What on Earth

A Canadian Newsletter for the Earth Sciences

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Chalcotrichite (*copper oxide*)
Christmas Mine, Gila County, Arizona U.S.A.
© Peter Russell

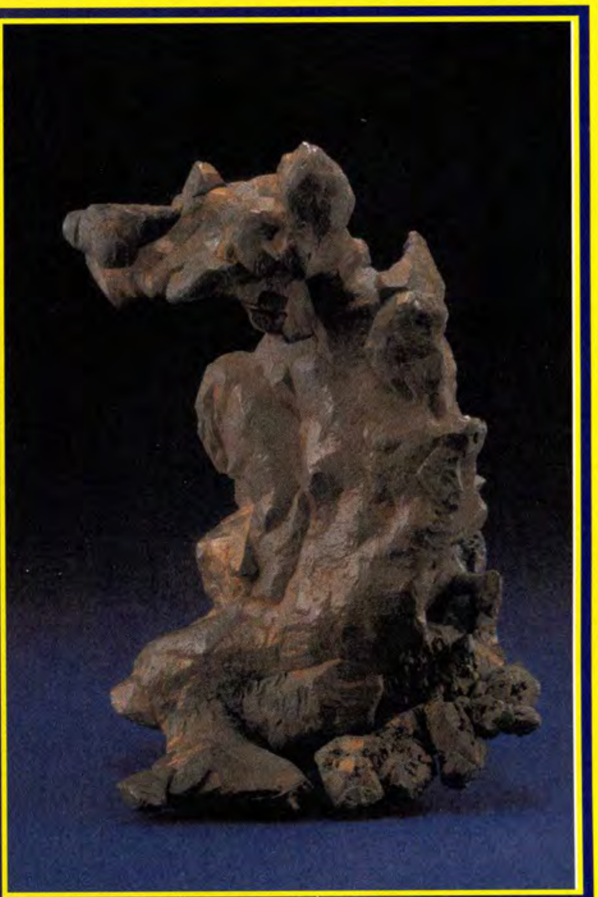
University of Waterloo

This publication is supported by a
Natural Science and Engineering Research Council Promo Science Grant

Copper

Wire copper on calcite, Tsumeb, Namibia.
© Peter Russell

Copper, White Pine Mine, Michigan. Donated to the Royal Ontario Museum by the Women's Association of the Mining Industry of Canada Foundation.



Copper, Copper Falls, Michigan.

Copper, Bonner Head, Michipicoten Island, Ontario.

Editorial

Well, here we are with the second issue of What On Earth, but actually at the end of our 16th year of the Newsletter. In case some new readers are puzzled, for the first 15 years the precursor of the current issue was produced as WAT ON EARTH. With a generous contribution from the Natural Sciences and Engineering Research Council in the form of a PromoScience Grant, the name was changed and colour was added to the issue. The website url was also changed to its present format (see cover page). The old WAT ON EARTH is still accessible by typing the title into "Google" for a web search. There are many interesting articles that are accessible on the back issues available at this site.

Reading through this issue brought back some memories of more "youthful" years, unlimited curiosity, and some lucky escapes. The first of these is related to copper, an element covered in "Copper; the Red Metal". In my very young days I had a piece of native copper. I had been told that it was an excellent conductor of electricity so I tried placing it between two exposed terminals when my father was replacing a light switch. It really does conduct electricity, and I made a careful note of that fact when I picked myself up from the far side of the room! Having 240 volts passing through copper and then you is one of those mind-altering experiences that lasts a lifetime! Associated with this mineral topic is a note for a essay competition from the Prospectors and Developers Association of Canada Mining Matters "Junior Miner of Ontario" that has a June 1 deadline in 2003.

In the last issue I started a summary of the three different rock families with an exposé of the fire-formed, or igneous, rocks. I have continued this series with colour pages including the centrefold, on the sedimentary rocks — the second major rock family. In the next issue I propose moving to the third major family, the metamorphic rocks. Commenting on flint, a siliceous chemical rock, also brought a smile to my face. As a child in junior school I couldn't afford a knife but I can clearly remember sharpening pencils using a flake of flint. Far later in life as a visiting professor at Kiel in Germany I encountered a flint whilst washing down a fossil beetle sample from the Hamburg area. I suddenly felt a slash across my thumb. I thought that I had come across a piece of glass, but imagine my surprise when I found a flint flake in the sample. It turned out to be a scraper used by the Hamburg culture (reindeer hunters that inhabited this region of northern Germany about 12,000 years ago). Contemplating a profusely bleeding thumb, I wondered whether a modern Solingen steel blade would have lasted 12,000 years in a water-saturated peat.

Paul Karrow has helped out with the second part of his article on "The Rise and Fall of the Great Lakes Revisited" illustrating this time, the longer term effects of isostatic recovery. Peter has contributed an article on "The Isle of Eigg and Hugh Miller" returning to this remote Hebridean Island to comment on both the geology and Hugh Miller, a famous Scottish geologist born 200 years ago in 1802. I have added another Waterloo connection on a short note on the "World's Largest Trilobite". This was discovered by Dave Rudkin (Royal Ontario Museum) and colleagues from Manitoba at Churchill five years ago this coming summer.

Two other promotional articles comment on an area that you see this summer if you attend the International Education Organisation meeting in Calgary, August 10 – 14th (www.geoscied.org). One mentions "Teachers and dinosaurs" and the fact that you can participate in a real dinosaur excavation in Alberta. The second, on the Frank Slide Anniversary is — like the dinosaur site — one of the localities to be visited on pre- and post-conference field trips. Other day trips will go to the Burgess Shale and the Columbia Icefield and Head Smashed In Buffalo Jump.

Lastly, but certainly not least, I mention the Geoscape project started by Bob Turner and John Clague in Vancouver and promoted by the Geological Survey of Canada. Geoscape has now illustrated a number of Canadian cities and regions. Each Geoscape tries to illustrate the importance of the geological significance and background of areas such as Victoria, Calgary, Southern Saskatchewan, Toronto, Montreal, Quebec City, Halifax, and others. Again these will be discussed and demonstrated at the Calgary Education Conference. If you are reading this and need more information go to the web site and pass the word.

I look forward to seeing you in Calgary!

Alan Morgan.

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INSIDE THIS ISSUE

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The Rise and Fall of the Great Lakes Revisited: Part 2

Paul F. Karrow

A couple of years ago in Wat on Earth (Fall, 1999) short-term variations in Great Lakes water levels, mainly resulting from meteorological effects, were described with passing reference to the effect of crustal tilting, which is a slow, long-term process.

Water-level gauges are located various places around the Great Lakes and show that the ground is tilting up to the northeast (Fig. 1). For example, measurements at gauges around Lake Ontario show that Kingston is rising relative to Hamilton about 30 cm per century. We know this tilting has been going on for thousands of years because the shorelines of ancient lakes such as glacial Lake Iroquois, which existed in the Ontario basin over 12,000 years ago, has been warped upward to the northeast. The Iroquois beach is at an elevation of 110 m at Hamilton today (Lake Ontario is 75 m above sea level) but north of Kingston is more than 280 m above sea level. That is, what was a horizontal water surface 12000 years ago has been tilted up to the northeast by about 175 m (Fig. 2).

If one continues northeast to Ottawa, evidence of even greater uplift can be found because there are old beaches there containing sea shells (the Champlain Sea) now at an elevation of 210 m. We know that at that time sea level was lower than present by about 60 m because of water diverted into the great glaciers of the northern hemisphere, so adding that on we can account for 270 m of uplift of the ground at Ottawa in the past 11000 years. This process of ground tilting is found wherever there were large ice sheets and we believe the weight of the glacier caused the Earths' crust to sink, then as the ice melted and the ice load lessened, the crust rose again in a process we call isostatic rebound.

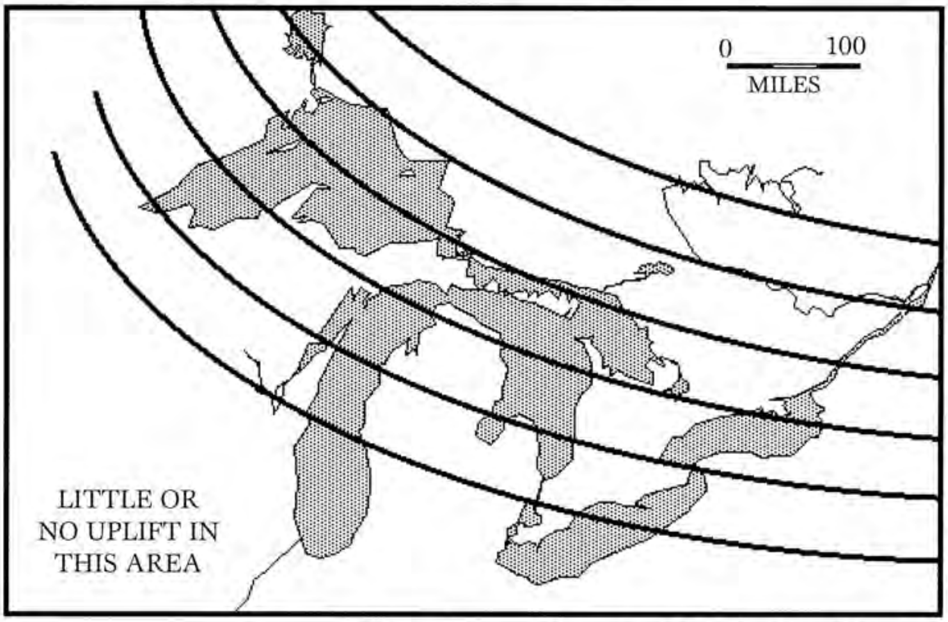


Figure 1. Trend of recent uplift in the Great Lakes area (generalised from Clark and Persoage 1970).

In the case of the Lake Ontario basin, the outlet (St. Lawrence River) is near Kingston. With the present drainage and water level in the basin controlled by the sill at Kingston, if that area is rising at the fastest rate of anywhere around the lake, then the water level in the lake will rise on the land all around the lake (Fig. 3). We can see this affecting landforms. For example, rivers flowing into Lake Ontario have their lower reaches drowned; a good example in the Niagara Peninsula is Jordan Harbour, but there are many others. Although this process is so slow in human terms we need precise instruments to measure it, this is another factor that affects Great Lakes water levels. The Lake Erie basin, with its outlet river (the Niagara) in the northeast end, is in a similar situation to the Ontario basin, and

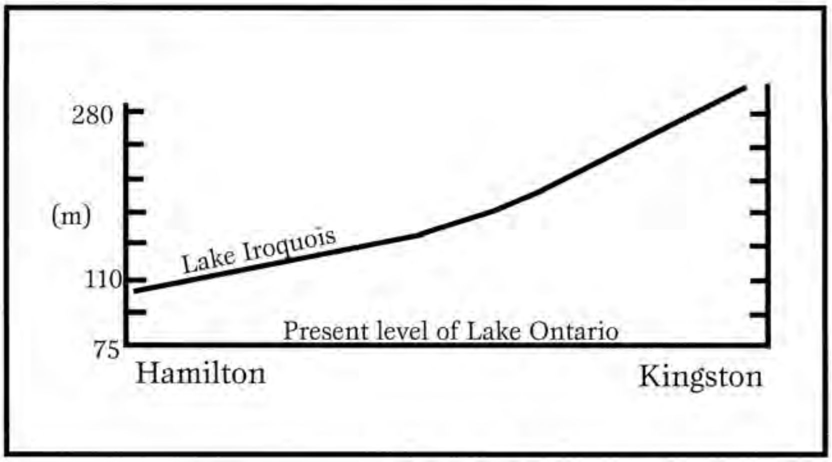


Figure 2. Lake Iroquois shoreline uplift.

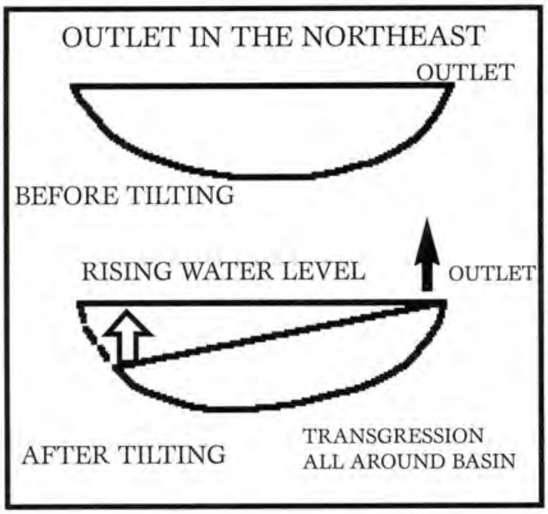


Figure 3. Uplift of a lake basin on the south side of the last ice sheet with outlet in the northeast. (e.g. Lake Ontario).

Key:
Solid arrow, uplift motion,
Hollow Arrow — relative water level change.

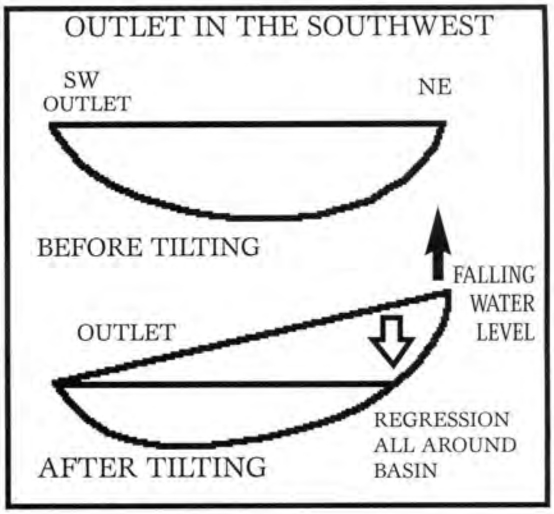


Figure 4. Uplift of a lake basin on the south side of the last ice sheet with outlet in the southwest
(e.g. Lake Huron).

drowned river mouths can be found in its southwest end as well. This process is not limited to the immediate vicinity of the lakes but all the land between as well, in fact over most of Canada. Rapid rise of the land around Hudson Bay is causing the Bay to shrink over time as the east shore has risen more than 300 m in the last 8000 years.

‘This tilting affects the gradient of streams too. Those that flow north have their gradient lessened (creating the marshes at Lake Simcoe — Holland Marsh — and at Lake Scugog), and those that flow south have their gradients increased.

In contrast to lakes Ontario and Erie, Lake Huron has its outlet in its south end (the St. Clair River). In this case the effect on water levels is just the opposite, with the sill at Sarnia left behind by the shoreline to the north rising more rapidly, so the water level in the lake is dropping relative to the land all around the basin (Fig. 4).

There's more to come — stay tuned!

ROYAL TYRRELL MUSEUM

Tyrrell Museum's Palaeo Week provides teachers with learning opportunities

Drumheller - Teachers from across Canada are signing up for a weeklong learning vacation with the Royal Tyrrell Museum, Alberta's internationally recognized palaeontology museum.

Palaeo Week for Teachers, July 21-25 and August 4-8, features five days of field studies in palaeontology and geology packed with information that teachers can apply in the classroom.

"This was the best professional development program I've taken in my 30-year career as a teacher," exclaimed Wendy Simmonds from Madeira Park, B.C. after taking part in Palaeo Week 2002.

Teachers registering for this year's field school will take part in a real dinosaur excavation, explore Alberta's unique badlands and learn about the latest discoveries in palaeontology. Each activity provides useful links to classroom lesson plans and each teacher takes home a comprehensive resource package that will help them share their experiences with their students.

The registration fee for Palaeo Week for Teachers is $400., including lunches, program materials and educational resources. Registrants are required to make their own transportation and accommodation arrangements.

Operated by Alberta Community Development, the Royal Tyrrell Museum is located 6 kms northwest of Drumheller, Alberta - 90 minutes from Calgary. Additional information on Palaeo Week for Teachers is available by calling 1-888-440-4240 (toll free outside Alberta) or by email at bookings@tyrrellmuseum.com

Copper the Red Metal

Peter Russell and Kelly Snyder

Native copper vein in shale
White Pine Mine, Michigan.

Copper, a soft red-coloured metal, was one of the first metals to be used in the ancient world. It has been exploited for at least 7000 years. The name comes from the Greek, ***Kyprios***, the name of the island of Cyprus in the Mediterranian Sea where copper occurs. The Latin, cuprum, (Cu) also means "metal of Cyprus," as the Romans had large copper mines on the island.

Copper is an excellent conductor of heat and electricity and is found in most of the flexible cables used in the world. Its softness also makes it suitable for tubing for water pipes and central heating systems because it can be easily bent to fit around corners. Above all, it can be mixed with other metals to make extremely useful alloys such as brass and bronze.

Copper is a metal that has been deposited from hot sulphur solutions, created in volcanic regions. The hot solutions concentrated the copper up to a thousand times more than would normally be found in rocks. The resultant enriched rocks are called copper ores.

About nine-tenths of the world's reserves of copper are found in just four areas: the Great Basin of the western United States, central Canada, the Andes regions of Peru, Chile and Zambia. In each case, the extraction of copper is of crucial importance to the country. The amount of copper in the ground is relatively small and most of it occurs in low-grade ores that have to be processed twice to extract the copper.

This is why it is important to reuse as much copper as possible, and why about one-third of copper consumed in most industrial countries is recycled from scrap.

Copper is found as the pure metal and in combination with other elements. There are over 166 known copper minerals. Copper minerals are divided into five groups based on their chemistry.

Native Copper
Sulphides – copper in combination with sulphur.
Oxides – copper in combination with oxygen.
Carbonates – copper in combination with carbon and oxygen.
Complex copper minerals – copper in combination with: iron, nickel, cobalt, lead, zinc or silver and other elements.

Volcanogenic Massive Sulphide deposits

Volcanogenic massive sulphide deposits are a major source of copper, zinc, lead, silver and gold. These deposits have been found actively forming at a temperature of 350°C. Hydrothermal vents on spreading ocean bottom ridges, such as those found in the eastern Pacific Ocean, are actively precipitating metal sulphides. These deposits are formed by the discharge of solutions into the seafloor.

Porphyry Copper Deposits

A Porphyry Copper Deposit derives its name from a porphyritic stock located at the center of the mineral deposit. A stock results from a cylindrical mass of magma, which moves up through the Earth's crust underneath a strato-volcano and cools. In a porphyritic rock, some of the minerals are very large crystals (up to 10 cm in length) and the rest are microscopic. Generally we find that the upper parts of the strato-volcano have been eroded away. The surrounding country rock, which has been intruded by the stock, is often metamorphosed by heat and pressure. During this metamorphism sulphide minerals form in the rocks surrounding the stock. Heat and pressure causes preexisting rocks to be altered into a new type of rock. An enriched mineral blanket or oxidized zone will then form near the surface of these deposits.

The porphyritic stock at the center of the system may not contain enough of the copper minerals to be an ore deposit. The rock that surrounds the stock however may be rich in copper mineralization.

The porphyritic stock is the engine that allows the development of the minerals. The ore minerals are found in a series of zones radiating outwards from the stock. Each of these zones contains a specific suite of minerals. These minerals include azurite, malachite, gold, silver, chalcocite, and chalcopyrite.
The largest porphyry copper deposit of

Ragging, riddling, spauling and cobbing copper ore in Redruth, Cornwall in the 19th Century.

the Canadian Cordillera is approximately one billion tonnes with grades just under 0.5 % copper; most are much smaller. At the present time, approximately half the world's copper reserves, 60 % of Canadian copper resources, and 90 % of British Columbia's reserves are contained in porphyry deposits.

Oxidized Zone Minerals

Copper generally starts as chalcopyrite, a sulphide, which is then oxidized and enriched by interaction with the atmosphere, naturally acidic rainwater and nearby rocks and minerals. The top of an enriched copper deposit is a spongy mass of iron oxides left behind when iron sulphate and sulphuric acid are removed from sulphide minerals. The liquid generated then converts the copper sulphides into copper sulphate, starting a chain reaction. As the copper sulphate solution trickles down through the unsaturated zone of the deposit (where air and water are available) the reaction continues. If the solution contacts limestone or other rock containing calcium, the copper sulphate will react to form malachite and azurite which are copper carbonates. It can also react with copper sulphide (chalcopyrite) to form bornite and chalcocite.

Oxidized zones reach considerable depths in arid regions. The bottom limit of the oxidized zone is always at the water table (where the saturated zone begins). Oxidation stops here and without oxygen the reaction cannot continue. Other reactions take place as the copper sulphate reacts with the copper sulphides. The copper sulphides are enriched from 34 % copper in chalcopyrite to 66 % in covellite, one of the minerals formed in this enriched zone. By this process, copper is taken from the upper parts of an ore body and deposited at the water table. Below the enriched zone, the sulphides may not be concentrated enough to carry the cost of deep mining. Oxidized zones are found in arid regions of the United States, Mexico, Peru, Chile and Africa. Many attractive and colourful minerals are found in oxidized zones of copper deposits.

Casting copper
Karnak, Egypt,
1450 B.C.

Pouring molten copper into ingot molds, Calumet — Hekla Mines, Calumet, Michigan.

Uses for Copper:

Copper is second only to silver in its ability to conduct electricity (and is far cheaper and more abundant).
Bacteria will not grow on copper.
Copper is essential to human beings as a micronutrient in our diets. It is used by the body to form bone cartilage, tendons and the sheathing around nerves. It is also a critical element in the manufacture of hemoglobin in the blood of higher animals.

About nine million tonnes of copper are used every year in a wide variety of ways. About half of all copper is used in the electrical industry.

Alcohol stills
Batteries
Bonsai trees — training wire
Boilers for electric power generation
Cash registers
Church bells
Circuit Boards
Clocks
Coins
Computers
Cookware
Conductor fittings — grounding rods for high voltage and lightening rods
Copper Cathodes
Decorative Metalwork
Electrical Industry
Engine gaskets
Gold paint on packages
Hinges
Jewellery — costume jewellery
Locks
Moulds for plastics
Musical Instruments
Paper manufacturing equipment
Pigments — green or blue colours
Printing plates
Printed circuit boards for computers
Refrigerators
Roofing
Ship building
Surgery
Thermostats
Tooth brushes — to hold the bristles in
Vehicle Radiators,
hydraulic tubes for brakes
Watches
Water Pipes
Wiring — electrical and telephone
Zip fasteners

In North America
40 % of copper produced is used in construction
24 % for electrical and electronic products
13 % Transportation equipment.
12 % Industrial machinery
10 % Consumer and general products.

Famous Copper deposits
Keweenawan Copper is associated with lava flows and conglomerates in the Keweenaw Peninsula of Michigan. This deposit is also seen at Mamainse Point, north of Sault Ste Marie. The copper was deposited mainly in conglomerates and flows of basalt, especially near the tops of the flows where the rock has gas bubble holes (vesicles). Hot water, containing sulphur and copper, migrated upwards through the basalt flows and moved across the top of the lava flows where it was sealed by the impermeable bar-

Drawing copper wire by water power in the 16th century.

rier of the overlying flow. Hematite (iron oxide) in the lava oxidized the sulphur, depositing copper. The iron and sulphur were carried away as iron sulphate.

Sometimes the copper was deposited in fractures in the rocks. Some masses formed in fractures are of unusual size. The largest of these was a mass found in the Minnesota vein on the Keweenaw Peninsula in 1880. The mass weighed 500 tonnes and was 14 metres long, 5.7 metres wide and 2.6 metres thick. These large masses were difficult to mine profitably, so they are still underground!

Copper pebbles and boulders from the Keweenaw Peninsula were moved south by glaciers during the ice age. Copper was used by the native people to make tools. They hammered copper into the desired shape. This hammering made the copper harder just as a blacksmith tempers steel. When tempered in this way, knives could be made which were much better than the stone or bone knives used before.

Copper was used as early as 15,000 years ago. The metal was found as lumps of native copper and could be easily fashioned into jewellery, tools, or cooking and storage containers. The use of copper increased about 5,500 years ago with the discovery that it could be easily mixed or alloyed with other metals such as tin, zinc or lead. These alloys produced bronze and brass with with a variety of useful properties.

Mamainse Point

In Ontario, native copper was first mined nearly 5,000 years ago along the eastern shore of Lake Superior. In the 1600's, Jesuit missionaries noted the widespread use of copper for fashioning jewelry and cooking utensils. These reports noted that pieces of copper were being cut from a large boulder of native copper on Michipicoten Island, near Wawa. Ontario's first copper mine was opened at Mamainse Point, north of Sault Ste Marie in 1770. Sparse ore reserves and a cave in, which caused the first mining fatalities in Ontario, closed the mine shortly after it opened.

Bruce Mines

The first successful copper mine in Ontario opened in 1847 at Bruce Mines on the north shore of Lake Huron, east of Sault Ste. Marie. Chalcopyrite ore was produced from this mine for 50 years. Deposits in the area were extensive and supported several mines, including the Pater Mine which opened in 1954. The Pater mine produced over 36,393 kilotons of copper prior to closing in 1970.

Sudbury

The nickel deposits of the Sudbury area were originally worked for copper. The abundant nickel sulphides in the ore were considered a contaminant and made the extraction of copper difficult. A method for separating the two metals was discovered in 1891, a market for nickel was found and copper was replaced as the primary metal mined in Sudbury.

Manitouwadge

Ontario's next discovery of copper ore was the rich deposits of the Manitouwadge area, north of Lake Superior. James Thompson, a geologist with the Ontario Department of Mines, located several areas of rusty weathering rock called gossan. Gossan, a spongy mass of iron oxides, forms by the weathering of sulphide minerals. Thompson's map and report sparked interest among the prospectors, though most were only interested in the gold potential. Finally prospectors realized the potential for copper in the area and staked what became the Geco and Wilroy Mines (Wilroy Mine is named for two of the prospectors – William Dawidowich and Roy Barker). The Geco Mine, owned by Noranda, is still in operation and has produced nearly 2 billion dollars worth of metals including copper, zinc and gold.

14th century brass cannon.

Timmins

Kidd Creek Mine in Timmins was found in 1959 by an airborne electromagnetic survey. Drilling, started in 1963, outlined what was the largest base metal mine in the world. Falconbridge's Kidd Creek Mine continues to produce most of Ontario's silver, zinc and a large percentage of the province's copper. Other products include indium and sulphuric acid.

Copper Alloys

Brass —

Brass is one of the most widely used alloys. It is mainly copper, alloyed with between 5 and 40 per cent zinc. Brass is often used for corrosion-resistant decorative purposes such as door handles, locks and knockers. It is much harder and stronger than copper and it will machine well.

A form of brass can be made that changes its shape above a certain temperature and returns to its original shape when it cools down. This "memory" brass can be used to operate safety devices and other applications. It is used, for example, in the automatic switching devices in many electric jugs and kettles.

Uses for Brass:
Curtain Rods
Decorative Items
Electronic connectors — cable T.V. etc.
Electric Jugs and Kettles
Fasteners — screws, nuts bolts and locks
Musical Instruments
Plumbing, taps and pipe fittings
Pots & Pans

Bronze —

Bronze is an alloy of copper that is significantly different from brass. Bronze is a copper alloy with tin as its major secondary constituent.

Bronze has been used since ancient times for decorative metal objects and also for coins. It was one of the earliest metal alloys used, giving rise to the first metal-working age, known as the Bronze Age, over 3000 years ago. Bronze Age people, however, did not know about alloying (mixing) metals, but used copper ores that naturally contained tin impurities.

There is a wide range of specialized bronzes, each one having its own distinctive properties. The brittleness of bell-making bronze makes bells liable to crack. However, this disadvantage is outweighed by the particulary sonorous tones made by the metal.

Uses for Bronze:
Bearings used on moving parts in motors, vehicles and heavy machinery.
Bells
Cannons
Coins
Gunmetal
Olympic Medals
Sculptures
Statues

WEB Resources

A Short History of Metals
http://neon.mems.cmu.edu/cramb/Processing/history.html

Ancient Copper mining in Cyprus
http://kypros.org/PIO/features/history/copper_mining.htm

Copper as Commodity: Past and Present, The Uses of Copper
http://www.azcu.org/cucommodity/factsheet1.html

Copper: The Red Metal
http:www.unr.edu/sb204/geology/copper2.html

Phelps Dodge Morenci, Inc.
From Arizona Ore to Copper for the World
http://morenci.phelpsdodge.com/history/arizona_ore.asp

Seaman Mineralogical Museum Michigan Technological University
http://www.geo.mtu.edu/museum/

Sixty Centuries of Copper
http://60centuries.copper.org/

What is a Porphyry Copper Deposit?
http://www.geo.arizona.edu/geos256/azgeology/porphyry.html

Copper recovery in the middle ages
http://www.rhosybolbach.freeserve.co.uk/midages.htm

Copper ingot, made from Pewabic Mine ore, Keweenaw Peninsula, Michigan.
This ingot was recovered in 1974 from the Pewabic steamer which was lost in 55 metres of water off Alpina, Michigan, in 1865.

Junior Miner of Ontario Competition

Inspire Your Students to Bring Earth Science to Life!

Earth materials are used in every facet of our lives. A walk through city streets provides an opportunity to observe various stones used in buildings, roads and pavements. Our homes, transportation systems and machinery contain metals derived from ore deposits. From computers to toothpaste, minerals are used in such a variety of products. We need only to observe objects used in everyday life to discover the unique and essential role Earth Science plays in today's rapidly changing world.

The **Junior Miner of Ontario Competition** is an annual contest held by ***Prospectors and Developers Association of Canada Mining Matters (PDACMM)***, and is intended to inspire students to discover the importance of rocks, minerals, metals and mining and the roles they play in our everyday lives. The competition features the outstanding work of students in grades 4 and 7 who submit a written composition describing why Earth's rock and mineral treasures are important in our day-to-day lives. Teachers that include this exciting competition in their yearly planning will provide students with a unique opportunity to be recognized for their interests and talents in the area of Earth Science.

Entries should be based on a solid knowledge of foundation concepts, be correct in all aspects and be presented in a unique and effective manner. Projects, essays, poems, stories, articles or other artistic expressions such as posters or photographic essays, are all equally encouraged. Creativity is very important. Small group or class projects may also be submitted for consideration. Written submissions may be in English or French, but must be no longer than 250 words, typed and double-spaced. Artistic expressions should be one page no larger than 11" x 17". The competition is limited to students residing in Ontario. Entries must be received before **June 1, 2003**. A team of teachers and Earth Science professionals will review submissions for each grade level and contact the winners before the end of the school year. Certificates of Achievement and cash awards will be mailed to the winners.

Visit www.pdac.ca/miningmatters to download a copy of the Competition Application Form.

Prizes

The cash awards will include five standards of achievement as follows:

	Grade 4	Grade 7
Diamond	$150	$150
Platinum	$125	$125
Gold	$100	$100
Silver	$75	$75
Copper	$50	$50

Mail your final submission along with the completed Competition Application Form to:
Prospectors and Developers Association of Canada Mining Matters
Junior Miner of Ontario Competition
Suite 1500, 120 Adelaide Street West
Toronto, ON M5H 1T1

Since 1994, ***PDACMM*** has equipped teachers across Ontario with information and resources that inspire students to unearth the importance of rocks, minerals, metals and mining and the roles they play in their everyday lives. This unique collaboration between teachers, minerals' industry professionals and Ontario government geologists has lead to the development of a series of educational resources to meet the high standards of the teaching profession in Ontario and to provide students with an exciting means to investigate Earth Science, including Ontario's geology.

Building on the success of ***PDACMM's*** original Mining Matters unit, subsequent units for grade 4, ***Deeper and Deeper***, and grade 7, ***Mining Matters II – The Earth's Crust***, have been designed to meet 100% of the Ontario Science and Technology Curriculum Expectations for the topics "Rocks, Minerals and Erosion" and "The Earth's Crust".

For further information about the programs of ***PDACMM*** please contact Laura Clinton, Project Coordinator, at **416-943-6278** or **pdacmm@teckcominco.com**

Sedimentary Rocks

In the last issue of *What On Earth* I covered the classification of igneous (or fire-formed) rocks. In this issue I would like to explore the topic of sedimentary rocks. This is the second great family of rocks and they are of interest to humans because they have provided many tools in the past and today give us most aggregate resources as well as providing (or housing) many of our energy minerals, and certain essential minerals of major economic importance. Sedimentary rocks are also of significance since they house the fossil record of life on Planet Earth.

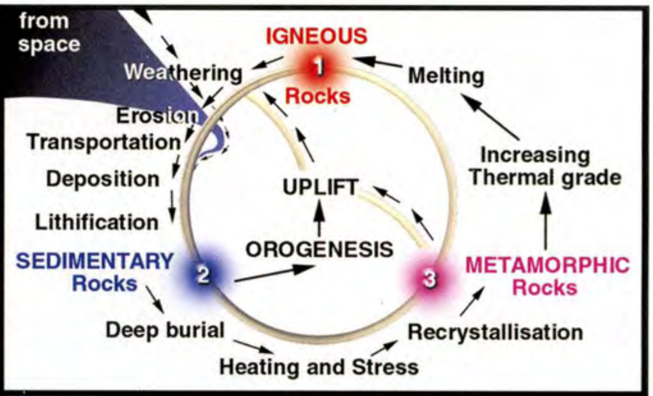
As their name suggests, sedimentary rocks are derived from pre-existing sediments. Two issues back in WAT ON EARTH I described the Rock Cycle; how rocks are broken down from still older rocks by weathering and erosion. The liberated grains are carried or transported by various mechanisms to a place where they accumulate in sequences of sediments. There are many transitional resting places, but ultimately most sediments end up in a marine depositional environment. Sedimentary rocks can therefore be composed of grains of various sizes, shapes and compositions that have been cemented together or compressed and recrystallised. These are the clastic sedimentary rocks. Other sedimentary rocks can be formed from deposits secreted by chemical solutions (chemical precipitates), or from deposits made up from the remains of dead organisms (both animals and plants). This last group forms sedimentary rocks of largely biological origin. Post-depositional change from sediment to sedimentary rock is called diagenesis, and the end result is usually lithification, where the former unconsolidated sediment is turned to rock. Two processes are common; compaction (where the sediments are compressed and water is driven from the pore spaces between grains), and cementation. Cementation is where certain minerals (for example, calcite, iron oxides and silica) get carried by percolating groundwater into the pore spaces. Here they precipitate and eventually cement the grains together.

As in the last copy of *What On Earth*, the centre page of this issue is devoted to an illustration of many of these different rock types. The page opposite illustrates several features associated with sedimentary rocks.

Clockwise around the page: top left — photograph of a group of Waterloo students examining a section of Carboniferous beds at Mullaghmore Head in northern Ireland. The section consists of alternating sandstones, siltstones and shales. The softer shales have been more easily eroded whereas the sandstones stand out as resistant beds. Top right —diagram illustrates the position of the sedimentary rocks (2) in the rock cycle. Note that there is an input from space that adds, particularly, to marine sediments. Immediately below the rock cycle diagram is a chart illustrating the Wentworth classification in terms of grain size and how the sediments form different sedimentary clastic rocks. Compare this chart with the first two columns (Sediments and Rocks) that make up the "Clastic Rock" portion of the centrefold Chart. The third and lowest diagram illustrates some of the more important sedimentary rocks that are either of chemical or biological origin. Most of these are also illustrated on the centrefold page. The bottom photograph illustrates Delicate Arch in Arches National Monument in Utah. This 26m high by 20m wide structure is made up of Entrada Sandstone of Upper Jurassic age. The feature has been produced by the erosion of "fins" of local bedrock that have been cut away by wind and frost action. Immediately above is a view looking down the Niagara Gorge where the water from Lake Erie falls over the edge of the Silurian Lockport Dolomite on the Niagara Escarpment. Each of the photographs illustrates geomorphology associated with sedimentary formations of various ages.

Centre fold page: Understanding sedimentary rocks is fairly simple since they relate to materials that we see on a daily basis. At the top is a panoramic view across one zmentary rock in the world, in the upper levels of the Grand Canyon. Practically all of the rocks that you can see are horizontal sandstones, limestones and shales deposited over about 250 million years in the seas of the Paleozoic Era. These same seas were occupied elsewhere by the giant trilobites illustrated in another article in this issue.

Moving lower on the centrefold page, I have tried to illustrate most of the common rock types. A few are more "exotic" but they are also important. The chart is divided into three sections that relate to clastic, chemically precipitated and biological sedimentary rocks. The left hand block consists of a double column. The first column illustrates examples of the sediment type (refer back to diagram 2 on the previous page), and the second column to their lithified equivalent. Angular clasts (rock fragments) are usually derived from frost shattering. The fragments have not traveled far and are usually moved under gravity, falling off mountains to accumulate as scree piles or talus cones at the bottom of slopes. Their counterparts are found in the rock type known as breccia. When the agents of erosion become involved and transportation takes place, particularly by water, the angular clasts become abraded, and form rounded boulders or cobbles. The rock equivalent is known as a conglomerate. Long distance transport gradually reduces the size of the clasts through granules to sand-size particles. The rock equivalent is sandstone. These are frequently cemented by different minerals, calcite, iron oxides or silica. The sandstone then acquires a secondary descriptor, such as "calcareous sandstone", or "ferruginous sandstone". A sandstone is normally made up of silica grains. When these grains are cemented by silica a different name is given — quartzite (see image to the right of sandstone). One rock type that is not illustrated is an arkose — a sandstone with more that



WENTWORTH SIZE CLASSIFICATION

Clast Name	Size (mm)	Rock Name	(Angular)		(Rounded)
BOULDER	256		BRECCIA		CONGLOMERATE
COBBLE	64		BRECCIA	1	CONGLOMERATE
GRANULE	4		BRECCIA		CONGLOMERATE
SAND	2	SANDSTONE *		2	
SILT	1/16	SILTSTONE			
CLAY	1/256	MUDSTONE / SHALE *		3	

COMMENTS

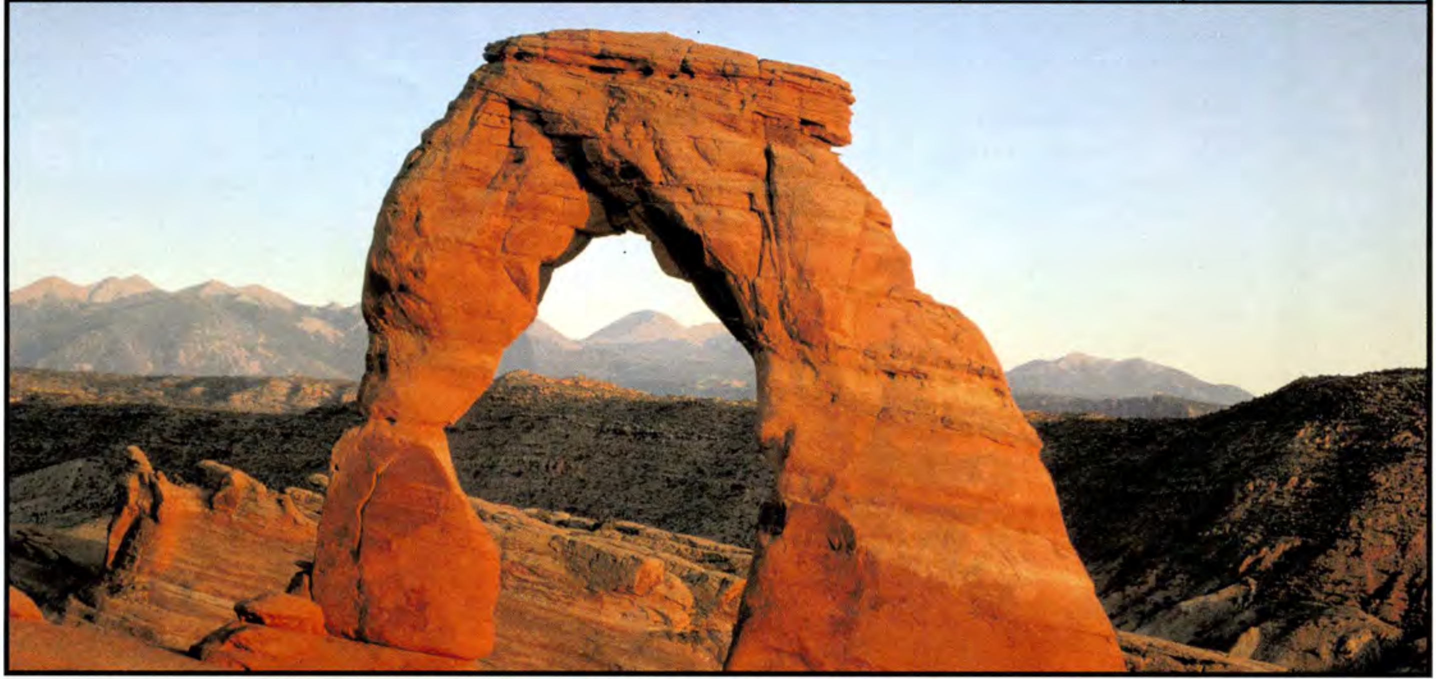
1 Rocks in size category 1 are also called Rudaceous; 2 = Arenaceous; 3 = Argillaceous

2* SANDSTONES are qualified by the nature of their cements. These might be siliceous, and the rock-type is then QUARTZITE, a carbonate-rich cement will provide a CALCAREOUS SANDSTONE, and an iron-rich cement will produce a FERRUGINOUS SANDSTONE.

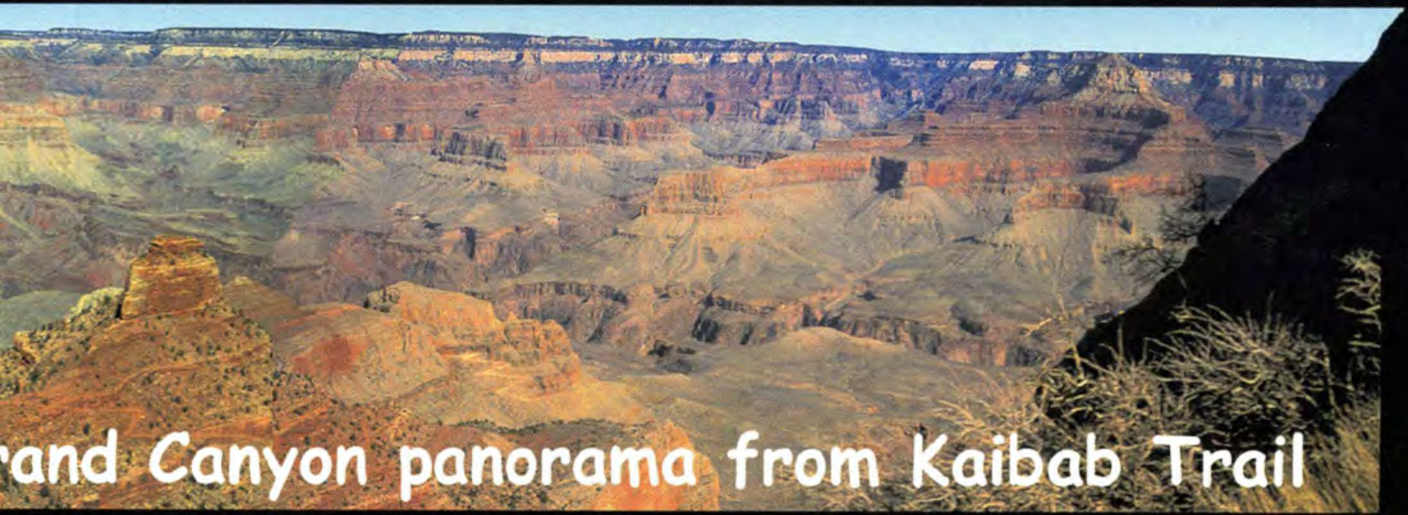
3* The bulk composition of the rock will also provide an additional descriptor, for example a CALCAREOUS MUDSTONE, or a BITUMINOUS SHALE.

Common Sedimentary Rocks

Rock Name	Composition	Comments
ROCKS LARGELY OF CHEMICAL OR BIOCHEMICAL ORIGINS		
Limestone	Mainly $CaCO_3$	Forms about 10 percent of all sedimentary rocks. Common rock type in Rockies.
Travertine	$CaCO_3$ with some impurities	Also known as calcareous tufa or dripstone. Common in caves, along calcareous springs.
Dolostone	Mainly $CaMg(CO_3)_2$	Seen in many parts of the Niagara Escarpment and in Rocky Mountains, W. Canada.
Chert, Flint	Mainly SiO_2 with some impurities	Often found in thin veins and nodules in limestone(chert) and chalk (flint); tool use.
Gypsum	$CaSO_4$	Very soft and soluble rock; principle use is in construction (gyprock) and fillers.
Rock salt	NaCl	Important economic mineral, made up of halite. Mined or pumped as brines.
ROCKS LARGELY OF BIOLOGICAL ORIGIN		
Coquina	$CaCO_3$ with some impurities	Shelly limestone, usually made up of broken fragments of calcareous shells of *Coquina*.
Chalk	Almost pure $CaCO_3$	Very pure, soft limestone, made up of the remains of calcareous microfossils.
Coal	Carbon with some impurities	Plant detritus that has accumulated under anaerobic conditions in lagoons or swamps.

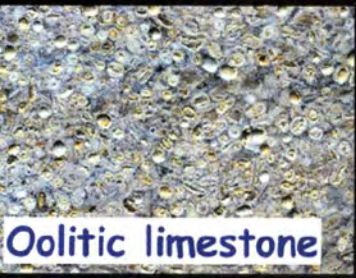



Fine
CLASTIC ROCKS
Coarse
Angular clasts
Breccia
Rounded cobbles
PENTAX
Conglomerate
Sand
Sandstone
Silt
Siltstone
Clay
Shale
CHEMICAL SEDIMENTARY ROCKS
Limestone
Dolostone
Quartzite
Gypsum
Rock salt



rand Canyon panorama from Kaibab Trail

© A.V. Morgan



Oolitic limestone

Travertine

Chert

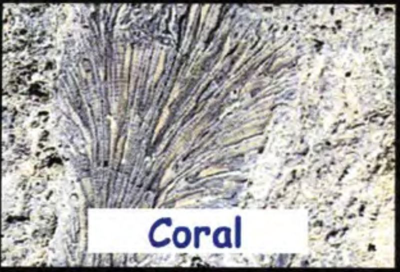
Marl

Banded ironstone

BIOLOGICAL SEDIMENTARY ROCKS

Coquina

Shelly limestone



Coral

Chalk

Peat

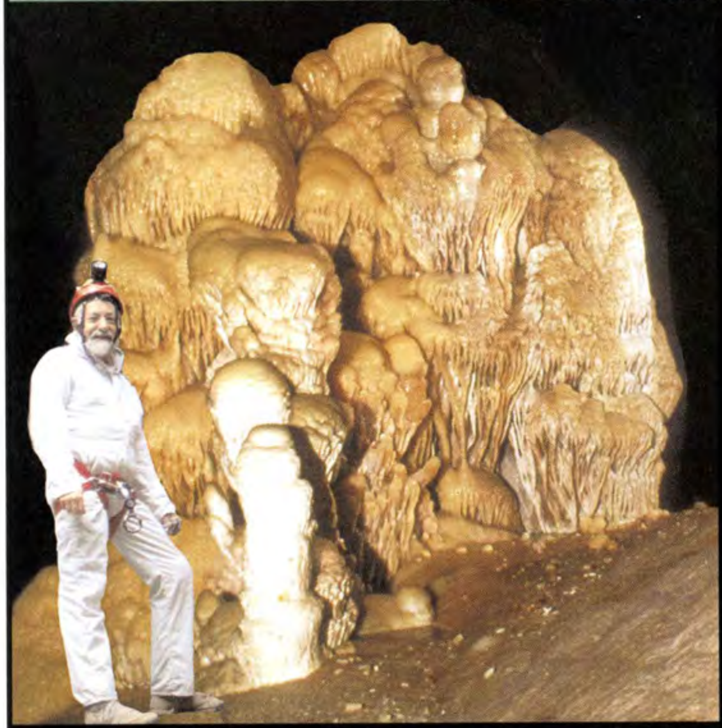
Lignite (coal)

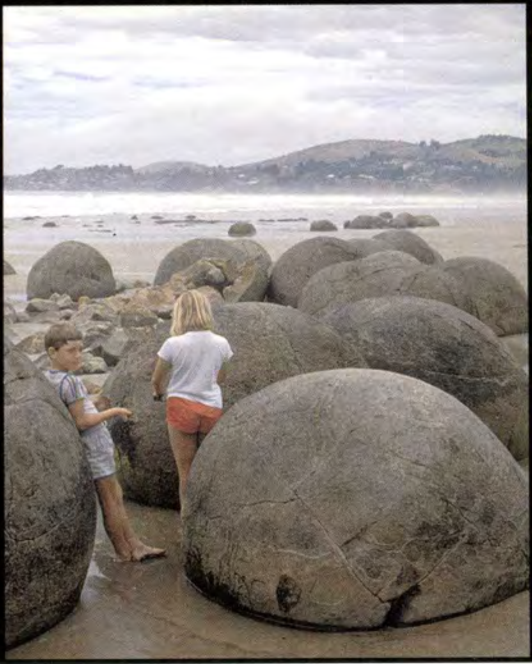
Bituminous coal

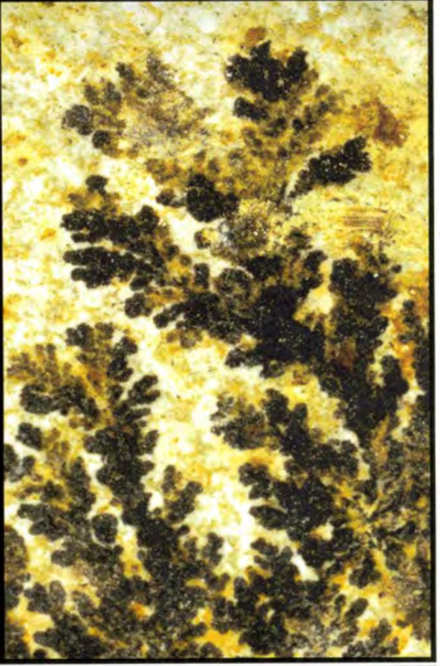
Anthracite (coal)

Fossiliferous shale

Oil shale







25 percent of the rock made up of feldspar. Such rocks are usually formed in montane, relatively dry, environments. Dry, because the clasts have not deteriorated too much (under hot, wet conditions feldspar is often easily weathered). The angular nature of the grains indicates that transport has not been that important.

However, if the sediment continues to be transported the grain size is still further reduced and silt is formed. Particle sizes are now reaching the point where they can easily be transported by wind as well as water. The wind-transported sediment that accumulates as loess falls into this category. The rock type known as a siltstone, is formed of very fine quartz, mica and other miscellaneous minerals, and is the lithified equivalent of silt. Finally the finest fraction in the clastic size range is clay. These fragments are so tiny they remain in suspension for a long time, usually only settling after they have coalesced to form larger particles. When they do accumulate the lithified rock type is known as shale. Highly organic equivalents can form very black shales with distinctive "oily" or "petroliferous" odours, since they are very rich in carbon and aromatic compounds. They form fossiliferous and "oil shales", that might be future sources of petroleum.

The second double column block illustrates rocks that are formed by chemical deposits. Such rocks are formed where material is carried in solution to the place, most usually a marine basin or a lake in a desert area, where water is evaporating. Solutions of certain ions are precipitated and form rocks rich in calcium, magnesium, silica, sodium, and (more in the past) iron. Some of these are illustrated, starting with the calcium-rich precipitates.

Limestones are an important example. All limestone fizzes easily when dilute (10% solution) hydrochloric acid is applied since the acid reacts with the calcium carbonate. The example shown is a grey, fine-grained limestone with white veins of calcite running through it. In warm tropical waters abundant calcium in solution in seawater subject to strong current movements may be precipitated around minute shell fragments. These can form oolitic limestones, when small grains of calcium carbonate have layers of calcite deposited in a concentric fashion around a nucleus.

Dolostone, a rock made up of calcium and magnesium, is closely related to limestone usually with the magnesium from the seawater replacing much of the original calcium content of a pre-existing limestone. Acid reaction is slower. Dolostones can be seen close to Waterloo in certain rock sequences along the outcrop of the Niagara Escarpment. Travertine and tufa (strong acid reaction) are chemically precipitated rocks formed from calcium carbonate. Travertine is usually dense and banded, while tufa is more spongy. Travertine (in the form of speleothems) is most frequently seen in cave deposits, particularly in the spectacular formations known as dripstone, flowstone, stalactites, stalagmites, helictites and columns.

Within limestones and dolostones you can frequently see layers or nodules composed of silica. These are layers of chert, or, in the case of the chalk, flint. Flints have been used since the Paleolithic with well known mass production sites for spear points, scrapers, arrowheads and tool kits described in the archeological literature from eastern England. They were also used until recently in firearms (flint-lock rifles) and in the construction of buildings where this rock type is common. Cherts from limestone and dolostone beds along the Niagara escarpment were used by Paleo-Indian hunters of caribou, mastodons and mammoth in southwest Ontario. Both flints and cherts are usually grey in colour (although they might range from almost white through buff to almost black or even red) and split with an even to slightly conchoidal fracture. The one thing they have in common is that they can be shaped by skilled tool makers and will retain an incredibly sharp edge for a long period of time.

Gypsum is a chemical precipitate (hydrous calcium sulphate) frequently found in beds of marl, a calcium-rich, clay-dominated, rock type. Beds of marls containing gypsum and rock salt were originally deposited in areas with high evaporation that were flooded by marine waters. Such areas today can be seen along parts of the sub-tropical Persian Gulf. Rock salt (made up almost entirely of sodium chloride) is an important economic mineral. In Ontario it is found around Windsor and northward to Goderich (see WAT ON EARTH 14 (2) Spring 2001). Salt deposits are also found in the Maritime provinces and also in western Canada. The western Canadian salt sequences are dominated by another economically important, red- and white-coloured salt rich in potassium, known as Sylvite. The last rock type illustrated in this group is the red- and grey-banded sedimentary ironstone, common in the region around upper Lake Superior. There is a vast literature associated with these deposits (Blatt *et al.*, 1980), but generally they are of Precambrian age and usually between 2600 and 1800 million years old. Some are considerably older and a few small deposits are younger. They are characterized by thin and thick bands of alternating jasper (red chert) and magnetite- and haematite-rich layers of iron. Other forms of iron may also alternate with the cherty horizons. These are economically important rocks and are the source of major iron deposits on both sides of the Canada/USA border.

The third block of images comprises common sedimentary rocks that have a strong biological component. As I mentioned when discussing igneous rocks, nature abhors being "compartmentalized" and some of these "boxes" transgress boundaries. However, seawater contains large quantities of calcium carbonate that not only precipitates to form the chemical sedimentary rocks but is also utilized by organisms that build carbonate shells. When they die the shells can make up huge deposits of shell-detritus that often gets preserved as "shelly limestone". This can be seen today in the form of coquina (made up almost entirely of complete or broken valves of the marine shallow water pelecypod, *Coquina*). In the past clams were not as common as they are today. The "Shelly Limestone" illustration shows brachiopods in a Devonian carbonate mud deposit from the Arkona region of southwest Ontario. Crinoidal limestones (not illustrated), are made up of fragments of the stalks of crinoids (Echinodermata) and form shelly-detritus bands in certain rocks along the Niagara Escarpment. Coral, made up of the remains of countless trillions of carbonate-secreting polyps, form massive deposits today as in the Great Barrier Reef, and also in the more distant geological past. Many of the drilling targets for oil and natural gas in southern Ontario (and elsewhere) are aimed at small patch reefs of corals and algal communities, where the porosity within and between the fossil organisms have allowed these energy minerals to accumulate. Chalk is a particularly pure limestone, and dilute hydrochloric acid applied to this rock type produces an extremely vigorous reaction. Chalk was originally formed as seafloor ooze, and made up with the remains of trillions of foraminifera organisms known as coccoliths. Electron scanning images are provided next to the chalk image, with the central, cream-coloured organism, providing an example of the modern calcareous foraminifera called *Globigerina.*

The next block of four images (peat to anthracite) illustrates another energy mineral —coal. Coal results from the accumulation of vegetation under anaerobic conditions. The detritus forms in swamps or lagoons and creates a water-saturated organic bed of peat. With time and compaction from overlying sediments, the peat looses water and other volatiles. The moisture content falls, the carbon content rises and peat changes to brown coal or lignite. These are low quality coals, often high in sulphur, not suited to long-distance transport and subject to spontaneous combustion. They form the types of coals found in southeastern Saskatchewan and many of the coals of eastern Germany. With further compaction and stress the carbon content continues to rise, more volatiles are lost, the potential energy output increases and a dull to shiny coal known as bituminous coal, forms. This is an excellent steam-raising coal and was the dominant coal that powered the first century of the Industrial Revolution in Britain. The western Canadian provinces and the former mining areas of New Brunswick and Nova Scotia mined bituminous coal. It is normally used for metallurgical feed and is used in electrical power production. The ultimate stage of coal as an energy mineral is Anthracite, a hard shiny coal that is difficult to burn unless crushed. This coal is mined in Pennsylvania and is used in electrical power production as a feed when mixed with bituminous coal. The changes that accompany the loss of volatiles, the increase of carbon and the increase of heat output is described as a change in the rank of the coal.

The last two images illustrate shale rocks that have high organic contents but are not defined as coals. Fossiliferous shales can contain abundant fossils (particularly plant materials, but they may contain others, such as ammonites). Oil shales (such as those found in a belt from Bowmanville, east of Toronto to the Collingwood region near Owen Sound, Ontario) contain abundant fossils of trilobites and other Ordovician animals. Such deposits, although not necessarily of the same age, are found in many parts of the world and may provide future sources of energy or petrochemical feeds.

Page 14 following the centrefold contains illustrations of several of the topics mentioned in the sedimentary rock descriptions above.

Top Row, left to right. All are examples of chemically-deposited silica: Hand axe made from flint, Swanscombe, Kent, UK; Flint nodule (knobbly white concretion) weathering from softer chalk matrix; Three Clovis-type chert points from the Brophey Site near Parkhill, Ontario. The largest is 10cm in length.

Centre Row, left to right: A large stalagmite (note "g" Grows up from the ground) composed of dripstone (chemically precipitated calcium carbonate deposits); Stalactite (note "c" grows down from the ceiling of a cave), with light-catching calcium-charged water about to drip from the tip; a peculiar, contorted, stalactitic form of dripstone known as a helictite, also made from calcium carbonate. Note that in parts it even grows upward!

Bottom Row, left to right; vug (cavity) with quartz lining centre of void in limestone; some very large chemically-precipitated concretions at Moeraki, South Island, NZ; moss-like dendrites. These are manganese precipitates on a limestone, and have no connection with organic growths.

Alan V. Morgan

A New Exploration of the Canadian Arctic

Ronald E. Seavoy

This new book is a very readable exploration adventure in the Canadian Arctic. The author worked as an exploration geologist for the International Nickel Company in 1960. This book describes new exploration techniques which began to be tested in the mid 1950's. Ronald Seavoy's exploration team used airplanes, helicopters and geophysics during that summer. The Lupin gold orebody was discovered. The book also introduces the reader to some of the interesting natural phenomena encountered during the exploration.

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GEOSCAPE CANADA: engaging the public in the geological issues and heritage of Canadian communities .

***Figure 1**. Vancouver geoscape poster.*

The Geological Survey of Canada produces large-format information posters and companion websites that describe the local geoscape, or geological landscape, of communities across Canada. Geoscape posters have been completed for Vancouver, Victoria, Québec, Montréal, Calgary, Fort Fraser (northern B.C.), Toronto, and Whitehorse. Others are in preparation for Nanaimo (B.C.), Winnipeg, Ottawa, Halifax, Grand River basin (southern Ontario), Southern Saskatchewan, and Nunavut. Posters and websites are produced in both English and French language versions.

The aim of Geoscape projects is to increase understanding of local geology and geoscience issues among students and the general public. Increased geoliteracy in communities will result in better land-use decisions concerning resources and environmental issues, such as:

- protection of groundwater and surface water supplies,
- mitigation of natural hazards such as floods, landslides, earthquakes, and radon gas,
- development of earth resources such as aggregate and minerals.

***Figure 2**. Québec geoscape poster.*

Geoscape projects are produced and delivered with the support of a vast network of partners, that include educators, provincial and municipal government agencies, and the private sector. The projects are based on the following principles:

1- Geoscapes focus on well known landscape features and their geological significance.

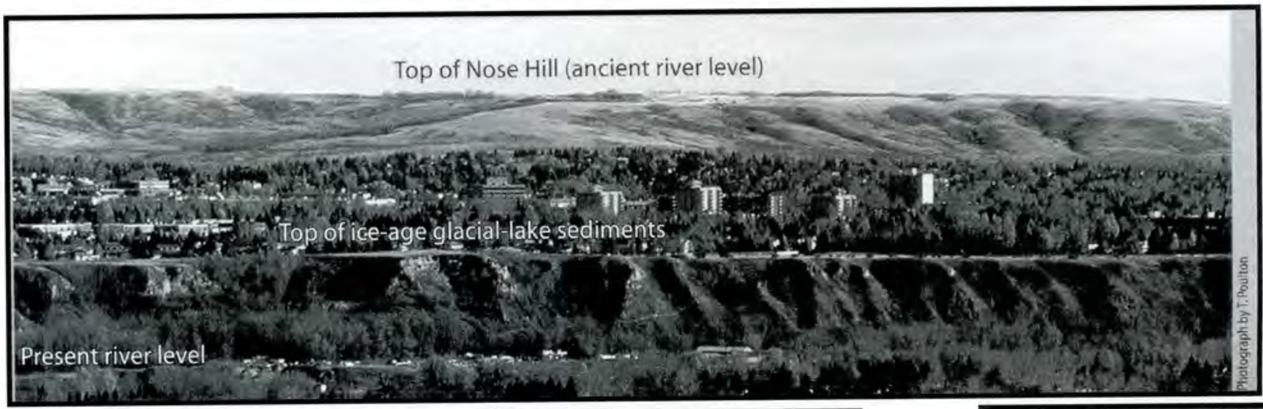


Figure 3. *Thrust fault origin of mountains near Calgary.*

Figure 4. *Is Mount Royal in Montreal an ancient volcano?*

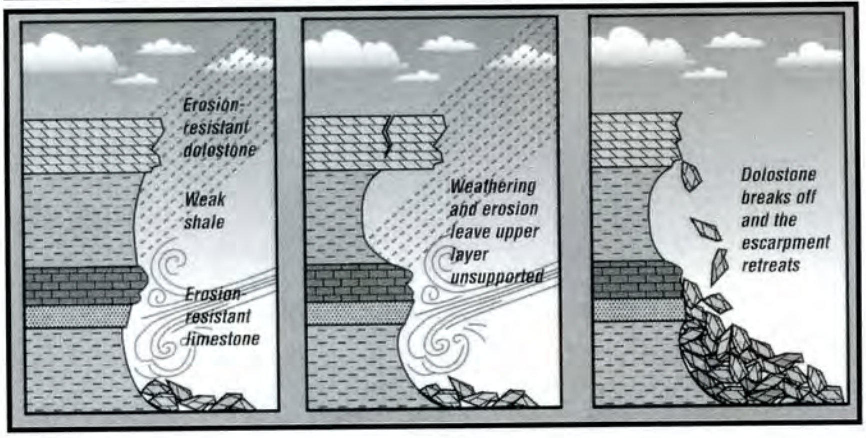


Figure 5. *Formation of the Niagara Escarpment near Toronto.*

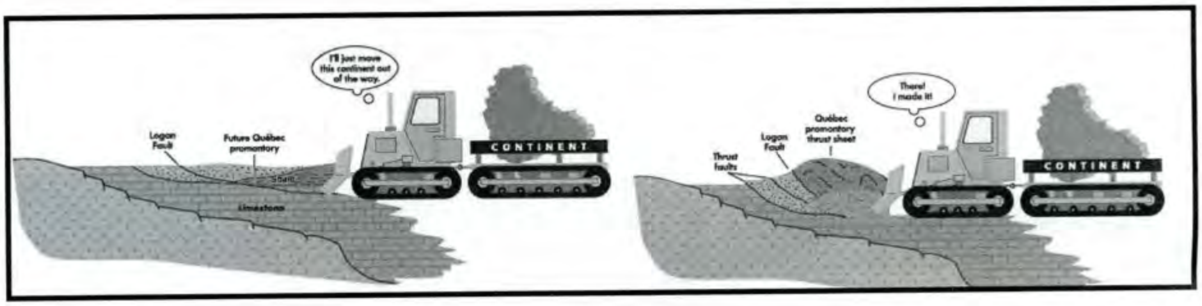


Figure 6. *Geological thrusting responsible for the Upper Town and Lower Town in Québec City.*

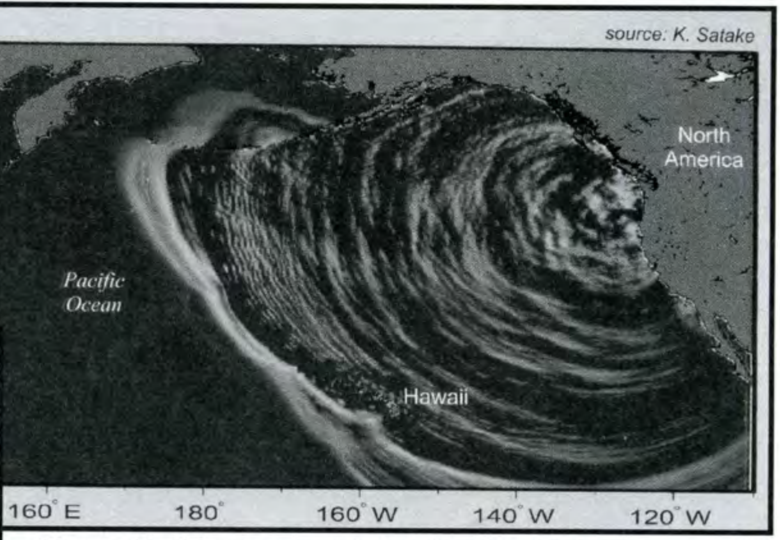
2- Geoscapes show the link between the regional and local geological history and social, cultural, and economic development.

Figure 7. *Before and After: Conversion of an old limestone quarry into the world-famous Butchart Gardens near Victoria.*

Figure 8. *Calgary: quarrying of stone to build the city.*

Figure 9. *Rocks that are part of our history: Quebec City building stone from the Appalachian Mountains.*

3- Geoscapes address geological issues rooted in the immediate surroundings and the daily lives of residents.



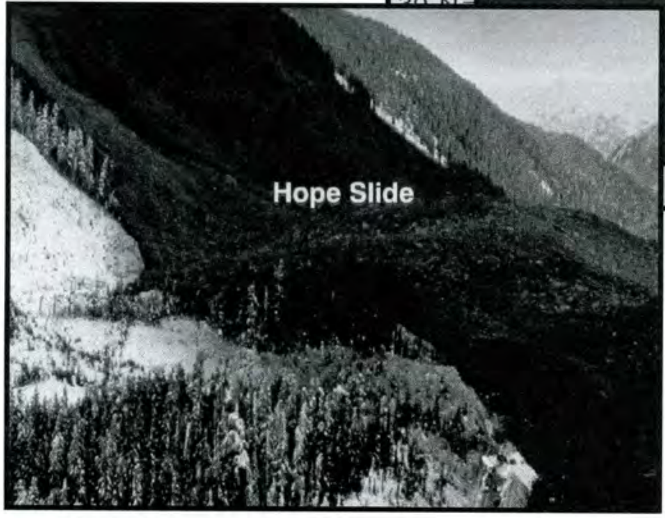
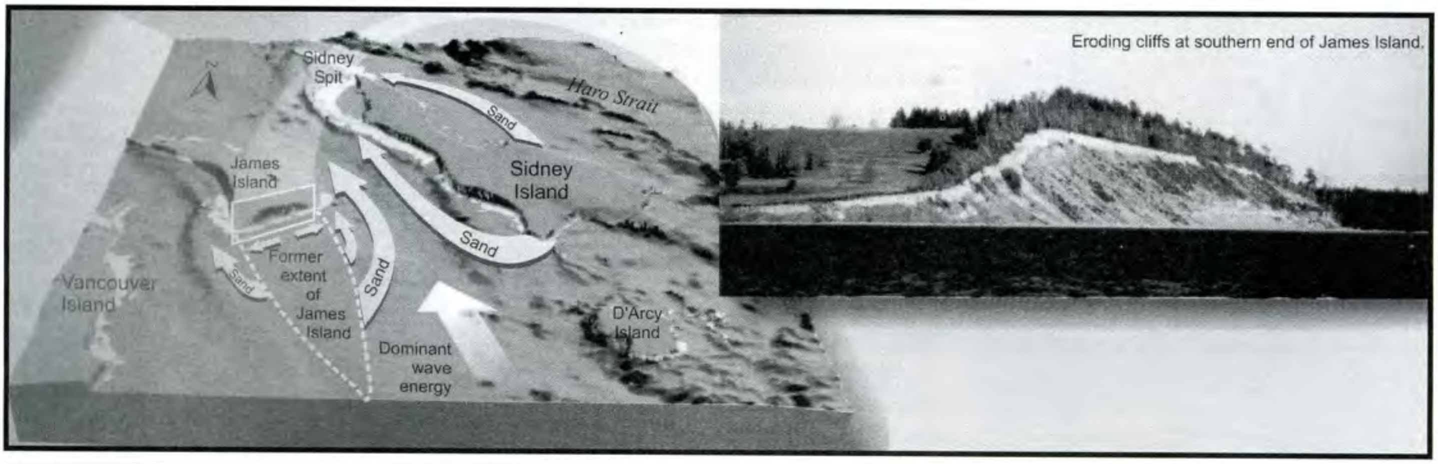


Figure 10. *When a mountain fell: Hope landslide near Vancouver.*

Figure 11. *Waiting for a giant earthquake in Victoria: a model of the tsunami associated with the magnitude 9 subduction earthquake in 1700.*

Figure 12. *Sediments on the move: coastal erosion of an island near Victoria.*



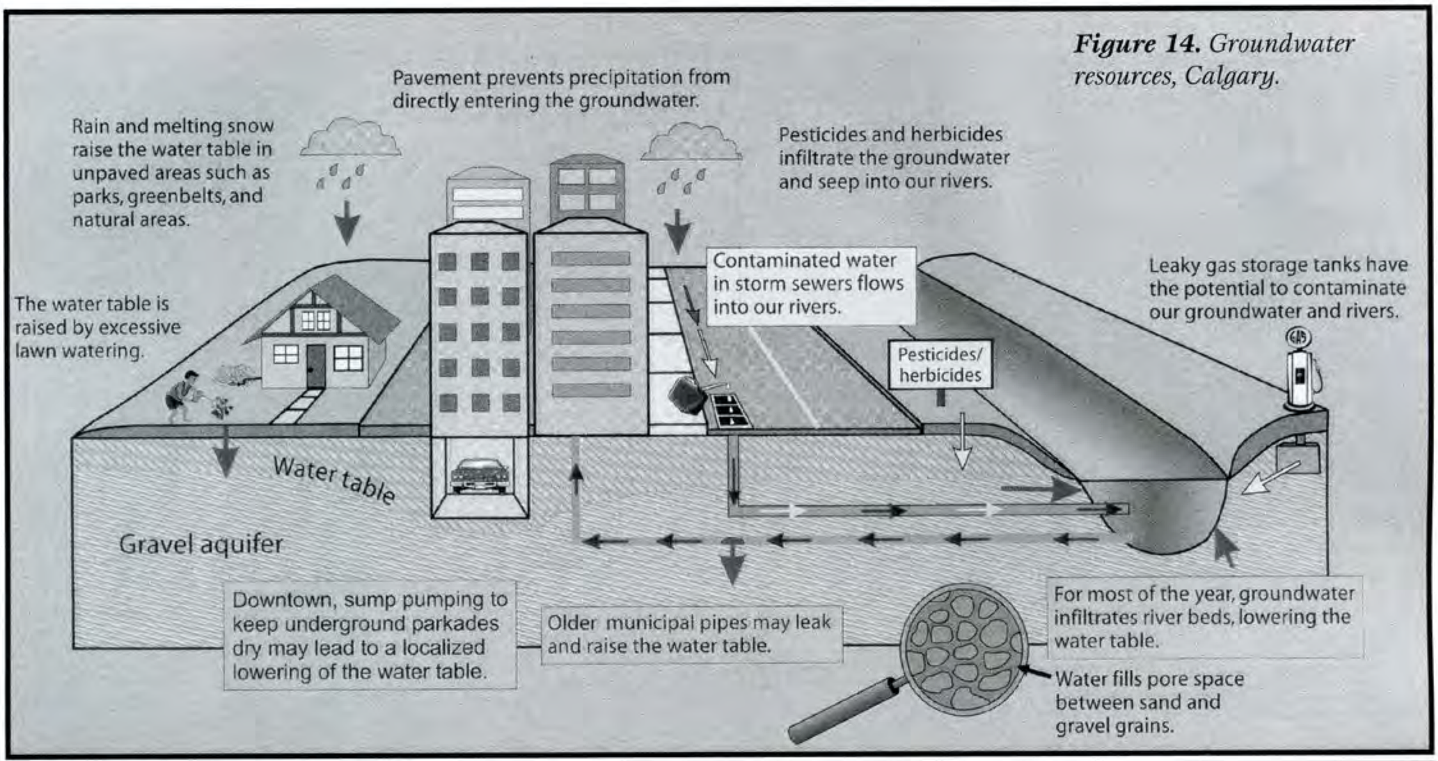


Figure 14. *Groundwater resources, Calgary.*

4- Finally Geoscapes cover themes related to resources and their relationship to local geology.

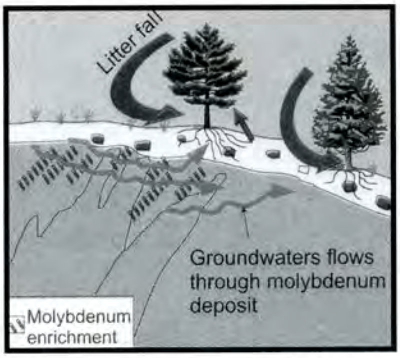


Figure 13. *Molybdenum in the environment: Fort Fraser area, northern British Columbia.*

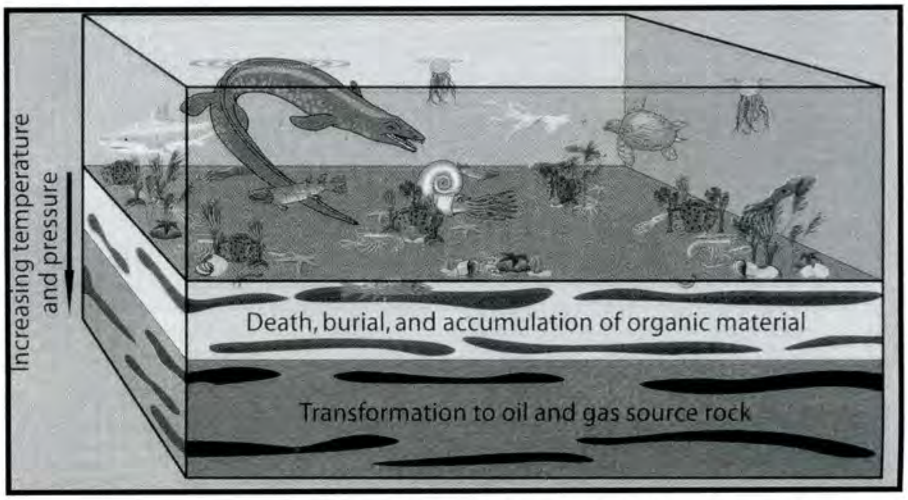


Figure 15. *Burial of marine life produces oil and gas: fossil fuels in Alberta.*

Conclusion

Canadians are increasingly faced with the problem that decision-makers deal with hazard and resource issues without an understanding of geology. The Geoscape project has been developed to provide geoscience information to educators, environmental professionals, planners, emergency preparedness personnel, and the general public. More than half of all Canadians live in the poster regions, so the posters will provide substantial benefits to Canada. Based on the Geoscape experience, the Geological Survey of Canada is presently developing a Waterscape project that will complement its groundwater program. Waterscapes will present key scientific information on important aquifers to decision-makers, such as municipalities, in a form they can readily understand.

For more information on the Geoscape Canada project:
http://www.geoscape.nrcan.gc.ca
To order (GSC bookstore) :
http://www.nrcan.gc.ca/gsc/bookstore/index_e.html

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The Isle of Eigg, and Hugh Miller.

Peter Russell

The Sgurr of Eigg

Everyone has special mileposts in their lives where interests take off. My interest in field geology received a burst of energy after reading "The Cruise of the Betsy," a book by 19th century geologist, Hugh Miller.

In August 1962 Fred Waller, a friend and mentor that I had met at meetings of the Leeds Geological Society, in England, traveled to Eigg and explored the island. We used Miller's book "Cruise of the Betsy" as a guide, together with information gathered from other sources.

My wife and I visited the Isle of Eigg again in October 2002 as a 40th anniversary visit. This happened to coincide with the 200th anniversary celebrations marking Hugh Miller's birth.

Why visit the Isle of Eigg you ask? For such a small isle, Eigg is blessed with much of interest: history, geology, scenery and minerals, all within an island 6.5 km by 8.5 km. Eigg is a fragment of a volcano which formed when the Atlantic Ocean was opened by plate tectonic movements (these volcanoes were formed over the mid Atlantic Ridge). The volcanic centres along the west coast of Scotland form a chain of volcanoes from the Isle of Arran in the south, to the Isle of Skye at the northern end.

The dominant feature of the island is the Sgurr. Here the highest part of the island has 375 metres high vertical columnar pitchstone cliffs, 120 metres sheer. The pitchstone flowed down tree covered valleys which had been eroded into the basalt flows. The resistant pitchstone remains as the softer basalt weathers away. Under the Sgurr is a cave, formed by erosion of Eocene sediments. Pieces of fossil pinewood may be found in these sediments.

Along the southern shore of the island pitchstone dikes, looking like ribbons of shiny tar, cut through the basalt flows. There are two caves in these basalt cliffs. In 1577 the population of Eigg was massacred by suffocation in one of these caves.

Pitchstone dike cutting basalt

A fire was built at the entrance to the cave killing 395 people. The fire was set by clansmen from the Isle of Skye who were seeking revenge.

On the northeast coast lies Hugh Miller's reptile bed. Here among the fish scales and teeth, bones of plesiosaurs and ichthyosaurs may be found. As you walk along this coast, the seals take an interest in visitors as they bob their whiskered faces out of the water. Further along the shore, the hull of a coal carrier (puffer) sits near the cliff. The salvage boat lies beneath the sea a hundred yards away after a futile salvage mission.

If I have peaked your interest in visiting my favorite Hebridean island, you may wish to visit and take part in a summer course.

Summer Course "Geology and Landscape in the Inner Hebrides"
9th-16th August 2003.

Glebe Barn Field Study Centre, & independent Hostel, Isle of Eigg, PH42 4RL

Cost £315 (reduced to £275 if you are prepared to share a bunk room.)

Tutor: Professor John Hudson. Recently retired from the University of Leicester, Prof Hudson has spent over 40 years studying the area, and is the author of The Geology of Eigg , and many papers on the subject.

No previous geological experience is necessary. However, long walks are involved and participants must be fit for walking over rocky shores and rough, hilly terrain with some steep ascents.

For details of the accommodation in the charming and characterful Glebe Barn and a booking form, contact: Karen and Simon Helliwell.

Tel/fax 01687 482417
Email: simon@glebebarn.co.uk
Website: http://www.glebebarn.co.uk/

Hugh Miller

Hugh Miller was born in Cromarty, Scotland in 1802. Miller started his working life at 18 years of age as a stonemason. Hugh Miller worked on the rebuilding of Edinburgh after the great fire in 1824. Stone dust from this project damaged his lungs forcing him to return to his home in Cromarty. Once he recovered, he took a job as a monumental mason in Inverness, but soon gave this up to become a bank clerk. He then worked in Edinburgh and Linlithgow. Miller was an evangelical Christian and self-taught geologist who wrote about the history of the Earth with imagination and wonderful descriptions. Some of his geological writings first appeared in the Free Church of Scotland biweekly newspaper "The Witness." Miller edited this publication and near the end of his life contributed 10,000 words of his own to each issue.

Hugh Miller helped to found the Presbyterian Church, and gave it its name, the Free Church of Scotland. His inability to reconcile his religious views with his scientific research, together with the strain of his work and silicosis, led to him taking his own life in a bout of depression. He shot himself in his home on Portobello High Street on Christmas Eve and was buried in Grange Cemetery (Edinburgh), following a funeral attended by thousands.

After his death, his wife, Lydia who was also a writer, finished the publication of some of his books in progress. His well-known geological works are "The Old Red Sandstone," "The Cruise of the Betsey" and "Testimony of the Rocks."

Miller's fossil collection of over 6,000 specimens was the founding core for the Scottish national collection in the Royal Scottish Museum in Edinburgh.

2002 marked the 200th anniversary of Hugh Miller's birth. His life was celebrated during the year, in Cromarty at the Miller Museum and the Isle of Eigg. Symposiums were held in Edinburgh and London by the geological community to celebrate Hugh Miller's contributions to geology.

The father of American landscape conservation, John Muir, named a glacier for Hugh Miller in Alaska; Some Devonian cliffs on the Restigouche River in Quebec also bear his name, as does a fossil species, *Hughmilleria socialis*, a type of euripterid and the state fossil of New York State. The euripterid was named in memory of Hugh Miller at the 100th anniversary of his birth. One of today's greatest Australian palaeontologists, Alex Ritchie, discoverer of the huge Canowindra Devonian fishbeds in New South Wales, always carries a copy of "The Old Red Sandstone" in his pocket. The Miller oil and gas field in the North Sea is still in production.

WEB SITES

http://www.hughmiller.org/
http://www.geo.ed.ac.uk/scotgaz/people/famousfirst260.html
http://www.isleofeigg.org/nature/nature_frame.htm
http://home.tiac.net/~cri/1998/miller.html
http://www.edinburghgeolsoc.org/z_38_04.html

The World's Largest Trilobite; the Waterloo connection!

Figure 1: A very large *Isotelus* trilobite crawls through soft sediments near the Ordovician shoreline of 445 million years ago. The location at that time was near the equator, today it is at Churchill, Manitoba. A specimen of *Isotelus* from this locality is currently the world's largest known trilobite.

Students and members of the public visiting the Earth Sciences museum (soon to be relocated in the new atrium in the Centre for Environmental Information Technology in Fall, 2003) have the opportunity of looking at casts of two very large trilobites. One of these has been in the museum since 1989, the second was purchased far more recently in 2002, and both originated from Churchill, Manitoba. So how is there a connection with Waterloo?

I suppose the connection started very indirectly on the 3rd of August 1973, when my wife Anne and I visited Diane and Bill Erickson at their home in Churchill. We were on our second Arctic beetle collecting trip through the Barren Lands of northern Manitoba and Keewatin (now Nunavut). Diane had been one of the first Introductory Geology Distance Education students at the University of Waterloo and had taken my course. It was a wonderful opportunity to stop in, chat and see the start of what was to be their Boreal Projects gardening operation. This early contact led to a third beetle collecting visit in July 1988 when, in a visit to their home, Bill revealed a very large trilobite (genus *Isotelus*) that had been found in the September of 1986 in the limestone beds on the foreshore of Hudson Bay below their home. The original discoverer was a visiting American professor. Bill had eventually retrieved the fossil by dint of a lot of crowbar, hammer and chisel work, managing to rescue it before the winter freeze-up threatened to destroy it. The specimen was eventually sent to the National Museum in Ottawa, but was ultimately accessed as Geological Survey of Canada Type Specimen 85292. The late Tom Bolton of the GSC prepared several casts that were sent to Diane and Bill Erickson and to the University of Waterloo.

Figure 2: A 120cm section of the track of a large *Isotelus*, exposed in thin limestone beds about 1.5 km east of the RCMP station on the shoreline of Hudson Bay in July 1988. The shotgun is 126cm in length. The lenscap is 5 cm. (Photo: AVM).

Late that July evening Bill and I wandered along the foreshore and I saw a huge trilobite track, illuminated by the light of a swiftly setting sun. I was able to take one photograph before poor light and a huge cloud of mosquitoes drove us back from the Ordovician (and modern) shoreline to the safety of the house.

We discussed the setting over a few after-dinner drinks. The Ordovician sea had lapped against the Precambrian rocks that formed the small rise on which Diane and Bill's home is located. In the near- and off-shore environments several very large trilobites had trundled through the soft lime-rich sediments leaving a series of corrugated and raised trackways (Figs. 1 and 2). Fortuitously these had finally been exposed that year on the modern Churchill shore some 445 million or more years later. Whatever these trilobites were, they obviously were very large to leave tracks this size behind. The original specimen found two years earlier was big (Fig. 3a), but the exposed tracks (Fig. 2) were far larger, dwarfing the usual trace trackways, known as *Cruziana*, that one normally finds in the Paleozoic record. There was little doubt that some very large trilobites were resident in the area at the time these sediments were laid down, but unfortunately there was no time left for a search of the shoreline outcrops and I left the following day.

A decade later Graham Young and Bob Elias of the Manitoba Museum of Man and Nature commenced their 1998 field season. They were accompanied by Dave Rudkin (a trilobite specialist from the Royal Ontario Museum), Janis Klapecki (collections manager at the Manitoba Museum of Man and Nature), Ed Dobrzanski and David Wright (volunteers, MMMN), and Curtis Moffat (a student at the University of Manitoba).

On the third day of the fieldwork David Rudkin discovered part of an extremely large trilobite projecting from the thinly bedded limestones along the foreshore. Rising tide and poor light prevented the excavation of the overlying strata until the following day. However, the specimen was finally exposed and retrieved. It turned out to be substantially larger than the 1986 specimen, measuring 72 cm from the front of the headshield to the end of the fused tail segments (Fig. 3b). This is the largest known trilobite.

The genus *Isotelus* is confined to the Ordovician Period. The specimens from Churchill (Fig. 3) illustrate the common characteristics of the genus, with a large, smooth headshield, a number of articulating segments in the central part of the body (in the case of the large specimen eight can be clearly seen), and then a large smooth tail shield that consists of a number of fused segments. Trilobites are interesting animals, confined to the Paleozoic Era (the time of ancient life) and are distantly related to the lobsters, crabs and shrimps that we see in our oceans today. If you want to see the original specimen you will have to travel to the Manitoba Museum of Man and Nature in Winnipeg. However, our casts are a little closer for those of you who live in southwestern Ontario. I hope that when you visit the museum or future atrium at the University of Waterloo, you will remember that these ancient animals have a distinct, "Waterloo connection"!

Acknowledgments.

My sincere thanks to Diane and Bill Erickson (Boreal Projects), Manitoba, for jogging some very old memories! (Photographs are all copyright of the author).

Alan Morgan

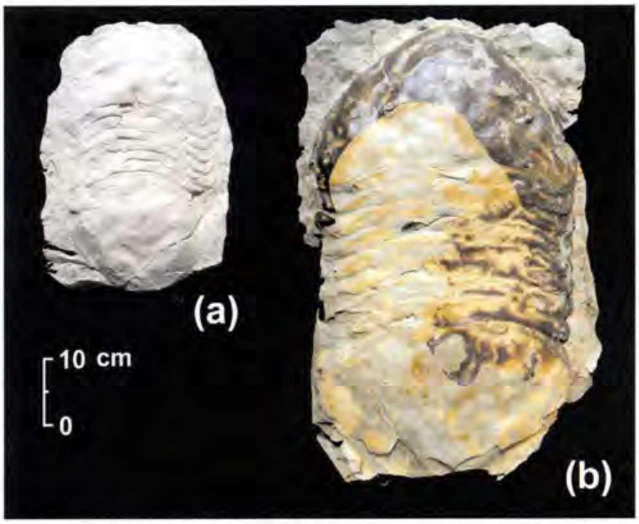

Figure 3: Giant *Isotelus* trilobites from Churchill, Manitoba. (a) — specimen collected in 1986 by W.R. Erickson (GSC type 85292; (b) – specimen collected in 1998 by D.Rudkin (Manitoba Museum of Man and Nature). (Both of these illustrations are from casts of the originals).

Figure 4: Detail of the headshield (cephalon) of the largest *Isotelus*. To give some impression of the immense size of this specimen, a complete more normal-sized trilobite, (*Pseudogytes* sp.), also Ordovician in age from Collingwood, Ontario, has been superimposed. The lenscap is 5 cm.

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