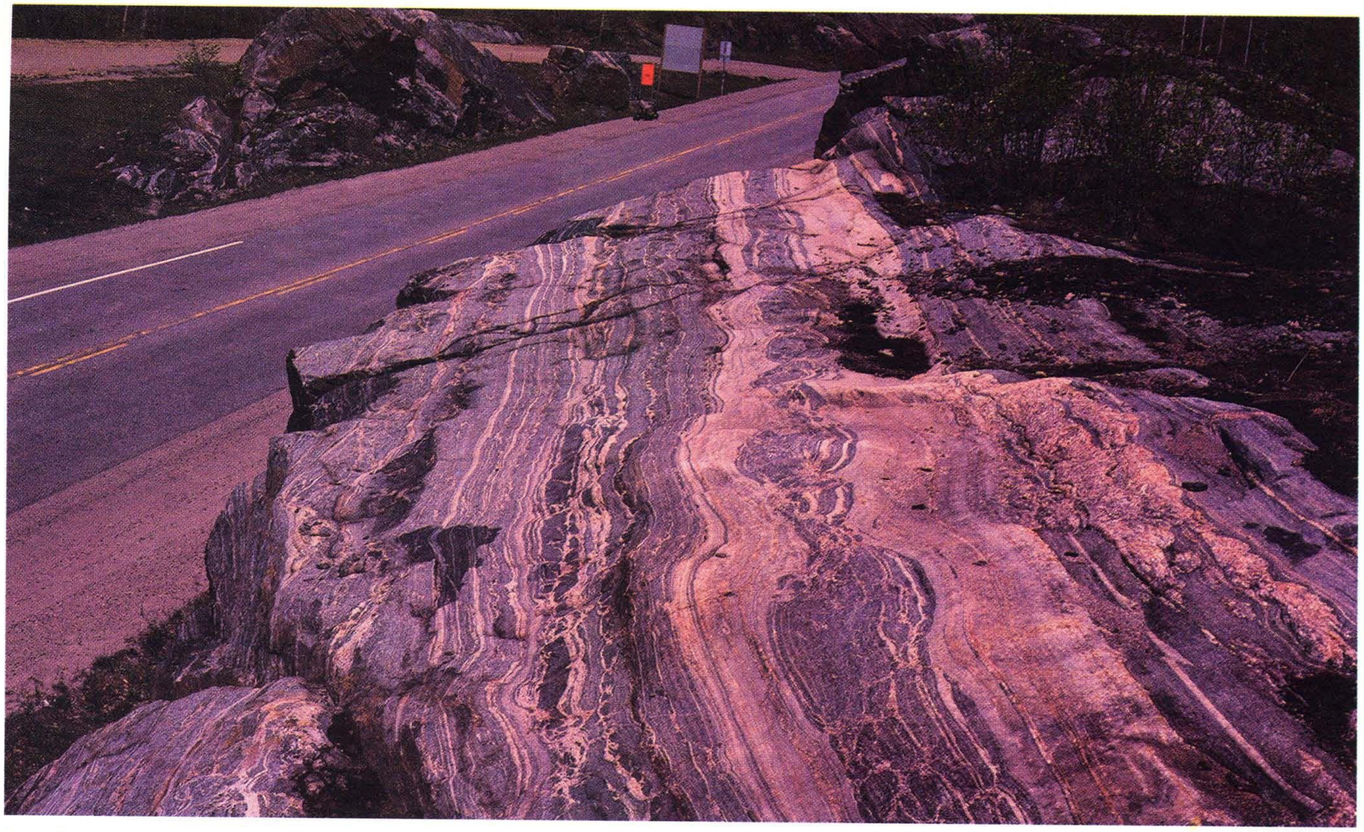
The Nipissing Terrane is a block of sedimentary and igneous rocks which formed the south margin of the Archean Superior Province. These rocks were folded and metamorphosed, and intruded by Grenville Province batholiths as a result of the collision of Grenville Province terranes to the south with the Archean rocks.



Migmatite, a rock with mixed layers of igneous and metamorphic rock, is common in the Nipissing Terrane



The rocks of the Central Gneiss Belt have been captured in paintings of Group of Seven Artists like "A September Gale, Georgian Bay", by Arthur Lismer



Banded gneiss like this is so abundant in the northern half of the Grenville Province it gives the "Central Gneiss Belt" its name

Easily recognizable sedimentary rocks, like this conglomerate between Madoc and Renfrew, are preserved in parts of the Central Metasedimentary Belt

The youngest is the Parry Sound Terrane. Most of its rocks are between 1.45 and 1.35 billion years old. In the middle are the rocks of the Algonquin and Tomiko terranes. They are between 1.68 billion and 1.45 billion years old.

Central Gneiss Belt Rocks

This northern piece of the Grenville Province is a vast sea of gneiss, cut by granite plutons. The gneiss formed when older rocks were deeply buried during mountain building activity. The resulting heat and pressure caused the rocks to change, or metamorphose, into gneiss.

The granite plutons of the Central Gneiss Belt were intruded about 1.45 billion years ago. One of the largest is the Algonquin Batholith. It formed about 30 kilometres below the Earth's surface when red hot magma flowed up from the mantle. Today, outcrops of the Algonquin Batholith make up the scenery of the Algonquin uplands.

A Window for Geologists

The Central Gneiss Belt is a window into the deep crust for geologists. Its gneisses—once buried to a depth of up to 20 or 30 kilometres—allow geologists to compare the shape of batholiths, folds and faults deep within the crust to those higher up in the crust. Normally, geologists must rely on images of the deep crust generated by studies of sound waves passing through the Earth's crust, like images made using ultrasound in medicine.

The Central Metasedimentary Belt Terranes

The Central Metasedimentary Belt is the largest section of the Grenville Province. It is divided into two sections, The Superterrane and the Frontenac Terrane.

The Superterrane

The large Superterrane is actually four formerly separate fault-bounded terranes, each a mix of distinct sedimentary and volcanic rocks which formed between 1.30 billion and 1.25 billion years ago. They were metamorphosed between 1.25 billion and 1.24 billion years ago, during the process of colliding to form one large superterrane. At the same time, they were invaded by plutons of granite.

The Frontenac Terrane

This small terrane has plenty of marble, quartzite and gneiss, but no volcanic rocks. It formed about 1.28 billion years ago.

Scenes like this view of Kamaniskeg Lake northeast of Bancroft are typical of the area of the Algonquin Batholith

In parts of the Frontenac Terrane, stromatolites have not been destroyed by metamorphism

Pillows preserved in volcanic rocks of the Central Metasedimentary Belt near Bon Echo Park tell us that the lava erupted under water

The Central Metasedimentary Belt Rocks

The making of the Central Metasedimentary Belt is a story of erupting volcanoes, island arcs, the erosion of sediments and mountain building. These are the same processes that made the Superior Province, but there are some important differences.

The volcanoes in the Central Metasedimentary Belt formed in a tropical environment, and were closely associated with carbonate sediments such as limestone. The volcanoes were far from the young Ontario—likely hundreds of kilometres away. Present-day Indonesia may be similar to the ancient Central Metasedimentary Belt.

Getting It All Together

The events which brought the rocks of the Central Gneiss Belt and the Central Metasedimentary Belt together were as big, and complex, as any ever seen on Earth. This makes the geology of the Grenville Province extremely difficult to decipher.

The clues geologists have been able to read in the rock so far have told us that the Central Gneiss Belt was partially assembled by about 1.68 billion years ago, and mostly together by about 1.45 billion years ago.

Meanwhile, in the Central Metasedimentary Belt, the four sedimentary-volcanic terranes came together to make up the superterrane by about 1.25 billion years ago.

Then, the final stages in the assembly of the Grenville Province took place. Between 1.18 billion years and 1.16 billion years ago the Central Metasedimentary Belt was completed when the Frontenac Terrane joined the superterrane, and the Central Gneiss Belt was completed when the Parry Sound Terrane was pushed over the Algonquin Terrane.

At about the same time, these two major belts were shoved into each other by immense plate tectonic forces pushing northward. With the Canadian Shield for a backstop, the rocks of the Grenville Province slowly crumpled, and a range of mountains to rival the Himalayas was formed.

Geological activity in the Grenville Province since then has been much less dramatic. Several tens of kilometres of uplift and erosion have taken place, with the result that the mountains have been eroded flat. This took several hundred million years, but by 570 million years ago the area was ready for the next stage in its geological history.

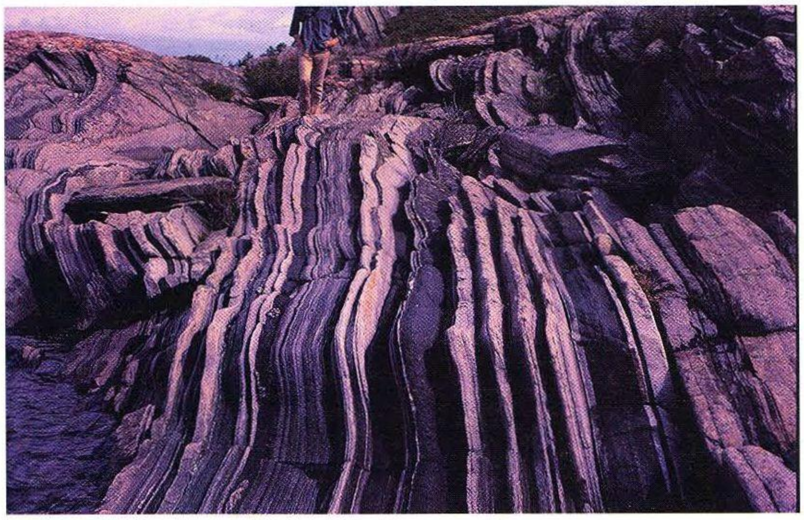
Finding Volcanic Rocks

Highway 62, between Bancroft and Madoc, offers excellent viewing of many volcanic rocks, including andesite, rhyolite and pillow lava.

Highway 41, near Cloyne, has much better examples exposed. Pillow lava is found in many other locations throughout the Superterrane, especially near the old volcanic centres. Broken pieces of pillow lava, called "pillow breccia" are also common.

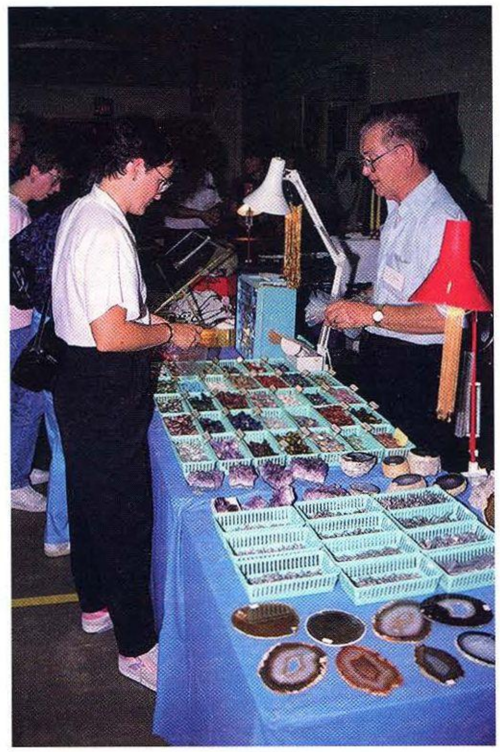
Tectonite is a type of fine-grained gneiss that lies along old fault zones which separate the terranes of the Central Gneiss Belt. Highway 69 in the Parry Sound area cuts through a tectonite zone dividing the Parry Sound and Algonquin Terranes.

Tectonites are called "flaggy" rocks. Their many fine layers can easily be broken into slabs, which are used as flagstone. These rocks pave many patios and walkways throughout the Muskoka-Parry Sound area.



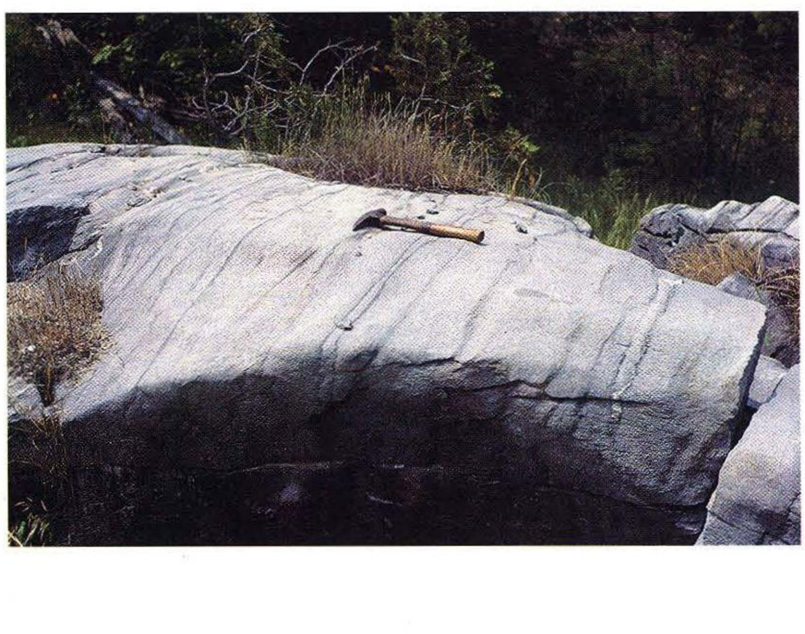
Bancroft claims the title "Rock Hound Capital of the World." Every summer, thousands of people flock to the town's Gemboree. They come to show and trade their rocks, gems and minerals and comb the surrounding hills and old mine sites for more.

Mineral specimens which may be found in the Bancroft area include ***sodalite, apatite, corundum*** *and many more. These gemstones and spectacular minerals formed in the metamorphic porridge of rocks about one billion years ago.*

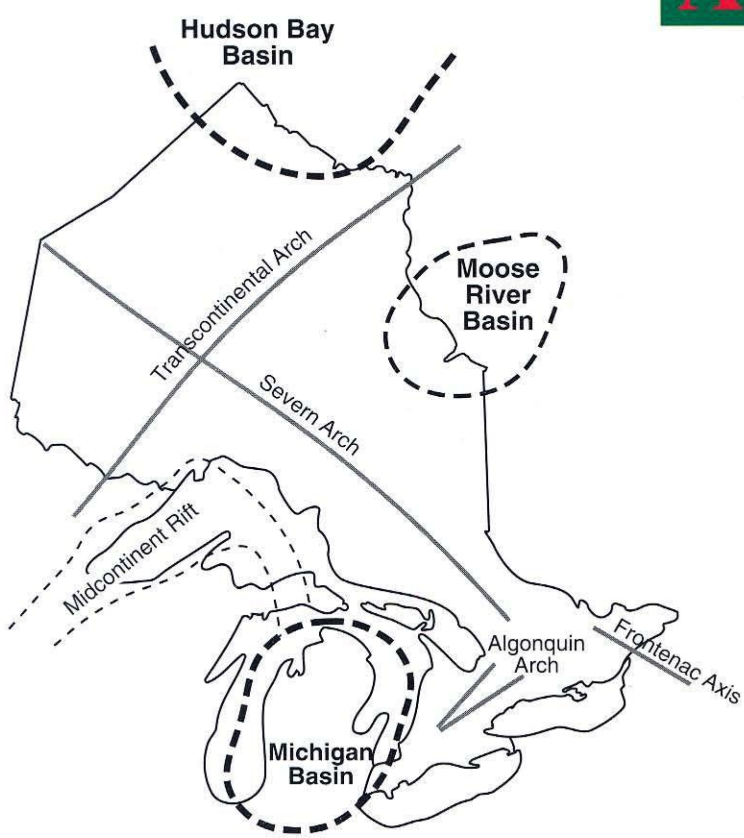


Limey sediments collect in warm, shallow water to form limestone, which becomes marble when it's metamorphosed.

Marble is common throughout the Central Metasedimentary Belt. This outcrop from the Frontenac Terrane just northwest of Perth, provides evidence that the terrane formed in a hot tropical climate.



9 Paleozoic and Mesozoic Basins of Ontario



Tropical seas flooded parts of Ontario between 570 million and 66 million years ago

Amazing as it may seem today, tropical seas once washed over James Bay and Hudson Bay, and the Niagara Escarpment was a rich coral garden growing in shallow tropical seas—much like today's Caribbean.

The familiar southwestern Ontario cities of Windsor, Sarnia and Goderich sat on the floor of a huge saltwater lagoon.

Welcome to the Ontario basins, present between 570 million and 66 million years ago. For most of that time, the young Ontario was under tropical shallow seas.

These warm seas left behind thick beds of sediments. Erosion has removed most of them. Today, they cover about 320,000 square kilometres, or about one-third of the province. They cover two areas—the St. Lawrence Lowland of Southern Ontario and the Hudson Bay lowland of Northern Ontario.

This chapter looks at the rocks and some geological events which made this section of Ontario.

Setting the Scene

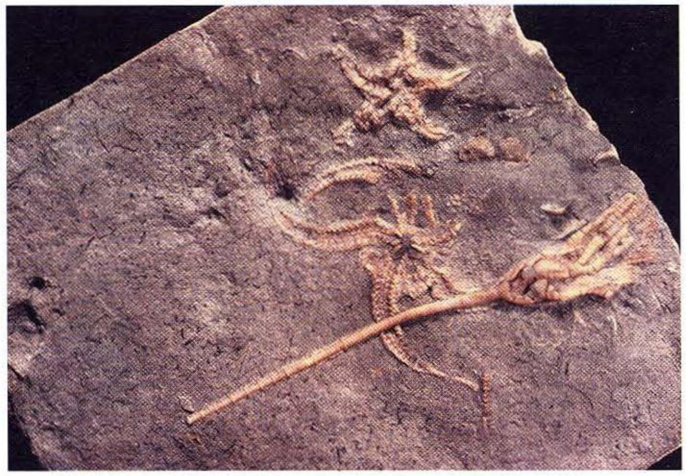
The Paleozoic and Mesozoic Eras are when life blossomed in the seas and later evolved onto land. Some key steps in this chain of events include:

575 Million Years Ago	Sea plants grow in the oceans.
550 Million Years Ago	Creatures with hard shells appear.
450 Million Years Ago	Jawless fish swim along the ocean bottom.
400 Million Years Ago	Fish with jaws—including 10 m long sharks—are plentiful in the seas. Plants share the land with insects.
360 Million Years Ago	Amphibians—including frogs, salamanders and alligator-like creatures—debut on land.
300 Million Years Ago	Insects—such as dragon flies—are common.
225 Million Years Ago	Reptiles live on land and swim in the seas.
200 Million Years Ago	Mammals start to evolve. The first were small and shrew-like.
144 Million Years Ago	Dinosaur acitivity peaks.
66 Million Years Ago	Dinosaurs mysteriously die out. Flowering plants flourish.

Ontario's Fossil Treasure

Ontario was a tropical underwater paradise for much of the Paleozoic era. Beetle-like **trilobites** crawled along the sea bottom, while clam-like **brachiopods** burrowed in the mud. Giant squid-like creatures called **cephalopods** hid in their cone-shaped shells in times of danger, and early relatives of the crab and lobster crept on the sea floor. There were tiny animals called **bryozoans,** sea worms called **annelids**, and sea lily-shaped creatures called **crinoids**. Corals and ancient sponges, called **stromatoporoids**, lived in colonies and built reefs.

You can see evidence of these strange creatures, preserved as fossils. Brachiopods, trilobites and cephalopods are common in the layers of limestone and shale on the southern shores of Georgian Bay. Other fossil collecting areas in Ontario include the limestones and dolostones of the Gull River Formation near Marmora, the Bobcaygeon Formation and the Dundee and Fossil Hill formations on Pelee Island in Lake Erie, dolostones throughout Manitoulin Island, the Guelph Formation near Lion's Head, and the shale beds of the Queenston Formation, near the Niagara Gorge and Oakville.



Descendants of these 475 million-year-old fossil starfish and crinoid live in our oceans today

Plate Action in Paleozoic and Mesozoic Time

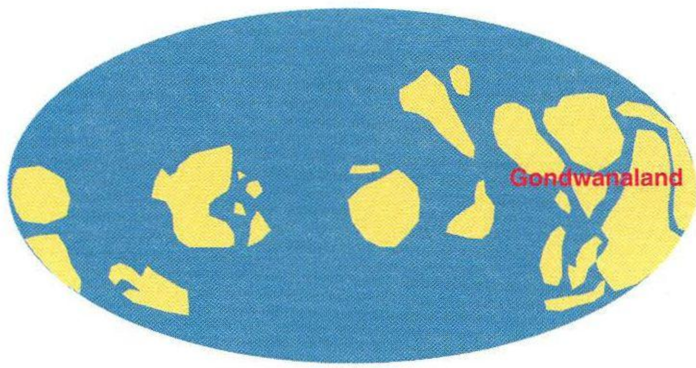
About 600 million years ago, India, South America, Antarctica, Australia and parts of Asia formed a supercontinent called **Gondwanaland**. This large continent sat south of the equator.

North America, Greenland and Europe were also south of the equator. They were separated by water and were north of Gondwanaland. Parts of Africa lay near the South Pole and were covered by a huge ice cap.

About 570 million years ago, Gondwanaland started to drift towards the South Pole. The **Iapetus Ocean** formed and separated North America and Europe.

The continents drifted together again about 400 million years ago. North America, Europe, Greenland and Asia joined into one big land mass called **Laurasia**. The Iapetus Ocean disappeared.

About 300 million years ago, Gondwanaland joined Laurasia near the equator. They formed the supercontinent **Pangaea**.



Much of the Earth's land mass was once part of the supercontinent Gondwanaland

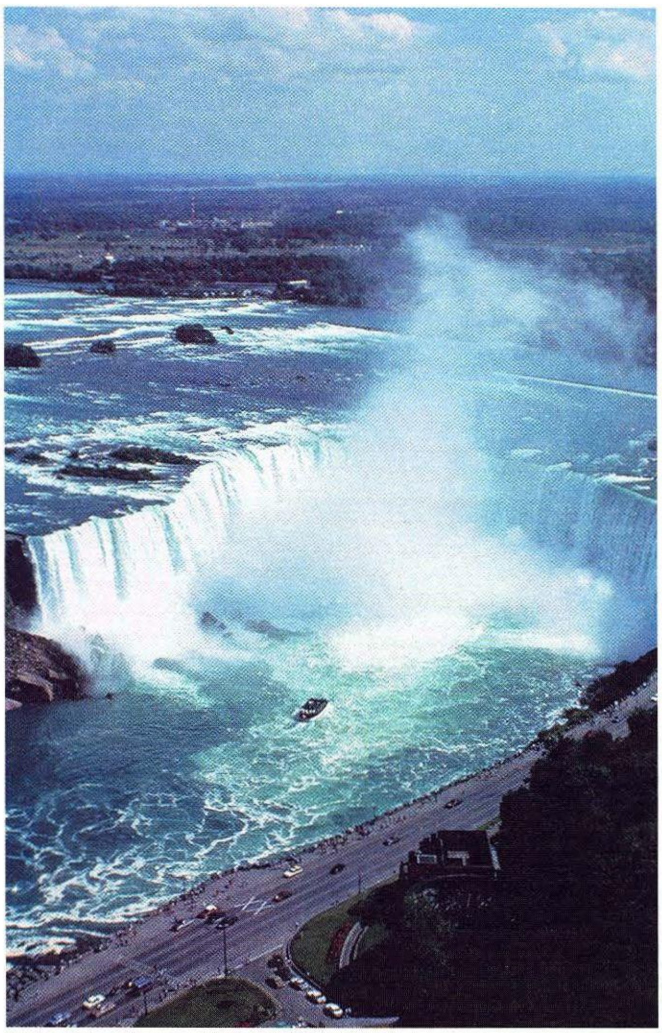
Here's an important fossil hunting hint. Don't bother looking in Ontario for remains of dinosaurs or any other creature which may have lived in the province between 358 million and 66 million years ago.

Geologists believe that erosion has removed all but a few small pockets of sediments laid down during this time.

These small pockets of sediments are found in the Moose River Basin and in the Hudson Bay Basin. They date from 186 million to 100 million years ago.

Niagara Falls is one of the wonders of the natural world. It is formed by the Niagara River as it rushes over the edge of the Niagara Escarpment between Lakes Erie and Ontario. Every year, the rushing waters cut away 30 cm of rock.

Millions of years from now all the rock will be cut away and like all falls, Niagara Falls will disappear.



Niagara Falls pours over the edge of an erosion-resistant layer of dolostone of the Michigan Basin

Pangaea did not last long. About 200 million years ago, it began to break apart. Deep oceans formed between the continents. The Atlantic Ocean formed between North America and Europe. Some 63 million years ago, the pieces of Pangaea became the continents we know today.

Though most of the plate activity took place outside Ontario's borders, its powerful effects were felt within the province. Here is how the creation and breakup of supercontinents and the formation and disappearance of oceans during this time helped to shape Ontario.

Basins of Paleozoic and Mesozoic Time

Basins are low regions in the Earth's crust, filled with layers of sedimentary rock. The Appalachian, Michigan, Hudson Bay and Moose River basins marked the fourth stage in the Ontario's geological history. Let's take a closer look at the various basins, how they were made, and the sediments that fill them.

The Appalachian is a **foreland basin**. It formed as a long trough on the western side of an ancient mountain range along the east coast of North America. The Michigan, Hudson Bay, and Moose River basins are **cratonic basins**.

These basins formed during active periods of plate movement. North America collided with pieces of early Europe and North Africa three separate times. Each time, a huge mountain range was pushed up on the east coast of North America. Geologists call these mountain building periods the **Taconic**, the **Acadian** and the **Allegheny Orogenies**.

The first collision created the Appalachian Basin. Sheets of crust from Europe were thrust over North America, weakening the crust just ahead of the collision and bending it into a long trough. The force was also strong enough to form sags and ridges in the Canadian Shield far from the mountain-building activity. These sags are the Michigan, Hudson Bay and Moose River Basins.

With each period of mountain building, the trough and sags deepened, and new sediments were washed into them.

The Sediments

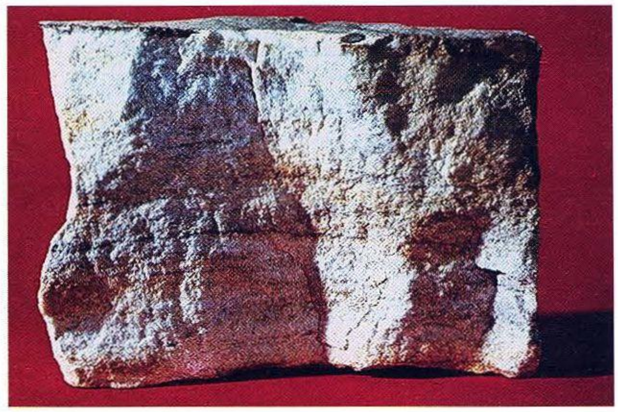
Four types of sediments fill Ontario's Paleozoic and Mesozoic basins: sediments eroded from high mountain ranges, those eroded from the Canadian Shield, limey sediments, and salt deposits.

Sediments eroded from high mountain ranges are mainly conglomerate, sandstone and shale. The rock fragments in the conglomerates include pieces of volcanic rock from the mountain range to the east.

The sediments eroded from the Canadian Shield are mainly sandstone and shale with some conglomerate. Geologists recognize pieces of metamorphic rock and granite from the Superior and Grenville Provinces in the conglomerate and sandstone.

The limey sediments are leftovers of tiny creatures which built large underwater reefs in warm shallow waters. They include limestone and dolostone, and many are full of fossils.

The salty remains or evaporite sediments were deposited when inland seas evaporated, and salt and other minerals were left behind.



On close examination, sandstones look and feel like the compacted masses of sand they are

Sedimentary Environments

The sediments in Ontario's basins tell many different stories. Some were laid down by mighty rivers; others were swept in by tides. Let's take a look at five major sedimentary environments:

River Deposits

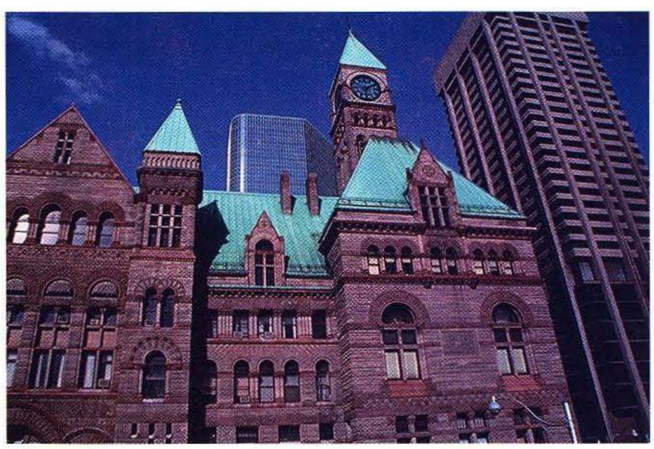
Mixtures of sand and gravel form river banks. When turned into rock, the mix contains many **cross-beds** in the sand, and large banks of conglomerate. The 570-million-year-old Covey Hill Formation in eastern Ontario is a 13 metre-thick fan of conglomerate and sandstone. It is the oldest Paleozoic sedimentary rock in Ontario.

Tidal Flats

This flat land is swept by tides, and is covered by a mix of mud, limey mud and sand. Good examples of modern tidal flats can be found along the shores of the Bay of Fundy and the lower St. Lawrence River. The 200 metre-thick Oxford Formation in Leeds and Grenville County, south of Ottawa, is a tidal flat deposit made of layers of dolostone, shale and sandstone.

Delta Wedges

Wedge-shaped deposits of sand, silt and clay form when rivers or streams flow into a lake or an ocean. The red shales and grey siltstone of the Queenston Formation, which stretch from Lake Ontario to Lake Huron, were deposited in a delta wedge by rivers flowing west from mountains on the eastern coast of North America. Rocks from the Queenston Formation were used to build the Legislative Building and the Old City Hall in Toronto.

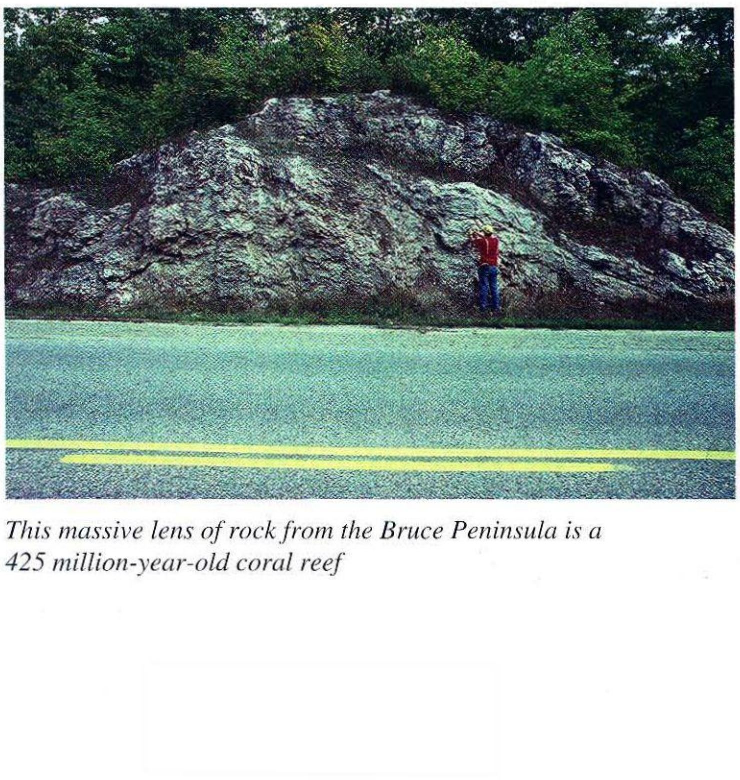


Old City Hall in Toronto was built of siltstone from delta wedge deposits

Deep Sea Plains

Flat beds of fine-grained mud and shale, sometimes mixed with limestone and other carbonate sediments, form on the bottom of the deep sea, well away from land. The Marcellus Formation in southwestern Ontario, a 12 metre-thick stretch of black shales mixed with limestone which extends from Port Stanley to Long Point on Lake Erie, was deposited in this environment.

Ripple marks like these tell us what the environment was like when the sediments were deposited



This massive lens of rock from the Bruce Peninsula is a 425 million-year-old coral reef

The Appalachian Basin is filled with sediments eroded from the mountains. The Michigan, Hudson Bay and Moose River Basins have a mix of eroded sediments from the mountains and the Canadian Shield, and carbonate and evaporate sediments.

Stormy Plains

Some sediments are laid down on the continental shelf during stormy weather. The layers of shale found in the Rochester Formation were deposited during high winds and huge waves. Geologists know this because of the deep grooves, cross-beds and ripple marks found in the rocks. Outcrops can be seen between Niagara Falls and Hamilton.

The Life Cycle of a Basin

It can take hundreds of millions of years to fill a basin with sediments. Coarse sandy sediments are usually laid down along the shores of a basin and in deltas. Fine clay particles which form mud and shale are deposited further from shore.

A basin begins as a sag in the Earth's crust filled by a sea. The first sediments are usually deep sea mud and shale eroded from either a nearby mountain or a craton. Next in the basin are conglomerate and sand. These sediments are also eroded from a mountain or a craton. The common sedimentary environments in the early stages of basin filling include river deposits and deep sea plains.

As more sediments fill the basin, the sea becomes more shallow. Tiny sea creatures build reef colonies of limestone and dolostone. More sediments may erode from a mountain or craton, wash into the basin, and mix with the limestone and other carbonate sediments.

Tidal flats, delta wedges, and stormy plains are the common sedimentary environments in later stages of basin development.

As the reefs grow, the shallow seas become isolated lagoons. When these pockets of salty water dry up, beds of salt and other sediments such as gypsum are left behind, mixing with the muds and burying the coral reefs.

This whole cycle may start again if the basin sags again because of jostling plates and mountain building.

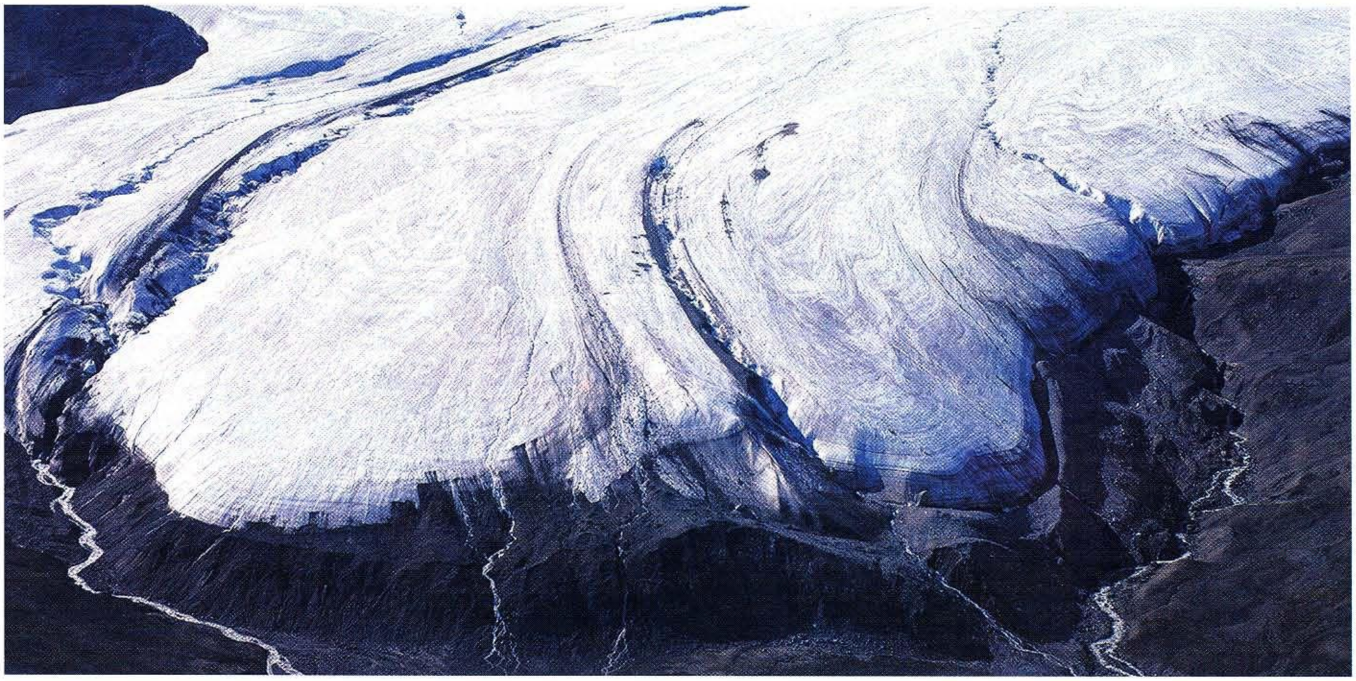
Sequence of Sediments

The sediments filling Ontario's basins were laid down in 10 stages called sequences. Each is a package of rocks deposited without interruption during the same time period. The boundary between each sequence is usually a break in the rock sequence, called an **unconformity**, that marks plate action such as collision and mountain building. These breaks are marked by indications that erosion has taken place.

We use salt like this, left behind when shallow lagoons of sea water dried up, on our food, on our roads, and in manufacturing

The boundary between the dark and light rocks in this outcrop near Madoc marks a 775 million-year gap of geological history, making the boundary an unconformity

10 The Quaternary Period



Like soft putty, glacial ice spreads out because of its own weight

Glaciers erode the land. As they move, they collect rock fragments which scrape and gouge the bedrock underneath the ice.

But as glaciers erode the land in one area, they leave behind a jumbled assortment of rock debris called "till" in another area. Plus, the meltwater flowing from a glacier also leaves deposits of sediments.

The Great Ice Age began 1.75 million years ago and ended just 10,000 years ago.

North America was not in the deep freeze alone, however. An icy blanket covered most of Greenland, north-western Europe, Asia, Antarctica, Australia, New Zealand and part of South America.

For most of us, ice is something we associate with winter. We skate on it, slide and slip on it. In summer, we put ice in our beverages or eat it as a fruit-flavoured treat. But 20,000 years ago Ontario was buried under a huge ice sheet.

This chapter looks at the Great Ice Age in Ontario, including a close-up look at glaciers and the landforms they left behind.

Glacial Activity during the Quaternary Period

About 66 million years ago, the shifting tectonic plates brought the continents close to their present position. At that time, glacial snow and ice started to build up for the first time on the land close to the North and South Poles. The ice sheets grew slowly until 1.75 million years ago, when at the start of the **Quaternary** Period the glaciers began to descend beyond the pole areas, triggering the Great Ice Age.

Vast sheets of ice about two kilometres thick gradually stretched across most of Canada, completely covering Ontario and ultimately reaching as far south as present day New York City. This wasn't the first time great ice sheets blanketed Ontario. Geologists believe parts of the province were covered by ice about 2.45 billion years ago.

During the peak of the Great Ice Age, temperatures were about 9°C lower than today, even in summer. As the ice sheets grew, the oceans became smaller, sea levels dropped as much as 120 metres around the world and land bridges appeared between continents. One joined Alaska and Siberia, one connected mainland Asia and Indonesia, New Guinea and Australia, and another existed between the British Isles and Europe.

Between approximately 35,000 and 10,000 years ago, Cro-Magnon Man developed a rich culture in Europe, which then spread east into Asia. Eventually, these people crossed the land bridge between Siberia and Alaska, and found a home in North America.

When the glaciers started to melt about 18,000 years ago, sea levels started to rise, covering the land bridges. The underlying crust, once weighed down by the ice, bobbed back up. Geologists estimate the Sudbury area has risen about 100 metres since then, while the Hudson Bay Lowlands have rebounded more than 250 metres. The land around Kingston is still rising, which will mean higher water levels in Lake Ontario, as its outlet rises.

The Great Ice Age in Ontario

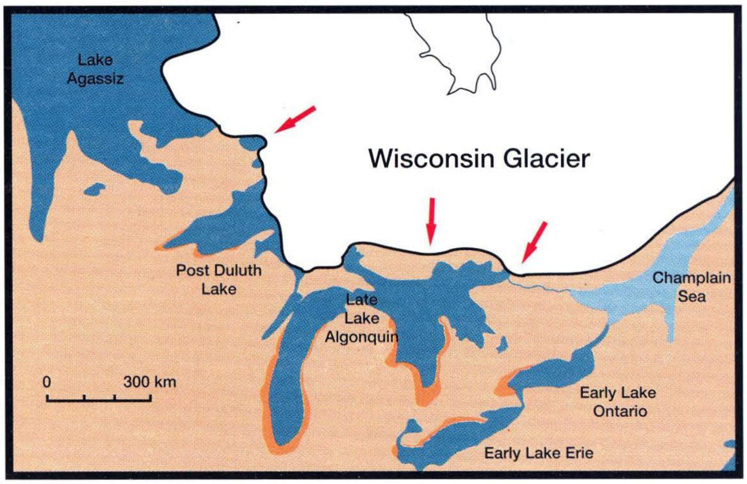
One of nature's most powerful forces, the **Laurentide Ice Sheet**, was a mammoth glacier which advanced and retreated across Ontario two times. The first time was during the **Illinoian Stage** between 190,000 and 135,000 years ago, when it reached south of Toronto.

The Laurentide Ice Sheet's second advance is its most famous. It covered not only all of Ontario but much of the northern half of the United States. Called the **Wisconsinan Stage**, it started 115,000 years ago and ended 10,000 years ago.

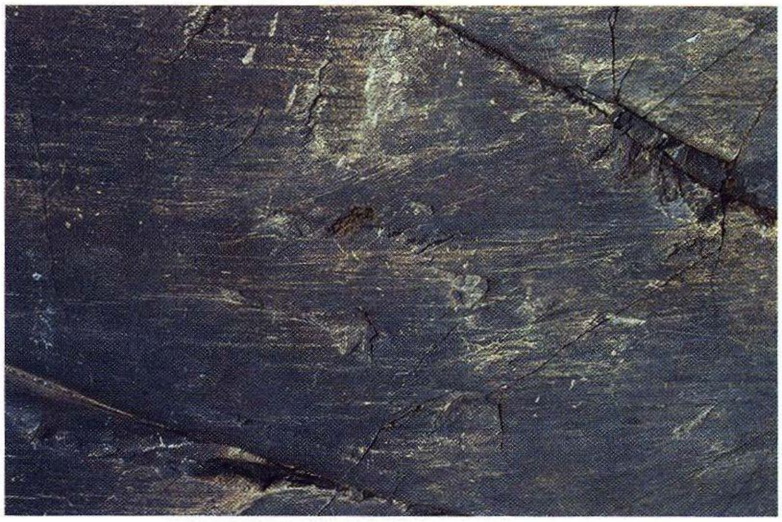
Despite its name, the Great Ice Age wasn't one long, continuous stretch of cold weather and glaciers. Separating the Illinoian and Wisconsinan Stages was a long stretch of warmer temperatures, the **Sangamonian Interglacial Stage**, when much of the Laurentide ice sheet melted and disappeared. Today, we live in another interglacial stage.

Glaciers are giant sheets of slow-moving or stagnant ice that cover about 10% of the world's surface. They are found in mountainous areas and polar regions, where more snow falls each year than melts. As the snow piles up, it gradually turns to ice. When this ice reaches a certain thickness and weight, it begins to move.

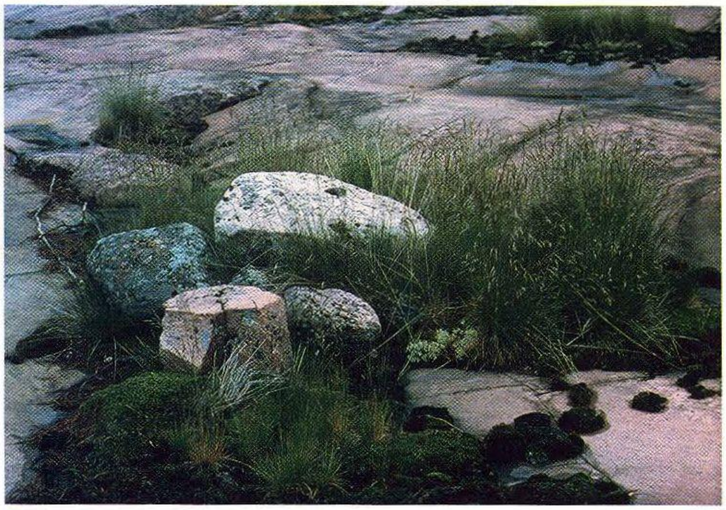
Most glaciers creep along a few centimetres each day, but in some cases they can advance several metres in a day.



Glaciers covered all of Ontario during the Wisconsinan Glacial Stage



Glacial striae tell us the direction the ice flowed



Glaciers deposit boulders, called erratics, far from their place of origin

The farmlands of Ontario lie over various types of glacial deposits

Glacial Erosion

Glaciers erode the land in two ways: scrape and scour, and pluck and quarry.

First of all, fragments of rock embedded in the glacier scrape and scour the bedrock, leaving behind scratches and grooves in the rock. These scratches, or **striations**, show the direction the ice flowed. They can be seen on rocks across Ontario, especially in the Fort Frances area.

As they move, glaciers can remove huge chunks of rock from the bedrock. This usually happens along **joint** lines or other weak spots in the bedrock.

Plucking and quarrying creates a special landform called a **roche moutonnée**, which is French for *sheep-shaped rock*. These large knobs of rock are gently rounded on one side and steep on the other. The rounded end points in the direction from which the ice flowed. Roches moutonnées are a common landscape feature in the Renfrew County area.

Glacial Deposits

In its travels, a glacier can pick up chunks of bedrock which range in size from small pebbles to house-size boulders, and then drop them far from their original location. Such rocks are called **erratics** because they are quite different from other rocks of the surrounding landscape.

Landforms and deposits left by the Laurentide Ice Sheet played an important role in the history and development of Ontario. Many of the early explorers' routes followed the ancient paths of glacial meltwater. Aboriginal peoples and early settlers made their homes around the lakes, rivers and streams formed during the Wisconsinan glaciation.

The Laurentide Ice Sheet also laid down fertile soils which are still farmed today. In addition, it deposited gravel and sand, providing construction materials for roads and buildings for hundreds of years.

Till, Till, everywhere Till

Till is the most widespread deposit left by the Laurentide Ice Sheet. It forms sheets of unsorted geological debris: clay, silt, sand, pebbles, cobbles and boulders. Unlike rivers, glaciers don't sort rock by size as they carry them. Everything, no matter how big or small, drops where the ice stops.

Two of the most common till landforms are **moraines** and **drumlins**.

A moraine is a heap of boulders, rocks, sand and other debris. One of the best known moraines in Ontario is the Oak Ridges Moraine, forming the height of land between Lake Ontario and Georgian Bay. This is an interlobate moraine. It formed between two lobes or long fingers of a glacier. Most interlobate moraines are large, and the Oak Ridges is no exception. It is more than 150 kilometres long and as much as 12 kilometres wide.

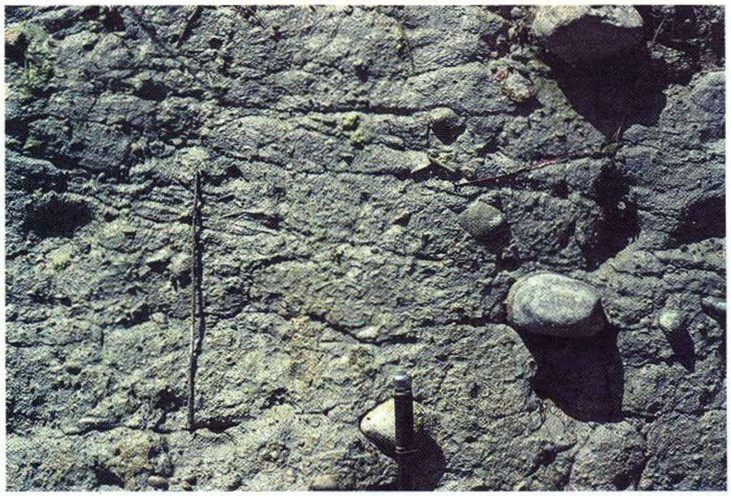
There are other types of moraines, which are classified according to where and how they formed.

Ground moraines are vast wrinkled sheets of till which were deposited beneath the glacier. They cover almost every area of the province and normally range in depth from three to five metres. They are thinnest over upland areas of the Canadian Shield, and along the crests of ridges such as the Niagara Escarpment.

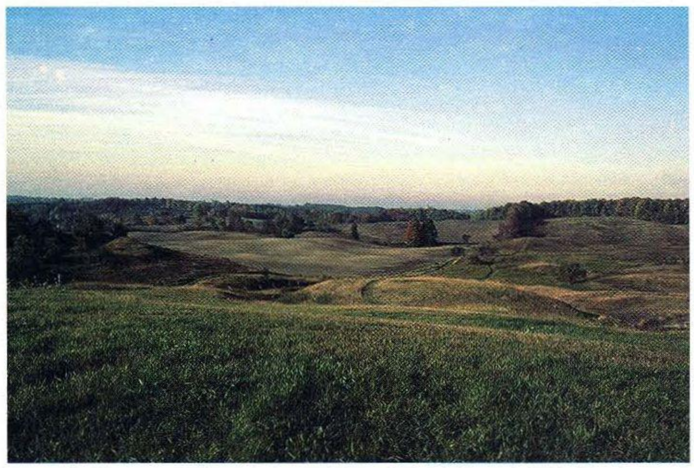
Hummocky moraines are a special type of ground moraine which formed when the glacier melted down from above, rather than back from its leading edge. The hummocky deposits of bouldery till, sand, and gravel along the southern shores of the Kawartha Lakes formed in this way.

End moraines are ridges of glacial till deposited along the sides or at the end of a glacier. They are also very common in Ontario. One of the larger ones in southern Ontario is the Wyoming moraine. It's nearly 200 kilometres long, several kilometres wide and stands up to 30 metres above the surrounding landscape. Another, the Lac Seul moraine in northwestern Ontario, stretches for 600 kilometres.

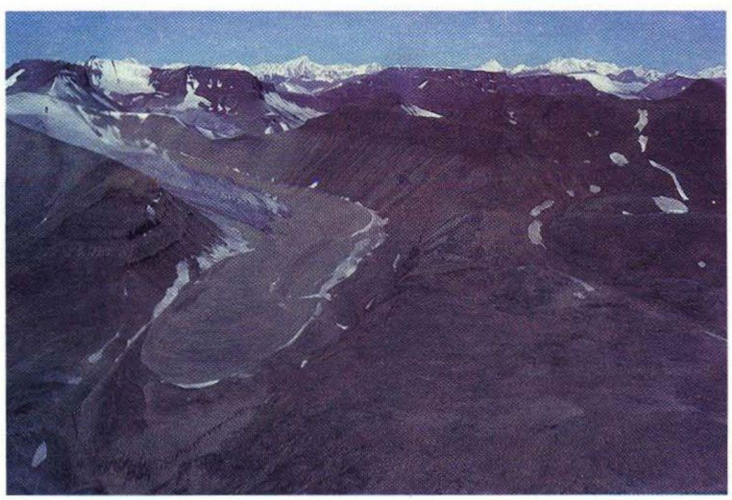
De Geer moraines are a series of narrow, regularly spaced ridges. They are made of glacial till and layered sediments. Most are less than 15 metres high, and spaced less than 300 metres apart.



Till, the most common type of material left by the glaciers, is a jumble of clay, silt, sand, pebbles, cobbles, and boulders

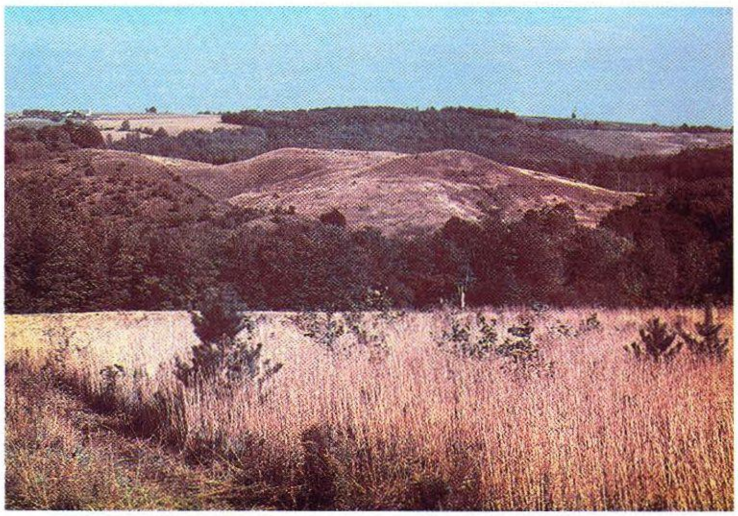


These gently rolling hills lie over the thick layer of till which makes up the Oak Ridges Moraine

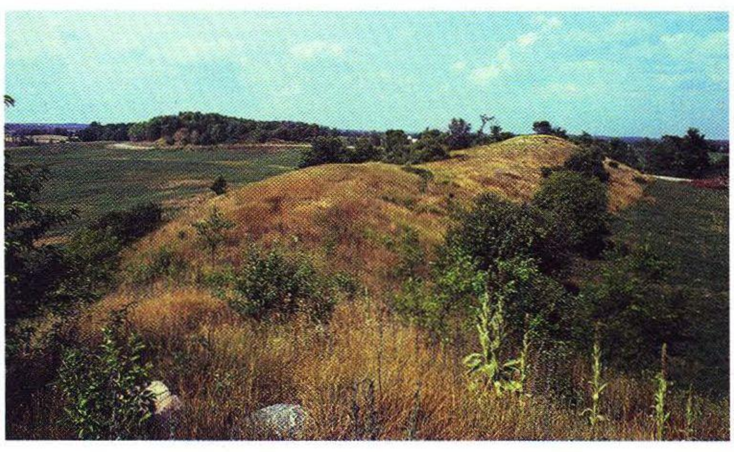


End moraines in Ontario formed in much the same way as the one left by melting at the end of this tongue of ice in Kluane National Park, Yukon

The drumlin shown in this aerial view has trees encircling most of it



Kames form at the edge of melting ice sheets



Winding ridges of sand and gravel up to several kilometres long, called eskers, mark the sites of stream channels in and under glacial ice

They likely formed at the edge of a glacier when it was in a large and deep body of water.

De Geer moraines make up much of the scenery in northwestern Ontario, especially in the Lake Nipigon area.

A drumlin is a long, low oval hill which looks like half an egg cut lengthwise. Some can be quite large, up to 60 metres tall and a kilometre long. They often occur in groups called fields. Most drumlins are made of sandy to silty till. Their streamlined shape indicates the direction of the ice flow. The end with the steep slope points in the direction of the glacier's origin.

In southern Ontario, there are more than 4,000 drumlins. The oldest field was formed between Orangeville and Guelph about 14,000 years ago. One of the most well known fields is in the Peterborough area. Here, more than 3,000 drumlins stretch across Northumberland, Peterborough and Victoria counties.

Rivers and Streams of Meltwater

Melting glaciers release a lot of water, through a network of rivers and streams which eventually flow into lakes or the sea. These waterways carry huge amounts of sediment which they leave behind in several types of deposits. Geologists have divided these deposits into four categories.

Ice-Contact Landforms

Sediments deposited beneath, or very close to, the edge of a glacier make two types of landforms: **kames** and **eskers**.

A kame is a small dome-shaped hill of sand and gravel. It is formed when a stream of sediment-laden meltwater flows into a crevasse or pours off the edge of a melting glacier. Unlike drumlins, kames are usually found alone. A typical kame sits at Baden Hills near Waterloo.

An esker is a steep-sided, winding ridge of sand and gravel. Examples can be seen all over the province, especially north of Stratford and Peterborough. They were deposited by streams of water snaking through passages in and under glaciers.

Outwash Landforms

Sediments deposited by rivers and streams beyond the edges of the glacier are called outwash landforms. The three most common in Ontario are **outwash plains**, **kettles** and **deltas**.

Outwash plains are layered sheets of sand and gravel which fanned out over lowlands ahead of an ice sheet. The largest particles of sediment settled near the ice and the finest particles ended up several kilometres away. A good example is the Caledon outwash plain.

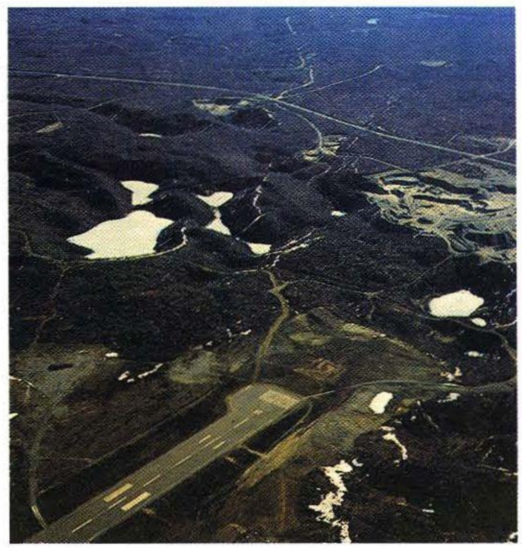
Kettles are circular holes in the ground. They formed when huge lumps of ice were buried by sediment as the glacier retreated. When the ice melted, the surface sediment collapsed. Most kettles today are small circular lakes or bogs. Musselman's Lake, north of Toronto, is an example.

Deltas are wedged-shaped deposits of sand, silt and clay that formed when meltwater streams slowed as they flowed into a lake.

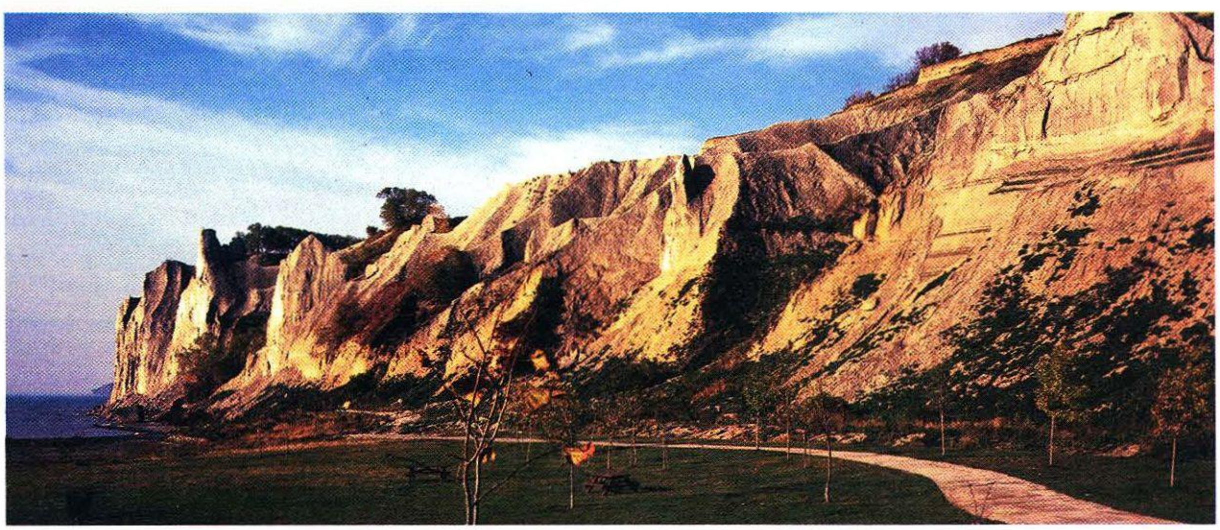
The Scarborough Formation, made up of more than 50 metres of clay, silt and sand that form the bottom half of the Scarborough Bluffs, was once a delta at the mouth of a large river that flowed into glacial Lake Scarborough.

Near London, the Komoka Delta was built from sediments carried by meltwater streams that flowed down the valleys where today's Thames River and its tributaries are found.

Outwash plains and their underwater equivalents, subaqueous fans, are good sources of gravel



These kettles, just east of the runway at Sudbury airport, formed when huge blocks of glacial ice which were buried by deltaic gravel later melted



The Scarborough Bluffs include deltaic deposits laid down about 110,000 years ago when lake levels were about 45 metres higher than at present

Each pair of layers in rhythmites, or "varved" clays and silts like these, is thought to represent one year

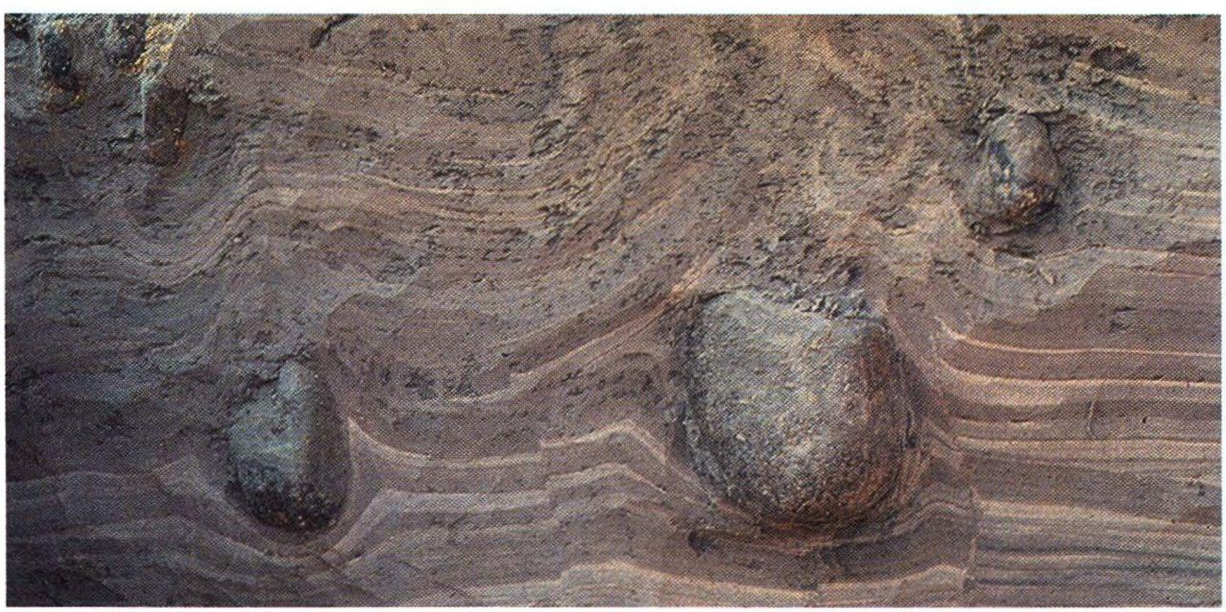
Lake Basin Sediments

The flat plains of clay and sand that cover most southern and some northern parts of the province were once the bottoms of glacial lakes. Here, meltwater streams and rivers dropped thick deposits of sediments. In addition, the lakes themselves left their calling card in several unique ways.

The most common type of sediments deposited in a lake by a glacier is called a **rhythmite**, from the word *rhythm*. This describes their unique annual repeating pattern. The sediments are found in pairs of layers. There is a bottom layer of sandy silt covered by a top layer of fine clay. The sandy silt accumulated during the summer melting season. The fine-grained clay settled on the lake bottom in winter.

There are many rhythmite deposits in Ontario. A typical example can be found around Timmins, where thick layers of sediments were deposited between 11,000 and 9,500 years ago in glacial Lakes Barlow and Ojibway.

Geologists can also locate old glacial lakes by other tell-tale clues. They look for beach bars, or spits or ridges made of sand and gravel swept to the glacial lake's shores by waves and currents. Deposits from several glacial lakes, including Lakes Agassiz, Barlow and Ojibway, can be seen in the area between Timmins and New Liskeard.



Rocks dropped from melting sheets of floating ice dent the lake sediments when they hit bottom

Wave action in the glacial lakes is also responsible for many of the scenic bluffs around Georgian Bay, Lake Huron and the western end of Lake Superior.

Saltwater Sediments

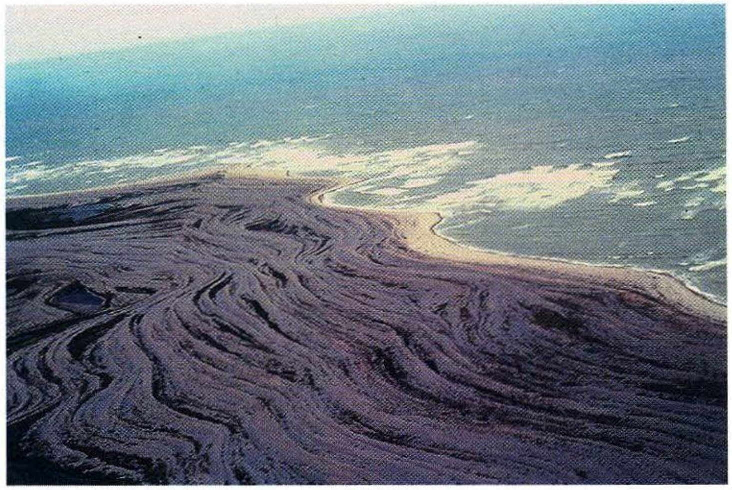
As the name suggests, these sediments are deposited by seawater. Like lake basin sediments, they are made of rhythmites of silty clay and clay, and are found in two spots in Ontario.

Around Ottawa, clay deposits up to 50 metres thick mark the location of the old Champlain Sea. When the Laurentide ice sheet retreated between 11,700 and 11,500 years ago, sea water rushed into the Ottawa, Champlain and St. Lawrence River valleys. A large variety of marine fossils has been found in these sediments, including the remains of whales, seals and several kinds of fish.

Bouncing Back

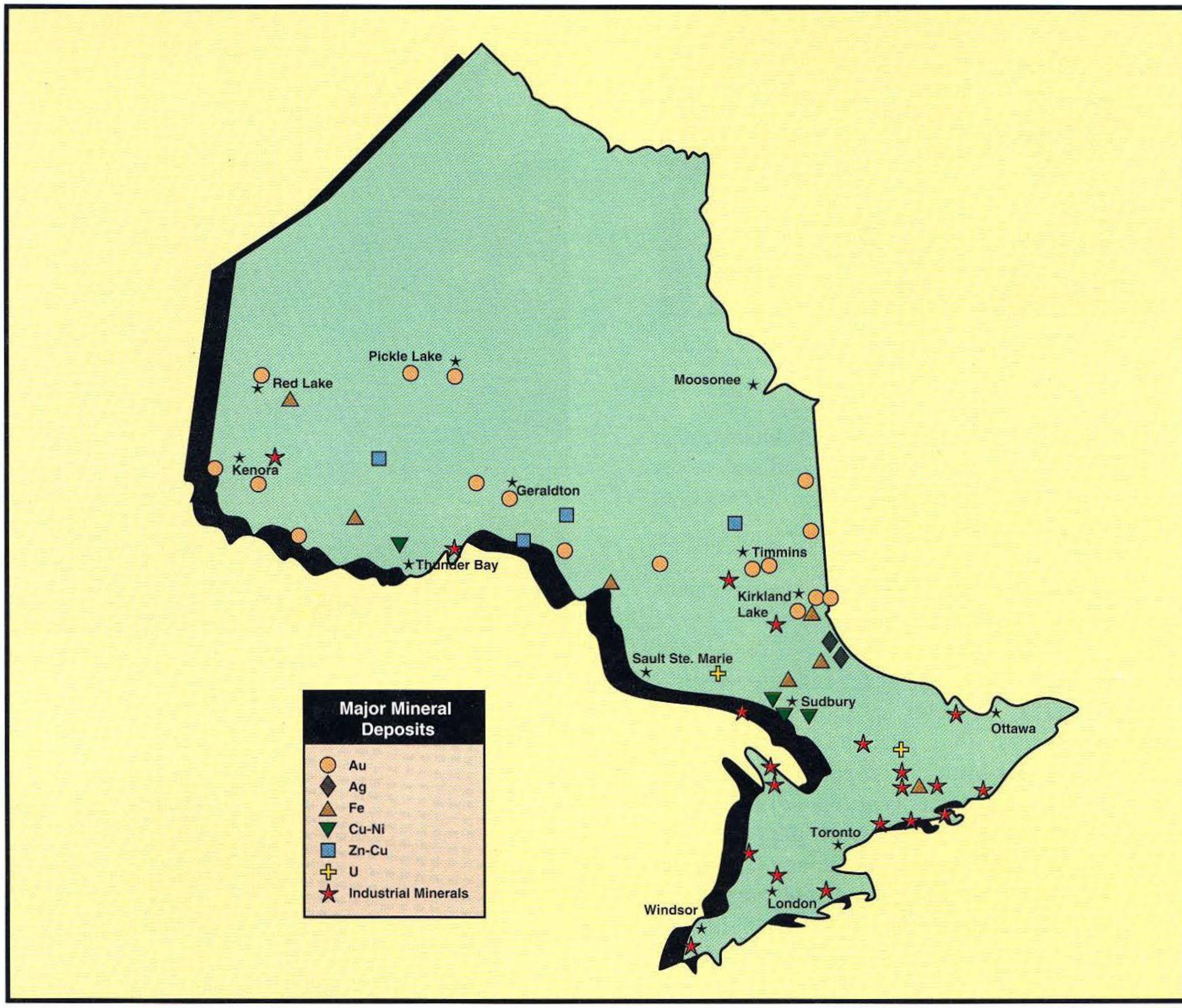
Without heavy ice and water weighing down the land, the Earth's crust began to rise, in a process called **isostatic uplift**. Today, we can see raised beaches in the Hudson Bay/James Bay lowlands that mark former sea levels as the Tyrrell Sea retreated across northern Ontario.

The process of isostatic uplift is still continuing, with uplift in some parts of the province of up to one centimetre per year.



This series of beaches along the shore of Cape Henrietta Maria, where James Bay meets Hudson Bay, is dramatic evidence of isostatic uplift

11 Geology in Practice



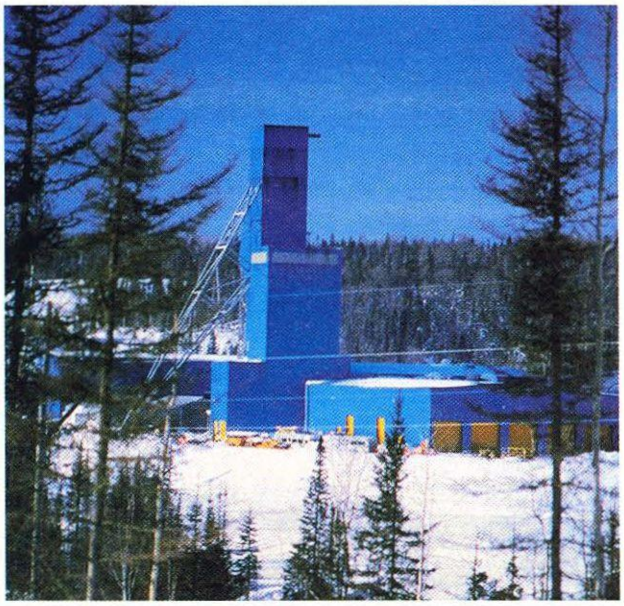
Valuable mineral deposits are mined throughout Ontario

Three billion years of plate action, volcanism, mountain building, glaciation and other geological forces have created more than Ontario's world-famous scenery.

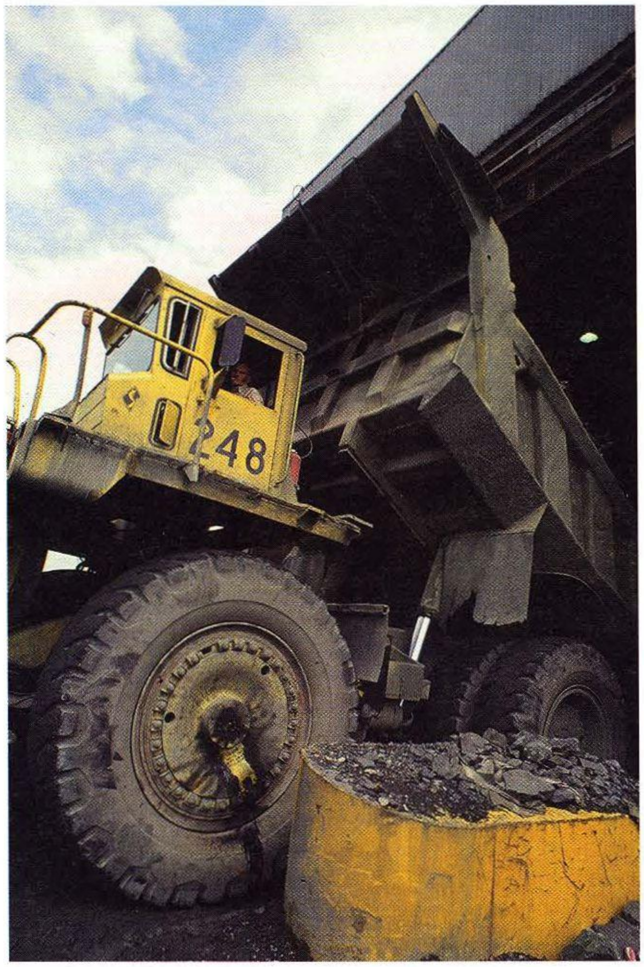
Geological forces have also created economic opportunities through mineral development.

With more than 50 operating mines, Ontario is Canada's largest producer of metallic minerals. It is a major player in several industrial minerals. Look at a map of Ontario and you'll see centres of gold, nickel, copper, zinc, cobalt, platinum group metals, iron, uranium, salt, gypsum, silica, talc, graphite and building stone production.

In the 1980s, over land long explored, two prospectors by the name of John Larche and Don McKinnon discovered the huge Hemlo gold fields near Marathon. Today the three gold mines in this part of northwestern Ontario have some of the largest reserves of any gold mine outside South Africa.



The Golden Giant Mine is one of three gold mines in the Hemlo area



Huge trucks bring ore from open pit mines to the crusher

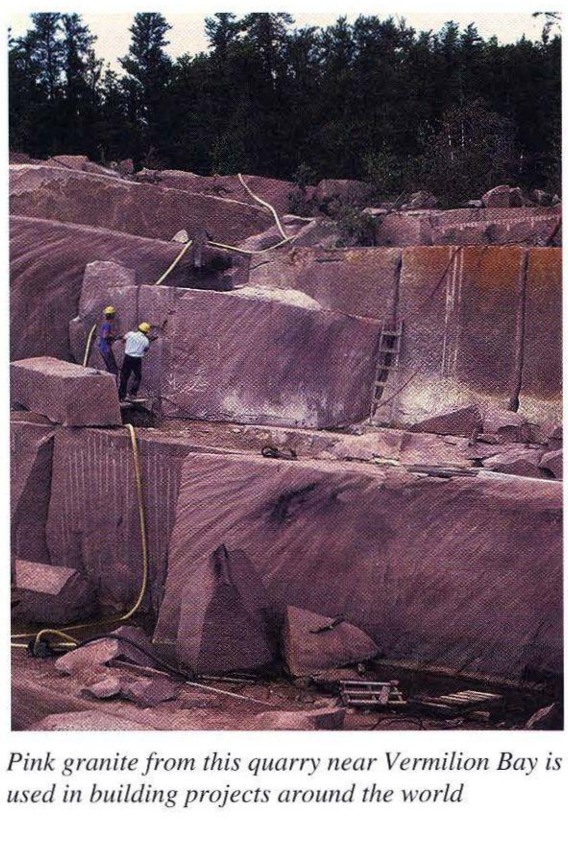
Annual values of mineral production in Ontario range between $4 billion and $6 billion, and the sector directly employs more than 25,000 people with an average wage of more than $950 a week.

Ontario has a wide variety of geological environments that host world-class mineral deposits.

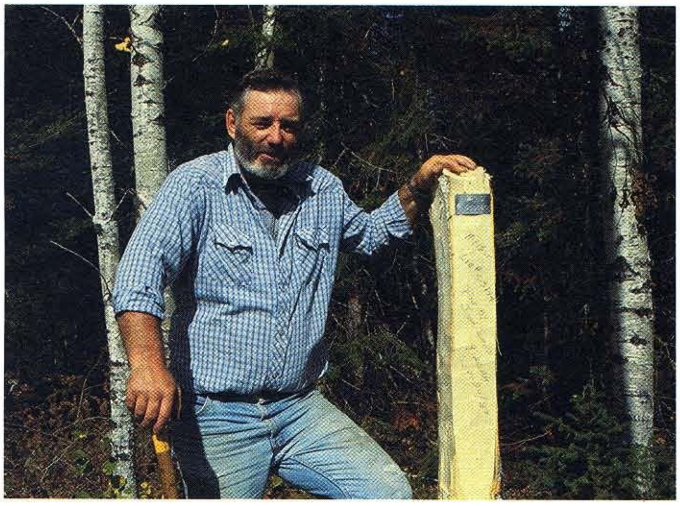
The Canadian Shield is one of the oldest geological regions on earth. It yields an abundance of zinc, copper, nickel, gold, silver, platinum and other minerals. The Kidd Creek Mine in Timmins, the Geco Mine in Manitouwadge and the Winston Lake Mine at Schreiber are leading copper-zinc deposits. The Sudbury Basin, with 17 operating mines, is one of the world's most prolific nickel-producing areas. The three mines of the Hemlo camp, on the north shore of Lake Superior, produce about one-quarter of Canada's gold.

Vast granite deposits throughout the Canadian Shield have high potential for building stone development. Producing quarries in the Kenora, Vermilion Bay and Sudbury areas deliver high-quality stone to world markets.

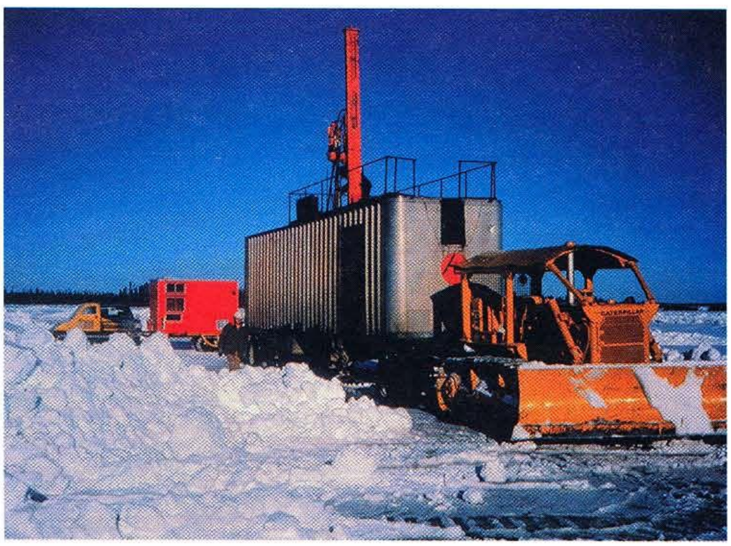
Today, southern Ontario is fertile ground for industrial mineral and building stone development. The area produces dolostone, limestone, graphite, talc, gypsum, salt, nepheline syenite, sand and gravel, cement and other important mineral products. In past days, southeastern Ontario had significant gold, iron and uranium producers.



Pink granite from this quarry near Vermilion Bay is used in building projects around the world



Prospectors stake claims when they find interesting mineral deposits



Holes are drilled into lake bottoms from winter ice to test indications that mineral deposits might lie under the lakes

The McIntyre Mine in Timmins operated from 1912 to 1988, yielding more than 10,750,000 ounces of gold from workings up to 2.4 kilometres below surface

Mining activity begins with a search for mineral deposits. Prospectors and other mine finders use everything from hunches to sophisticated scientific technology to locate a mineral deposit. When they find one, they outline the deposit's boundaries and determine its quality, size, shape and nature. They then consider commodity prices, potential energy sources and transportation links for a new mine, as well as labour and other development costs.

These factors tell them if they have an ore deposit. An **ore deposit** is not just another name for a mineral deposit. An ore deposit has enough valuable mineral in it to make it worth the effort and expense to mine. It has a high enough concentration of those minerals that it can be mined and processed at a profit.

How the Mining Areas of Ontario Came to Be

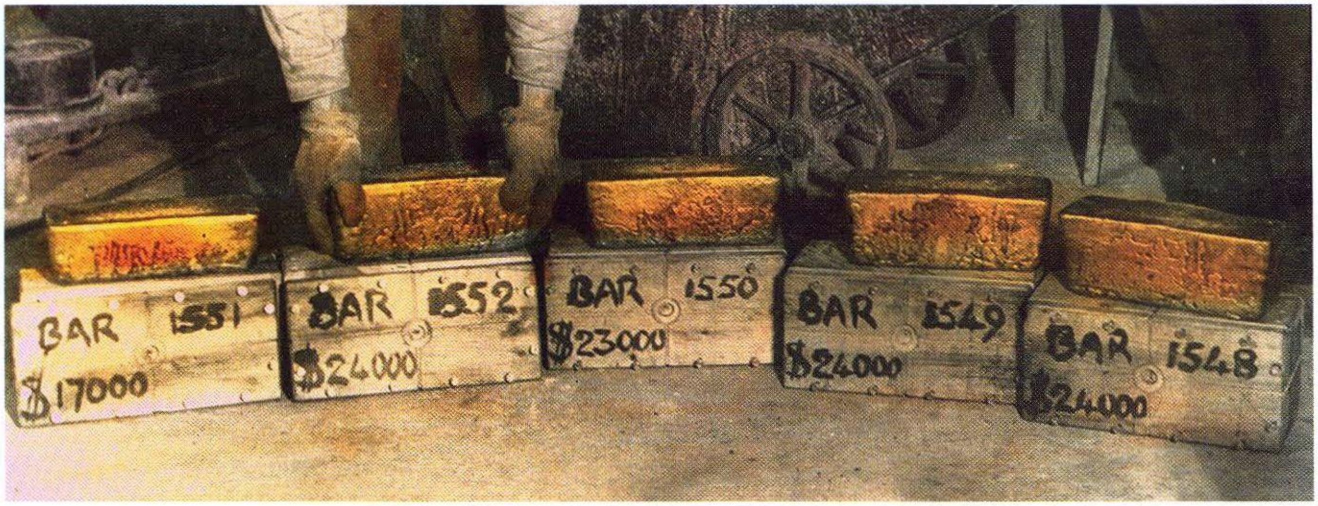
When ore is discovered, mine development can take place at the site. Service and support industries and sometimes new communities spring up, creating new wealth for the region.

Depending on how deep the deposit is in the ground and other factors, the ore will be mined as either an open pit or an underground mine. In the case of an underground mine, either a vertical shaft will be sunk or a ramp built. Testing is done to determine the best way to extract the valuable minerals from the rock to produce a mineral concentrate. Metallic mineral concentrates are **smelted** to produce metals which are then purified in a **refinery**.

The Superior Province: Greenstones and Gold

Some of the world's most famous mining camps are found in the Superior Province. They include the rich Hemlo gold camp near Marathon and the giant Kidd Creek copper, zinc and silver deposit in Timmins.

The Superior Province gold camps are the richest of Ontario's gold producers. Since 1909, the Timmins district has produced 60 million ounces of gold. The Kirkland Lake district has produced 38 million ounces of gold so far, and the Red Lake area has turned out almost 16 million ounces.



These gold bars, worth $112,000. when produced, would be worth more than $3.5 million today

In all, about 145 million ounces, or 4,500 tonnes of the yellow metal have been extracted from gold mines in the Superior Province.

Greenstones and gold seem to go together. Gold deposits are formed when fault-bounded assemblages jostle against one another during the formation of a greenstone belt. Most of the gold in the Superior Province has been found in the fault zones between the greenstone belts and wrench basins. Wrench basins were described in Chapter 6.

Tough red rock like this iron formation has provided much of the iron produced in Ontario

Base metal deposits, on the other hand, are leftovers of volcanoes which erupted between 2.75 billion and 2.71 billion years ago. These volcanoes spread lava and pushed up island arcs throughout this part of Northern Ontario. Today, they make up the granite-greenstone belts of the Superior Province.

A volcano as violent as the present-day Mount St. Helens exploded about 2.75 billion years ago and likely made the giant Kidd Creek base metal deposit in Timmins.

There are many other base metal deposits formed by volcanoes in the Superior Province, although not all were caused by violent eruptions. In Ontario, they include deposits of the Kamiskotia, Manitouwadge, Winston Lake and Sturgeon Lake camps.

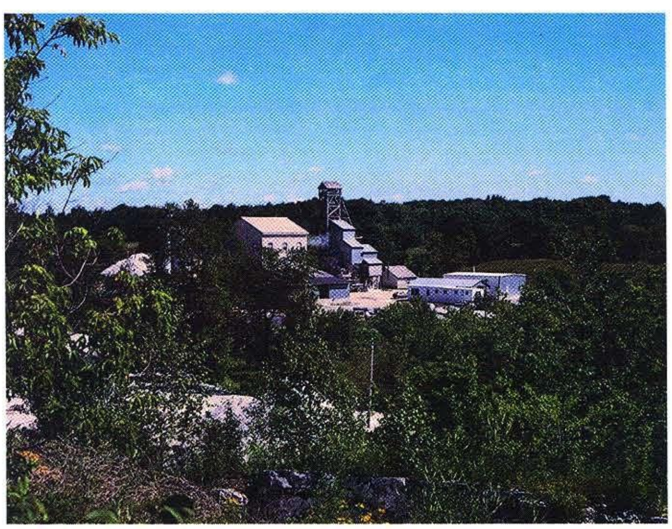
Powerful currents eroded the island arcs and laid down sediments in basins. Among these sediments was an iron-rich rock called **iron formation**. It is found throughout the Superior Province, including the Steep Rock, Atikokan, Algoma, Michipicoten and North Spirit Lake areas. These deposits have provided much of the iron ore mined in Ontario.

Ontario produces two-thirds of Canada's nickel and is second only to the former Soviet Union as a nickel producer. In 1993, a total of 17 mines in the Sudbury Basin produced 124 million kilograms worth $836 million.

Cobalt is produced as a byproduct of Ontario's mining operations in the Sudbury area. One of cobalt's main uses is in superalloys which are used in turbine blades for aircraft jet engines and in gas turbines for pipeline compressors. Ontario produces about 80 per cent of Canada's cobalt.

In 1993, Ontario produced nearly 2.0 million kilograms of cobalt with a value of $76 million.

The discovery of the Kidd Creek copper-zinc-silver deposit in 1964 near Timmins has been the most significant base metal discovery since Sudbury in the late 1800s. There was no exposure of the mineralization to tell mine finders what lay below their feet. The discovery came solely though the effort to trace and explain a geophysical anomaly—an area of unusually conductive rock recorded by a survey using special equipment towed behind an airplane.



The Henderson Talc Mine, near Madoc, has produced talc continuously since 1896

The Southern Province: Sediments and Sudbury

This busy time in Ontario's geological past created a great deal of the province's mineral wealth. First, sediments eroded from the Superior Province about 2.45 billion years ago were laid down as sand and gravel deposits along the northern shores of Lake Huron. These sediments included granite that contained grains of uranium minerals. When the sediments were deposited, bands of sand and gravel were converted to conglomerate. The grains of uranium minerals formed Elliot Lake's uranium deposits.

More sediments eroded between 2.10 billion and 1.85 billion years ago and settled along the north shore of Lake Superior. They developed into the "iron formation" which has been mined in Minnesota, southwest of Thunder Bay.

The world famous nickel-copper deposits of the Sudbury Structure were also formed at about this time. Many geologists believe the structure was caused by a huge meteorite crashing to earth about 1.85 billion years ago.

About 1.11 billion years ago, mineral deposits were formed when the young North American continent tried to split apart along a line centred through Lake Superior. They include copper in the volcanic rocks along the north shore of Lake Superior, and silver-bearing veins and **amethyst** deposits near Thunder Bay.

Amethyst, a purple gemstone, was named Ontario's provincial mineral in 1975.

The Grenville Province: Gold and Much More

The Grenville Province is a patchwork of small pieces of crust called terranes. They were thrust together like a deck of cards between 1.68 billion and 1.16 billion years ago in a series of mountain building episodes.

This plate action left behind many valuable minerals. The first gold discovery in Ontario was made in the Grenville Province in 1866. This gold deposit, north of Madoc in Hastings County, was left behind by mountain building activity between 1.18 billion and 1.16 billion years ago.

Iron, copper, zinc, molybdenum and uranium have all been mined in the Grenville Province. A variety of industrial minerals, such as graphite, nepheline syenite, talc, marble and dolomite, are also found here.

The Basins of Paleozoic and Mesozoic Time

Warm seas flooded much of Ontario between 570 million and 66 million years ago. The seas deposited layers of sedimentary rocks in four basins: the Michigan, Appalachian, Hudson Bay and Moose River.

Sediments deposited in these basins include beds of gypsum, salt, clay and limestone. They provide material for bricks, cement, crushed stone, plaster and building stone used by the construction industry.

In southwestern Ontario, these layers of sedimentary rock trap oil and natural gas. The town of Oil Springs in Lambton County had the first operating oil well in North America. It started pumping in 1858.

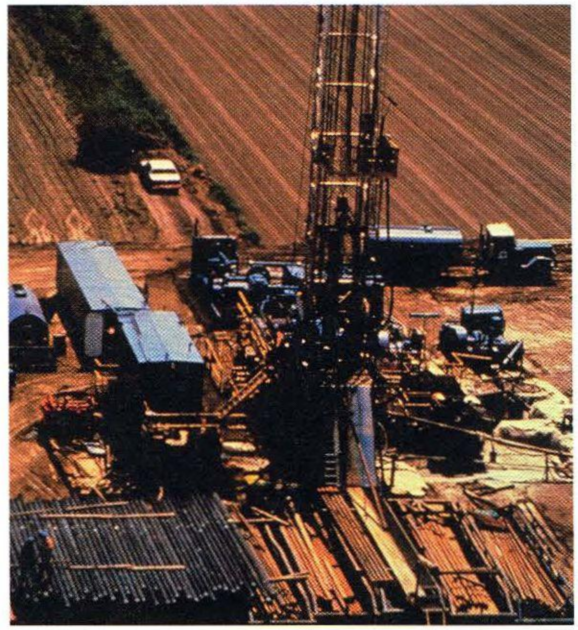
The Quaternary Period: Great Sheets of Ice

Huge sheets of ice (glaciers) covered Ontario several times between 190,000 and 10,000 years ago. They left behind thick deposits of earth material called **drift**. The drift covered much of Ontario, making the search for mineral deposits more difficult.

While mine finders (prospectors) dislike glacial drift since it complicates the task of finding minerals in the underlying bedrock, these glacial deposits bring important benefits to Ontario.

For one thing, these deposits have left southern Ontario with some of the best agricultural land in the world. They have provided the sand and gravel used by the construction industry. They have also trapped huge stores of groundwater, which are used by many Ontario communities as sources of drinking water.

And don't forget the beautiful lakes, rivers and streams which are scattered across the province today. These natural landforms were made by glaciers. They have made much of our province a prime vacation spot.



Large drill rigs test for oil and gas beneath the fields of southwestern Ontario

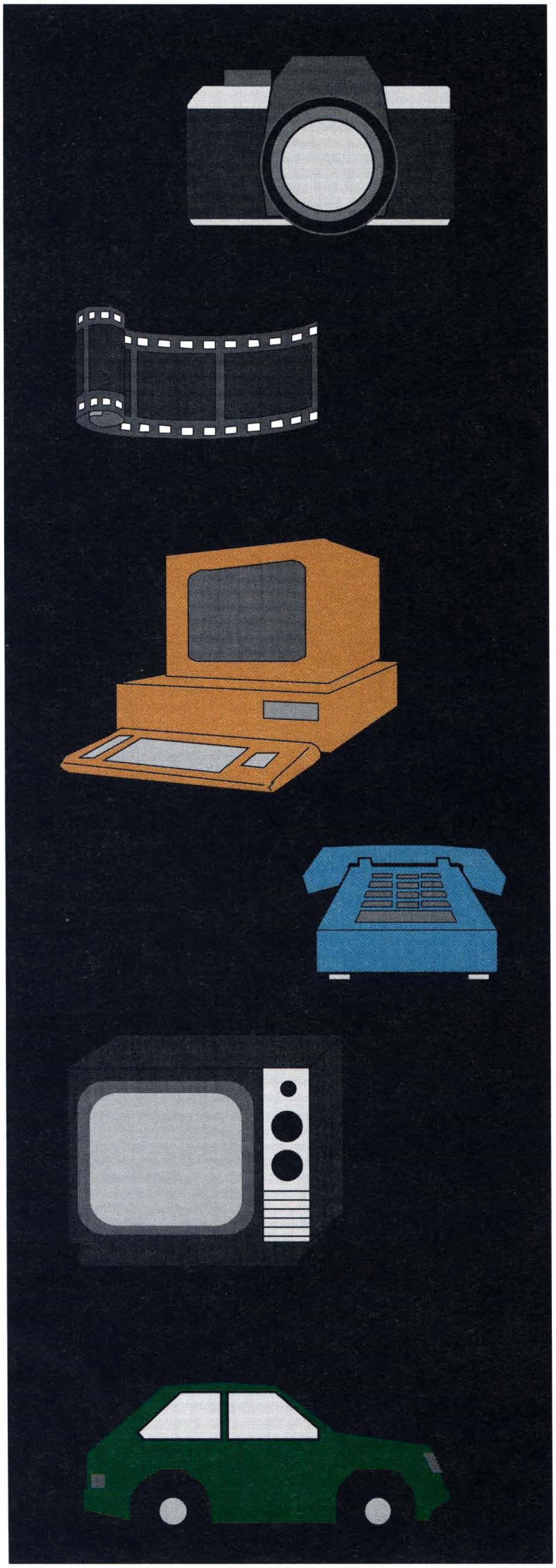
Ontario produced 4.1 million tonnes of cement in 1993. The $302 million value made this mineral product Ontario's fourth most valuable, after nickel, gold and copper.

Major cement plants are located in southern Ontario, close to their main markets. They produce Portland cement by burning a fine-ground mixture of limestone, silica, alumina and iron oxide. This "clinker" is then further processed into cement products.

Ontario produces nearly 45 per cent of the crushed, broken and dimension stone quarried in Canada. In 1993, 33 million tonnes of stone, worth $194 million, were produced in Ontario. Most stone is crushed for use in road construction, concrete and asphalt.

Flowerpot Island at Bruce Peninsula National Park brings geology and scenery together

12 Ontario's Geology and You



The geology of Ontario touches us every day in every way. It's the scenery we see along the highway. It's the bricks in the buildings and the gravel on the country roads. It's the salt on our popcorn, the coins in our pocket, the toothpaste on our brush. It's our favourite picnic spot. It's even the muddy football field and the slippery ski slope. And it's much more.

Almost everything we see and touch in our homes, cars, schools, offices and places where we play and vacation has to do with geology of Ontario.

The province, as you discovered in this book, has a very long and exciting geological history. It started more than three billion years ago, just when the Earth was forming. This geological history has left its mark in the rocks and minerals across Ontario.

This chapter looks at one of the most important ways Ontario's geology touches us: through its many minerals and metals which are found right beneath our feet.

From "A" to "Z"

Ontario produces a very long list of minerals. More than 30 different kinds come from the many mines which dot the province. These minerals span almost the whole range of the alphabet starting from "A" and ending at "Z."

Under the under letter "A," you will find two very important precious metals: "Au" and "Ag." You may know them by their more common names: gold and silver. "Au" and "Ag" are the chemical short forms for these two important metals. Under the letter "Z", you will find the base metal "zinc."

Besides gold, silver and zinc, Ontario produces a huge variety of other minerals. Some—such as copper and nickel—are very familiar to you. Others, you may not have even heard of. These include such tongue-twisters as tellurium, selenium, rhenium, rubidium, iridium and osmium. Though you may not be acquainted with these minerals, they are very important in your everyday life. Did you know that selenium added to shampoo helps fight dandruff?

Where Does It Come From?

ITEM	MINERAL CONTENT
Desk	silica, feldspar
Linoleum	limestone, clay, wollastonite, petroleum products
Cement	limestone, gypsum, iron, clay, diatomite, feldspar
Carpet	limestone, selenium, lime, soda ash, zeolite, bentonite, titanium, sulphur
Paint	rutile, limestone, wollastonite, talc, quartz, mica, clay
Bricks	bauxite, chromite, zircon, silica, graphite, kyanite, andalusite, sillimanite, clay
Books	clay, limestone, sodium sulphate, feldspar
Pencils	graphite, clay
Pens	limestone, wollastonite, mica, talc, clay, silica, petroleum products, sulphur
Bus	copper, platinum, iron, aluminum, lead, coal, barite, boron, calcium carbonate, bentonite, silica, chromium, perlite, wollastonite, mica, industrial diamonds, zeolite, clay
Cosmetics	iron, limestone, mica, petroleum products, silica, talc, zinc
Plastic	limestone, wollastonite, coal, talc, silica, petroelum products
Computer	gold, silver, copper, silica, aluminum, zinc, iron, petroleum products
Television	gold, silver, copper, silica, aluminum, zinc, iron, petroleum products
Camera	aluminum, iron, gold, nepheline syenite, nickel, petroleum products, silica, silver
Roller Blades	iron, aluminum, wollastonite, calcium carbonate, clay, sulphur, silica, talc, mica
Skateboard	aluminum, calcite, iron, mica, nickel, petroleum products, clay, silica, talc
Car	aluminum, barite, calcite, iron, lead, mica, nepheline syenite, nickel, petroleum products, clay, silica, zinc, chromium, limestone, feldspar, sulphur, graphite, copper, antimony, platinum, talc
Toaster	copper, iron, nickel, mica, chromium, petroleum products
Toothpaste	fluorite, barite, calcite
Telephone	copper, gold, petroleum products, zinc, mica, quartz, calcite
Microwave Oven	copper, gold, iron, nepheline syenite, nickel, silica
Bicycle	barite, iron, nickel, petroleum products

The first prospecting rush for gold in Ontario took place near Eldorado in Hastings County in 1866

Engine of Growth

New Liskeard, Cobalt, Red Lake, Timmins, Sudbury, Wawa, Thunder Bay, Kirkland Lake, Goderich, Hagersville and Caledonia.

What do these familiar cities and towns in Ontario have to do with geology? Everything. In fact, they may not be around today had it not been for mining. All these towns and cities started as mining camps around new discoveries.

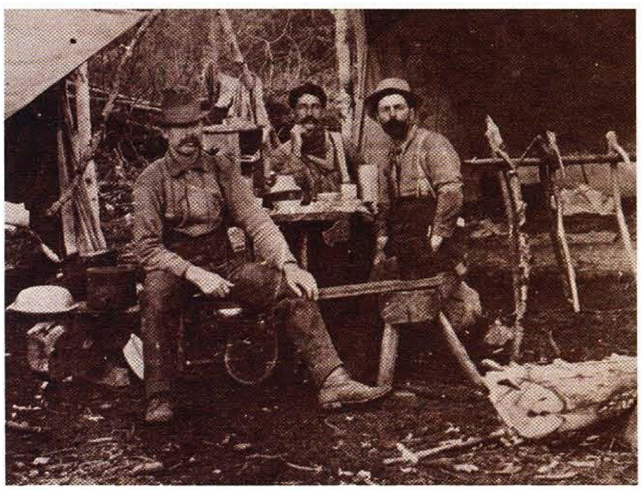
Since the first mineral discovery in Ontario more than 200 years ago, the mining industry has played an important role in the building of the province. Early prospectors hoping to strike it rich opened much of the northern part of the province.

The search for minerals even affected the routing and development of the railway. Sometimes, the railway was built to reach areas where mineral exploration was going on. Other times, as in the case of Sudbury, valuable metals were discovered during railway construction.

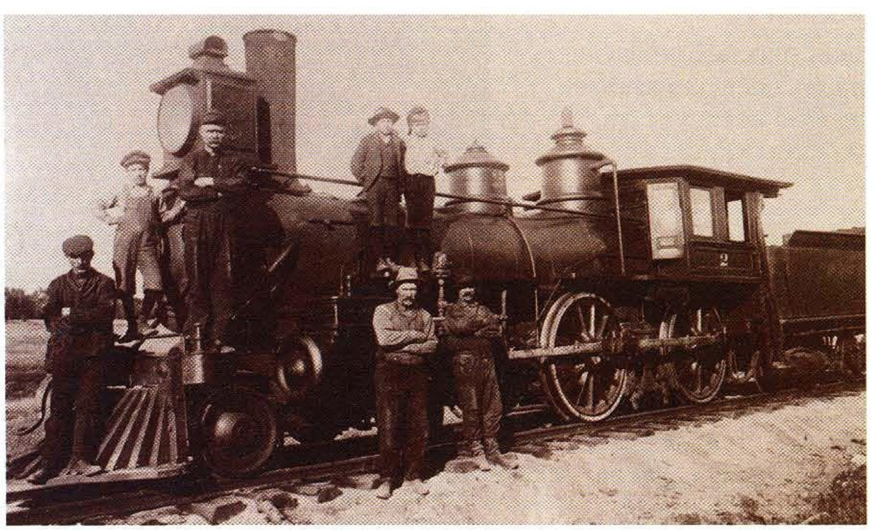
Communities and towns quickly grew around the sites of mineral discoveries. Farms and factories soon sprang up. The rest, as the saying goes, is history.

Today, mining continues to be an engine of growth for the province. It creates jobs and wealth. Every year, mining adds billions of dollars to the economy of Ontario.

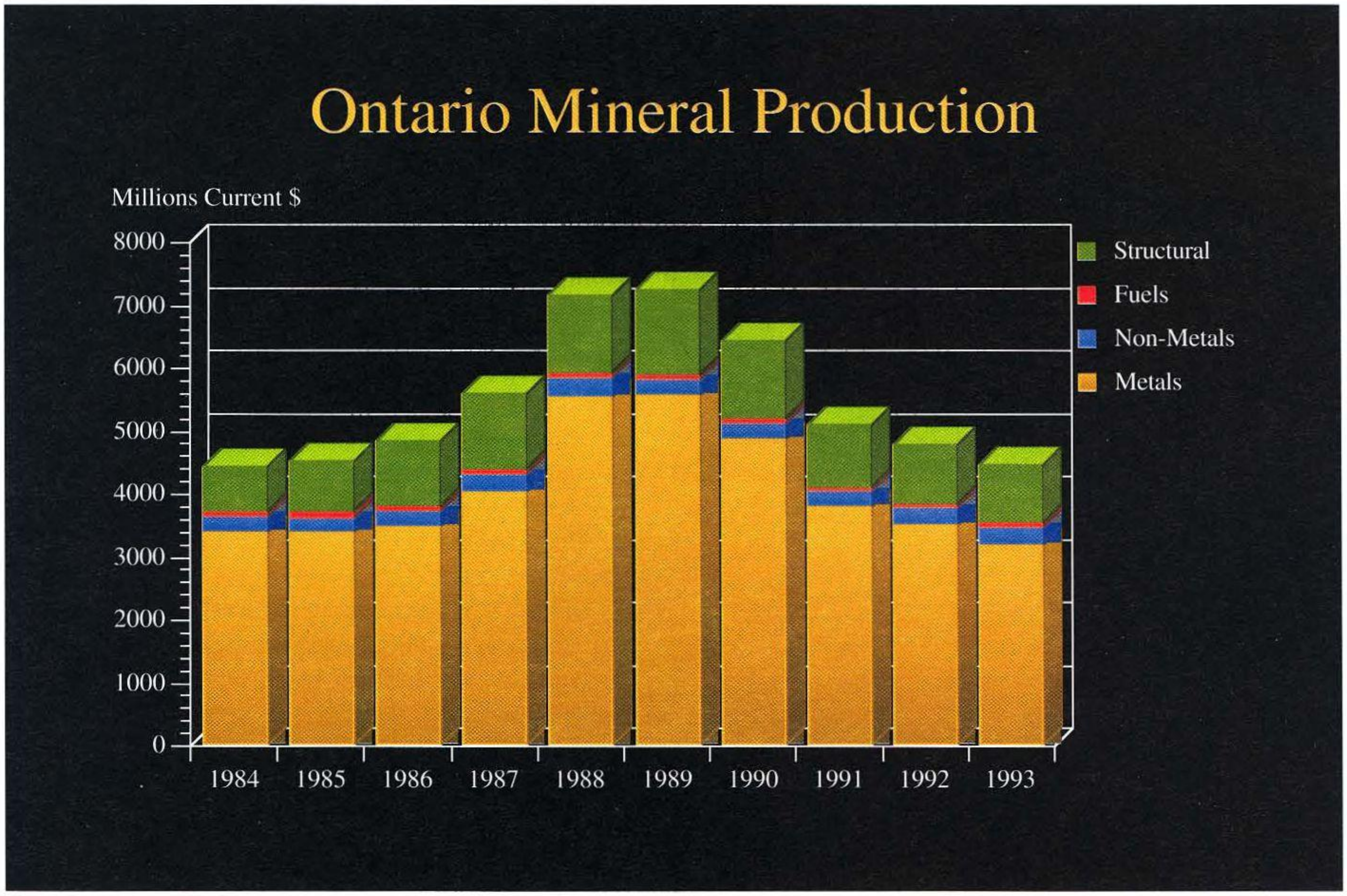
Here's a look at the mining industry's important contributions to the province.



Living conditions for early prospectors and miners were basic



In some cases, the coming of the railway led to discovery of mineral deposits; in others, it followed the development of new mines



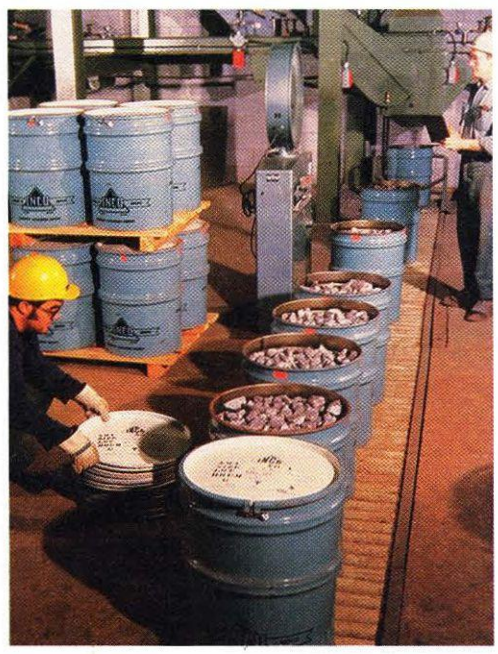
Nickel, gold, copper, zinc, uranium and cobalt account for 95 per cent of the value of Ontario's metal production

How does Ontario Rank in the World?

If Ontario were an independent country, it would be in the top ten of metallic mineral producers of the world. The province would be the world's second largest nickel producer after the former Soviet Union. Ontario would be the fourth largest producer of zinc, the fourth largest producer of cobalt, the seventh largest producer of gold, the seventh largest producer of silver and the eighth largest producer of copper.

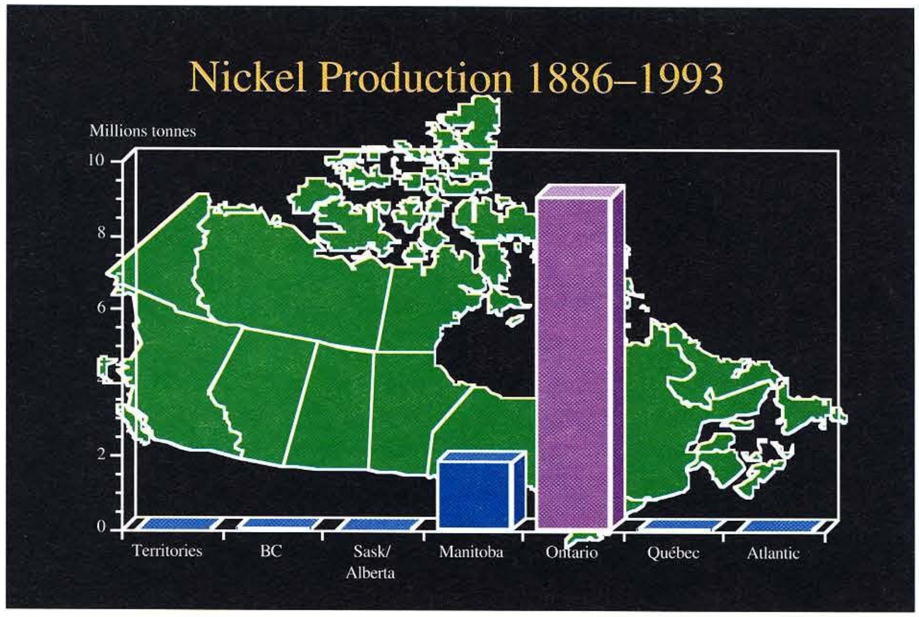
How does Ontario Rank within Canada?

Ontario is Canada's largest producer of metallic minerals, producing about three times as much as Quebec or British Columbia and about 40 percent of the nation's total.

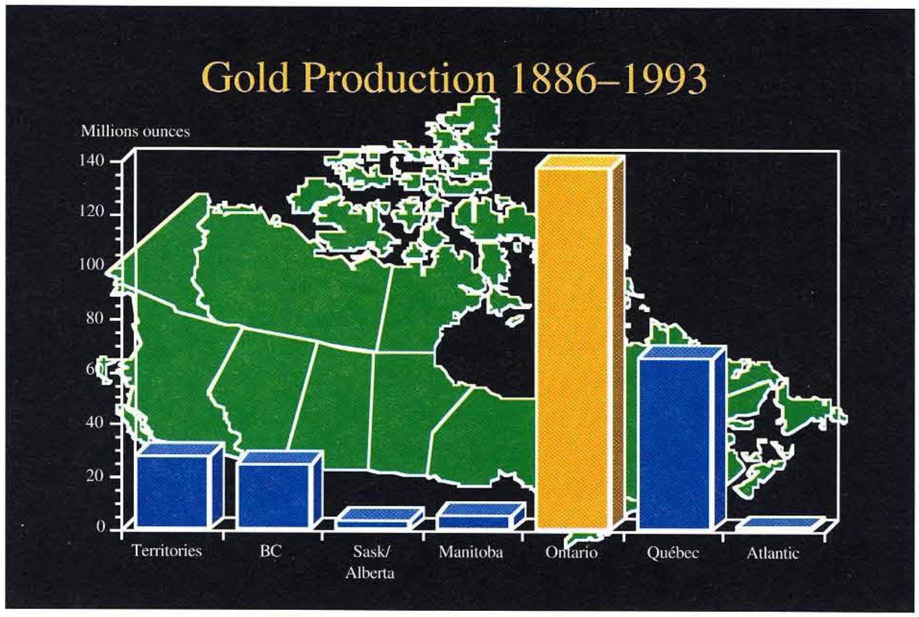


Ontario nickel is sold in a variety of forms, and accounts for two-thirds of Canada's annual production

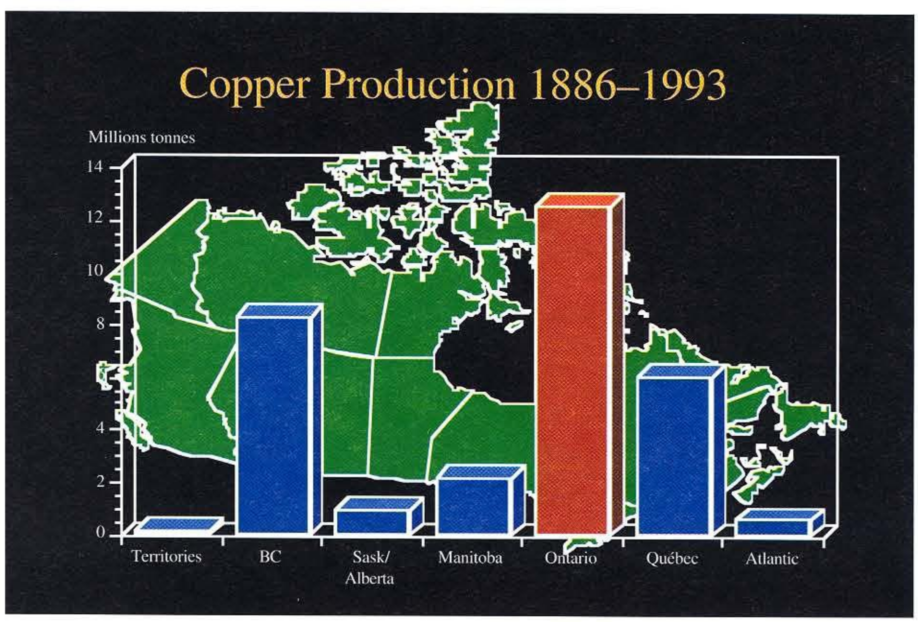
Total nickel production in the province exceeds 9 million tonnes



In more than a century of mining, Ontario has produced about 145 million ounces of gold



More than one third of Canada's current copper production comes from Ontario mines



How Much does Ontario Produce?

- about two-thirds of Canada's nickel and salt;
- nearly half of Canada's gold and decorative stone;
- a third of Canada's sand, gravel, cement, copper and uranium;
- more than a quarter of Canada's silver and zinc.

What's It All Worth?

The value of Ontario's mineral production adds up to billions of dollars every year: more than $4.5 billion to be exact. That money pays for all of the imports of clothing, footwear, books and other printed materials, and glass products that Ontario brings into the province.

Jobs, Lots of Jobs

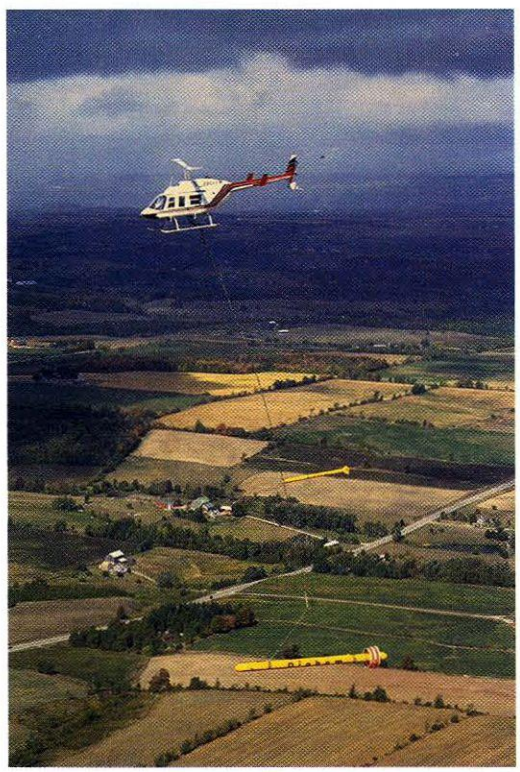
About 23,000 men and women work in the mining and metallurgical industries in Ontario. Another 75,000 people work at jobs which process these minerals.

Mining's Top Ten

Nickel is Ontario's top mineral. Also ranking in Ontario's mining hit parade are gold, copper, cement, zinc, stone, sand and gravel, uranium, platinum and salt.

Good Things Come in Small Packages

In Ontario, mining operations cover a total area of 214 square kilometres. That is only 0.02 percent of all of Ontario's land area. In comparison, roads take up about 0.5 percent. Parkland covers about 7.3 percent of Ontario's land.



Sophisticated instruments like the ones trailing below this helicopter help in the difficult search for new mineral resources

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Ontario's Timeline

5,000 years ago:	Towards the end of the ice age, lake levels change and Ontario starts to look much like it does today.
10,000 years ago:	The ice age in Ontario comes to an end, and humans appear in Ontario for the very first time.
15,000 years ago:	Temperatures warm again, and the ice sheet starts to melt in southern Ontario.
115,000 - 135,000 years ago:	The clay beds of the Don Valley in Toronto start forming when the glaciers start melting.
190,000 years ago:	Temperatures drop to 9°C below current levels, and glaciers cover Ontario.
91 - 186 million years ago:	The supercontinent, Pangaea, breaks apart, and the Atlantic Ocean begins to expand.
278 - 358 million years ago:	North America collides with Africa, and the Appalachian mountains are formed.
380 - 401 million years ago:	The St. Lawrence River and Hudson Bay are again joined by a vast seaway.
401 - 417 million years ago:	North America collides with Europe, and the sea covering Ontario begins to dry up.
438 - 450 million years ago:	A vast sea spreads across Ontario, connecting the St. Lawrence River and Hudson Bay.
700 million years ago:	The Iapetus Ocean, a pre-Atlantic ocean, opens up between the cores of North America and Europe.
1.00 billion years ago:	All mountain-building activity ceases and the mighty Grenville mountains begin to erode.
1.16 - 1.18 billion years ago:	A powerful mountain-building event creates rugged peaks in much of southern Ontario.
1.42 - 1.45 billion years ago:	The rocks of the Parry Sound area form on volcanic islands.
1.85 billion years ago:	The Sudbury Structure forms. It is not known whether is was caused by a crashing meteorite or a violent volcano.
2.45 billion years ago:	Streams and rivers deposit gravel which forms the uranium ore mined at Elliot Lake.
2.71 - 2.75 billion years ago:	An ocean plate slips below the southern edge of the young Ontario and causes a series of volcanoes.
More than 3 billion years ago:	The province's first piece of crust forms just south of Red Lake.

What Happened in Ontario?

When did the Niagara Escarpment form? When did the drumlins around Peterborough make their debut? And when did the Sudbury Basin form? If you have ever wondered about the answers to these and other questions, this time line is for you.

It highlights some important geological processes and plate actions which made the province. It starts more than 3 billion years ago when the first piece of crust appears in the province and ends when the Great Lakes take on their present shape about 5,000 years ago.

You might wonder how we know when events happened thousands, millions, and even billions of years ago. Geologists use two types of age dating: relative and absolute.

It's All Relative

As early as the 1700s scientists began to label some rocks older or younger than others. They did this by using three "laws".

First, they established the law of superposition: each layer of sedimentary rock is younger than the one underneath it. Then, they developed the law of cross-cutting relationships: intrusive rocks are younger than the rocks they cut across. Finally, they developed the law of inclusion: any rock is younger than the inclusions it contains.

Later, they noticed that the fossils of many species are found in only certain beds of sedimentary rock. They also noticed that the orders in which the fossil species appear in those rock sequences are very similar, even in widely separated geographic areas. This made geologists believe that rocks containing the same fossils are of the same age.

These observations let them determine the **relative ages** of rocks, even though they couldn't say exactly how old those rocks might be.

Absolutely Aged

It took sophisticated laboratory techniques to determine exactly how old rocks are. Minute quantities of radioactive elements in the rock can now be measured, and those amounts can be compared with the amounts of products left after the radioactive elements have given off radiation.

By using these measurements, and knowing how long it takes for a radioactive element to give off a certain amount of radiation, geologists can calculate how old the rock is. This is a rock's **absolute age**. It's something like knowing how long a battery will work, and counting used batteries to calculate how long a flashlight has been on!

Finding out the ages of the rocks in Ontario has been one of the most important steps in unravelling the geological history of the province, as described in this book.

14 Glossary

Absolute Age Date — The age of a fossil, rock, or geologic feature, given in years.

Acadian Orogeny — A period of deformation in the northern Appalachians between 325 million and 375 million years ago.

Alleghany Orogeny — A period of deformation in the central and southern Appalachians between 250 million and 325 million years ago.

Amethyst — A variety of quartz that is purple, violet or red. This mineral contains an excess of iron within its structure. It is used as a gem, and for decorative, landscaping, and construction material.

Annelid — A wormlike creature with a segmented body, and distinct head and appendages, usually known as fossils only from burrows and trails.

Apatite — A fairly common mineral with the composition calcium phosphate. Human bones and teeth are made of apatite.

Archean — Precambrian rocks more than 2,500 million years old.

Assemblage — A group of rocks of similar age and geologic history.

Basalt — Dark-coloured, fine-grained volcanic rock which is formed when molten rock cools and hardens rapidly at the Earth's surface. It is high in iron and magnesium.

Base Metal — Any common metal other than iron, including copper, lead, zinc, nickel, tin and mercury.

Basin — A depression of the Earth's surface which originated by erosion or structural changes.

Batholith — A large body of intrusive igneous rock, with a surface exposure of more than 100 square kilometres, and no known bottom or floor.

Bedrock — Solid rock of the Earth's crust, either exposed at the surface, or overlain by unconsolidated materials.

Belt — Large-scale geological zone, generally a particular kind of rock strata exposed at the surface in the form of a zone or band.

Bomb — A piece of volcanic rock larger than 64 millimetres across, that was blown out of a volcano while fluid, and which received its rounded shape while in flight.

Brachiopod

A large family of shellfish, with the left side of each shell a mirror image of the right side of the shell. This is unlike the more common molluscs, where the top shell is the mirror image of the bottom.

Bryozoan

Tiny, colonial animals which produce skeletons somewhat like those produced by coral.

Breccia

Rock consisting of angular fragments in a fine-grained matrix.

Bullion

Precious metal such as gold or silver, formed into bars, ingots or other uncoined form after smelting and refining.

Calcite

A common mineral and principal constituent of limestone.

Canadian Shield

The main continental block of the Earth's crust underlying North America. It has been relatively stable over a long period of time and has undergone only gentle warping. It is composed of Precambrian rocks.

Cenozoic

An era of geological time from about 66 million years ago to the present.

Cephalopod

A marine animal with a definite head, and the mouth surrounded by tentacles. Some varieties have a single "snail" shell, which may be curved, straight, or coiled. Others, like the octopus, have no shell.

Conglomerate

A rock made up of compacted gravel.

Contact Metamorphism

Alteration of the rocks surrounding an igneous intrusion because of the effects of heat and the addition of new chemical elements.

Continental Drift

A general term for the theory proposed by Wegener in 1912, that continents can move freely across oceanic crust.

Continental Crust

Relatively light-weight rock which floats higher on the soft mantle than does the oceanic crust. It ranges in thickness from 10 to 70 km, and is made up mainly of granites and other silica-rich igneous rocks. It also includes sedimentary and metamorphic rocks.

Continental Shelf

The part of the continental margin between the shoreline and the continental slope. It has a very gentle slope, and generally extends to a depth of about 200 metres. From there, the 3° to 6° gradient of the continental slope runs down to the deep ocean.

Convection Current

This up-and-down current within the mantle is caused by the intense heat deep inside the Earth. The heat makes the soft, hot mantle rocks less dense, causing them to rise. When they rise, they cool, become heavier and sink back down. This circular flow of mantle rock is thought to be the main force which moves the tectonic plates.

Core

The spherical region at the centre of the Earth with a diameter of about 6,920 km. It is thought to be composed of a nickel-iron alloy. The thousands of kilometres of overlying rock exert tremendous pressure on it. Its temperature is estimated to be as much as 4,200°C.

Corundum An extremely hard mineral composed of aluminum and oxygen. It is used as an abrasive. Gemmy varieties are ruby and sapphire.

Craton This is the geological centre of a continent. It marks the area where the continent first started to evolve. The Canadian Shield is the largest craton in the world. It covers an area of more than 5.5 million square kilometres.

Cratonic Basin A broad depression atop a craton, large enough to hold an inland sea.

Crinoid A marine animal related to starfish, crinoids are often called "sea lilies" because they look like flowers rooted on the sea floor.

Cross-bedding A sedimentary structure in which thin beds of rock are at an angle to the main bedding planes. Cross-beds are remnants of ripples or dunes caused by flowing water or wind when the sediments were deposited. They can be used to determine the flow direction of the wind or currents at the time of deposition.

Cuesta An asymmetric ridge with a gentle slope on one side and a steep slope on the other. The gentle slope is, in many cases, the top of a bed of sedimentary rock.

Delta A flat-topped wedge of sediment formed where a river enters a lake or ocean. The transporting power of the river water decreases when it slows as it enters the lake or ocean. The sediments carried by the river are then deposited to form the delta.

Diabase A rock with the same chemical composition as basalt and gabbro, consisting mainly of labradorite (feldspar) and pyroxene.

Dike A sheet-like igneous intrusion that cuts across the structure of older rocks. This is spelled "dyke" by some geologists.

Dimension Stone Building stone that is quarried and prepared in blocks.

Dip The angle between a flat surface in the rock and a horizontal surface.

Dolostone Any sedimentary rock consisting essentially of dolomite, a mineral very similar to calcite.

Drift A general term applied to all rock material including clay, sand, gravel, and boulders transported by a glacier and deposited either directly by the ice, or by water running from it.

Drumlin A low, smoothly rounded oval hill deposited under glacial ice, and shaped by its flow. Its blunt end points "upstream".

Earthquake The localized release of energy within the earth's crust. Earthquakes may be too small to be felt, or may cause severe damage. The amount of damage depends in part on how deep within the crust the release of energy takes place.

Elements

These are the basic chemicals that occur naturally in the Earth. Some of the most common are oxygen, silicon, aluminum and iron. Elements combine in different ways to form minerals.

Erosion

A process where earth or rock material is loosened or dissolved, and then removed from any point of the Earth's surface by water, ice or wind.

Erratic

A rock carried some distance from its source by glacial ice.

Esker

A long, winding ridge of sand and gravel formed by water flowing through or under a glacier. Eskers run parallel to the direction of glacial ice flow.

Fault

A fault is a fracture or zone of fractures in the Earth's crust along which some movement has taken place. Faults are caused by the action of tectonic plates, and may stretch for many kilometres or may be only a few centimetres long. One of the most famous is found in California. It is the San Andreas Fault, which separates the Pacific Ocean plate from the North American plate.

Feldspar

A group of abundant minerals, feldspars can be cream, pink, grey, or black. They occur in all types of rocks.

Foreland Basin

A long, narrow trough-shaped basin which forms along the edge of a continent when the continent and another tectonic plate collide.

Gabbro

A coarse-grained, mafic igneous rock which is low in silica and high in magnesium and calcium.

Glacier

A large ice mass made of recrystallized, compacted snow, which originates on a land surface and flows under the influence of gravity.

Gneiss

Banded rocks formed during intense regional metamorphism due to the effects of heat and pressure on pre-existing rocks.

Gondwanaland

An ancient supercontinent in the Southern Hemisphere, which joined with Laurasia to form Pangaea.

Granite

A coarse-grained, felsic igneous rock consisting of feldspar and quartz with minor amounts of dark minerals.

Granophyre

A fine-grained granitic rock with intergrown quartz and feldspar.

Greenstone

A geological field term applied to any fine-grained green, volcanic rock. Its colour is attributed to its high content of the green minerals chlorite, actinolite, amphibole and epidote.

Greywacke

A dense grey to greenish grey sedimentary rock composed of sand, silt and clay.

Group

A general term for a consecutive sequence of related layers of volcanic or sedimentary rocks.

Hematite — The principal ore of iron, used for centuries as a red pigment.

Hornblende — A common black or dark green mineral.

Iapetus Ocean — A sea that existed in the general position of the present Atlantic Ocean before Europe and Africa collided with North America.

Igneous Rock — Rock formed from the cooling and crystallization of hot, molten magma at or below the surface of the Earth.

Intrusive Rock — Igneous rock which has forced itself into pre-existing rocks, either along some definite structural feature, or by deforming and cross-cutting the intruded rocks.

Illinoian Stage — The second last major period of glacial advance in North America, it lasted from about 135,000 to 190,000 years ago.

Iron Formation — A hard, iron-rich sedimentary rock, which is generally Archean in age, and in most cases contains abundant magnetite.

Ironstone — A hard, iron-rich sedimentary rock, which is generally younger in age than Archean, and in most cases contains little magnetite.

Island Arc — A curving chain of volcanic islands and earthquake activity commonly found where an oceanic plate is colliding with another plate.

Isostatic Uplift — Slow upward movement of the surface of the land because a great weight has been removed, whether by erosion or glacial melting.

Joint — A flat fracture surface in a rock, where no movement has occurred. This is different than a fault, where movement has taken place.

Kame — A steep-sided, conical hill of sand or gravel deposited by a glacier.

Kettle — A depression formed when a detached block of glacial ice left behind in glacial drift melts.

Komatiite — A type of dark volcanic rock with low iron, and high magnesium contents compared to other volcanic rocks.

Laurasia — An ancient supercontinent in the Northern Hemisphere, which joined with Gondwanaland to form Pangaea.

Laurentide Ice Sheet — The great ice sheet that advanced and retreated twice between 190,000 and 10,000 years ago. When at its maximum size, it covered all of Canada east of the Rocky Mountains, as well as the northern part of the United States.

Lava — Molten magma that reaches the Earth's surface and is extruded by a volcano. It also refers to the same material in its solidified form, after cooling.

Limestone — Any sedimentary rock consisting essentially of calcite.

Magma — Molten rock which is below the surface of the Earth.

Mantle — The zone between the Earth's crust and its core. It is approximately 2,870 km thick.

Marble — A metamorphic rock made of recrystallized calcite or dolomite, polished marble has many architectural uses.

Mesa — An isolated, nearly level landmass surrounded by steep slopes or cliffs, which stands high above the surrounding countryside.

Mesozoic — An era of geologic time, the Mesozoic extended from about 225 to about 66 million years ago.

Metamorphic Rock — Rock formed by transformation of any type of pre-existing rock, while it remains in the solid state.

Metamorphism — The process of altering a rock in the solid state as a result of heat, pressure, stress, and the chemical environment.

Meteorite — Meteors are solid chunks of rock which race through space. Most disintegrate into dust as they pass through the Earth's atmosphere. Those that do fall to earth are called meteorites. Some geologists think that a meteorite crashed into the Earth around Sudbury about 1.85 billion years ago to make the world-famous Sudbury Structure.

Mica — A group of common minerals that form large, flat mineral grains that can be easily split into very thin, tough, flat sheets.

Mid-Ocean Ridge — An active volcanic mountain range that extends along the centre of an ocean. The Mid-Atlantic Ridge is a mid-ocean ridge which formed when the Atlantic Ocean grew between the separating continents of Europe and North America, and is the site of continued spreading in the Atlantic Ocean.

Midcontinent Rift — A rift valley which split the North American craton about 1.11 billion years ago. It extends from Minnesota, under Lake Superior to Sault Ste. Marie, and from there under Michigan to Windsor. It filled with a 30 kilometre thick pile of volcanic rocks, the thickest known on Earth.

Migmatite — A banded rock made up of a mixture of igneous and metamorphic rocks. Most migmatites have a "stirred" appearance.

Mineral — Minerals are naturally occurring chemical compounds. There are about 3,500 minerals in the world, but only about 20 or so common ones. Rocks are made of minerals. Some rocks consist of grains of just one mineral. Quartzite, for example, contains only quartz. Granite is made of several minerals including quartz and feldspar.

Moraine — A mound, ridge, or other accumulation of glacial debris left behind by direct glacial action. Different forms have their own names.

Mudstone — A blocky, massive sedimentary rock formed of hardened mud.

Norite — A dark, coarse-grained igneous intrusive rock similar to gabbro.

Oceanic Crust — A relatively dark, heavy igneous rock, which comprises the Earth's outer rock shell beneath the oceans. It is only 5-10 kilometres thick. Oceanic crust is relatively heavy and less buoyant than continental crust, so floats lower on the mantle than does the continental crust.

Ore Deposit — An ore deposit is any type of mineral deposit which can be mined and processed at a profit.

Orogeny — This is the Latin word geologists use for the process of mountain-building. There have been several orogenies, or mountain building periods, in Ontario from its earliest history to about 1.00 billion years ago.

Orthogneiss — The gencral name for gneiss formed of metamorphosed igneous rock.

Outwash Plain — A broad, gently sloping sheet of sediment deposited by streams flowing out from in front of a glacier.

Outcrop — Geologists love outcrops. These are exposures of rocks or mineral deposits that can be seen on the Earth's surface because they are not covered by other deposits or water.

Paleozoic — An era of geological time from about 570 to 225 million years ago.

Pangaea — The name given to the huge supercontinent that included all the land masses that existed on the Earth 300 million years ago.

Phanerozoic — The portion of geological time when evidence of life is abundant, that is from about 570 million years ago to the present.

Photosynthesis — The process by which plants use the sun's energy to combine water and carbon dioxide to make carbohydrates and oxygen.

Pillow Basalt — Rock formed when lava oozes from underwater fissures and cools in the form of distorted, globular masses.

Plate Tectonics — This geological theory says that the Earth's crust is made up of about 10 major plates which are always on the move. This movement is thought to be the main cause of most geological processes: mountain building, the formation of continents and oceans, volcanic eruptions, and earthquakes. The theory even helps explain how mineral and metal deposits are formed, and why certain types of deposits are found with certain types of rocks. Ontario scientist, John Tuzo Wilson, was instrumental in developing this important theory in the 1960s.

Plutonic Rocks — These are igneous rocks which formed when magma cooled and hardened beneath the Earth's surface. They are named after Pluto, Greek god of the underworld.

Precambrian — The period of time from 4,600 million years ago to 570 million years ago. The name also refers to rocks formed during this time.

Proterozoic — The more recent of the two great subdivisions of the Precambrian.

Pumice — A volcanic rock containing so many gas bubbles it may float.

Pyrite — A widespread mineral found in many rock types, whether igneous, sedimentary or metamorphic. It usually forms small, brass yellow cubes and is commonly known as *"fool's gold"*.

Quartz — A mineral composed of silicon dioxide and found in many rock types. It is the most abundant mineral in continental crustal rocks. Amethyst is a coloured variety of quartz.

Quartzite — A sedimentary rock made up mostly of sand-sized grains of quartz, or the rock formed by metamorphosing the sedimentary rock.

Quaternary — The period of time from about 1.5 million years ago to the present.

Refinery — A place where various techniques are used to remove impurities from metals. Refining is the final stage in the production of metals.

Regional Metamorphism — A general term used for metamorphism, generally as a result of heat and pressure which affects a large area.

Relative Age Date — The age of a fossil, rock, or geologic feature, whether older or younger, as compared to other fossils, rocks, or geological features.

Rhyolite — A common type of light-coloured volcanic rock.

Rhythmite — A unit of silt and mud or siltsone and mudstone, with alternating coarser and finer grained layers. Rhythmites form in glacial lakes, with each pair of layers representing one year's deposits.

Rift — A rift occurs where the crust has been stretched and fractured, forming an immense crack. Hot magma from the upper mantle pushes up into the region. If the crust continues to stretch, the crustal plate splits into two separate plates, and a new ocean develops between them. Topographically, a rift is marked by an elongated valley with steep parallel sides.

Rift Valley — These are valleys which mark spots where continents tried to break apart, but haven't had enough time to split up, or didn't succeed in splitting up. There is a huge rift valley in Ontario called the Midcontinent Rift. It formed 1.11 billion years ago when the North American continent tried to split. The valley is along a line centred beneath Lake Superior and stretches under the state of Michigan to the Windsor area.

Roche Moutonnée — A small knob of bedrock, sculpted by flowing ice to have a gentle slope on the side from which the ice advanced, and a steep, rubbly drop-off on the other side.

Rock Cycle — This is the never-ending rock-making process. Here's how it works. Hot magma from inside the Earth rises to the surface. In some places, the magma cools and forms igneous rocks within the Earth's crust.

Rock Cycle - cont'd

Before the fiery hot magma cools, however, it bakes the surrounding rocks and changes them into metamorphic rock. In other places, volcanoes erupt and spew out lava which cools into volcanic rock.

Rocks on the Earth's surface are broken up and worn down by the wind, rain and ice. The bits and pieces of rock are carried back to the sea by wind, rain and rivers. These fragments collect as sediment on the bed of the sea and over time are cemented together into sedimentary rocks. Layers of sedimentary rock may eventually reach the surface as sea levels change or if two plates collide and force the rocks up into mountains.

The heat and pressure generated by the collision of two plates may be so great that sedimentary and igneous rocks caught between them are changed into metamorphic rocks.

When an oceanic plate crashes, it can be pulled down into the mantle, where it starts to melt into new magma. The cycle then begins again.

Sandstone

A sedimentary rock made up mostly of sand-sized grains of quartz, or the rock formed by metamorphosing the sedimentary rock.

Sangamonian Interglacial

The Sangamonian Interglacial Stage, from about 135,000 years to 115,000 years ago, was a period between glacial advances in Ontario when the climate was as warm as, or warmer than, it is today.

Schist

A metamorphic rock that can be easily split into thin slabs, due to the parallel orientation of the abundant flat mineral grains in it.

Sedimentary Rock

Rock that formed by the accumulation of sediment in water or air. The sediment may consist of rock fragments, particles of various sizes, or the remains or animals or plants.

Shale

A sedimentary rock which is formed from mud and clay, and which breaks easily into flat sheets.

Shatter Cones

Conical fragments of rock from a few centimetres to more than a metre high, with distinctive longitudinal striations. Formed by very high-energy shock waves, they are thought to indicate sites of meteorite impact.

Sill

An intrusion forced between layers of pre-existing rock, roughly parallel to these layers, like the filling of a sandwich.

Siltstone

A compact, blocky sedimentary rock composed mainly of silt.

Smelter

A place where metal-bearing minerals are heated until they melt and the sulphur they contain burns off. The remaining material is mixed with quartz, which reacts with the mixture, leaving molten slag and impure metal. The slag then forms one layer, and the impure metal another, allowing them to be separated.

Sodalite — An attractive blue mineral used as a semi-precious gem.

Striation — One of multiple scratches, generally parallel, made on the surface of the bedrock by rocks dragged along by an advancing glacier.

Strike — The direction pointed out by the line where a flat surface in a rock intersects with an imaginary horizontal surface.

Stromatolite — A layered sedimentary structure formed when bits of sediment are trapped by colonies of micro-organisms such as algae. They form some of the world's oldest fossils, and are still being formed today.

Stromatoporoid — A general name for an extinct group of marine animals, possibly related to sponges, which secreted calcarous skeletons.

Subduction — When a continental plate collides with an oceanic plate, the dense oceanic plate is usually forced under the lighter continental plate in a process called subduction.

Sudbury Basin — A huge, oval-shaped bowl 27 by 60 kilometres across, filled with Precambrian sedimentary rocks. For many years, it was thought to be the site of an immense volcanic explosion, but new evidence suggests that it may be the remnant of a meteorite impact crater.

Sudbury Igneous Complex — A thick bowl-shaped layer of igneous rocks of widely debated origin. The world-famous Sudbury copper-nickel deposits are located at the bottom of this layer, and in offshoots from it. Cobalt, gold, silver, platinum, palladium, and several other metals are also recovered from Sudbury ores.

Sudbury Structure — The unique geological structure made up of the Sudbury Basin and the Sudbury Igneous Complex. The rocks of these two features are not found anywhere outside the Sudbury Structure.

Supergroup — A formal name used to link related formations or groups of rock.

Suspect Terrane — This is a block of land which has been carried along the Earth's plate tectonic conveyor belt. The Parry Sound Terrane in the heart of Ontario's cottage country is a suspect terrane. Geologists think it was a part of an ancient volcanic island arc which formed thousands of kilometres away from Ontario - but no-one knows where.

Taconic Orogeny — A period of deformation in the Appalachian region between 460 million and 440 million years ago.

Talus — Pieces of rock of all shapes and sizes which have eroded from cliffs or steep hills, and fallen in a pile of rubble at the base of the cliff.

Terranes — These are sections of land, such as island arcs, which have been swept against the edge of cratons to enlarge continents. Geologists study terranes to discover the history of continents.

Till

These sheets of jumbled geological debris such as clay, silt, sand, pebbles, cobbbles, and boulders are deposited by glaciers.

Trilobite

These marine creatures had three-part exoskeletons consisting of a head, thorax, and tail. Some modern insects resemble these bottom-dwellers, which lived between 570 and 225 million years ago.

Turbidity Current

Turbidity currents form when piles of sediment on the continental shelf overbalance, mix with water, and rush down the continental slope at speeds of up to 60 kilometres per hour.

Unconformity

This is a major break in the sequence of rock layers within sedimentary rocks. It separates a younger layer of rock from older rocks, and usually represents a period of erosion.

Volcano

A vent or fissure in the Earth's crust through which molten magma, hot gases and other fluids escape to the surface of the land, or in some cases, the bottom of the sea.

Volcanic Eruptions

As oceanic plates are dragged under other plates during plate collisions, the high temperatures and pressures involved generate magma. Because the magma is less dense than the overlying plate, the magma rises slowly through the crust. If and when it reaches the surface, it pours out as lava from a volcanic eruption.

Weathering

The decomposition of rock due to the forces of nature, leading to the formation of soil.

Wisconsinan Stage

The last major period of glacial advance in North America, it lasted from about 10,000 years ago to about 115,000 years ago. During this period, there were a number of glacial advances and retreats. Parts of Ontario were ice-free during the times of glacial retreat.

Zircon

This mineral is made up of zirconium, silicon and oxygen. It is one of the minerals isolated for testing during absolute age determinations, because many grains of zircon contain minute amounts of radioactive elements as impurities. Some varieties of zircon are used as gemstones.

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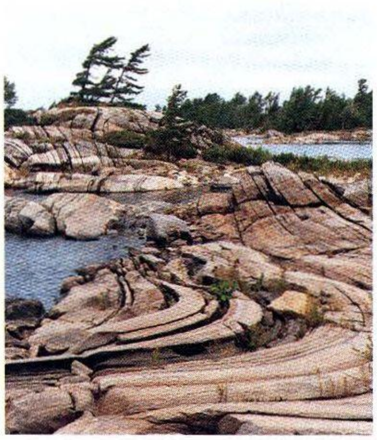

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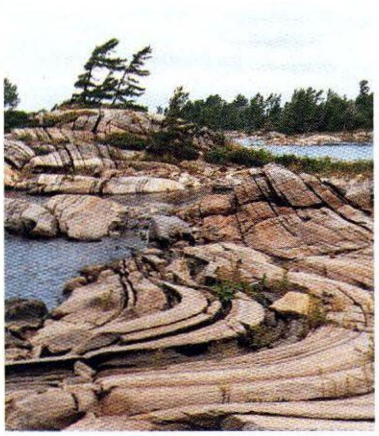

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