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GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8280

Québec, fortified city: geological and historical heritage — fieldtrip guidebook

S. Castonguay

2017

Celebrating 175 yrs

Canada

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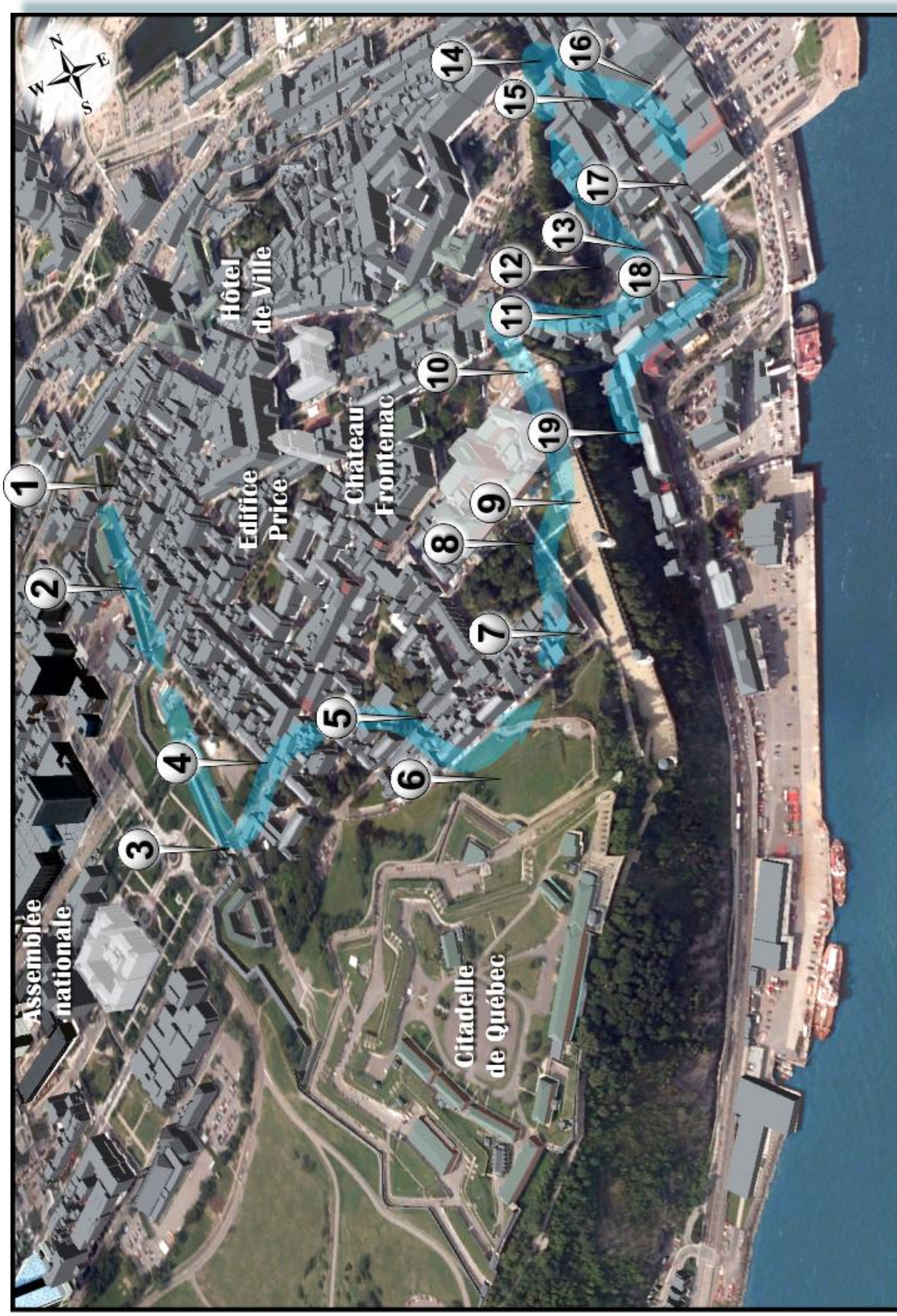

Figure 1. Location map of the stops
(Modified from Google Earth, 2015)

INTRODUCTION

Quebec City is located at the junction of three geological provinces, bestowing upon it a unique geological panorama, which includes a historical district that dates back to the first days of the colony. Since 2004, Natural Resources Canada has been organizing, in collaboration with Parks Canada, a multidisciplinary urban tour through the streets of Old Quebec, combining geology and history.

The geological history of the Quebec City area goes back more than a billion years and can be explained by plate tectonics. According to this theory, the Earth's crust is divided into plates that slowly move against one another. At each of the selected stops, fieldtrip participants will discover clues to a long-disappeared ocean, the movement of massive rock masses over long distances, up to the very threshold of the city, and the passage of immense glaciers that covered the region for thousands of years. We live on a dynamic planet and various elements remind us of this on a periodic basis. We will also see how earthquakes and scree are the result of the region's geological heritage.

Quebec, a UNESCO World Heritage Site, is the only city in North America to have retained major parts of its original defence system. The Fortifications of Quebec are a 4.6-km-long defence system that encircle the Upper Town promontory. Like nowhere else in North America, the old city's defence system follows a classic urban style, characterized by flanking, defence in depth, adaptation to the city's topography and urban layout. More than just the vestiges of the military art of war, the Fortifications of Quebec also bear witness to the era of fortified cities between the 17th and 19th centuries. Everywhere within Old Quebec's walls, you can feel the military presence that dominated the city and is a reminder that the city's past was punctuated by the beat of the war drum.

We hope that this guidebook will be a great addition to the tour you are about to take and that it will also be useful to science teachers as a source of examples taken from the local urban environment.

Have a great tour and good reading...

Celebrating 175 yrs
Célébrons 175 ans

The year 2017 marks the Geological Survey of Canada's 175th anniversary. Founded in Montreal in 1842, the GSC is the oldest scientific government agency in Canada and one of the first geological surveys in the world. Its initial mandate was to prepare an inventory and an evaluation of the mineral wealth contained in the Province of Canada. Today, its contributions to the country's economic development spans subjects large and varied, supporting the competitiveness of mineral and energy sectors, stewardship over the continental interior and coasts as well as the safety of Canadians.

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STOP 1 – ARTILLERY PARK

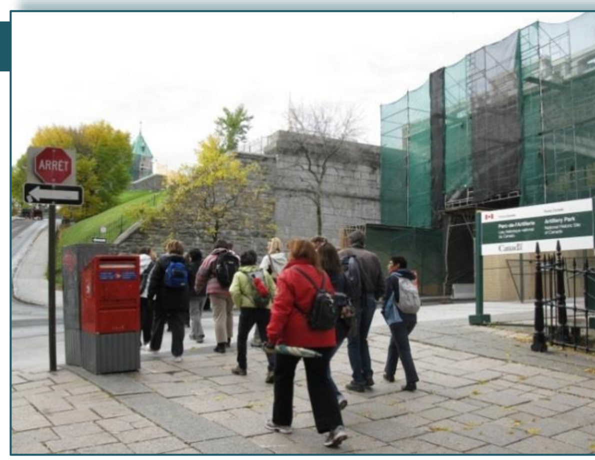


Figure 2. Main entrance to the Artillery Park
(Photo by Jean-François Bureau,
Geological Survey of Canada, 2010)

What is a Geological Map?

A geological map is a graphic representation of the underlying geological terrain and its lithological characteristics (composition and aspect of rocks). The rock units are generally represented by a colour based on their nature and age. On a geological map of the bedrock, superficial formations such as recent soils and glacial deposits (clay, sand, gravel) from the Quaternary Period, the current geological era, are ignored.

Quebec City is located at the junction of three large and distinct geological areas, termed geological provinces. The boundaries of a geological province can differ from those of a physiographic region. For example, even if the relief of the Appalachians is visible far away on the south shore of the river, this geological province covers a vast territory with a relatively flat relief, including the Quebec promontory.

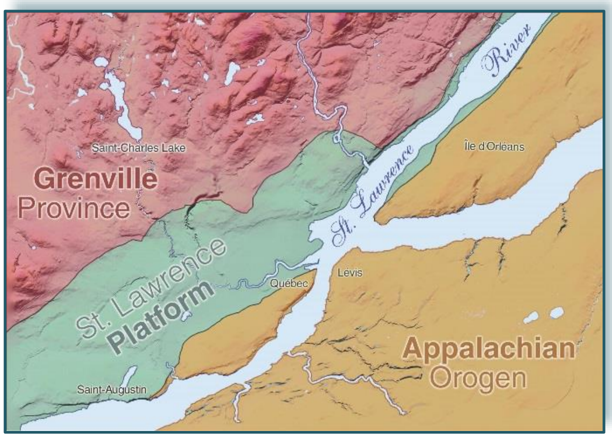


Figure 3. Map of the three geological provinces in the Quebec City region
(Modified from Castonguay and Nadeau, 2012)2012)

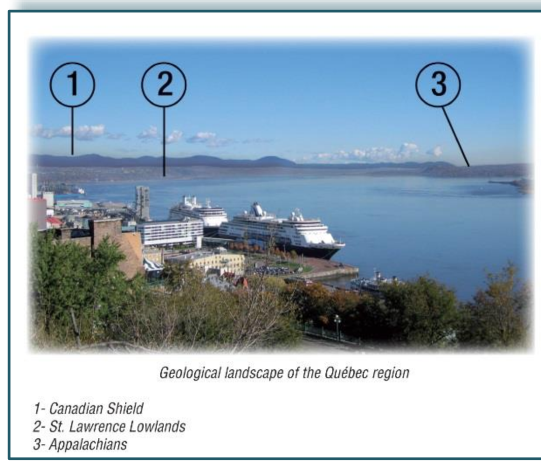


Figure 4. Panorama of the relief associated with the three geological provinces in the Quebec City region
(Photo by Jean-François Bureau,
Geological Survey of Canada, 2007)

Simplified Geology of the Quebec City Region

The Laurentians (in pink on the map) are part of a mountain chain that corresponds to the **Grenville Province**, the youngest of the Canadian Shield provinces, but formed by the oldest rocks in the Quebec City region. The rocks in the Grenville Province are metamorphic rocks, such as gneiss and amphibolites, which stem from old igneous or sedimentary rock buried at great depths, transformed and "cooked" at elevated pressures and temperatures. The Grenville rocks represent the deep roots of an old mountain chain the size of today's Himalayas, but that have been worn down by erosion.

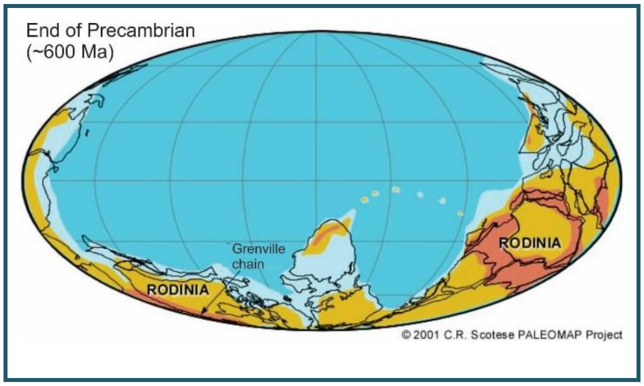
The rocks of the **St. Lawrence Platform** are jammed between the Laurentians and the Appalachians. Today, they form the St. Lawrence Lowlands (in green on the map). The St. Lawrence Lowlands consists of sedimentary rocks, such as sandstone and limestone, which are frequently fossiliferous and occur in regular beds of variable thickness with little to no deformation. Fossils are particularly abundant in certain layers of limestone, a type of rock that is very common in the Quebec City region. At the time they were formed, life was limited to the oceans. Consequently, the fossil species observed in these limestones are strictly marine species.

The rocks of the **Appalachians** in the Quebec City region (in orange on the map), are mainly comprised of deformed and folded sedimentary rocks, which were transported over dozens of kilometres along geological faults to their position adjacent to the St. Lawrence Platform where they have slowly eroded.

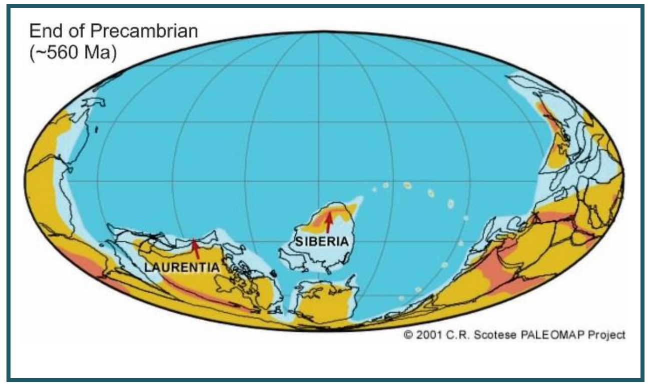
The geological diversity of the Quebec City region is unique and has been recognized for 175 years. Sir William E. Logan, founder of the Geological Survey of Canada in Montreal in 1842, as well as other important scientists from the 19th century, studied and mapped the region's geology and published important reports, maps and articles in the main scientific journals of their time.

From the Past to Present... Plate Tectonics

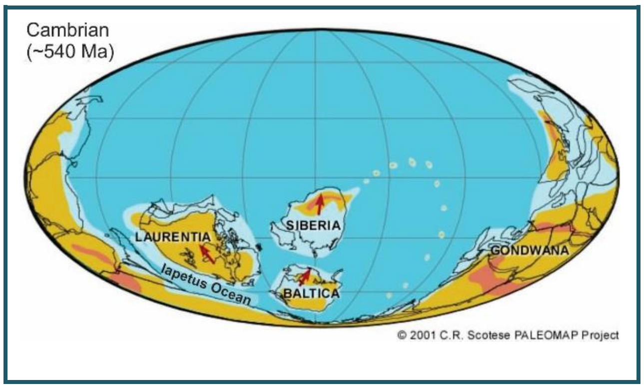
The Earth is a dynamic planet that is evolving and transforming. Looking at a globe, the continents resemble puzzle pieces that fit almost perfectly into each other. The continents are not stationary, they move a few centimetres per year, approximately at the same speed as our nails grow, which represents dozens of kilometres per million years! According to the theory of plate tectonics, certain continents (continental plates) are moving apart, creating oceanic plates (under the oceans) and others are moving closer (subduction zones) ultimately creating collisions between continents and forming mountain chains. The bedrock in the Quebec City region therefore migrated through geological time, moving from the south hemisphere to the equator to now sit in the northern hemisphere. At several times during Earth's history, stretching back 4.55 billion years, supercontinents have formed, giving birth to immense oceans! Fragmentation of the last supercontinent, named Pangea, approximately 200 million years ago, resulted in the continents and oceans we know today. A few of the steps are represented schematically on the next page.



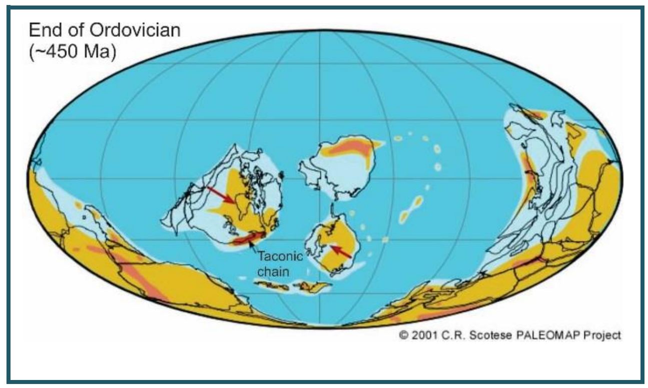
1) Supercontinent Rodinia formed approximately 1.1 billion years ago.



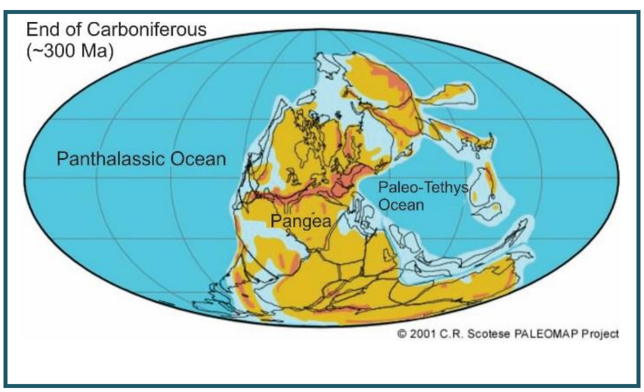
2) Between 750 and 540 million years ago, the supercontinent broke up into different pieces (cratons) including Baltica, Siberia and Laurentia (Canadian Shield) through the formation of oceanic plates giving birth to several oceans including Iapetus.



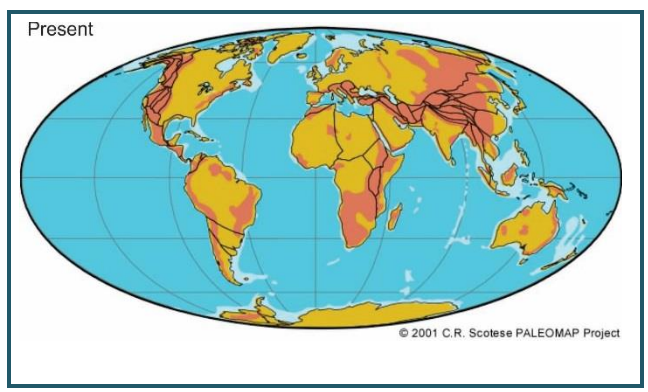
3) Between 540 and 460 million years ago, there was sedimentation of the rocks of the St. Lawrence Platform and Appalachians, along the continental margin of Laurentia.



4) Between 475 and 380 million years ago, the Iapetus Ocean progressively closed forming the Appalachian Mountains.



5) Approximately 290 million years ago, several continents once again came together to form the supercontinent Pangea. This one began to fragment around 200 million years ago, creating new oceans such as the Atlantic and separating the current continents.



6) Current configuration.

- Continents (cratons)
- Mountain chains
- Continental plateaus
- Oceans

Figure 5. Schematic representation of the formation of the supercontinents and oceans starting 750 Million years ago
(Modified from Scotese, 2001 and Bourque, P.-A., Planète Terre)

STOP 2 – SAINT JOHN GATE

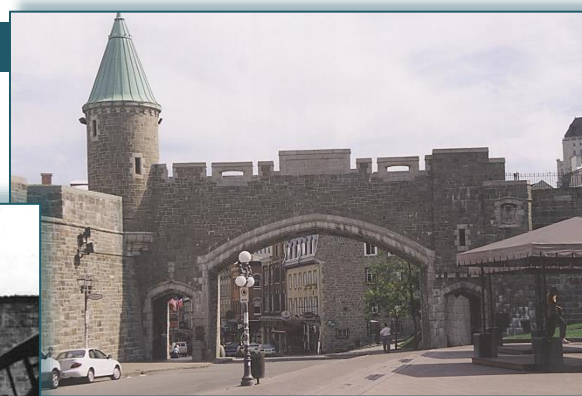


Figure 6. Photo of the current Saint John Gate
(Taken from Geoscape Québec,
Côté et al., 2001)

Figure 7. Photo of Saint John Gate in 1867
(Taken from the 2011-2012 Catalogue,
Quebec City Field Unit, Parks Canada)

The Saint John Gate in its current location was built starting in 1745 when the fortifications were moved slightly to the west by engineer Gaspard-Joseph Chaussegros de Léry. This gate was reconstructed in the 1860s (see image) and destroyed in 1897. The current gate was constructed in 1938-1939 and matches the architectural style used for the Kent and Saint Louis gates, which were reconstructed at the end of the 19th century.

At the end of the French regime, around 1740, the quarrying of green sandstone between Sillery and Cap-Rouge began. The rocks belong to the Cambrian Sillery Group (approximately 510 million years ago), which is part of the Chaudière thrust sheet in the Appalachians. This coarse-grained sedimentary rock contains quartz and feldspar pebbles, and fossil fragments. The rigidity which made it difficult to shape as well as its tendency to break into thin layers explain why it was only little used at the beginning of the colony, despite its proximity. Chaussegros de Léry used it to erect part of the Quebec fortifications. The English would make extensive use of it for their military structures, namely the Martello Towers and the Citadel. It is still possible to see remnants from its use along Champlain Boulevard and this stone is visible along the trails near the Aquarium of Québec.

The green sandstone of the Sillery Group was used to construct part of the fortification walls and was also used for the Citadel, the Martello Towers and to renovate the Saint John Gate in 1938.

Figure 8. Stone blocks made of Sillery sandstone
(Photo by Léopold Nadeau,
Geological Survey of Canada, 2006)

STOP 3 – SAINT LOUIS GATE

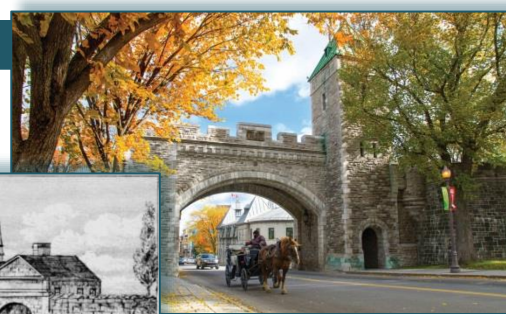


Figure 9. Current Saint Louis Gate
(Photo by Guy Lessard, Office du tourisme de Québec, 2015)

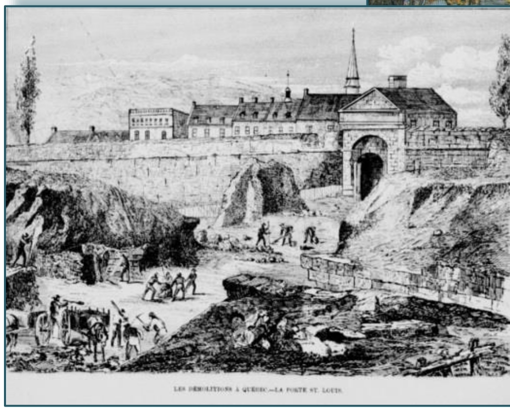


Figure 10. Saint Louis Gate in 1871
(Taken from the 2011-2012 Catalogue, Quebec City Field Unit, Parks Canada)

Like the Saint John Gate, construction on the Saint Louis Gate began in this sector in 1745. It was destroyed in 1871, the year the British garrison left. In fact, there was pressure from the population in favour of better traffic between the old and new city that resulted in the elimination of the original gate. Lord Dufferin, Governor General of Canada from 1872 to 1878, intervened to prevent the complete demolition of the defensive works that had become outdated. His plans included, among other things, to construct new gates and create a pedestrian trail all around Old Quebec.

The current Saint Louis Gate, erected between 1878 and 1881, was made of grey limestone from the St. Lawrence Platform. In use since 1714, this limestone was first mined at Pointe-aux-Trembles in Neuville. Over the last 135 years, this same limestone formation has been mined in Saint-Marc-des-Carrières. It is one of the best construction materials found in the Quebec City region. It is generally very fossiliferous, massive and occurs in light grey beds of uniform thickness, which can be easily carved. Generally, only the wealthy used this quality stone to build their homes. It was used for door and window frames or load-bearing partition walls in several buildings.

Figure 11. Blocks of grey limestone
(Photo by Léopold Nadeau, Geological Survey of Canada, 2006)

Several prestigious buildings are covered with limestone from the St. Lawrence Platform, including: the Parliament Building, the Palais Montcalm and the former banks on Saint-Pierre Street.

STOP 4 – CUREUX HOUSE

Figure 12. Cureux House
(photo by Léopold Nadeau
Geological Survey of Canada, 2003)

The Cureux House, at 86 Rue Saint Louis, was built in 1729 by innkeeper Michel Cureux. It is the second oldest residence on Rue Saint Louis. The house standing today is a reconstruction of the original, which was destroyed in 1709 to make way for the fortifications. It was only after a long trial followed by the whole colony that the French government was forced to back down and rebuild the house.

Maison Cureux is one of the rare examples of houses constructed from what was called "pierre noire du Cap" or "Black Cap stone", the first type of building stone used in Quebec City. When the early settlers built their homes on the promontory, they dug the foundations, setting aside the excavated stone to build walls with it. It is a black argillaceous limestone (Quebec City Formation, dating back to the Middle Ordovician, nearly 470 million years ago) which easily split in thin layers parallel to sedimentary bedding after being exposed to water and air. It does not allow for good quality external masonry and it was mostly used to cover the interior walls of buildings. For exterior walls, the stone was covered with parget as was the case with this house until 1968. Despite its poor quality, this stone was very popular during the French regime due to the proximity of the quarrying sites and consequently its lower cost. There were numerous quarries at the foot of Cap Diamant and we will get to visit two of them on this tour.

Figure 13. Blocks of black argillaceous limestone, "Black Cap stone"
(Photo by Léopold Nadeau,
Geological Survey of Canada, 2006)

Figure 14. Representation of Rue Saint-Louis around 1830
(By J.P. Cockburn,
taken from the National Archives of Canada)

A few metres from the Cureux House, between the Saint Louis and Ursulines bastions, stands the Esplanade Powder Magazine (1815), restored and open to the public. At the time, the effectiveness of fortifications largely depended on the location of the powder magazines. That is why the British would distribute them strategically around the city, while at the same time avoiding having an overly large concentration of gunpowder in any one place. In 1816, there were 12 powder magazines in Quebec City. To protect the surrounding area, the walls of the powder magazines were 1.5 metres thick, their ceilings were arched and they were surrounded by a thick outer wall.

STOP 5 – CAVELIER-DU-MOULIN PARK

Figure 15a. Low stone walls of fossiliferous stone
(Photo by Pascale Côté,
Geological Survey of Canada, 2007)

Figure 15b. Military relics
(Photo by Pascale Côté,
Geological Survey of Canada, 2007)

The Cavelier-du-Moulin Park is considered one the most romantic parks in Old Quebec. A remnant of the 17th century French fortifications, this defensive installation sits on a small mound called Mont Carmel. In 1663, there was a small windmill ("moulin") that became part of the city's first fortifications. The Cavelier-du-Moulin lost his defensive functions around 1755 when the second enclosure, constructed more to the west, definitively closed off the Upper Town enclosure on the southwest side.

At this stop, you can see an abundance of fossils in the limestone rocks that were used to construct the polished slabs and the wall that surrounds the small courtyard near the park on Rue Mont Carmel. The fossils are of marine invertebrates that populated a shallow sea during the formation of the St. Lawrence Platform limestone. The rapid burying of their calcite skeletons in the sediment contributed to their fossilization. The ones that can be seen at this stop still exist in modern oceans, although they are distant cousins (or species).

One can observe branched stalks measuring 2 to 5 cm, which are the remnants of bryozoans (Figure 16). They played an important role in the construction of limestone reefs on the St. Lawrence Platform when it was located in the Tropics. The bryozoans secreted a calcite skeleton that was either branched or in the shape of small mounds and formed thousands of small pockets for creating colonies. We can also see small doughnut-shaped fossils (Figure 17) that are approximately 5 cm long. These are the disarticulated stalks of crinoids, which are echinoderms like the starfish and sea urchins of today. However, crinoids were immobile and lived fixed to the marine substrate. The flexible calcite stalks were topped by a calyx and crown of branched articulated arms. During storms powerful enough to devastate the sea floor, the crinoids were uprooted and transported far enough to precipitate their disarticulation.

In the limestone blocks forming the wall, we can also see brachiopods (Figure 18) with their radiating ribs and concentric growth lines. Although not very common today, brachiopods were prolific organisms in the shallow marine habitats of the Ordovician, approximately 485 to 445 million years ago. These animals lived in calcite shells formed by two valves. Despite their resemblance, they do not belong to the same group as mussels, oysters and clams.

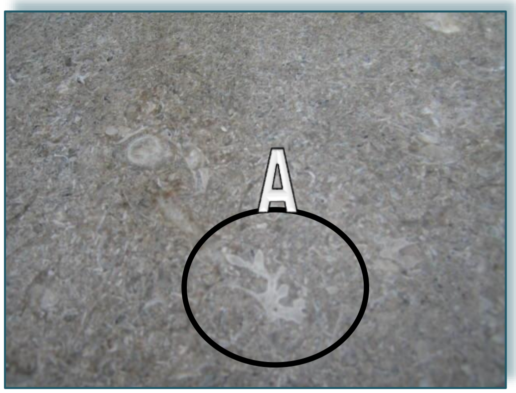


Figure 16. Remnants of bryozoans (A: approximately 1.5 cm)
(Photo by Jean-François Bureau, Geological Survey of Canada, 2016)

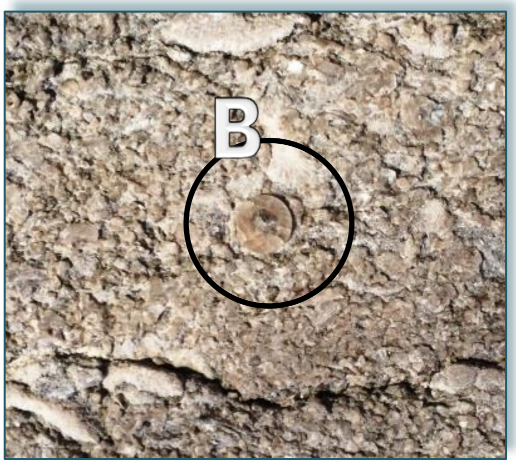


Figure 17. Disarticulated crinoid stalks (B and C: approximately 4 mm)
(Photo by Jean-François Bureau, Geological Survey of Canada, 2016)

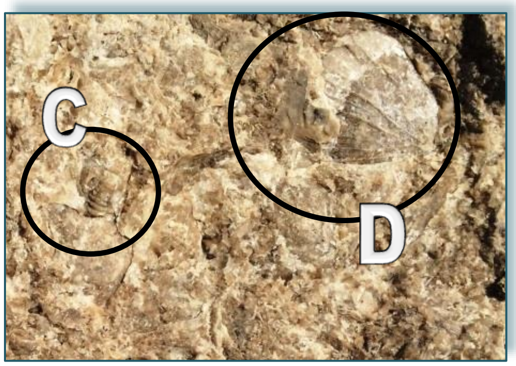


Figure 18. Brachiopod valve (D: approximately 1 cm)
(Photo by Jean-François Bureau, Geological Survey of Canada, 2016)

STOP 6 – QUEBEC CITADEL (PIERRE-DUGUA-DE-MONS TERRACE)

Figure 19. Quebec Citadel and bust of Pierre-Dugua-De-Mons
(Photo by Jean-François Bureau, Geological Survey of Canada, 2007)

Engineers and military strategists have always considered the heights of the Plains of Abraham to be a strategic location. The French occupied the heights as early as 1693, when they built the Cap Diamant Redoubt. The redoubt is one of the oldest military structures in Canada and remains an integral part of the Quebec Citadel. The British also sought to fortify the strategic site. In 1789, they built a temporary citadel, which they replaced in 1832 with the permanent one that still stands today. After the construction of the Citadel, Quebec City became known as the Gibraltar of the Americas. Nowadays, the Citadel is home to the Royal 22nd Regiment and is the location of one of the official residences of Canada's Governor General.

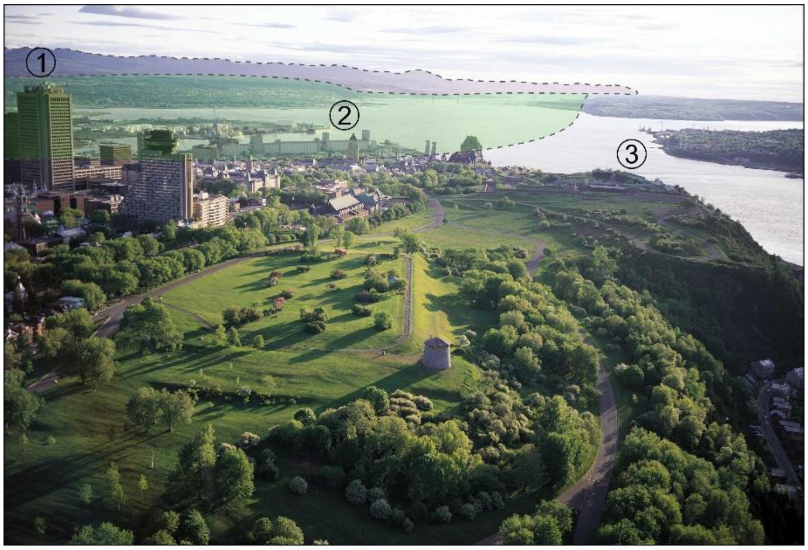
The Citadel is the most important fortification built in Canada under the English. The star-shaped stone polygon was built to protect the city against a possible American attack, but also to contain a rebellion by the city's French-speaking population. This is why the Citadel faces Old Quebec's centre as much as its periphery.

Pierre Dugua de Mons (1560-1628) was the first colonizer of New France and Samuel de Champlain was his lieutenant. He founded Tadoussac in 1599. Henri IV appointed him "Lieutenant General of North America" in 1603. He initiated and financed a vast enterprise that he entrusted to Samuel de Champlain to establish the first colony outpost in New France. The site chosen by Champlain was Quebec City, where he disembarked on July 3, 1608 with 27 companions.

Figure 20. Canon on the King's Bastion at the Citadel
(Photo taken from: www.pinterest.com/pin/481955597593678015, 2016)

The canon situated in the King's Bastion is an Armstrong canon that was positioned in this location when the Lévis forts were constructed (1865-1872). Named Rachael, this 9-ton rifled gun had an effective range of approximately 3 kilometres. Just to compare, 32-pounder long guns had an effective range of approximately 1 kilometre. In Old Quebec there are several English canons of this calibre that date back to the early 19th century. The English deployed this Armstrong canon in the Citadel in order to reach the Lévis forts. In fact, in the event an enemy force succeeded in taking these forts, the English were ready to destroy them with this powerful canon. The United States would remain Canada's main enemy until 1871, the year the Washington Treaty was signed by the English and Americans.

Panorama of the Quebec City Region's Geological Diversity



1. Canadian Shield / 2. St. Lawrence Lowlands / 3. Appalachians

Figure 21. Panorama of the reliefs associated with the three geological provinces in the Quebec City region
(Photo by Jean-François Bureau, Geological Survey of Canada, 2007)

From the glacis of the Citadel, you can get an overall view of the geological diversity of the Quebec City region. The gneiss, granites and gabbros of the **Grenville Province** (Canadian Shield) are the oldest rocks in the region. They are part of a large mountain chain that, in Quebec, extends from the Ottawa River to the Côte-Nord region. Although imposing, the current relief of this mountain chain is nothing like what it was approximately a billion years ago. At that time, Mount Sainte-Anne was part of a mountain chain similar to the Himalayas! Since then, they were considerably eroded and today only their deep roots remain, that is to say the part that was originally buried several kilometres beneath the surface.

The sandstones, limestones and mudstones of the **St. Lawrence Platform** formed in various coastal and marine environments along the margin of the continental platform of the ancient continent of Laurentia, approximately 530 to 440 million years ago. These rocks are therefore much younger than those of the Grenville. The rocks of the St. Lawrence Platform form the bedrock of the lowlands of the same name, i.e. the plain without actual relief that we can see north of Île d'Orléans and that extends to the west going through Beauport, Ancienne-Lorette and the regions of Portneuf and Montreal. Approximately 460 million years ago, the Quebec City region was situated near the equator and covered by an ocean that was the precursor of today's Atlantic Ocean. It was along the edge of this ocean, in its shallow waters, where sediment was deposited from the erosion of the Canadian Shield (detrital sediment) along with calcite particles from the sedimentary basin, mainly shells or fragments of the abundant organisms that lived in the ocean.

The relief of the **Appalachian** mountain chain is visible on the south shore of the St. Lawrence River. However, the Appalachian geological province extends to Quebec City's upper town, represented by the Quebec promontory and Chaudière thrust sheets. The entire south shore of the St. Lawrence as well as the largest part of Île d'Orléans (Bacchus thrust sheet) are part of the Appalachians, even though the relief is relatively flat. The boundary between the Appalachians and the St. Lawrence Platform is marked by a series of fault zones called Logan's Line. The position of this fault line on the surface is located to the north at the base of the Quebec promontory and extends across the north side of Île d'Orléans, creating an important break in the relief on the Sainte-Pétronille side. This mountain chain was formed when rocks were transported and stacked up along large thrust faults, at the very doorstep of Quebec City, approximately 450 million years ago.

FROM OBSERVATION TO INTERPRETATION… THE GEOLOGICAL HISTORY OF THE QUEBEC CITY REGION		
In Grenville times: Quebec City at the foot of the highest peaks	**The St. Lawrence Platform: Quebec City in the Tropics**	**Origin of the Appalachians: mountain building forces**
A billion years ago, the Canadian Shield's ancestor, the continent of Laurentia, was part of the supercontinent Rodinia, a group of continents or cratons grouped together through collisions. A mountain chain was created when Laurentia collided with other cratons. These became the Laurentians, which are greatly eroded today. The rocks of the Grenville Province stretch over an area of more than 4,000 km (from Labrador to Texas); in some areas, they are overlain by younger rocks while in other areas they are exposed at the surface.	Approximately 750 million years ago, the supercontinent became unstable and slowly began to fragment. The motion of the tectonic plates reversed itself and another cycle of opening ocean basins began. The continental blocks drifted apart creating a long rift. As it widened, the rift progressively gave birth to the Iapetus Ocean. Approximately 540 to 460 million years ago, sediment began to accumulate on the continental shelf on the ocean's edge. Rocks from the St. Lawrence Platform represent the remnants of a vast sedimentary sequence covering most of the Canadian Shield, as evidenced by their presence in Lac Saint-Jean and Manicouagan Lake areas.	Approximately 475 million years ago, the motion of the tectonic plates reversed itself once again and a new cycle of closing ocean basins began. Along an active continental margin (subduction zone), the Iapetus Ocean gradually closed up over a period of more than 200 million years, progressively creating a new mountain chain on the edge of Laurentia. The sedimentary rocks from the deep-sea trench were pushed up onto the continent, over thrusting those of the St. Lawrence Platform. The Appalachians extend over 3500 km from Alabama to Newfoundland in North America. However, the chain actually extends all the way to the British Isles and Scandinavia: that section is called the Caledonides, today separated from the Appalachians by the Atlantic Ocean.

A Step in the Construction of the Canadian Shield

Approximately 600 million years ago, as Rodinia broke up, the Canadian Shield became dislocated along three fault systems, tilting approximately 120° to each other, causing a large piece of the supercontinent to split off. The Ottawa River Valley represents one of these fault systems. The faults that formed the scarped relief on the north shore of the St. Lawrence River and mark the boundary with the Laurentians are the expression of another of these systems. The third fault system is probably buried under the Quebec and New England Appalachians.

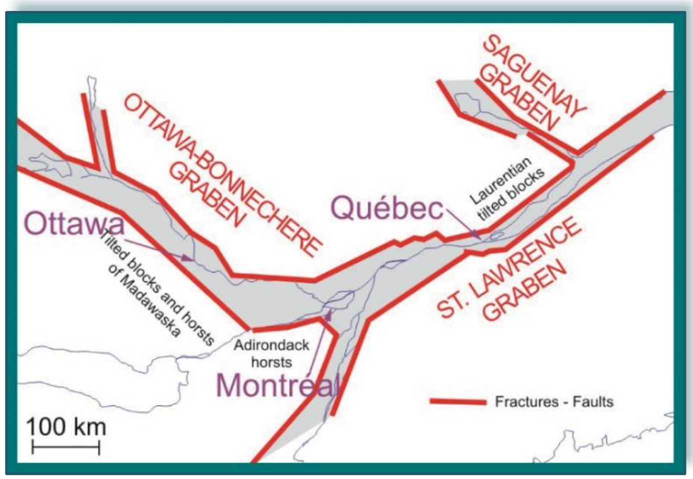


Figure 22. Map of fault systems bordering the grabens of southwestern Quebec
(Modified from Kumarapeli and Saull, 1966)

Montmorency Falls: Witness to a fault and the work of erosion...

Montmorency Falls, 84 m tall, mark the location of a major structure, the Montmorency fault. The latter is quite steep, extending northeast and is at the source of the Côte-de-Beaupré and the contiguous slopes northeast of Route 138. It is part of a family of normal faults cutting the Laurentian continental margin and was active during the deposit of sedimentary rock of the St. Lawrence Platform. The glaciers and river waters were more successful in eroding the inclined sedimentary layers of the St. Lawrence Platform than the gneiss and granite of the Canadian Shield, giving birth to these majestic falls.

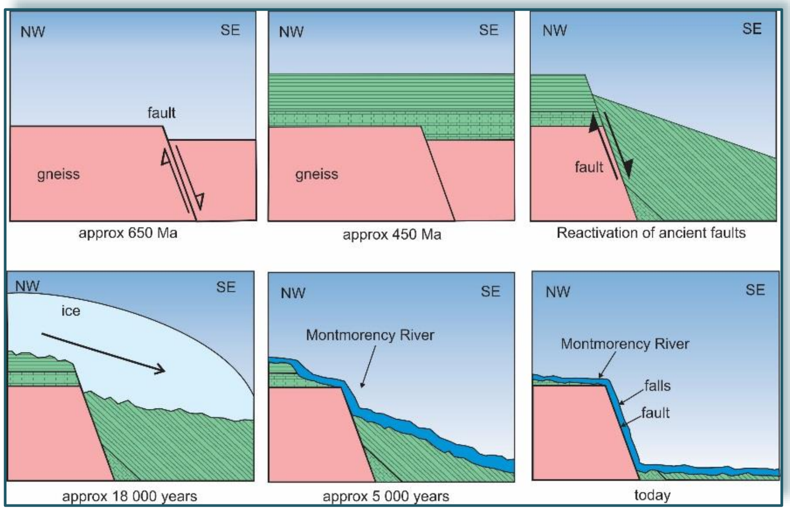


Figure 23. Diagram of the geological evolution that resulted in the formation of the Montmorency Falls
(Provided by Donna Kirkwood, Université Laval, 2003)

Logan's Line: Fault Zone between the St. Lawrence Platform and the Appalachians

When climbing from Lower Town to the Upper Town of Québec, we are actually moving between the St. Lawrence Platform and the Appalachians. The boundary between these two geological provinces is marked by a fault zone, named Logan's Line, which extends along Rue Arago, the Côte de la Pente-Douce or Versant-Nord Boulevard. This zone extends from Gaspé region to Lake Champlain, going through Île d'Orléans, Quebec City, Sainte-Foy and Cap-Rouge. This is the current western boundary of the Appalachians, along which rock masses were transported to the northwest by thrust sheets during the progressive shrinking of the Iapetus Ocean. Also called "Logan's Fault", it is now considered to be inactive.

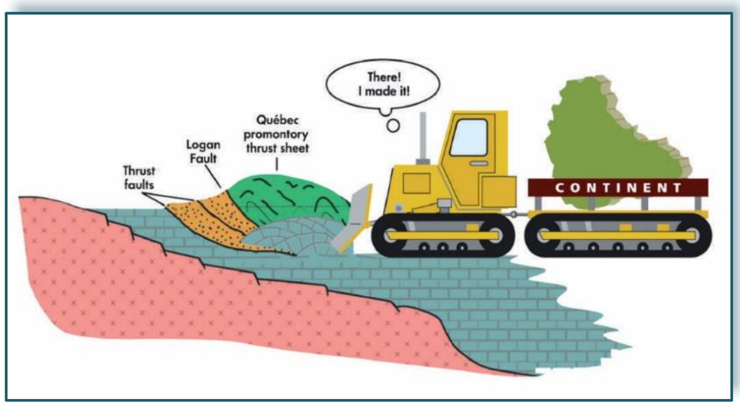


Figure 24: Pictorial representation of the development of Thrust Sheets
(Taken from Geoscape Québec, Côté et al., 2001)

STOP 7 – RUE DES CARRIÈRES

Figure 25. Outcrop of argillaceous limestone
(photo by Léopold Nadeau,
Geological Survey of Canada, 2003)

At the bottom of the Pierre-Dugua-de-Mons Terrace and the stairway leading to Rue des Carrières, there is an outcrop of fine-grained argillaceous limestone. We can see a clear stratification (piling of rock layers) and several fractures showing rounded surfaces (resembling the pipes of a pipe organ). The stone reacts to chlorhydric acid, indicating the presence of calcite.

This is one of the sites where Black Cap stone was quarried beginning in the 17th century, under the French regime. Quarry workers nicknamed this stone "stinking stone" because of the odour of "oil" that is released when the stone is crushed. This odour is due to the fossil fuels (gas, oil) that migrated and were trapped in the folded sedimentary rocks of the Appalachians.

The dark-coloured rocks of Cap Diamant contain numerous fractures, crevasses and cavities, in which a number of minerals have crystallized. The best known of these is bipyramidal quartz crystals. When Jacques Cartier found some of these crystals in New France, in 1542, he thought he had discovered diamonds, hence the French expression "Faux comme les diamants du Canada," which means "as phony as Canadian diamonds." After many years of geological work and exploration, we have now discovered several deposits of real diamonds in Canada and even in Quebec.

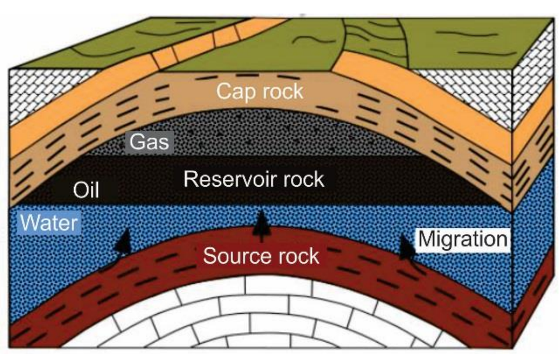


Figure 26. Simplified Diagram of a Conventional Petroleum System

Fossil fuels, commonly called hydrocarbons, are found in the sedimentary rock and are the result of geological processes that transform sediment into rock. Several conditions are required for hydrocarbons to develop, including the presence of sediment rich in organic materials, located in subterranean conditions favourable to its thermal maturation. These sediments will form the source rocks. The hydrocarbons then undertake a long ascending migration, carving a path over the millennia through the rock layers toward reservoir rocks, which are porous and permeable and in which the hydrocarbons can accumulate. These reservoir rocks must be covered by impermeable layers, seal rocks that stop the rising of hydrocarbons toward the surface, forming traps in which the oil and gas is contained in variable proportions depending on the subterranean conditions and the maturation of the organic materials. Hydrocarbons separate from one another based on their respective densities: water at the base of the reservoir, followed by oil then gas. The metamorphism of rocks rich in organic materials or containing hydrocarbons can cause the crystallization of graphite, formed essentially from carbon.

STOP 8 – GOVERNORS' GARDEN

Figure 27. Governors' Garden
(Photo by Jean-François Bureau,
Geological Survey of Canada, 2007)

Rue des Carrières separates the Dufferin Terrace from the Governors' Garden, located west of the Château Frontenac. This green space dates back to the beginnings of Quebec City when Charles Jacques du Hault de Montmagny, first governor of New France, laid out the first garden in 1648. It was adjacent to Fort Saint-Louis, the main fortification at the time and place of power. The Governors' Garden also had a defensive function. Faced with an Iroquois threat, the French authorities decided to build enclaves and a wooden palisade to ensure the safety of the population. Other defensive structures were also built in the Governors' Garden, including several in stone. In the 18th century, the walls enclosing the area ensured the privacy of the governor and his guests. Lord Durham made it open to the public starting in 1838.

The obelisk found in the Governors' Garden is the oldest monument in Quebec City. It is made of limestone and came from a locality situated between Neuville and Saint-Augustin. It was erected in 1828 in commemoration of Wolfe and Montcalm, the two enemy heroes who died on the field of honour on September 13, 1759. Wolfe was only 32 years of age and Montcalm was 47.

Figure 28. Governors' Garden
(Illustration by J.P. Cockburn, taken from the National Archives of Canada, 1829)

STOP 9 – DUFFERIN TERRACE

Figure 29. Dufferin Terrace
(Photo by Jean-François Bureau, Geological Survey of Canada, 2007)

The remains of the St. Louis forts and chateaux, the governors' residences until 1834, can be found under the Dufferin Terrace. Fort St. Louis was first built in 1621 by Samuel de Champlain. It was modified and repaired several times, by both the French and the British, to adapt it to new functions. In fact, it was in the Château St. Louis that Governor Frontenac made his infamous 1690 statement: "Je vous répondrai par la bouche de mes canons." ["I will reply from the mouth of my cannons"]. The structure burned down in 1834, and Lord Durham had a terrace built in 1838 to cover the ruins of Château St. Louis. The terrace was extended in 1878, and was henceforth known as the Dufferin Terrace.

As a key part of the St. Louis Forts and Châteaux National Historic Site, the Dufferin Terrace is one of the most popular tourist attractions in Quebec City. It has been open to the public since 1838, when it was 50 metres long, and has since been extended to its current length of 433 metres. Since its official inauguration on June 9, 1879, the Terrace has offered a panoramic view of the St. Lawrence River and Quebec City's surroundings to the millions of visitors that stroll down the boardwalk every year.

Figure 30. Château Frontenac
(Photo by Jean-François Bureau, Geological Survey of Canada, 2007)

Figure 31. Archaeological digs under Dufferin Terrace by Parks Canada between 2005 and 2007
(Photo by Léopold Nadeau, Geological Survey of Canada, 2006)

The ornaments at Château Frontenac, one of the most photographed hotels in the world, are made of limestone.

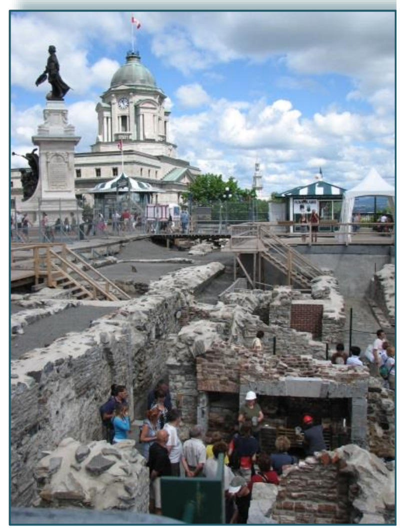


Figure 32. Archaeological digs under Dufferin Terrace
(Photo taken from the 2011-2012 Catalogue, Quebec City Field Unit, Parks Canada)

The River: History of an Ephemeral Sea

Figure 33. St. Lawrence River separating Quebec City and Lévis
(Photo by Léopold Nadeau,
Geological Survey of Canada, 2005)

The position of the St. Lawrence Valley corresponds to the site of an ancient system of downthrow faults, the St. Lawrence Graben, formed 600 million years ago while Rodinia was breaking up, creating a continental rift and ultimately the opening of the Iapetus Ocean. The collapse of the Earth's crust along these faults resulted in the progressive development of a continental margin that was swallowed up by a deepening sea where sandstone, limestone and shale were deposited and which today comprise the St. Lawrence Lowlands.

The river's current path, however, is the result of the last glacial period. The melting ice gradually allowed the waters of the Atlantic Ocean to reach southern Quebec, forming a post-glacial sea (Champlain Sea), present for a few thousand years before the river progressively carved its bed through the deposits of sediment left in place by the melting glaciers and the retreating sea. Approximately 9500 years ago, the Quebec promontory was an island surrounded by two channels. The northern channel, now occupied by Lower Town in Quebec City, dried out as the land rose (see capsule on the glacial era following Stop 18), forcing the waters from the river as well as the tides to use the current channel to the south.

STOP 10 – MONUMENT CHAMPLAIN

Figure 34. Samuel de Champlain Monument
(Photo by Jean-François Bureau,
Geological Survey of Canada, 2007)

The monument to Champlain on the esplanade in front of the Château Frontenac was constructed in 1898 using the same limestone used the build the Arc de Triomphe in Paris and the Montmartre Basilica. Its restoration, completed using the original stone, was completed for the 400th anniversary of Quebec City.

There is no official portrait of Quebec City's founder. A false portrait of Samuel de Champlain bears the features of Michel Particelli, an unscrupulous French finance inspector, from a 1654 portrait. The monument was created by Paul Chevré, a survivor of the 1912 Titanic shipwreck off the coast of Newfoundland.

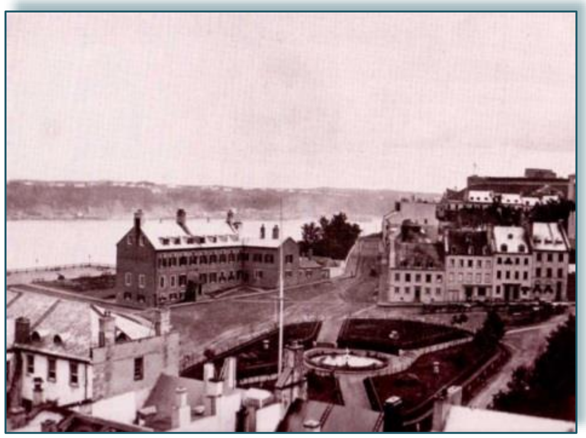


Figure 35. Monument de la Foi
(Photo provided by the Société historique de Québec)

Place d'Armes, located close to the Château Saint-Louis, and once the seat of political and military power, was the main assembly grounds for the soldiers who were needed to respond quickly in the event of an attack. Quebec City's main streets (Saint-Jean, Saint-Louis and Sainte-Anne) lead away from Place d'Armes toward the fortifications, in the European tradition. During the British period, in the 19th century, Place d'Armes became an urban park complete with horseback riding and public hangings. Nowadays, the centre of Place d'Armes features the Monument de la Foi [Monument to Faith], built in 1916 to commemorate the 300th anniversary of the Récollet fathers' arrival in Quebec City.

STOP 11 – BREAK-NECK STEPS

Figure 36. Break-Neck Steps
(Photo by Jean-François Bureau, Geological Survey of Canada, 2012)

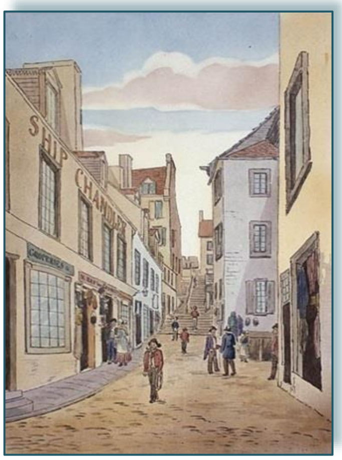


Figure 37. Break-Neck Steps
(Illustration by J.P. Cockburn, 1830, taken from the National Archives of Canada)

The Break-Neck Steps were one of the first links between the Lower and Upper Towns. On a Quebec City plan from 1660, they were called "Escalier Champlain". Its current name dates back to the 19th century and can apparently be traced to a nickname given by American seafarers passing through the city.

The Quebec promontory is formed by part of the thrust sheet of the same name at the front of the Appalachians. The Lower Town stairs and the cliff allow us to see the rocks transported by the Quebec promontory thrust sheet. The funicular would be another way of seeing these reliefs.

STOP 12 – CÔTE DE LA MONTAGNE

Figure 38. Olistostrome Outcrop
(Photo by Pascale Côté,
Geological Survey of Canada, 2006)

The street Côte de la Montagne was built under the supervision of Champlain in 1620. It was the first official link between the city's Lower and Upper Towns. The Appalachian thrust sheets are responsible for the steep relief of the city. The different levels modelled Quebec City's development along the lines of a medieval town: an Upper Town for the political, military and religious elite and a Lower Town for the merchants, craftspeople and workers. At the start of the colony, most of the houses were located in Place-Royale and in the Petit-Champlain district. This facilitated port exchanges along with access to water supplies and resources. Only dignitaries and government and religious institutions were located in the Upper Town, which guaranteed their safety and set them apart socially.

The cliff located at the junction of Côte de la Montagne and Rue Sault-au-Matelot displays an olistostrome, a rock that features blocks of various sizes contained in an argillaceous matrix. The matrix originated as mud deposited in the depths of an ancient sea located near the foot of the Appalachian Mountains. The erosion of the bedrock creating a submarine relief caused rock fragments to drop and slide into the mud. This mix of sediment and rock gradually became buried, and then was overlain by thrust sheets moving towards the foreland. Under the pressure and increasing temperature cause by gradual burial, the sediment transformed into rock through a process called diagenesis or lithification.

STOP 13 – PLACE ROYALE

Figure 39. Notre-Dame-des-Victoires Church in Place Royale
(Photo by Stéphane Audet/Audet Photo
Office du tourisme de Québec, 2016)

Place Royale was the site chosen by Samuel de Champlain for the 1608 founding of the first permanent French settlement in America, evolving from a trading post to the city that we know now. The Government of Quebec decided to restore and revitalize the area in 1967. Since the neighbourhood was poor and dilapidated, the provincial government took charge of the restoration and reconstruction of the buildings in the area to restore the New France ambience, and thus recall the urban development of Quebec City's origins. Nowadays, Place Royale is largely a tourist and commercial district; the site of the city's early colonization now moves to the rhythm of the tourist season, because few people live there.

Stone houses are one of the most typical features of Place Royale. These residences, like part of Quebec City's fortified walls, were built with limestone blocks from the city's surrounding areas. The Notre-Dame-des-Victoires Church was constructed in 1688, on the very site of Samuel de Champlain's "Abitation". It was designated a historical monument in 1929.

If you take a close look at the front of the Elizabeth Douaire House, between street numbers 3B and 3C, you will note a large number of bryozoans and brachiopods (Figure 40) in the coarse-grained limestone that form the decorative framing around the doors. A bit further ahead, the cut stone forming the corner of the Notre-Dame-des-Victoires Church, to the right of the Place Royale sign, features an abundance of crinoids (Figure 41).

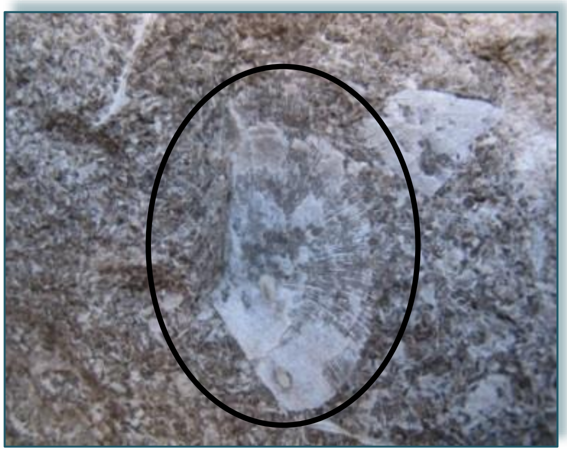


Figure 40. Brachiopod (approximately 1 cm) in the fossiliferous limestone of Douaire House
(photo by Jean-François Bureau,
Geological Survey of Canada, 2007)

Figure 41. Crinoid stalk (approximately 4 mm) in a limestone block of the Notre-Dame-des-Victoires Church
(photo by Jean-François Bureau,
Geological Survey of Canada, 2007)

Other Fossils at the Price Building

The exterior of the Price Building is composed in part of limestone originating from the Niagara escarpment containing pink calcite crinoid stalks that are quite visible in the building's columns. This stone is rough to the touch and weathers over time to a brownish colour. The use of stone from Ontario in the construction of this large building suggests that the local quarries could not keep up with demand.

Figure 42. Pink crinoid stalks that can be seen in the limestone blocks of the Price Building
(Photo by Jean-François Bureau, Geological Survey of Canada, 2017)

Figure 43: Price Building
(Photo by Jean Gagnon, Wikimedia Commons, 2012)

The Price Building was built in 1929 by the Price Brothers pulp and paper company, at a cost of $1 million. The 17-storey building was the tallest in Old Quebec for a long time, and spawned a 1932 municipal by-law prohibiting the construction of any building taller than 20 metres, to protect the visual landscape of the Old Town.

The Jesuit College could once be found across from the Price Building, where City Hall currently stands. Following the 1759 Conquest, British military authorities transformed the Jesuit College into soldiers' barracks. As was the case for the Dauphine Redoubt and the new barracks of Artillery Park, the British occupied the Jesuit College until 1871. In addition to the barracks, the site holds a guardhouse, an armourer shop, a bakery and a parade ground. The Jesuit College was destroyed in 1877 to make room for City Hall.

Figure 44. Jesuit College
(Illustration by R. Short, 1761, taken from the National Archives of Canada)

STOP 14 – RUE SOUS-LE-CAP

Figure 45. Retaining wall and installation of rock bolts on Rue Sault-au-Matelot
(Photo by Léopold Nadeau, Geological Survey of Canada, 2003)

On Rue Sous-le-Cap and at the intersection of Rue Barricade and Rue Sault-au-Matelot, there is an outcrop of the thrust sheet that forms the Quebec promontory. You can see massive argillaceous limestone interbedded with thin layers of black shale. The rocks underwent considerable deformation (folding, faulting).

The lane between Rue Sous-le-Cap and Rue Sault-au-Matelot is now blocked and fencing was recently installed to prevent accidents connected with the landslide risk. Draped wire mesh, rock bolts and fences installed in the cliff along Rue Sault-au-Matelot serves as a reminder that the Place-Royale sector of Cap Diamant is unstable and prone to rockfall and landslides. Corrective work was carried out to make the site safer, including the construction of a retaining wall (Rue Sault-au-Matelot) and the installation of rock bolts.

When the Americans invaded Quebec City in 1775, during the American Revolution, Benedict Arnold's troops landed with the intention of overtaking the city and preventing the British from deploying reinforcements to the 13 colonies. Arnold was joined by General Richard Montgomery, who had already conquered Montreal in early December. While Montgomery launched an attack on the Cap Diamant side, Arnold attacked near Rue Sous le Cap, at the Sault au Matelot barricade on the other side of town. Arnold succeeded in seizing several barricades, but in the end was defeated by Captain Dumas and his militia. The Americans laid siege to the city in 1775. Knowing that the contracts of several of their soldiers would expire at the end of the year, the two American generals launched the attack on December 31, 1775 during a snowstorm. The Rue Sous le Cap attack was a complete failure and marked the end of the American invasion of Canada.

Figure 46. End of the American Invasion of Canada
(Illustration by J. Trumbull, 1786, taken from the Library of Congress)

STOP 15 – RUE SAINT-PIERRE

Figure 47. Ornamental motifs on the facades along Rue Saint-Pierre
(Photo by Jean-François Bureau,
Geological Survey of Canada, 2017)

Along Rue Saint-Pierre, important stone buildings, built between 1850 and 1915, were home to banks and important business institutions. In the early 20th century, this sector of Lower Town was known as the "Wall Street of Quebec City." You can see the different finishes on the limestone blocks in the building facades: hammered, combed, sanded, vermiculated, etc.

ARRÊT 16 – RUE SAINT-ANTOINE

Figure 48. High tide lines
(photo by Pascale Côté,
Geological Survey of Canada, 2006)

Rue Saint-Pierre is situated where the high tide line would have been when the colony first began. Markers have been installed in the cobblestones in rue Saint-Antoine where the water was at its maximum in 1700, 1800 and 1900. A portion of the lowering of the St. Lawrence level is due to the fact that all the houses east of Rue St-Paul were built on embankments. The river level has fluctuated several times since deglaciation; the post-glacial retreat of the waters also contributed to the lower high tide levels.

STOP 17 – PARENT HOUSE (11 RUE SAINT-PIERRE)

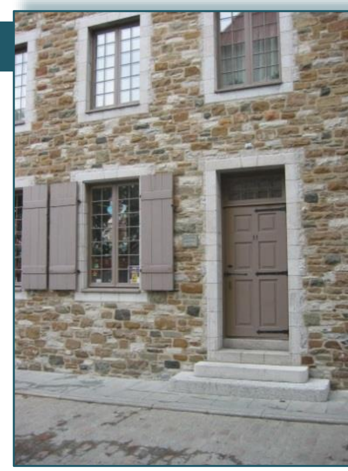


Figure 49. Parent House
(photo by Léopold Nadeau,
Geological Survey of Canada, 2003)

A large number of characteristic rocks from the Quebec City region were used in the construction of Parent House. Located at the corner of Rue Saint Pierre and Rue Sous-le-Fort, this house was rebuilt in 1761, after being demolished during the siege of Quebec City by the British in 1759. The exterior wall coverings contain various stones, some of which were salvaged from the former building. They include Ange-Gardien calcareous sandstone of varying grain size whose ochre and red colouration is attributable to the oxidation of ferruginous minerals, Beauport limestone, Sillery sandstone, Rivière-à-Pierre granite and "Black Cap stone." The door and window frames are made of Pointe-aux-Trembles limestone.

Grenville Granite

The presence of a block of granite in the facade of Parent House is due to recent restoration work. This is granite from the Canadian Shield in the Rivière-à-Pierre region. This rock, twice as old as the other rocks in the Quebec City region, is also a lot more resistant. Granite is a grainy igneous rock, resulting from slow cooling, at depths, of large masses of intrusive magma. It is composed of quartz, feldspar and mica. It is used for cobblestones, monument stands and sidewalk edges. The blocks forming the pillars of the Quebec Bridge were chiseled from Rivière-à-Pierre granite, just like the base for the Statue of Liberty in New York. The opening of a railway in 1875 between Saint-Gabriel-de-Valcartier and Rivière-à-Pierre made it possible to quarry this stone and ship it to clients. This old 68-km railway is now the Jacques-Cartier/Portneuf bikeway.

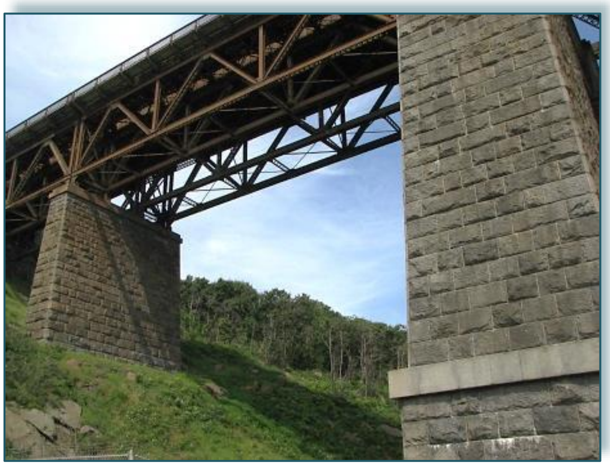


Figure 50. Granite blocks forming the pillars of the Quebec Bridge
(Photo by Léopold Nadeau,
Geological Survey of Canada, 2007)

STOP 18 – ROYAL BATTERY

Figure 51. Reconstruction of the Royal Battery
(photo by Pascale Côté,
Geological Survey of Canada, 2007)

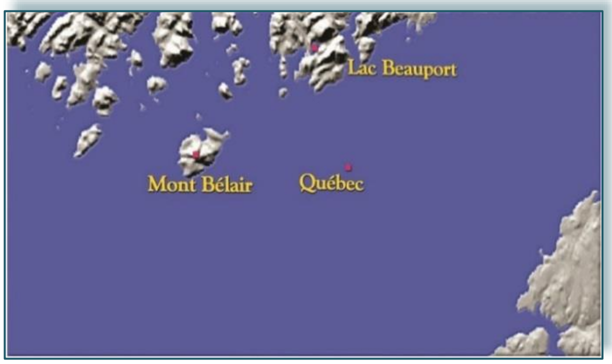
The Royal Battery can be found right next door to Parent House. Built in 1691 on Governor Frontenac's orders, it was intended to fill a defensive void. The British invasion led by Phips in 1690, while pushed back, compelled Frontenac to improve Quebec City's defences. The Royal Battery was in the shape of a bastion, as you can see from its present-day configuration. The reconstruction completed in 1977 houses replicas of French canons.

This location is ideal to introduce the current geological period, the Quaternary, which has been marked by several glaciation periods. The course of the St. Lawrence River is an example illustrating the history of deglaciation in the Quebec City region. In fact, the river's position can be explained by the presence of old faults, inherited from the Rodinia rift nearly 600 million years ago, but its current course stems from the last glaciation period dating back 18,000 to 10,000 years ago.

The Glacial Era and the Ice Melt

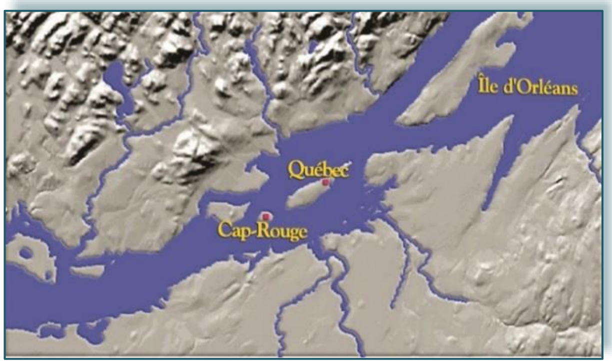
Between 1,800,000 and 10,000 years ago, several glacial periods succeeded one another. Each one caused the accumulation of an imposing thickness of ice covering nearly the entire North American continent. Like a gigantic bulldozer, the glaciers flattened and eroded the Grenvillian and Appalachian mountains and plateaus, making considerable changes to the physiography. The glaciers scoured debris from the bedrock, leaving behind till deposits (a heterogeneous mixture of clay, sand, gravel and boulders) and erratic blocks, which are scattered over the three physiographic regions. The Jacques-Cartier and Montmorency river valleys have the typical U-shape of glacial cut valleys. The most recent of these glaciations, the Wisconsin glaciation, began nearly 75,000 years ago and ended about 10,000 years ago. At is apex, 18,000 years ago, the region was covered in 3 km of ice. The continent subsided under the weight of the ice and the area where the city is located was more than 200 metres below sea level.

Around 12,000 years ago, following the progressive ice melt, the waters of the Atlantic Ocean poured into the St. Lawrence Lowlands and created the Champlain Sea. This sea covered a surface area of approximately 55,000 km^2, extending from Quebec City to Pembroke in Ontario and from the Appalachians to the Laurentians. The average temperature of the Champlain Sea waters was similar to what we see in James Bay, between -1 and 8 ^{o}C. It was therefore a cold sea in which lived marine mammals such as the beluga, the bowhead whale, the walrus and various types of seals.



The glaciers retreated as the Earth's climate experienced a warming trend. They left behind depressions that were deeper than sea level. The waters of the Atlantic Ocean then invaded the St. Lawrence Valley, forming the Champlain Sea. As the glacial melt waters mixed with the seawater, the Champlain Sea eventually reached its maximum extent 12,000 years ago.

Around 11,000 years ago, the area that is now Quebec City gradually rose because of isostatic rebound, and the Champlain Sea began receding. The first two high points on Île d'Orléans emerged.



The sea kept receding, making way for an estuary and then a system of rivers representing the forerunner of the St. Lawrence. This happened 9,500 years ago. The highest points in the region, namely Saint-Augustin, Cap-Rouge, Sainte-Foy, Quebec City and Lévis, existed as islands. Today, Île d'Orléans alone bears witness to the islands scattered around Quebec City. As it retreated, the Champlain Sea covered the St. Lawrence Lowlands with a thick layer of sediment, which gave rise to the fertile soils of today.

The level of the St. Lawrence has fluctuated, changing by tens of metres several times over the last 9,000 years, in response to climatic changes, which were minor, compared with the glaciations but had a considerable effect on riparian ecosystems. The present-day course of the St. Lawrence is the result of a long tectonic, glacial and marine history extending over 600 million years!

Figure 52. Map showing variations in the water levels in the Quebec City region following the last deglaciation and isostatic rebound
(Taken from Geoscape Québec, Côté et al., 2001)

STOP 19 – RUE DU PETIT-CHAMPLAIN

Figure 53. Dufferin Terrace (built in 1838) and Rue du Petit-Champlain
(Illustration by J.P. Cockburn, 1833, taken from the National Archives of Canada)

You are currently in the Petit Champlain district, which was long held to be the gateway of Irish immigrants in the 19th century. It topped all other districts with a 72% Irish population. The nearby harbour, shipyard and lumber coves provided employment for the district's low-skilled workers.

Figure 54. Félix-Leclerc Park
(Photo by Léopold Nadeau, Geological Survey of Canada, 2003)

The Félix-Leclerc Park is an old quarry that was active starting in the 17th century, under the French regime, and it is where Cap Diamant Black Cap stone was mined. It was the cheapest stone and the most available right there in the heart of the city. Back in the days when the quarry was in operation, the waters of the St. Lawrence River reached the foot of the cliff. It is believed that ships took on loads of stone during low tide and set sail at high tide. Mining quarries at the foot of the cliff and near houses resulted in many problems, namely the risk of rockfall. It appears that one of the most important black cap stone quarry sites of the time was on Rue Berthelot.

The landslides at Cap Diamant caused numerous deaths and considerable property damage, particularly in the early days of the colony. The two most serious landslides on the site of present-day Champlain Boulevard were on May 17, 1841, in which six houses were destroyed and 27 people killed, and on September 19, 1889, in which 45 people lost their lives. This part of the Quebec promontory was among the most dangerous inhabited zones and landslides killed at least 85 people during the 19th century. The area around Rue du Petit-Champlain has also seen some dramatic events, the most memorable of which took place in 1841 and 1889.

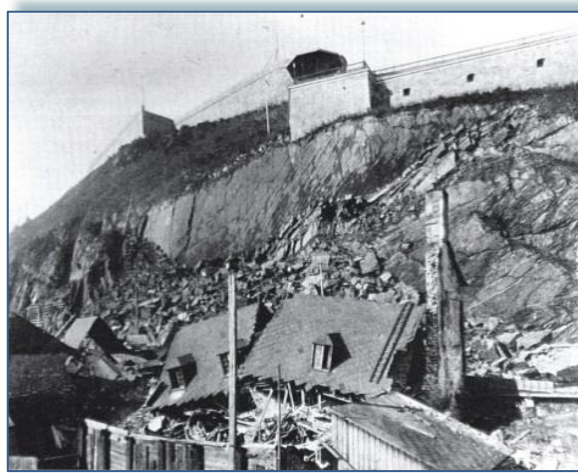


Figure 55. Landslide at Cap Diamant on September 19, 1889
(photo provided by the Société historique de Québec)

A number of conditions led to these catastrophic landslides: the very steep cliff and unstable slope, the highly friable sedimentary rocks and the bedding plane (corresponding to the plane of weakness) is parallel to the slope. Vegetation that would otherwise help to retain the debris and stabilize the slope could not establish itself easily. Furthermore, in the early days of the settlement, the river waters lapped against the houses at high tide. Owing to the limited space available for building, workers would excavate deeply into the cliff base, thereby increasing the instability of the upper slope. Climatic conditions such as heavy rains and frost-thaw action played a role in triggering landslides, as did the vibrations associated with earthquakes or, historically, cannon shots.

In response to these dangers, effective techniques were employed to minimize the risk of landslides all along Champlain Boulevard and Rue Sault-au-Matelot: unstable material was removed in order to create a gentler slope, and draped wire mesh, rock bolts and fences were installed.

The Whims of Nature

Because of its geological heritage, certain areas in the Quebec City region are more prone to natural hazards.

Earthquakes

Seismic activity in Quebec is centred in the Charlevoix-Kamouraska region where a meteorite once struck around 400 million years ago, weakening the Earth's crust. It is expressed mainly through reactivation of the faults that delimit the St. Lawrence rift valley, which is undergoing readjustment owing to isostatic rebound. In Quebec City, the seismic risk is limited and the effects are weak. However, the city is not immune to earthquakes. On November 5, 1997, a magnitude 5.2 earthquake shook the city and even stopped the Parliament clock at 9:34 pm, which is when the event occurred. Its epicentre was located in the Cap-Rouge area. In 1988, it was an earthquake centred in the Saguenay that rattled the capital. Historically, in 1663, 1791, 1860, 1870 and 1925, several earthquakes with a magnitude exceeding 6 in the Charlevoix-Kamouraska region also shook Quebec City, damaging buildings and fraying nerves.

The strong earthquakes of the past have taught us that the scope of damage is often linked to the quality of the construction and the type of geological materials on which the building was built. For example, at an equal distance from the epicentre of a magnitude 6 earthquake, a building resting on thick deposits of clay or sand will be subjected to greater vibrations than a similar building sitting directly on bedrock. This amplification of the seismic waves generally results in greater damage. This explains why the Lower Town and Port of Quebec regions have suffered the most damage due to earthquakes. Earthquakes can cause rockfall along rocky slopes whereas clay or sandy slopes can become the site of landslides.

Ice Dams

The Montmorency River is not only known for its famous falls. It is also known for spectacular jams that occur on a regular basis. During a winter or spring thaw, the ice cover breaks up and the blocks carried away by the current gather in narrower passages. A temporary dam can form, causing water levels to rise and the riparian zones located upstream to flood. This ice chaos can sometimes reach heights of 5 to 7 metres, which is twice the height of a house. These ice dams can also sometimes release suddenly due to the push of the water. It can create a shock wave that heads downstream flooding the lowlands.

CONCLUSION

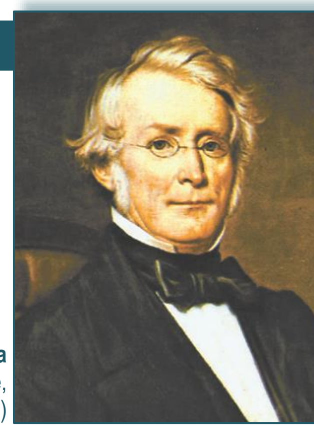


Figure 56. Sir William Logan, founder of the Geological Survey of Canada (Photo Catalogue, Geological Survey of Canada)

Introducing William Logan is a fitting way to end this geological overview of the Quebec City region. He was one of the first geologists to study the diverse geology of the area and the fault zone that bears his name. In 1842, Logan founded the Geological Survey of Canada (GSC), which he directed for 27 years.

Born in Montreal in 1798, the son of a baker, Logan studied for a short time at the University of Edinburgh. While working in England and Wales, Logan became interested in coal exploration and began studying geology, which at the time was a young discipline. In 1842, at age 44, Logan was appointed to conduct a geological survey of the Province of Canada, which at the time consisted of the southern half of the present-day provinces of Ontario and Quebec.

On its list of the 100 most important Canadians in history (1998), Maclean's ranked William Logan (1798-1875) first among scientists and sixth on the general list. This is in addition to a long list of honours that Logan was given, including his name on the highest mountain in Canada, Mount Logan (5,959 m high) in the Yukon as well as the title of Knight bestowed upon him in 1856 by Queen Victoria.

As the founder and first director of the Geological Survey of Canada (1842-1869), Logan was a passionate observer and interpreter of the unexplored geology of Canada. Thanks to the substantial notes that he took while out in the field, the observations made by Logan and his staff provided precise details on the extent of mineral and energy resources in the Province of Canada which could support its economic growth. At that time, the offices of the GSC were located in Montreal.

Logan also kept a personal journal, providing anecdotes regarding his fieldwork and his observations about life in Canada in the 19th century. These notes were written after a long day out in the field and they provide a fascinating account of early Canada as well as a glimpse at the engaging and extraordinary personality that was Logan.

Although William Logan was a rich man, he paid little attention to his physical well-being and his attire. At times, he was taken for a vagabond, and there are many confirmed cases where his appearance led strangers to believe that he was mentally unbalanced. On one of these occasions, Logan was doing some field work while staying in a hotel in Quebec City. On the first morning, he asked the hotel clerk to arrange for a horse-drawn carriage, or calèche, to pick him up. At the sight of Logan coming out of the hotel, the driver immediately assumed that this was a patient from the insane asylum in Beauport coming back from an outing. Without heeding Logan's protests, the driver began heading for the asylum. Even though he was being labelled a crazy person, Logan had a solution... He pulled out his geologist's hammer, and brandishing it near the driver's head, he demanded to be taken to his chosen destination. The driver obeyed. At the end of the day, Logan asked the driver to take him back to the hotel. While the director of the GSC unloaded his rock samples, the driver told his fellow drivers about the awful day he had spent in the company of this dangerous lunatic. Without saying a word, Logan went up to the driver, paid him his due and added a large tip. Upon leaving his hotel the next morning, he found a crowd of drivers all wanting to provide conveyance for a generous lunatic.

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GLOSSARY

Translation of the French text, which is adapted from Foucault, A. and Raoult, J.F. (2001) or from Jacob H.-L. and Ledoux R. (1998)

BRACHIOPODS: Small invertebrate that has a bivalved shell (one valve is larger than the other) and is bilaterally symmetrical.

BRYOZOANS: Colonial animals that build a branched or mounded calcareous skeleton comprising thousands of box-like divisions, each housing an individual animal.

CALCITE: Mineral species composed of calcium carbonate ($CaCO_3$).

CONTINENTAL RIFT: Part of a continent where the Earth's crust thins under the action of extension forces, causing a graben. A rift can be the final stage in the rupturing of the lithosphere, leading ultimately to the formation of an oceanic plate.

CONTINENTAL RISE: type of relief consisting of a flat and slightly angled surface.

CRATON: Old and stable portion of continents (continental lithosphere) that has a geological identity, as opposed to geologically active zones.

CRINOID: An invertebrate with a cup (head) and a stalk comprising many small disks by which the animal attaches itself.

DIAGENESIS: Processes that alter a sedimentary deposit, gradually transforming it into solid sedimentary rock.

EROSION: Process of the relief (rocks) being degraded and transformed.

ERRATIC BLOCK: A large rock fragment transported over a great distance by a glacier and left in place when the glacier melts.

GRABEN: Tectonic trough bounded by two parallel normal faults. The raised compartment in relation to the graben is called a horst.

GRANITE: A homogeneous, coarse-grained, intrusive igneous rock composed mainly of quartz and feldspars, with one or more black silicate minerals.

ISOSTASY: State of hydrostatic equilibrium that is attained at a depth inside the Earth called the compensation depth. In the event of an imbalance due to the addition of weight (formation of a mountain chain, glacier), the crust sinks progressively into the mantle. Similarly, reducing the weight (erosion, ice melt) will have a tendency of raising the crust.

LIMESTONE: Sedimentary rock composed of over 50% calcium carbonate.

LITHOSPHERE: Rigid terrestrial envelope of the Earth's surface, which includes the Earth's crust, and a portion of the upper mantle.

MATURATION: Natural thermal transformation of organic material into hydrocarbons.

NORMAL FAULT: A plane (often steeply-dipping) separating two rock compartments. Sliding along this fault plane results in a separation of the two compartments and a lowering of the upper block in relation to the lower block.

OLISTOSTROME: Sedimentary deposit composed of a chaotic mixture of heterogeneous materials such as mud and large sediment blocks following submarine sliding.

OUTCROP: A segment of bedrock that can be seen at the Earth's surface.

PHYSIOGRAPHY: Part of physical geography that describes and studies the forms of the Earth's relief.

PLATE TECTONICS: Widely accepted theory, derived from the concept of continental drift, characterizing the various movements of plates of the lithosphere triggered by active convection in the mantle.

QUARTZ: Most common form of silica (SiO_2).

SANDSTONE: Sedimentary rock composed of rounded or angular grains about the size of sand, bound together by a cement of carbonate or silica.

SHALE: Very fine-grained sedimentary rock, which is homogeneous, clayey and often calcareous.

STRATIFICATION: The layering or bedding of sedimentary rocks.

SUBDUCTION: The sinking of an oceanic plate beneath an overriding, usually continental, plate, which gives rise to a subduction zone, a deep-sea trench and active volcanoes.

THRUST SHEET: Land or rocky compartments moved over large distances by a fault following tectonic movements.

THRUSTING: Tectonic movement during which one block overrides another along a gently inclined fault (thrust fault).

SIMPLIFIED GEOLOGIC TIME SCALE

(Modified from Bourque, P.-A., Planète Terre; and the International Stratigraphic Chart, 2012)