Geoscape Ottawa-Gatineau

Grade 9 - 11 Lesson Plans to accompany the Geoscape Ottawa-Gatineau poster and website

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Theme 2 :   DEEP TIME : ANCIENT ROCKS

OVERVIEW

- Students analyze and appreciate the concept of Geologic Time
- Students interpret the sequence of geologic events that have created the Ottawa-Gatineau Geoscape
- Students identify the bedrock and surficial geology of the area
- Students construct geological cross-sectional profiles across the Ottawa-Gatineau Geoscape

DURATION   **175 minutes + 45 minutes enrichment**

ACTIVITY

1. Students search the Internet (Google) for the essay "But a watch in the night, a scientific fable" by James C. Rettie. Read it to begin to appreciate the age of the earth and the insignificance of human time in geological time.

2. When was the "Quaternary" time period? Since publication of the Geoscape poster, the geological time chart was revised. Search the Internet to discover what has replaced the Quaternary and Tertiary periods.
   - Geological Survey of Canada's Geoscience Data Repository http://gdr.nrcan.gc.ca/mirage/index_e.php
   - American Geological Institute website: http://www.agiweb.org/education/teachers/online_resources.html

3. Students construct a geologic time scale on a roll of paper towels, demarcating significant events and relative ages. Use a roll with 46 sheets to represent a time line of geologic history from the present (0) to 4 600 000 000 years ago. Each sheet will represent 100 000 000 years. Use colour lines to mark the major geologic events according to the accompanying geological time scale. Start with the most recent and work backwards to the oldest events. Since most information will be near the present, be careful as it will get crowded. Provide a legend and time scale.

4. Optional enrichment opportunity should be completed at this time. It may be used as an individual assignment. Using Arcview 3.2 and Arc Canada 2.0 students construct 4 world maps that display areas of the earth that were created during the Cenozoic, Mesozoic, Paleozoic and Precambrian Eras. Describe the occurring patterns that emerge. Reference: ESRI Canada www.esricanada.com . Alternatively, the shape and position of the continents on the globe are illustrated and the geological history well described on the Geological Survey of Canada (GSC) website: Urban Geology of the National Capital Area http://gsc.nrcan.gc.ca/urbgeo/natcap/his_introduction_e.php .

5. Referring to the bedrock map of the region on the GSC Urban Geology web site (http://gsc.nrcan.gc.ca/urbgeo/natcap/index_e.php) , students shade in and label the bedrock geology (rock types) on a blank outline map of the Geoscape region or on a black and white print of the satellite image. Draw in the major faults and label the Gloucester Fault, the Eardley Escarpment, the Bonnechere Graben, Gatineau Hills, and Hogs Back.

6. Students read
   - Geoscape poster; Deep Time: Ancient Rocks
   - The general background paper " A Brief Introduction to the Geology of the Ottawa area"

Funding for this project came from Natural Resources Canada and the Ontario government

- Detailed information is on the Urban Geology of the national Capital Area website. This site includes geological history, geological maps, faults, stratigraphic sections, borehole data and more. The geological history is summarized in the attached paper "The Geological History of the National Capital Area".

The following questions are completed in their notebooks. Outside sources such as their textbooks may be necessary to answer all the questions completely.

1. Summarize in chart form the major events, geological and biological, that occurred in each of the 4 major geologic eras in sequence starting with the most recent at the top.
2. Explain the 3 fundamental principles on which geologists base their reading of the geologic record of the past.
3. Why are there no rocks in this region from the Tertiary to the Silurian periods?
4. A. What is a fault? B. Why are there faults in this area? C. What caused them? D. Where generally are they located? E. Why are they not easy to find today?
5. A. What is a graben? B. How is it formed? C. Why is it called the Bonnechere Graben? D. What is the difference between a graben and a rift valley?
6. A. Where is the Eardley Escarpment located? B. Why is it located there? C. What is a fault scarp?
7. Since publication of the Geoscape poster, the geological time chart was revised. What has replaced the Quaternary and Tertiary periods?
8. A. What significant event occurred during the Pleistocene? B. What caused it to occur? (several reasons) C. What is the significance of these states in the study of glaciation in North America – Wisconsin, Illinois, Kansas, Nebraska.

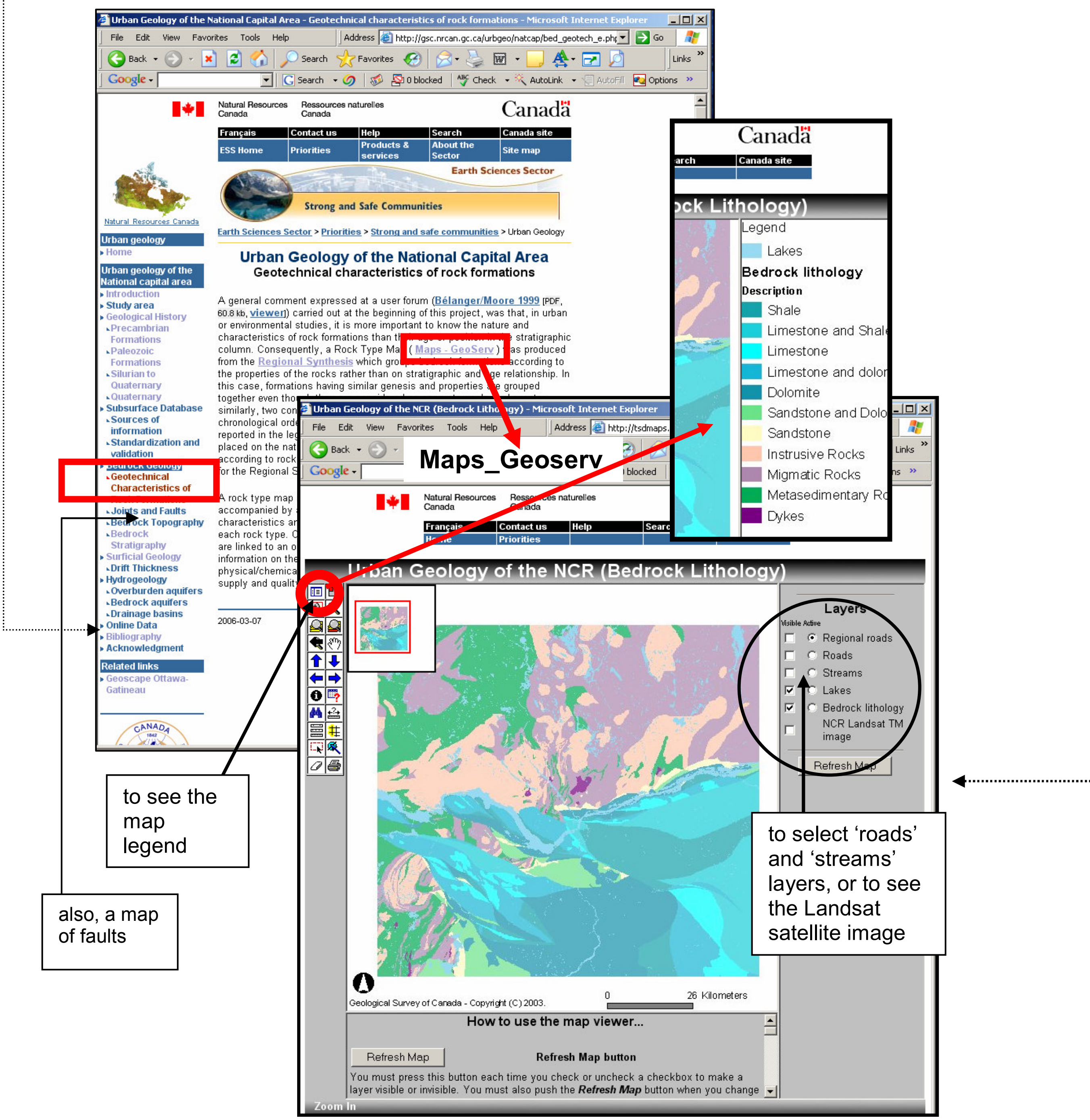
6. Students construct two cross-sectional profiles of the surficial geology of the region, one north–south and the other east–west, using information derived from borehole data found on the web site for Urban Geology of the National Capital Area http://gsc.nrcan.gc.ca/urbgeo/natcap/index_e.php (select subsurface database and go to the geoserv map). The Subsurface Database contains information on the nature and thickness of the Quaternary unconsolidated, or surficial, sediments that overlie the bedrock. Locate the axis intersect of the profiles at the site of your school. At least 8 boreholes per profile should be used. Draw the profiles on graph paper or on computer and label the appropriate geological layers. Compare your results with the two profiles found on the Urban Geology Web site http://gsc.nrcan.gc.ca/urbgeo/natcap/hydrogeology2_e.php . (Note the surficial sediments are depicted above the red line in these profiles and the surficial legend is on the right.) In note form, account for the differences and note the similarities. Comment on the degree of accuracy of the profiles. How could you make them more accurate?

To use the website for Urban Geology of the National Capital Area – Bedrock Geology

http://gsc.nrcan.gc.ca/urbgeo/natcap/index_e.php

For map of bedrock formations, go to	For map of bedrock types (lithologies), go to
Bedrock Geology http://gsc.nrcan.gc.ca/urbgeo/natcap/bed_regional_e.php and select < **Maps_Geoserv** >	**Bedrock Geology >> Geotechnical characteristics of rock formations** http://gsc.nrcan.gc.ca/urbgeo/natcap/bed_geotech_e.php and select < **Maps_Geoserv** >

NB: maps available for printing or to download as layers in GIS applications are available on this site.



GEOLOGICAL TIME SCALE (old scale)

Era		Period	Epoch	Age*	Fossils	Geological Events
Phanerozoic	Cenozoic	Quaternary	Recent		• human civilizations • domesticated animals	• minor postglacial gradation • Western North America rising
			Pleistocene	0.01	• primitive humans • large mammals die out	• worldwide glaciation • ice ages and interglacial periods • Western Cordillera rises
		Tertiary	Pliocene	1.8	• earliest humans • large carnivores	• continents in present shape • Appalachians uplifted
			Miocene	5	• grazing animals thrive • elephants migrate to America • horses migrate to Asia	• volcanic activity in Rockies • North America jointed to Asia
			Oligocene	23	• development of whales, bats and monkeys	• India collides with Asia
			Eocene	34	• pygmy horses • flowering plants thrive	• mountain building in Rockies, Andes, Himalayas
			Paleocene	53	• many new mammals	• Rockies, Andes, and Himalayas rising
	Mesozoic	Cretaceous		65	• first flowering plants • dinosaurs die out at the end of the period	• Laramide orogeny (Rockies, Andes, Himalayas start forming) • Marine deposits on east coast of North America
		Jurassic		135	• first birds appear • dinosaurs thrive	• Nevadan orogeny (volcanoes in Rockies, Juras Mountains formed) • shallow seas cover interior of North America and Europe
		Triassic		192	• first mammals • first dinosaurs	• widespread volcanism • red sedimentary deposits
	Paleozoic	Permian		230	• conifers thrive • insects thrive • many reptiles and amphibians • trilobites extinct	• Appalachian orogeny • ice age in South America
		Carboniferous		290	• first reptiles • giant forests of spore bearing plants	• coal deposits form in eastern and central North America
		Devonian		350	• fish thrive • emergence of amphibians • earliest forest	• Acadian orogeny (eastern North American mountains)
		Silurian		410	• first appearance of plants and animals on land	• widespread marine deposits
		Ordovician		438	• first vertebrates (fish) • marine invertebrates thrive	• Taconic orogeny (mountains in New England)
		Cambrian		485	• marine invertebrates (trilobites)	• invasion of shallow seas and marine deposits
Precambrian		Proterozoic		560	• first marine plants, worms, • jellyfish evolve • stromatolites dominant	• great volcanism, lava flows, • metamorphism of rock • ferrous metals formed
		Archean		2500	• no fossil evidence • first life (bacteria)	• earth cooling • oldest known rocks
				4600		

* **Date** when the period/epoch started, in millions of years before present

NEW GEOLOGICAL TIME SCALE (2004)

	Era	Period	Epoch	Age*	Fossils	Geological Events
Phanerozoic	Cenozoic	Neogene	Holocene (Recent)	0.01	• human civilizations • domesticated animals	• minor postglacial gradation • Western North America rising
			Pleistocene	1.8	• primitive humans • large mammals die out	• worldwide glaciation • ice ages and interglacial periods • Western Cordillera rises
			Pliocene	5	• earliest humans • large carnivores	• continents in present shape • Appalachians uplifted
			Miocene	23	• grazing animals thrive • elephants migrate to America • horses migrate to Asia	• volcanic activity in Rockies • North America jointed to Asia
		Paleogene	Oligocene	34	• development of whales, bats and monkeys	• India collides with Asia
			Eocene	53	• pygmy horses • flowering plants thrive	• mountain building in Rockies, Andes, Himalayas
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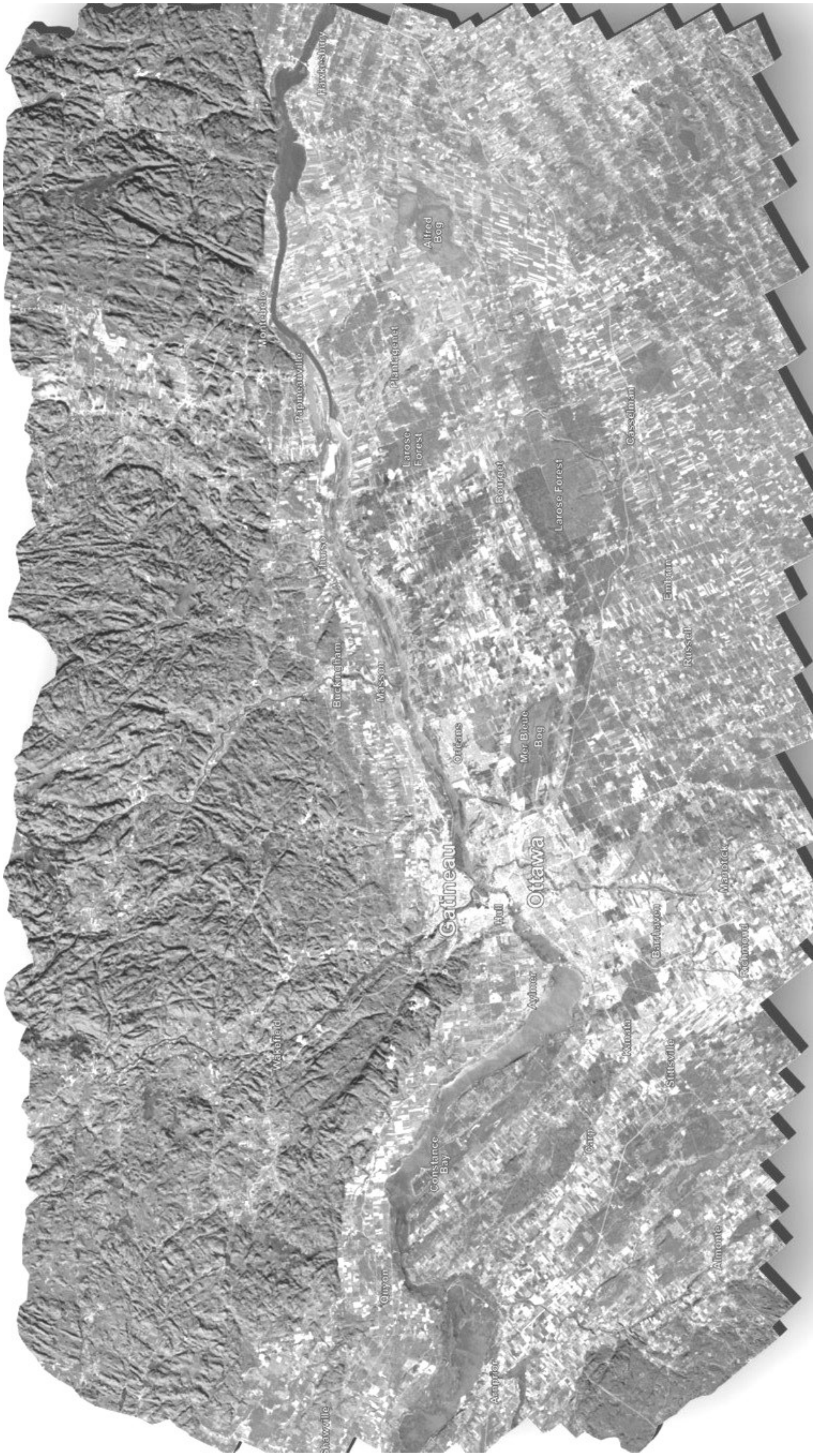
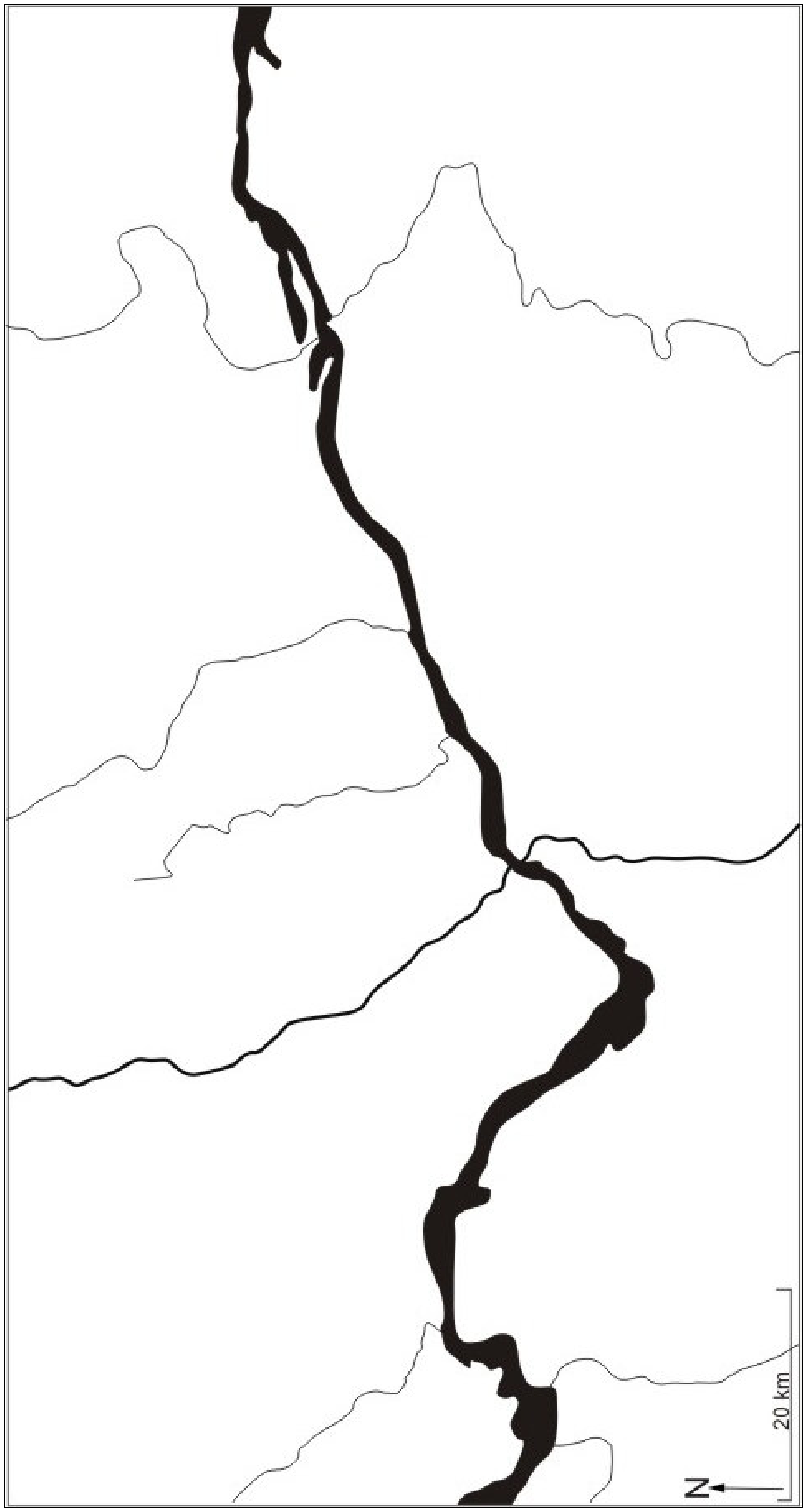
		Archean		4600	• no fossil evidence • first life (bacteria)	• earth cooling • oldest known rocks

* **Date** when the period/epoch started, in millions of years before present



Landsat TM (5/7) Shaded Relief Fusion (Landsat TM 7.) Data collected by USGS/EROS Data Center and provided courtesy of Canada Centre for Remote Sensing.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A BRIEF INTRODUCTION TO THE GEOLOGY OF THE OTTAWA AREA

Ottawa is situated at the junction of the Rideau, Gatineau and Ottawa Rivers. Canada's capital can perhaps be made more interesting as a little of its geological history is understood.

The beautiful rounded hills of the Gatineau, which are so much a part of Ottawa's scenery, are part of the Canadian Shield, which extends over a vast area of Canada. These hills, once towering mountains, have been reduced to their present height by the action of water, ice and wind. The rocks in these hills are Precambrian, and more than 1000 million years old. We can find marble in this area, and since this rock is metamorphosed limestone, we deduce that, before the mountains were pushed up, seas must have covered the area where the hills now stand.

Following the uplift of the mountains, a long process of erosion occurred that continued until the Ottawa area was an almost feature-less plain of eroded mountain roots. This plain was then depressed and an ancient sea slowly crept over the land, and the sediment deposits from this sea gradually filled in valleys and depressions, eventually covering even small hilltops. As the edge of the sea advanced, so did its beaches. These beaches were sandy and today we have the evidence of these ancient beaches as we observe the yellowish white sandstone (the Nepean Formation) at Kanata. This stone has been used to build flagstone paths and many major buildings including our Parliament Buildings.

The rock that overlies the Nepean sandstone is many metres thick and is a very sandy dolomite. This rock represents a transitional period in the history of the area. Below it lie the beach sandstones and above it is found limestone. The limestone and sandstone represent two different chapters in the history and two different environments. It seems then, that beach sands were still being produced, but back currents were transporting the sand grains to deeper water where they mingled with the sea muds, rich in calcium carbonate and magnesium carbonate, to form the dolomite. Rocks of this age belong to the March-Oxford Formation.

Above the dolomite lie thick layers of shale, which can be seen in the Ottawa River banks at Rockcliffe Park. This shale, and some sandstone, mark the shoreward limit of marine deposition at that time. That is to say, the sea that covered the area was much deeper to the east of Ottawa and the shoreline somewhere not far to the west.

The next stage in this historical account is that of a marine invasion. For thousands of years, living things were abundant in this sea and, as they died, their tiny shells dropped to the muds. With time, pressure and chemical action, limestone was formed several hundreds of metres thick. Shales were formed as the next layer of rock, which brings us up to 400 million years ago.

There is very little direct evidence of what happened during the next 400 million years. We do know that the region was pushed up, pushed down, faulted, folded and eroded. About 175 million years ago, in the Mesozoic, the Ottawa-Bonnechere graben formed when the land surface moved downward between two major fault zones.

About 1.6 million years ago, the climate over a large portion of the world including North America, began to very gradually cool. Each year, a little less snow melted and eventually as the climate became cooler and cooler, the snow stayed all year and snow of successive years began to accumulate. As the snow grew to be thousand's of metres thick, the lower snow was compressed and became ice, which subsequently became plastic in character and began to flow from the centre of accumulation to the edges. As the great mass of ice continued to grow, it spread out to cover a good part of North America. Great ice sheets flowed over the Ottawa-Gatineau region several times during the last 1.6 million years. The last one covered the region from 20 000 to 11 000 years ago. Our landscape reflects this glacial heritage.

During the Ice Age, the intensely heavy ice scraped, gouged, tore up, broke off and carried both great blocks and small particles of rock. Hills were rounded, valleys filled in, rivers blocked, new river channels formed and new landforms created. It is calculated that the ocean levels were lowered by at least 60 metres and as much as 120 metres in the creation of the massive ice sheets. The ice was, in fact, heavy enough to depress the land on which it lay. When the ice eventually melted and retreated, the land very slowly rebounded – indeed it is still doing so in some places. Naturally, while the land was still depressed but the ocean levels were restored, the Atlantic Ocean invaded the region.

During the last 25 000 years, there are three effects to consider - the effect of the ice, the effect of the sea, and the effect of the rebound of the land.

Rock outcrops have rounded shapes and smooth surfaces created by glacial abrasion, and display scratches (striae) and grooves eroded by particles embedded in the base of the moving ice sheet. Isolated boulders, not indigenous to the area, but left behind by glaciers and known as erratics, occur scattered across the region. The bedrock is covered in places by till (the mixture of clay, silt, sand, pebbles and boulders) that was carried by and deposited from the glacier. Elongated hills (drumlins) were created. In other places, meltwater in the glacier deposited sand and gravel, forming low hills (kames) or long, linear ridges (eskers).

As the glacier retreated, about 12 000 years ago, the Atlantic Ocean flooded the Ottawa valley, forming the Champlain Sea. Beaches and deltas, now lying 220 m above present sea level, and a widespread blanket of marine mud (Leda clay) containing fossils ranging from tiny seashells to whale bones, are evidence of this sea in the present landscape. As the glacially depressed lands gradually rose, the sea receded, finally leaving the Ottawa valley about 10 000 years ago.

The modern Ottawa River evolved as the ancestral river and its tributaries adjusted to the retreat of the Champlain Sea. Between 10 000 and 8000 years ago, there was a much larger flow of water through the ancestral Ottawa River than at present. Large glacial lakes in northern Ontario and the Prairie Provinces, and the upper Great Lakes all drained into the Ottawa River. Several times during this period the Ottawa River shifted into new channels. The rivers cut new channels, created terraces, flood plains, sand bars and deltas. By about 8000 years ago, the Ottawa River was in its modern position. Peatlands, such as the Mer Bleue and Alfred bogs, have developed in abandoned earlier Ottawa River channels.

Urban Geology of the National Capital Area

http://gsc.nrcan.gc.ca/urbgeo/natcap/index_e.phpz

Geological history

The geological formations in Canada's National Capital Area (NCA) represent three distinct geological times. Each of the three differ substantially not only in age and time span, but also in the nature of the geological process involved and the type of material produced. The geological formations produced are: Precambrian metamorphic and igneous rocks of the Canadian Shield, Cambrian and Ordovician sedimentary rocks of the continental platform, and Quaternary unconsolidated sediments comprising the surface materials. Each of these formations were separated by long erosional periods. In order to understand how each geological unit was formed and how they are related, it is necessary to place each event in the global history of the Earth.

Since the formation of the Earth, approximately 4.6 Ga (billion years ago), the shape and position of continents have changed considerably. The earliest evidence of possible continental emergence from the melted mass of rocks can be traced to approximately 4.5 Ga, but the only preserved crustal rocks are in the range of 3.9 to 3.7 billion years. It is unlikely that the overall amount of continental crust at that time was greater than several percent, but by 2.5 Ga, as much as 50-75% of the continental crust may have been in place. The early fragments of continents were probably thin, but they gradually increased in thickness due to orogenic activities. Since the granitic material that formed the continents was lighter than the underlying magma and surrounding oceanic crust, they formed plates that emerged from the surrounding solidified crust. Convection movements in the magma under the crust caused the crust to crack and move laterally over the Earth's surface, this movement of the crust is at the origin of continental drift.

Very little is known of the size, shape and position of continents until the late Proterozoic 600Ma (million years ago), but it is likely that the continents periodically collided to form super continents, and subsequently drifted apart. In the NCA the Precambrian metamorphic and igneous rocks that comprise of the Canadian Shield belong to that ancient and rather obscure portion of the Earth's history. However, as we move closer in geological times to the Late Paleozoic, the available geoscientific evidence increases substantially, permitting a better understanding of the formation and position of continents. That is why the formation of the Cambrian-Ordovician sedimentary rocks can be reconstructed with greater precision and detail (Bally et al.1989, McLennan, 1992). Much of the Cambrian-Ordovician formations and any rock deposited subsequent to the Ordovician Period were removed during the long erosion period that lasted until the Late Quaternary. For that time interval, no evidence of the geological events, other than tectonic, is known. Surficial deposits consist of Late Quaternary (<25 thousand years) glacial and related sediments, all other sediments having been removed by the last glacial advance.

Precambrian Formations

Precambrian rocks are located north and west of the NCA. They belong to the North American craton, known as Laurentia, and form part of the Canadian Shield. North America is considered to be an old continent because the craton has been coherent since 1.7 Ga, compared to South America and Africa that were formed 0.7 Ga, and Eurasia, 0.3 Ga. Laurentia was formed by the aggregation of several microcontinents in the interval between Archean (~3.80 Ga) and Early Proterozoic (1.65 Ga) time. The Precambrian rocks of the NCA were formed during the youngest orogen indigenous to Laurentia. This orogen, called the Grenville orogen, occurred between 1.3 and 1.0 Ga and consisted of extensive reworking of older crust.

At the end of the Grenville orogen, the Laurentian Mountain Range extended over much of southern Ontario and Québec. Although the exact position of continents surrounding Laurentia at that time is uncertain, it is generally accepted that North America was at the centre of a late Precambrian supercontinent. At the end of the Precambrian Era, 600 Ma ago, at the breakup of the North American supercontinent, the continent of Laurentia was located at the equator, oriented at 90° from its actual position, and Avalonia (Appalachian Mountains) and Florida were located far away from Laurentia, close to the African craton.

The Precambrian terrane of the NCA is characterized by rolling hills that rise above the flat-lying Paleozoic rocks and is generally covered by only a thin layer of unconsolidated sediments. The Precambrian rocks that are now exposed correspond to the roots of the Laurentian Mountain Range that was much higher but has been eroded through weathering and erosion and glacier action during the billion years that followed their formation.

The geology of Precambrian rocks is extremely complex, due to the numerous faults, folds, and rapid successions of rock types. Precambrian rocks underlie the entire region, forming a basement complex. They outcrop as the Gatineau Hills, north of the Ottawa River; as the Carp Ridge, a narrow band extending South eastbound in the West NCA; and as highlands to the Southwest where they form a geological structure known as the Frontenac Arch.

The bedrock geology map, http://gsc.nrcan.gc.ca/urbgeo/natcap/bed_regional_e.php (Maps - GeoServ), groups the Precambrian rocks according to their origin, into intrusive (felsic, mafic and ultramafic), migmatic, metasedimentary and dyke formations. The intrusive rocks formed from slowly cooling magma , are characterized by large mineral crystals. Massive and foliated light coloured felsic intrusive rocks (granite, quartz, monzonite, syenite) are abundant and often form large batholiths (Wakefield Batholith) north of the Ottawa River. The dark coloured mafic and ultramafic intrusive rocks (diorite, gabbro, anorthosite) are much less abundant and outcrop only in a few areas. Contact zone rocks along the margins of intrusive rock bodies, which are partly igneous and partly metamorphic, are grouped as migmatic rocks (amphibolite, greenstone, gneisses). In these transition zones, the nature of the rocks is reflected by the nature of the invading and invaded rocks. Metasedimentary rocks, which are mostly located in the western part of the area, are differentiated by their origin: carbonate sedimentary rocks (limestone) were transformed to marble or lime silicate rocks, and non-carbonate rocks (shale and sandstone) were transformed to gneiss and quartzite. Dykes reported on the map are composed of pegmatite either associated with granite (pink pegmatite) or marble (white pegmatite). Several younger (675 to 450 Ma) east-west trending diabase dykes are also present in the area.

Paleozoic formations

At the beginning of the Paleozoic Era, the supercontinent split, with the continental fragments drifting apart and the proto-Atlantic ocean, called Iapetus Ocean opening between them. The eastern margin of the Grenville orogen rocks formed the east coast of the North American continent and were open to the ocean. At that time the Avalonian tectonic plate (Appalachian mountains) was still drifting at a distance from North America . The National Capital Area was located at the north-western end of a bay, called the Ottawa Embayment, that extended into the continental mass, bounded by the Frontenac Arch and Adirondack mountains.

Late Cambrian and Early Ordovician: Marine transgression.

The sea slowly transgressed into eastern Québec during the Early Cambrian, reaching the Ottawa area in the Late Cambrian. The first sedimentary deposits were derived from Precambrian quartzites and conglomerates to form the feldspathic conglomerates and sandstones of the Covey Hill Formation. This unit was formed near the margins of the invading ocean and corresponds to alluvial fan and braided fluvial deposits. It outcrops only in a few locations (north-west of Rockland, see Maps - GeoServ), and its distribution is limited to topographic depressions on the Precambrian surface.

During the Late Cambrian to Early Ordovician, the first marine sediments were deposited in shallow water, close to shore, within the tidal zone. These early marine deposits, called Nepean Formation, consist of fine-to coarse-grained quartz sandstone of marine and terrestrial origin, indicating fluctuations of the sea level. The upper part of the formation contains dolomitic beds which are characteristic of marine transgression (increase in water level).

During the Early Ordovician, the sea continued to advance covering Precambrian knobs which protruded through the Nepean Formation, and deposited shallow marine carbonate and clastic sediments. The lower unit, the March Formation, consists of interbedded sandstones and dolostones, with boulder-and cobble-sized interclasts of quartzite where the unit is in contact with Precambrian rocks. As the depth of water was increased, the sediments became finer-grained, slowly grading into clay-size sediments and carbonate precipitates (CaMg) of the Oxford Formation (dolostone), characteristic of hypersaline environment. The last occurrence of sand corresponds to the transition between the March Formation and the Oxford Formation.

Middle to Late Ordovician: Fluctuating sea level.

In the Middle to Late Ordovician, the drifting Avalonian microcontinent was approaching North America and the convergent plates produced an orogenic belt (Appalachian Mountains) along the eastern margin of the Laurentian craton. Consequently, the continental shelf upon which the Late Cambrian and Lower Ordovician deposits accumulated was progressively deformed. The uplift of the continental shelf in early Middle Ordovician, caused a regression of the sea which resulted in subaerial exposure and erosion of a large part of the Early Ordovician rocks.
The erosional period was followed by a second period of marine transgression in the Ottawa Embayment that deposited sediments (Rockliffe Formation) derived from the surrounding uplifted Precambrian rocks . The rocks of the Rockliffe Formation grade from sandstone, with quartz-pebble conglomerate locally

present, to shale and limestone with silty dolostone interbeds, indicating a gradual deepening of the water, with deeper water conditions to the east. The sedimentation period that produced the Rockliffe Formation was followed by a marine regression, which exposed the sediments to erosion.

A third marine invasion followed the hiatus subsequent to the Rockliffe Formation deposition. The depositional sequence begins with nearshore sediments of the Shadow Lake Formation which disconformably overlies the Rockliffe Formation. This formation does not outcrop (at the bedrock surface) in the NCA area but can be observed between the Rockliffe and Gull River Formations in a section eroded by the Rideau River at Prince of Wales Falls (Hog's Back Park). The base of the formation consists of sandstone which grades upward to sandy shale interlayered with carbonate rocks.

The overlying succession of shales, dolostones and limestones, of the Gull River, Bobcaygeon, Verulam and Lindsay formations represent a near-continuous deposition on a deepening shelf.

A characteristic of the Middle Ordovician formations is the increasing presence of organic matter in the younger rocks. Although fossils are present in the March and Oxford formations, it is only with the Gull River, and more so with the Bobcaygeon, formations that the fossils are abundant enough to influence the characteristics of the rocks. The Verulam Formation is described as fossiliferous limestone with inter-beds of calcareous shale, whereas the Lindsay and Eastview formations are inter-bedded black, organic-rich limestone and highly calcareous shale. The increasing abundance of vegetation and marine life in the Ottawa Embayment indicates ideal conditions for the development of life, such as warm water temperature and protected shallow marine environment.

Late Ordovician: Deep water sedimentation and regression.

During the first part of the Late Ordovician the sea continued to rise, leading to deep shelf sedimentation conditions. During the second part, the continued northwestward migration of the Appalachian structural front caused an uplift of the shelf between the Laurentian and Avalonian cratons. The crustal uplift combined with a possible continental glaciation of the North African craton, lead to a drop in the sea level to a point that the Ottawa Embayment was isolated from the open sea and eventually dried up.

The Billings Formation consists of shale with thin interbeds of dark grey limestone, and is distinguished from the underlying Eastview Formation by its noncalcareous nature, indicating deposition in a deep shelf environment. The sediments of the Billings Formation were therefore deposited during the high-stand of marine transgression. The Billings Formation grades into the Carlsbad Formation which consists of interbedded shale, fossiliferous calcareous siltstone, and silty bioclastic limestone, indicating that the conditions were evolving from deep sea to shallow sea. The depositional sequence indicates marine regression that continued during deposition of the Queenston Formation, reaching marginal marine to shallow marine environment. The Queenston Formation consisting of red to green-grey shales, siltstone and minor limestones, is the youngest preserved Paleozoic unit.

Silurian to Quaternary

Between the end of the Ordovician to the Quaternary, a geological record of deposition is absent. During that period much of the Precambrian and Ordovician rock formations were eroded, with as much as 1000 metres of rock removed in some areas. During that time, the Grenvillian depositional shelf was deformed by the Appalachian orogeny, showned by numerous faults and vertical displacement of Paleozoic and Precambrian blocks. The general smoothness of the modern surface between fault blocks, as indicated by the smooth bedrock topography, bears witness to erosional levelling since the Ordovician period.

During the ~185 million year interval separating the Ordovician and Middle-Permian, Florida and Avalonia continued to drift toward the Laurentian craton to become part of North America. During the same period of time, continents collided together to form the Paleozoic-Mesozoic supercontinent called Pangea that lasted for nearly 120 million years, from the late Carboniferous to Early Jurassic. A reconstruction of the position of continents indicates that the supercontinent started to break apart at the end of the Triassic to Early Jurassic periods, and the plates drifted to their modern position forming continents as presently known. North America slowly migrated to higher latitudes bringing changes in the climate, fauna, flora and geological processes that shaped the surface of the Continent. (Bally, 1989; Bally et al.,1989; Hoffman, 1985; Johnson et al.,1992; McLennan, 1992; Rast,1989; Williams, 1991; Hogarth, 1962)

Quaternary

(Since publication, the geological time scale was revised and the Quaternary and late Tertiary periods have joined to become the Neogene Period.)

The Quaternary, which started 1.64 million years ago, is the most recent and best known geological period in Canada. The drifting continents were located at approximately their present position. In North America, this period is characterized by climate changes that induced many geological processes such as buildup and decay of continental ice sheets, marine transgressions and regressions, advance and retreat of deserts, extensive erosion of bedrock, removal of pre-existing unconsolidated sediments and deposition of newly eroded materials. The Quaternary Period also corresponds with the advent on Earth of the human race.

Most of Canada has been covered by ice at least once during the Quaternary, and in several parts of the country, there is evidence of at least four major glacial periods. The number of times ice sheets have covered the National Capital Area is unknown, as erosion during subsequent ice advances and during non glacial periods removed evidence of earlier events. Consequently, unconsolidated deposits in the NCA area consist of glacial and related sediments from the last (Wisconsinan) glaciation, marine sediments related to the Champlain Sea, and the reworking of these same sediments by modern geomorphic processes.

During the Upper Wisconsinan (23-10 Ka), a continental ice sheet, called the Laurentide Ice Sheet, covered most of Canada. In the NCA, the ice sheet flowed southward across the Gatineau Hills, the Ottawa River valley, and southwestwards across the Frontenac Arch. During the early stages of glaciation, a major ice stream flowed in the Gatineau and adjacent north-south trending valleys but eventually the entire area was covered by an ice sheet that could have been thousands of metres thick (Gadd, 1987). Unconsolidated sediments older than the Upper Wisconsinan glaciation and the upper layers of bedrock were eroded by the Laurentide Ice Sheet and transported along the path of ice flow over distances up to hundreds of kilometres. In turn, the materials deposited locally by the ice sheet, were derived from sources hundreds of kilometres up-ice of the NCA. The materials eroded upstream were deposited in the form of till and related landforms. (see surficial geology map http://gsc.nrcan.gc.ca/urbgeo/natcap/surf_introduction_e.php , Maps - GeoServ)

Towards the end of the Wisconsinan, as the margin of the continental glaciers retreated from their maximum extent, the Laurentide Ice Sheet thinned over the NCA. The highlands started to emerge and glacier tonques became restricted to the valleys of the Gatineau hills. The abundant meltwater from the decaying glaciers transported an enormous amount of debris beyond the ice margin, depositing it on flood plains in valleys, in glacial lakes, and in the Champlain Sea .

The weight of the Wisconsinan ice sheet isostatically depressed the earth crust below sea level. At the time of deglaciation, proglacial lakes formed by the meltwater of glaciers were soon replaced by a marine invasion, called the Champlain Sea, along the St Lawrence Valley. The marine invasion lasted 2 500 years, between 12 and 9.5 ka. Locally, it lasted 1 500 years, between 11.5 and 10 ka and the marine limit reached approximately 210 m above present sea level. During the marine invasion, a layer up to 100 metres thick of marine clays and silts (commonly known as Leda clay), was deposited over the glacial sediments. Isostatic rebound of the earth's crust caused the Champlain Sea to begin retreating from the Ottawa area at about 11.2 ka. As the sea level lowered, wave action eroded and reworked the surface of marine and glacial sediments, redepositing the coarser sediments nearshore and transporting the fine material into deeper water.

During the retreat of the Champlain Sea, the ice front temporarily stabilized (11.1 to <11 ka) approximately 30 km north of Ottawa. The ice retreated from the upper Ottawa valley between 11 and 10 ka, opening a series of outlets that permitted the drainage of glacial meltwaters from the Upper Great Lakes and large glacial lakes in northern Ontario and from the Canadian Prairies through the Ottawa valley. The high rates of flow of the early-Ottawa River down cut through the glacial and marine deposits until approximately 5.5 ka., forming numerous terraces along the valley. The gradual isostatic uplift eventually diverted the drainage of the northern and prairie lakes into the Hudson Bay, and the Upper Great Lakes into the Lower Great Lakes and into the St Lawrence valley, abandoning a number of river channels of the early-Ottawa River. By 4.7 ka, the basin drained by the Ottawa River was approximately the same as today. (Aylsworth et al., 1997; Fulton and Richard, 1987)

Bibliography

Aylsworth, J.M., Lawrence D.E., and Evans, S.G., 1997: Landslide and settlement problems in sensitive marine clay, Ottawa Valley; Geological Association of Canada, Mineralogical Association of Canada, Joint Annual Meeting, 1997, Ottawa, Field Trip B1, 63 p.

Bally, A.W., 1989: Phanerozoic basins of North America, in The geology of North America- An overview, Bally, A.W. and Palmer, A.R. eds., The Geology of North America, v. A, GSA, Boulder, Colorado, Chapt. 15.

Bally, A.W., Scotese, C.R., Ross, M.I., 1989: North America; Plate-tectonic setting and tectonic elements, in The geology of North America- An overview, Bally,A.W. and Palmer, A.R. eds., The Geology of North America, v. A, GSA, Boulder, Colorado, Cht. 1.

Fulton, R.J. and Richard S.H., 1987: Chronology of late Quaternary events in the Ottawa region; in Quaternary Geology of the Ottawa Region, Ontario and Québec, Fulton, R.J., (ed.), Geological Survey of Canada, paper 86-23.

Gadd, N.R., 1987: Geological setting and Quaternary deposits of the Ottawa region, in Quaternary Geology of the Ottawa Region, Ontario and Québec, Fulton, R.J., (ed.), Geological Survey of Canada, paper 86-23.

Hoffman, P.F., 1989: Precambrian geology and tectonic history of North America, in The geology of North America- An overview, Bally,A.W. and Palmer, A.R. eds., The Geology of North America, v. A, GSA, Boulder, Colorado, Chapt. 16.

Hogarth, D.,D., 1962: A guide to the geology of the Gatineau-Lièvre district, Can. Field-Naturalist, Vol. 76, pp. 1-55

Johnson, D.K., Armstrong, D.K., Sanford, B.V., Telford, P.G., and Rutka, M.A., 1992: Paleozoic and Mesozoic Geology of Ontario, in Geology of Ontario, OGS Special Vol. 4, Part 2, Chapt. 20.

McLennan, S.M., 1992: Continental Crust, in Encyclopedia of Earth System Science, V.1, Academic Press, Orlando.

Rast, N., 1989: The evolution of the Appalachian chain, in The geology of North America- An overview, Bally, A.W. andPalmer, A.R. eds., The Geology of North America, v. A, GSA, Boulder, Colorado, Chapt. 12.

Williams, D.A.,1991: Paleozoic Geology of the Ottawa-St. Lawrence Lowland, Southern Ontario; Ont. Geol. Surv., O.F. Report 5770

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