2023 NCF-ENVIROTHON NEW BRUNSWICK

SOILS AND LAND USE STUDY RESOURCES

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Introduction: Soil in the Literature

Excerpt from: The Principals of Soil Management, L.H. Bailey, 1909

"This marvellously thin layer of a few inches or a very few feet that the farmer knows as "the soil," supports all plants and all humankind, and makes it possible for the globe to sustain a highly developed life. Beyond all calculation and all comprehension are the powers and the mysteries of this soft outer covering of the earth. We do not know that any vital forces pulsate from the great interior bulk of the earth. For all we know, the stupendous mass of materials of which the planet is composed is wholly dead; and only on the veriest surface does any nerve of life quicken it into a living sphere. And yet, from this attenuated layer have come numberless generations of giants of forests and of beasts, perhaps greater in their combined bulk than all the soils from which they have come; and back into this soil they go, until the great life principle catches up their disorganized units and builds them again into beings as complex as themselves."

"Adapting to a changing climate" requires understanding of cycles, feedback loops, and mechanisms, the processes which happen in the critical zone, and how altering these processes can make a difference in our impact on climate change.

The landscape we occupy as a species has a long and intricate history, continents come and go, glaciers advance and recede. Forests grow, burn down, or get harvested … and then start anew. Water tables fluctuate and the water cycle adapts. As the dominant species on planet Earth and one of the few who can significantly alter and manage its environment, now is a critical time for us, and for other species that are affected by our (in-)actions.

When people first moved into the North American landscape, they very much lived in harmony with their natural surroundings, but their need for food and shelter soon started having an impact on the environment. Humans have such an impact on even geological processes that we are informally calling this epoch the Anthropocene.

This century is already seeing large (some unexpected) changes, some of a geological scale, but "life finds a way". As a species we are highly adaptable and have a tremendous amount of technological knowledge and ability. Those traits will do us well, but with the 'privilege' comes responsibility.

2023 NCF-Envirothon New Brunswick

Soils and Land Use Study Resources

Key Topic #1: Geology

1. Explain the impact of geomorphology on landforms and landscapes, and how these processes relate to soil formation.
2. Identify unique geological features of the province New Brunswick, Canada/North America, and the world.
3. Describe the characteristics of the three major types of rocks (igneous, sedimentary, and metamorphic) and give examples of each.
4. Describe the carbon cycle, and the role that soil and geologic processes play in it.

Study Resources

Resource Title	Source	Located on
Exploring Geoscience Across the Globe	*Chris King of the International Geoscience Education Organisation, 2019*	Pages 4-23
Journey Through Time: Places of geological significance in New Brunswick and Prince Edward Island	*Atlantic Geoscience Society, 2022*	Pages 24-28
Our Landscape Heritage: New Brunswick Physiography and Surficial Geography	*Zelazxny V. (ed), New Brunswick Department of Natural Resources (Chapter 3), 2007*	Pages 29-33

Study Resources begin on the next page! ➡

Exploring Geoscience Across the Globe

1. Earth as a changing system

1.2 Interactions

The geosphere, hydrosphere, atmosphere, and biosphere are very open systems because they all interact, exchanging both energy and matter. Interactions between these four subsystems go on everywhere, all the time, acting over very short to extremely long timespans. It is these interactions that make our planet so dynamic. Wherever you go, whatever you do, these systems will be interacting all around you at different rates, from very fast to extremely slow.

1.3 Feedback

Feedback is a vital part of systems. A simple example of feedback is a water boiler with a thermostat (a thermometer with a switch). When the water becomes cool, the thermometer feeds back this information to the switch and the boiler is switched on. When the water becomes hot, this information is fed back to the switch by the thermometer, and the boiler is turned off again. Feedback systems can be positive or negative, but these can be confusing terms. Negative feedback keeps systems in a stable state and so is often a good thing, whilst positive feedback can make a system unstable, with devastating results.

When there is positive feedback, the system can become unstable. When sunlight hits ice sheets, most of it is reflected and so there is little warming effect on the Earth. The reflection of sunlight by pale-coloured surfaces like ice is called albedo. This reflection of sunlight is one of the factors that keep Earth's temperature stable. However, positive feedback can have an effect in two different directions. If Earth becomes cooler, the ice caps grow, increasing the albedo effect, so causing the Earth to become even cooler; this could trigger an ice age. But, if the Earth becomes warmer, the ice caps will melt, reducing the albedo reflection, so causing the Earth to become even warmer. Eventually the ice could melt completely, moving the Earth into a much warmer state.

1.4 Processes and Products

1.4.5 The Carbon Cycle

When you breathe, you breathe out more carbon dioxide than you breathe in. This is because one of the body processes is respiration, where oxygen reacts with carbon compounds in the cells of your body, releasing energy and producing carbon dioxide. The respiration process releases a flux of carbon dioxide into the atmosphere, which stores a small amount of carbon dioxide all the time (about 0.04%).

The residence time of carbon dioxide in the atmosphere is short because it is removed quickly, mostly by the photosynthesis of plants. In the photosynthesis process, energy from sunlight causes carbon dioxide to react with water to form the carbon compounds that make up plants. So the Earth's plants, particularly the algae in the oceans, form a large store of carbon. This carbon is released when they die (or through being eaten by animals), or when land plants are burnt, either deliberately or through wildfires.

This is the short carbon cycle, as studied by many biologists. It involves photosynthesis and respiration, egestion and decay. This seems to be a balanced cycle, with as much carbon being added to the atmosphere as is removed. However, there are much longer parts of the carbon cycle as well; for example, some of the carbon dioxide from the atmosphere can become dissolved in the ocean, with residence times of thousands of years.

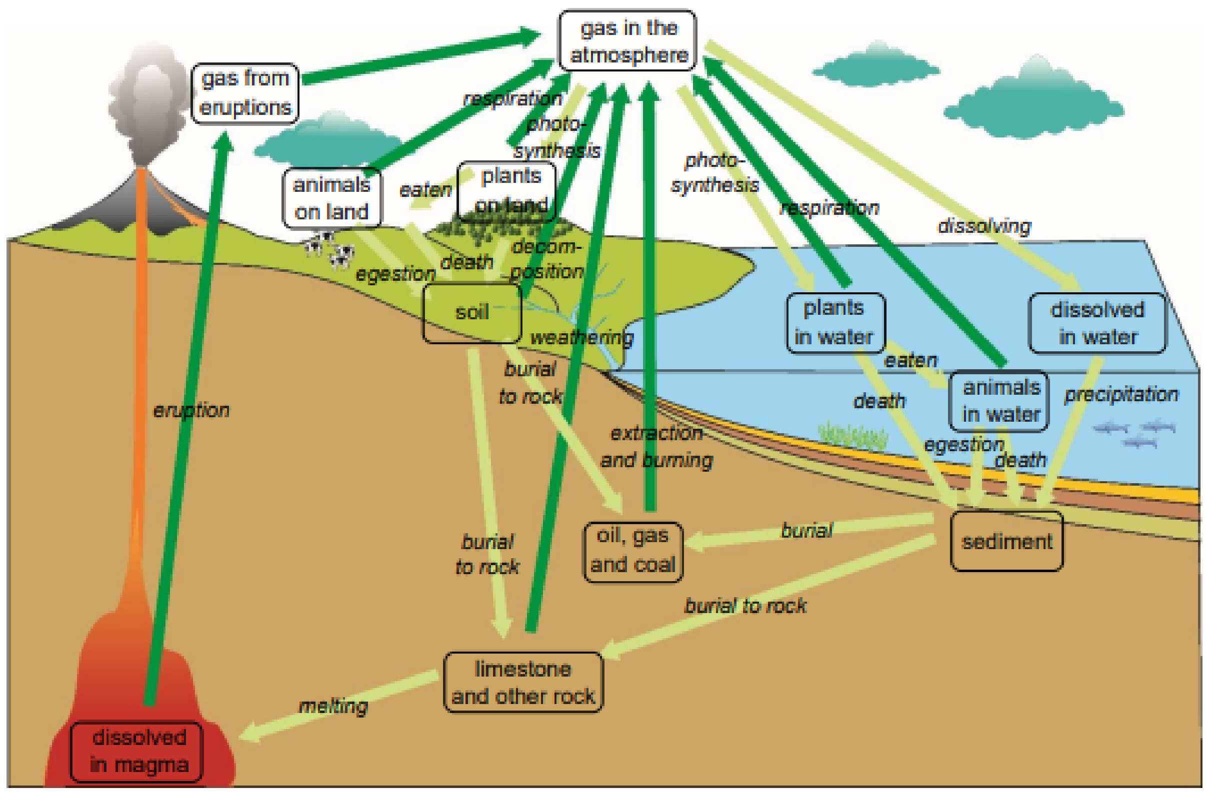
Some animals and plants contain ‘hard parts’ made of calcium carbonate. The chemical formula for calcium carbonate is $CaCO_3$ and the second ‘C’ in the formula is carbon, which makes up some 12% by mass of calcium carbonate. Your bones and the bones of most animals contain calcium carbonate. Shells are made of calcium carbonate and some microscopic plants also contain calcium carbonate. When these animals and plants die, parts of them are deposited as sediment and can become part of sedimentary rocks, with residence times of millions of years. The calcium carbonate-rich rock made mostly of marine animal remains is called limestone; the rock made mostly of microscopic calcium carbonate plant remains is chalk.

When plants die, they usually decay, but if they are buried by sediments and preserved, the carbon in them is also preserved. When land plants are preserved, thick layers can form coal, releasing natural gas as it matures. As microscopic animals and plants in the oceans die, they can also be preserved in sediment, and later be changed to oil and natural gas. Natural processes release these stores of carbon back to the atmosphere over millions of years.

Sedimentary rocks containing limestone, chalk, coal, oil and natural gas can become involved in mountain-building episodes and metamorphosed or even partially melted. Then the magma produced by partial melting will contain dissolved carbon, which may be brought to the surface and released in volcanic eruptions.

These longer-term parts of the carbon cycle also seem to be in balance. However, human activities may be changing this balance, by removing and burning coal, oil and natural gas.

Figure 1.8. Carbon cycle products (in boxes) and processes (*in italics*) – processes ‘fixing’ carbon are shown by pale green arrows, processes releasing carbon by dark green arrows.



3.3 Absolute Dating

Table 3.5. The main subdivisions of geological time based on the latest International Chronostratigraphic Chart published by the International Commission on Stratigraphy*

Eon	Era	Period	Abbrev-iation
Phanerozoic	Cenozoic	Quaternary	Q
		Neogene	N
		Paleogene	Pg
	Mesozoic	Cretaceous	K
		Jurassic	J
		Triassic	T
	Palaeozoic	Permian	P
		Carboniferous	C
		Devonian	D
		Silurian	S
		Ordovician	O
		Cambrian	Cm
Precambrian	Proterozoic		
	Archaean		
	Hadean		

Age (Millions of years ago (Ma))
0
2.6
23
66
145
201
252
299
359
419
444
485
541
2,500
4,000
4,600

Major events	
3.3	Oldest stone tools
50	Himalayan mountains
66	K-Pg mass extinction
130	Early flowering plants
160	Early birds
190	Opening of Atlantic Ocean
220	Early mammals
252	'Great dying' mass extinction
299	Supercontinent Pangaea first formed
315	Early reptiles
370	Early amphibians
400	Early insects
430	Early land plants
530	Early fish
541	Life with shells/hard parts
2,000	Early multicelled organisms
2,100	Early eukaryotes
2,700	Free oxygen in atmosphere
3,500	Early bacteria and algae
4,000	Oldest known rocks
4,600	Origin of the Earth

* As rock-dating methods improved, some of the dates in the table have changed over time. Table 3.5 shows the latest version.

4. Earth's system comprises interacting Spheres

4.1 Geosphere

4.1.1.1 Minerals

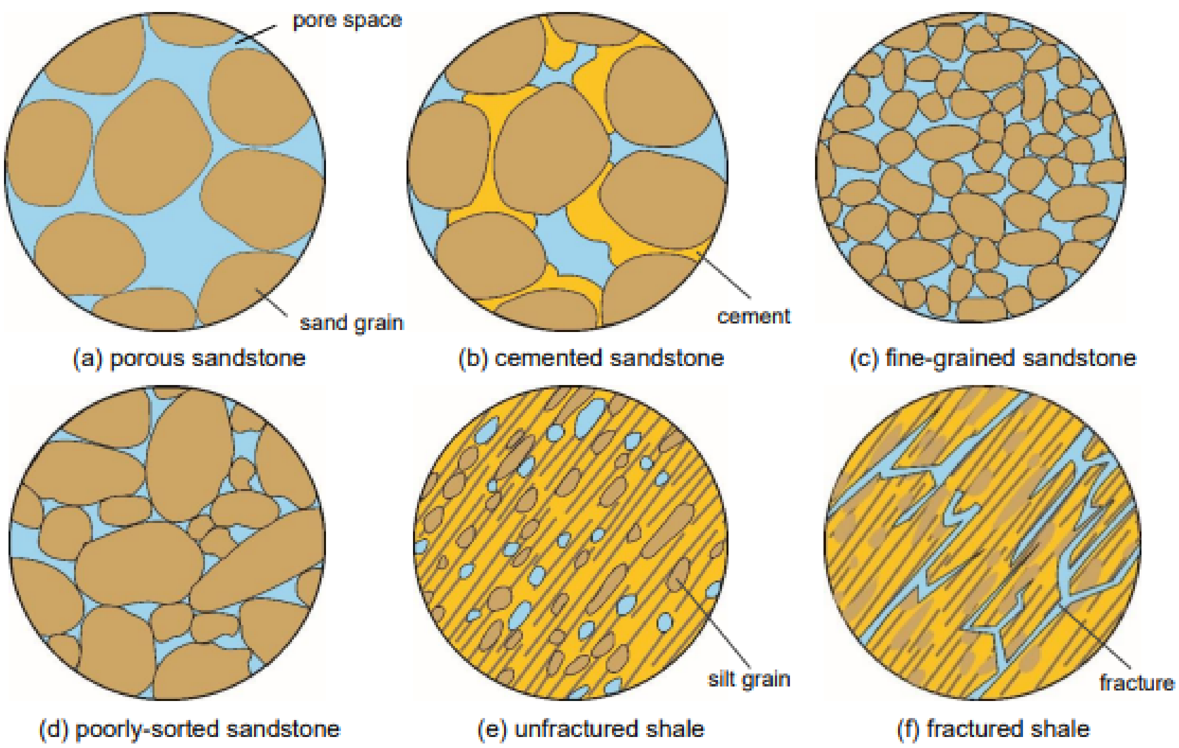
Minerals are naturally-formed non-organic substances with fixed crystal structures and properties. They can be made of single elements, but most are chemical compounds of two or more elements. Different minerals can be recognized by their properties – key properties are colour, crystal shape, hardness and the way they break. Some minerals have particular properties that aid their identification, such as the reaction of calcite with dilute hydrochloric acid, the salty taste of halite, or the high density and metallic shine of ore minerals like galena.

4.1.1.2 Rocks

Rocks are naturally formed substances. They are made of minerals, fragments of other rock, or fossils and are formed through the rock cycle processes. Rocks are identified and described based on their chemical composition and their physical texture. The chemical composition is linked to the minerals that form the rock, while the texture of the rock depends on the types and sizes of particles and how they are arranged. These features link in turn to the resistance of rocks to being worn away, and to their porosity and permeability.

Porosity is the amount of space or pores in a rock, measured as a percentage. 15% porosity is a high porosity for rocks; most rocks have porosities much lower than this. The permeability of rock measures how quickly fluids can flow through rocks. Rocks with high porosity have high permeability if the pores are large enough for fluids to flow through and the pores are linked together. Rocks with very small pore spaces, like clays, do not allow fluids to pass through, and are therefore porous but impermeable. Similarly, the gas bubble holes in some lavas are not joined, so the rock again is porous but impermeable (Figure 4.1) . Rocks made of interlocking crystals, or which are well-cemented or very fine-grained, stop fluids flowing through and are impermeable, unless they contain cracks and fractures. Porosity and permeability control the amounts of natural fluids such as water, oil and gas that can be stored in and flow through rocks.

Figure 4.1. Porosity and permeability in rocks. The porosity and permeability in (a) has been reduced by cement in (b); permeability in (c) is quite low because the pore spaces are small; permeability in (d) is also low because the pore spaces between larger grains have been filled by smaller ones; the unfractured shale in (e) is impermeable until it is fractured in (f).



Rocks formed of grains that are compressed together and/or naturally cemented together are sedimentary rocks – these can have a range of compositions and textures. The most common sedimentary rocks are rich in quartz, feldspar and clay minerals. These can have a range of grain sizes from coarse-grained conglomerates (with rounded grains) and breccias (angular-shaped grains), through medium-grained sandstones, to fine-grained sedimentary rocks such as mudstones, shales and clay/claystone. Limestones are also common sedimentary rocks and are formed mainly of fragments of calcium carbonate minerals like calcite, mostly from broken shells. Limestones can be identified because calcium carbonate reacts with dilute acid – a drop of hydrochloric acid on limestone will produce a fizzing reaction. Limestones also range from coarse to fine-grained and in colour from grey, to cream-coloured, to the white of fine-grained chalk.

Igneous and metamorphic rocks are formed of interlocking crystals which normally make them very resistant to being worn away and also make them impermeable, unless they are fractured. In coarser examples, the interlocking crystals can be seen by eye or with a hand lens. Igneous rocks were once molten rock called magma, and usually formed as the magma cooled down. As the magma cooled, crystals of minerals grew until they interlocked, as the rock became solid. Minerals of different compositions have different colours and crystallise at different temperatures, so igneous rocks are mixtures of minerals of different colours, shapes and sizes.

Metamorphic rocks are formed from sedimentary, igneous or older metamorphic rocks by metamorphism caused by increases in temperature, pressure or both. They form in the solid state, so there is no melting (rocks formed by melting are igneous rocks). The increase in temperature comes either from baking by a nearby magma, or from becoming deeply buried. Where pressure is involved, metamorphic rocks can only form in plate collision situations and not simply by the burial pressure of thick overlying sequences of rock. Metamorphic rocks produced by increased temperature alone have randomly-orientated interlocking crystals, whereas metamorphic rocks formed by increased plate-tectonic pressures have interlocking crystals which are orientated at right angles to the pressures. Marble, being a metamorphic rock formed of calcium carbonate crystals, reacts with dilute hydrochloric acid in the same way as limestone.

These properties enable the three great groups of rocks to be distinguished from one another: by studying the grains or crystals, by testing permeability (through dropping water onto the surface or by putting specimens into water and watching for rising bubbles), and by scratching the rocks with a fingernail or a piece of metal, such as a coin.

Table 4.2. The results of simple tests to distinguish the three main rock groups

Observation/test Rock group	Examination of grains/ crystals	Permeability test	Scratch test
Sedimentary	Grains cemented or compressed together	Water sinks in or streams of bubbles rise from specimen, unless fine-grained or well-cemented	Easily scratched unless well-cemented
Igneous	Crystals interlocking, randomly orientated	Water does not sink into surface; bubbles do not rise from specimen	Difficult to scratch unless well-weathered
Metamorphic	Crystals interlocking; randomly orientated if formed mainly by heat; parallel or sub-parallel if formed by pressure and heat together		

4.1.1.4 Sedimentary rocks

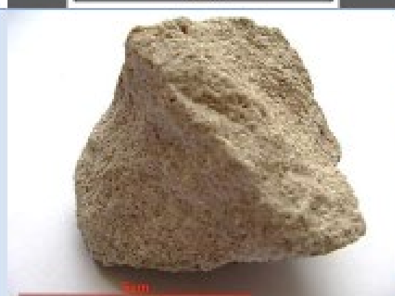
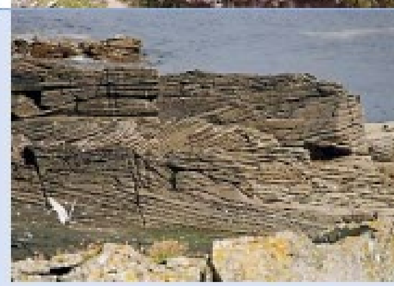
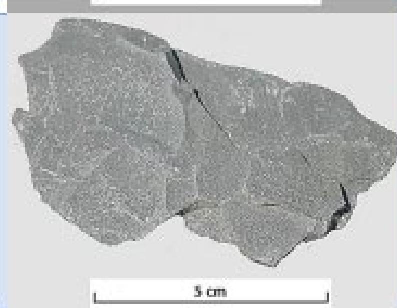
Sedimentary rocks were laid down as sediments and are identified using their mineral composition and grain size (Table 4.4). Sedimentary rocks are usually permeable unless they are well-cemented or fine-grained, and most are easy to scratch. The grains are easy to see in sand-grade rocks, but usually impossible to see in mud-grade rocks, even with a hand lens.

Table 4.4. Classification of sedimentary rocks

Chemical composition		Silicon-rich	Calcium carbonate-rich	Sodium chloride-rich	Carbon-rich
Characteristics		The most common sedimentary rocks; resistant if well cemented, otherwise easy to scratch; commonly dark or pale grey, brown, cream or red	React with dilute hydrochloric acid; easy to scratch; commonly pale grey, cream or white	Made of halite with salty taste; cubic crystals; very easy to scratch; pink, white or colourless	Very easy to scratch; often break into cubic shapes; black; may contain plant fossils
Common rock types – see Table 4.5					
Grain size	Fine < 0.0625 mm	Mudstone; shale; clay; claystone	Limestone; chalk	Rock salt	Coal
	Medium 0.0625 – 2 mm	Sandstone; siltstone	Limestone		
	Coarse > 2 mm	Conglomerate; breccia			

Most sand-grade sediments are laid down in beds, whilst muds are deposited in thinner layers called laminations. As the sediment became buried, muds became compressed into more compact mudstones, shales or clay stones and lime mud was compressed into limestone or chalk, as water was squeezed out. Meanwhile water flowed through the pore spaces of coarser sediments, such as pebble beds, sands and shell sands, and minerals crystallised from the water as natural cement, which glued the grains together; these sediments became lithified into coarse-grained conglomerates and medium-grained sandstones or limestones, as shown in Table 4.5. So, for sedimentary rocks, the two main rock-forming processes are compaction and cementation.

Table 4.5. Common sedimentary rocks

Sedimentary rock	Images		Source of exposure image
	Specimen	Exposure	
Conglomerate			Conglomerate exposure, near San Sebastian, Spain Cretaceous age
Cream sandstone			Cross-bedded cream sandstone, Isle of Bressay, Shetland Islands, UK Devonian age
Red sandstone			Red Navajo sandstone in Antelope Canyon, Arizona, USA. The red colour is due to the hematite iron cement Triassic/Jurassic age
Mudstone			Permian red mudstone with paler siltstone beds, Bassin de Lodève, Hérault, la Lieude, Mérifons, France

4.1.1.5 Igneous rocks

Igneous rocks formed from once-molten magma, either as the magma cooled and crystallised or as it erupted explosively from a volcano. Most igneous rocks are impermeable and resist scratching because of their interlocking crystals; they are identified using their crystal size and chemical composition. The crystals in coarse-grained rocks are easy to see, those in medium-grained rocks need a hand lens, and the crystals in fine-grained rocks are usually impossible to see without a microscope. Coarse-grained rocks formed by slow cooling of magma deep beneath the surface are called plutonic rocks; fine-grained igneous rocks were erupted as volcanic rocks.

The chemical composition of the rock is linked to the minerals present and these produce the overall colour of the rock. Rocks that are rich in iron and magnesium have dark-coloured iron/magnesium-rich minerals whilst silicon-rich rocks have mainly pale-coloured minerals like feldspar and quartz. This gives the classification system in Table 4.6.

Table 4.6. Classification of igneous rocks

Chemical composition		Iron/magnesium-rich	Intermediate	Silicon-rich
Characteristics		Dark minerals; dark in colour; higher density (feel heavy)	Intermediate characteristics	Pale minerals; pale in colour; normal rock density
		Common rock types – see Table 4.7		
Crystal size	Fine (< 1mm)	Basalt	Andesite	Volcanic ash
	Medium (1-3mm)	Dolerite	Uncommon	Uncommon
	Coarse (>3mm)	Gabbro	Uncommon	Granite

Table 4.7. Common igneous rocks

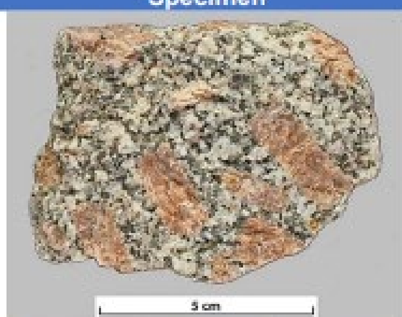
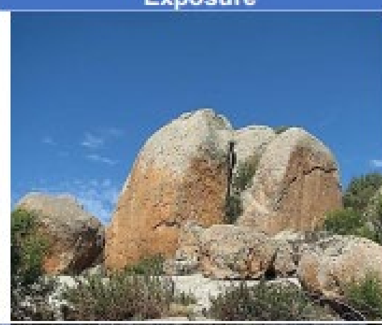
Igneous rock	Image: Specimen	Image: Exposure	Source of exposure image
Granite			Granite exposures, Mount Hope, Victoria, Australia Devonian age
Gabbro			Gabbro from the Ukraine in a geological wall in the Botanical Folk Park, Blankenfelde Pankow, Berlin, Germany
Dolerite			Dolerite dyke on the edge of a river, Agwa Rock, Lake Superior Provincial Park, Canada

Table 4.7. Common igneous rocks, continued

Igneous rock	Image		Source of exposure image
Basalt			Basalt columns (formed as the basalt cooled) at the Giant's Causeway, Northern Ireland Tertiary age

4.1.1.6 Metamorphic rocks

Metamorphic rocks are formed when sedimentary, igneous or older metamorphic rocks re-crystallize in the solid state under increased heat and/or pressure. Rocks do not melt during metamorphosis; otherwise, they would become igneous rocks.

Most metamorphic rocks result from the increased heat and pressure of the mountain-building caused by plate collision. This is regional metamorphism. Under the intense conditions, some minerals are transformed into other minerals, some minerals re-crystallize to become thinner and longer, while other minerals rotate until they are lined up at right angles to the direction of the pressure.

Metamorphic rocks also form when rocks are baked by a nearby hot igneous body. Since the mineral re-crystallisation here is mainly by heat, and there is no tectonic pressure, the crystals in the new rocks are randomly orientated.

The type of metamorphic rock formed either by heat and pressure or mainly by heat depends on the make-up of the rock it originally came from, as in Table 4.8

Table 4.8. Classification of metamorphic rocks

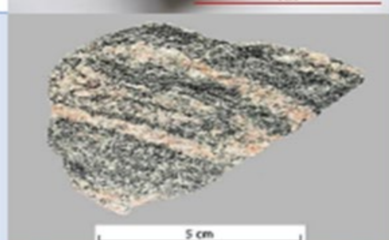
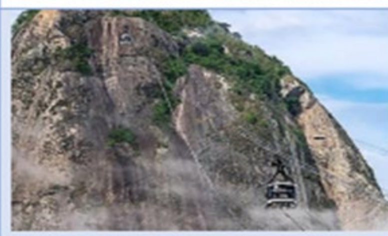
Mineral composition		Quartz and clay minerals in mudstone or shale	Quartz in sandstone	Calcite in limestone
		Common regional metamorphic rock types – see Table 4.9		
Increase in heat and pressure ↓	Low-grade	Slate	Metaquartzite (or quartzite)	Marble
	Medium-grade	Schist		
	High-grade	Gneiss		
		Common thermal metamorphic rock types		
Increase in heat		Hornfels	Metaquartzite (or quartzite)	Marble

Since metamorphic rocks are made of interlocking crystals, they are usually impermeable and resist scratching more than most sedimentary rocks. The regional metamorphic rocks can be identified from their aligned minerals. In fine-grained slate, they produce weaknesses in the rock, which can be broken into thin sheets along the weaknesses or cleavage planes. In coarser-grained schist, the aligned minerals can be seen reflecting the light in flashes when a specimen is moved. The minerals form bands in gneiss; sometimes the bands are deformed into complex folds.

Table 4.9. Common metamorphic rocks

Metamorphic rock	Images		Source of exposure image
	Specimen	**Exposure**	
Slate			Slate in a road cutting protected by rock anchors and wire mesh, Rothaar Mountains, North Rhine, Germany Devonian age

Table 4.9. Common metamorphic rocks, continued

Metamorphic rock	Images		Source of exposure image
	Specimen	**Exposure**	
Schist			Mica schist, La Pierre Blanche, island of Groix, Brittany, France Devonian age
Gneiss			The banded gneiss of Sugarloaf Mountain, Rio de Janiero, Brazil Precambrian age
Marble			Marble block in Carrara quarry, Italy – widely used as a building stone and for sculpting statues Jurassic age

4.1.1.7 Soil

Soil results from the interaction between life and Earth's surface materials – so where there is no life, there is no soil. Soil forms through interactions between the solid geosphere, the hydrosphere, the atmosphere and the biosphere. Soils form on loose surface materials like river or glacial deposits or by the biological weathering of bedrock. The many different soils that can form depend on many factors, including climate, altitude, steepness of slope and the type of bedrock or other surface material.

4.1.2 Earth's processes and observed characteristics

Earth processes are linked together through the rock cycle. The rock cycle includes the surface processes of weathering, erosion, transportation and deposition that are closely linked to the surface part of the water cycle. After sediments are deposited, they can become buried by overlying sediments when compaction and the crystallisation of natural cement transforms them into sedimentary rocks.

Plate tectonic processes drive the internal part of the rock cycle, deforming rocks, causing metamorphism, igneous activity and uplifting rocks to the surface.

4.1.2.1 Surface processes

The atmosphere, hydrosphere and biosphere interact with the geosphere, moulding the landscape and forming and depositing sediment. Surface rocks are attacked by weathering and erosion. Weathering is the breakup (physical breakup) and breakdown (chemical breakdown) of material at the Earth's surface without the removal of solid material. Erosion is the removal of solid material, which can then be transported further away.

Although weathering processes tend to act together, they can be divided into separate physical, chemical and biological effects, as shown in Table 4.10.

Table 4.10. Common weathering processes

	Process	Description	Image	Source
Physical	Freeze/thaw	Water enters cracks, freezes, expands, then thaws and trickles deeper; as freeze/ thaw cycles continue, the crack is widened. Important where freezing/ thawing is common, as on mountain tops		Broken boulder, southern Iceland
	Heating /cooling	Rocks become very hot during the day and very cold at night; since the minerals expand and contract at different rates, the rock is weakened and cracks. Important in hot regions that become very cold at night		Sheets of granite breaking away due to heating/cooling, Half Dome, Yosemite National Park, USA
Chemical	Acidic water on limestone and marble	Rainwater dissolves carbon dioxide from the atmosphere and takes in more CO_2 as it flows through soil. The weak carbonic acid dissolves calcium carbonate. When limestone is dissolved along joints, they become wider and caves can form		Carboniferous limestone pavement with widened joints (grykes), Doolin Quay, Ireland
	Oxidation of sandstone and quartzite	Rainwater flows along joints, oxidising (rusting) iron minerals to bright yellow, brown and red colours		Chemical weathering along a joint in the Khondalite Rock formation at Rushikonda beach, Visakhapatnam, India

Table 4.10. Common weathering processes, continued

	Process	Description	Image	Source
Biological	Lichens and mosses	Lichens are the first plants to colonise bare rock. Their tiny rootlets grow into the pores between rock grains, and weaken the rock as the lichen dries and contracts. They also have biochemical effects. Lichens are often followed by mosses, then soil		Lichens growing on bare rock, USA
	Soil-formation	Biological effects of weathering on bedrock produce soil		Soil layers in the Rhine Valley near Rastatt, Germany

Erosion is the removal of solid material. Landscapes are moulded and sediments are formed by four major processes of erosion, as highlighted in Table 4.11.

Table 4.11. Important erosional processes

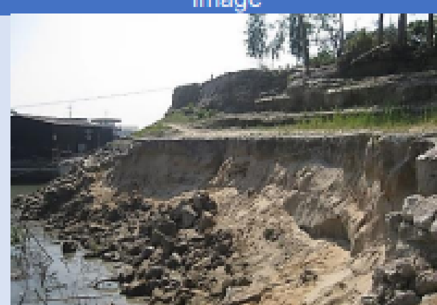
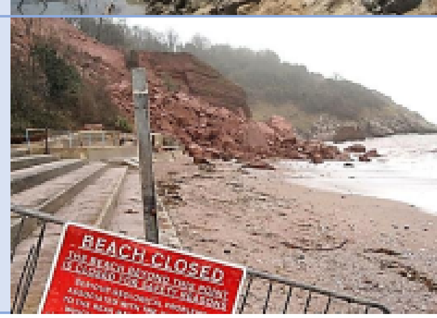
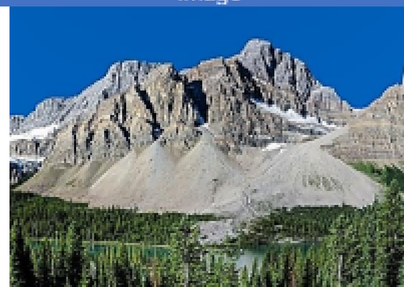
Process	Description	Image	Source
Moving water (in rivers and the sea)	Flowing water picks up and erodes particles and also carries sediment that erodes bedrock. Most erosion occurs during floods, when river banks can fail catastrophically		Bank collapse due to undercutting by erosion, Tista River, Sundarganj Thana, Bangladesh
	Waves and the sediment they carry erode the foot of coastal cliffs, often causing rock-falls. These later become broken up by the waves		Beach closed by a coastal erosion rockfall, Oddicombe, Devon, England

Table 4.11. Important erosional processes, continued

Process	Description	Image	Source
Gravity	Rock fragments, often weakened by weathering, fall off because of gravity. Large-scale rock-fall produces sloping screes which have cone-shapes under gullies. Erosion by gravity includes rock-fall and the sliding rocks of landslides		Scree cones, Bow Lake near Crowfoot Mountain, Alberta, Canada
Moving air (wind)	Wind erodes sand-sized, silt and mud-sized particles; the sand may form local sand dunes but silt and mud may be carried far away as dust clouds		A sand storm cloud blowing over Al Asad, Iraq
	Wind erosion of a rock outcrop; in a strong wind more sand grains hit and erode the base of the outcrop than the top, which is why the base is so narrow		Árbol de Piedra ('stone tree'), Eduardo Avaroa Andean Fauna National Reserve, Bolivia
Moving ice	Although ice itself cannot erode bedrock, the sediment it carries can. As ice sheets or glaciers move, the bedrock becomes eroded in the direction of the ice-movement, cutting scratch-marks or striations. The debris carried by the ice is ground down at the same time		Person on bedrock scratched by glacial movement, Gorner Glacier, Zermatt, Switzerland

Together, weathering and erosion shape the landscape. The resistance of rocks to weathering and erosion depends on how chemically stable the minerals are at the Earth's surface, and how the grains of the rock are interlinked. Rocks formed of interlocking crystals and of well-cemented grains tend to resist erosion, and form higher land, coastal cliffs and headlands, whilst less resistant rocks form valleys and bays. The angle of dip of resistant rocks and other geolo[illegible] often control the shape of the landscape, producing a variety of landforms and coastal features (Table 4.12).

4.1.2.2 Sedimentary processes

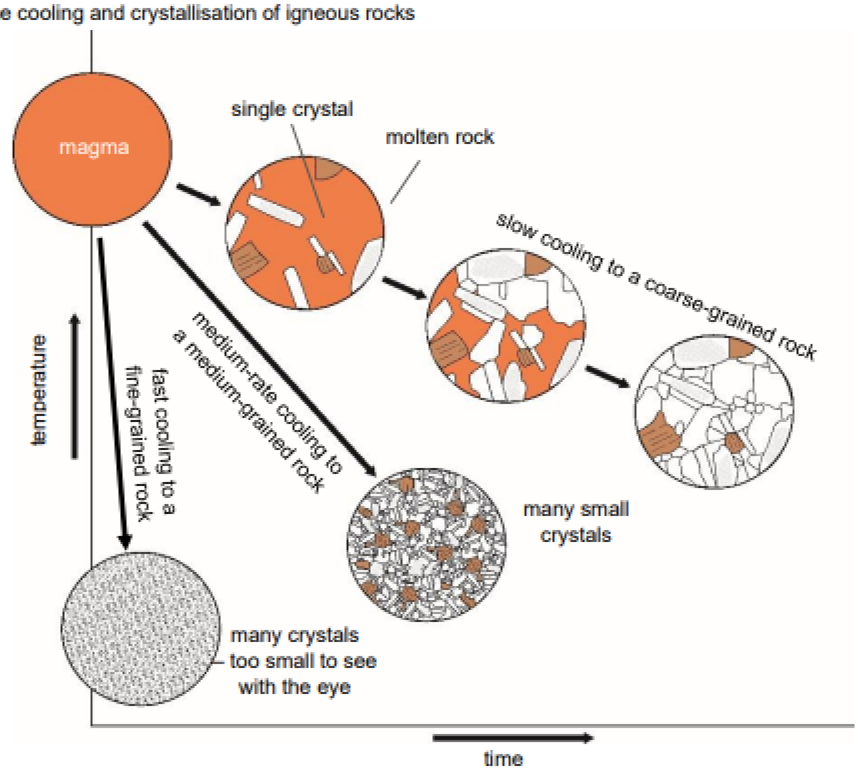
Weathering and erosion produce sediment, which is broken down during transportation. Rock fragments become rounded. Less stable minerals break down, usually to clay minerals, while more stable minerals, like quartz, become ground down. Under quieter conditions, rock fragments, quartz, clay and other minerals are deposited and sediments build up. Lime sands and muds, formed of calcium carbonate minerals, are usually deposited in warm shallow seas.

4.1.2.3 Igneous processes

When rocks become hot enough, they melt. Since rocks are usually a mixture of minerals, they often do not melt entirely but only partially melt, with the lowest-melting point minerals melting first. If the magma produced by partial melting flows away, it has a different chemical composition from the original rock, because the higher melting point minerals are left behind. So partial melting processes produce a range of different magmas with different compositions.

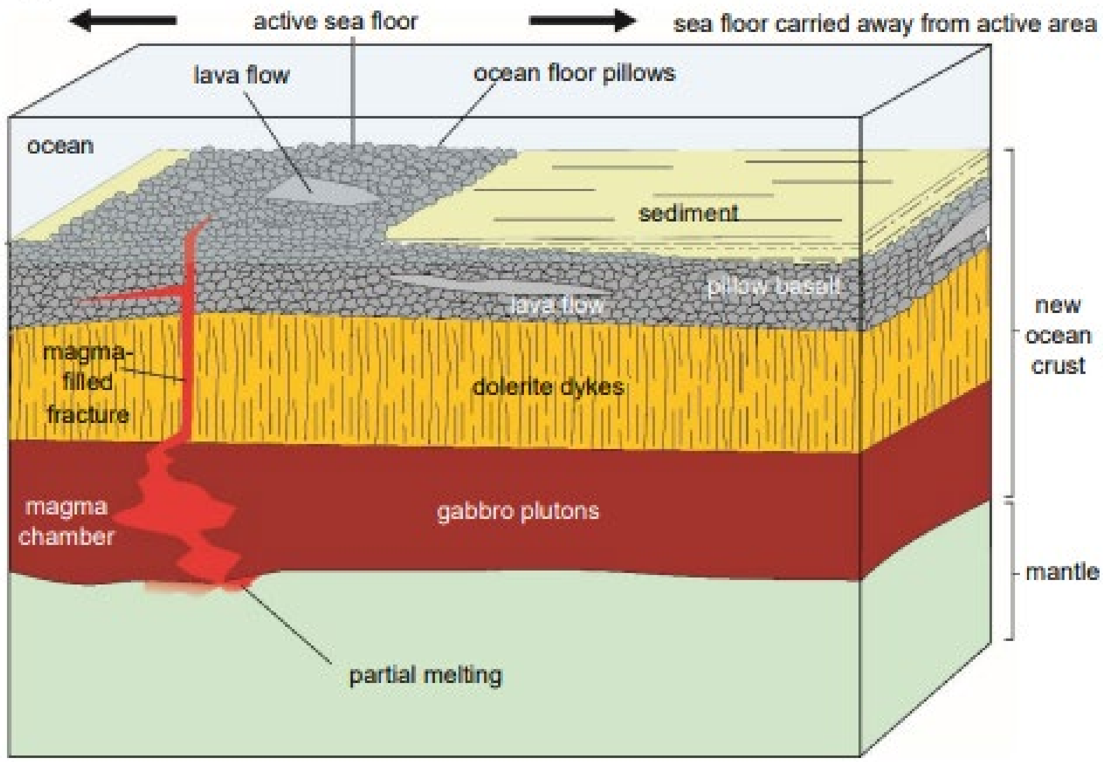
Rising magmas may stop deep underground, cool down and crystallise in magma chambers. The magma has plenty of time to cool and for crystals to grow in the cooling melt. The result is a coarse-grained igneous rock. If the magma rises higher it becomes cooler and so crystallises more quickly, into medium-grained rock. If it rises right to the surface, it is erupted by volcanic activity. Lavas formed like this cool down very quickly into fine-grained igneous rocks (Figure 4.5).

Figure 4.5. The cooling and crystallisation of igneous rocks



Under oceans, where tectonic plates are moving apart, the solid mantle beneath is very hot and so flows very slowly upwards. In flowing upwards, pressure is reduced and so the very iron/magnesium-rich mantle partially melts into magmas that are still iron/magnesium-rich. These rise, and some cool down slowly in magma chambers to form coarse-grained gabbro plutons at the base of the newly-forming oceanic crust. These iron/magnesium-rich magmas are very runny (low viscosity) and so some continue to rise through fractures. These cool down more quickly into medium-grained dolerites, as dykes. Other magmas rise to the ocean floor and flow out as lavas, usually with pillow shapes (pillow lava). This usually produces new oceanic crust of iron/magnesium-rich igneous rocks, with coarse gabbro at the base, vertical sheets of medium-grained dolerite above, and layers of fine-grained pillow basalt at the surface (Figure 4.6).

Figure 4.6. Igneous bodies in oceans



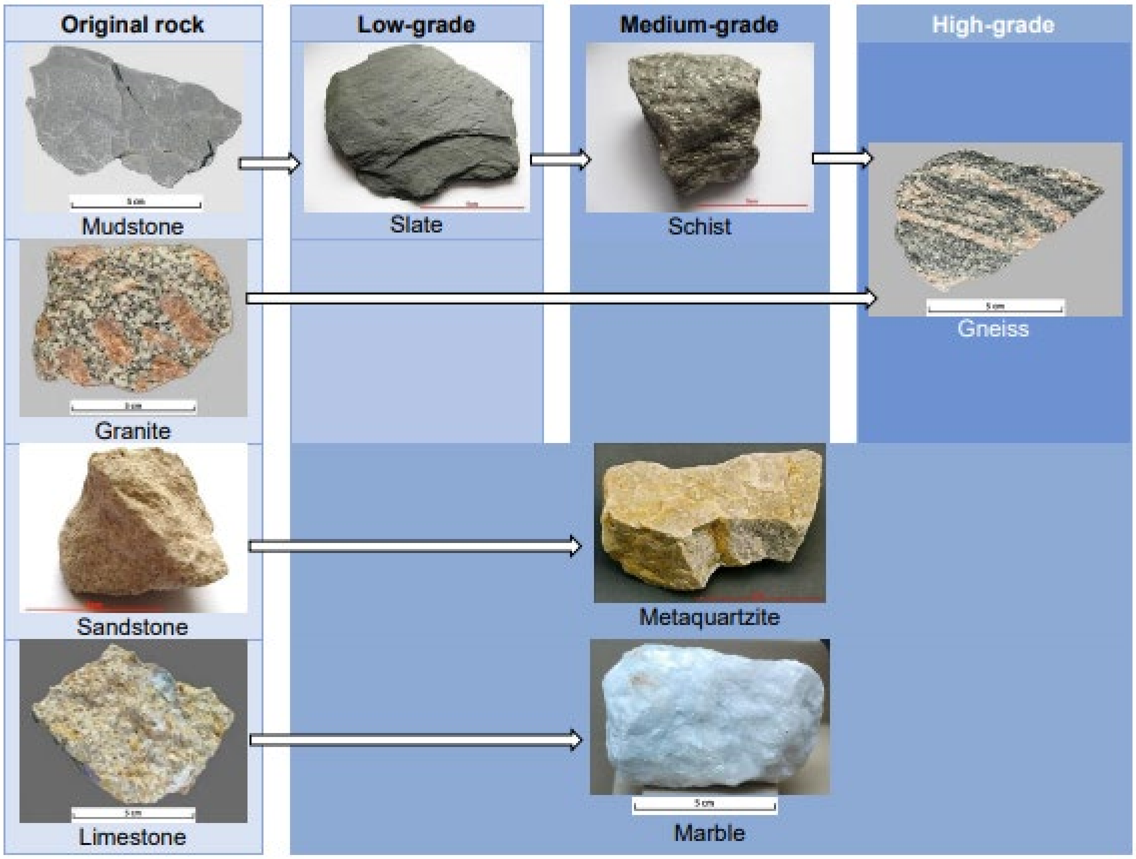
Beneath continents, in areas where tectonic plates are converging, rocks become heated up. Water in the rocks lowers the melting point, causing them to partially melt. The magmas that form depend upon which rocks melt, so that a range of magma chemical compositions is possible. Some melts are rich in iron/magnesium, some are intermediate between iron/magnesium and silicon-rich types; the most common magmas are silicon-rich.

4.1.2.4 Metamorphic processes

Rocks are metamorphosed when tectonic plates collide in mountain-building episodes, with great underground increases in temperature and pressure; this process is called regional metamorphism. Rocks can also be metamorphosed through baking by nearby igneous magmas in thermal metamorphism. In both cases, the original sedimentary, igneous or other metamorphic rocks recrystallize in the solid state into metamorphic rocks.

Regional metamorphism, caused by plate collision, produces rocks ranging from low-grade slates to high grade gneisses, together with marbles and metaquartzites, as shown in Table 4.16. These resistant rocks are usually impermeable and tend to form higher land and fairly rugged landscapes.

Table 4.16. Metamorphic rocks formed by regional metamorphism



The amount of thermal metamorphism caused by igneous magmas depends on the size of the magma body. Small bodies simply bake the surrounding rock producing narrow baked margins. Larger bodies contain a lot more heat energy and produce broad baked zones called metamorphic aureoles, where fine-grained rocks are changed into hornfels, sandstones become metaquartzites and limestones become marbles (Figure 4.8 and Table 4.16).

Figure 4.8. Thermal metamorphic effects

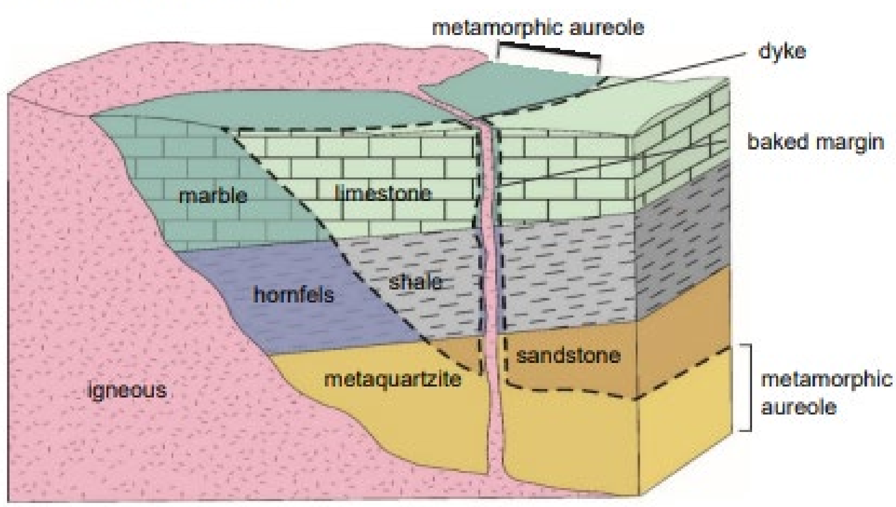
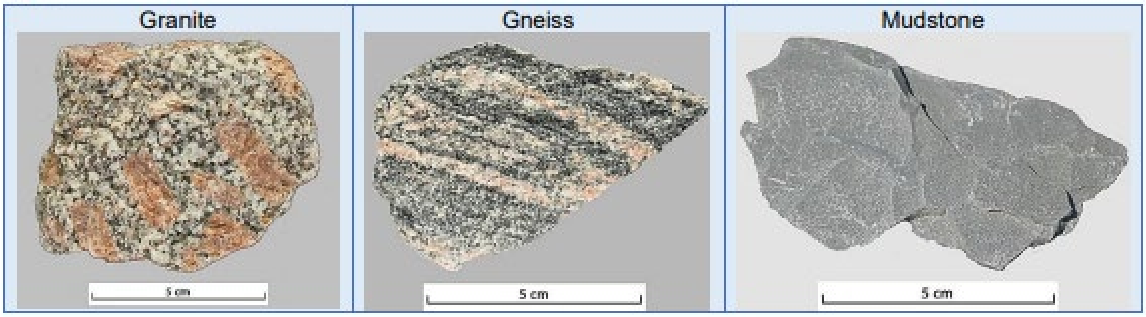


Figure 4.11. The most common rocks of the continental crust

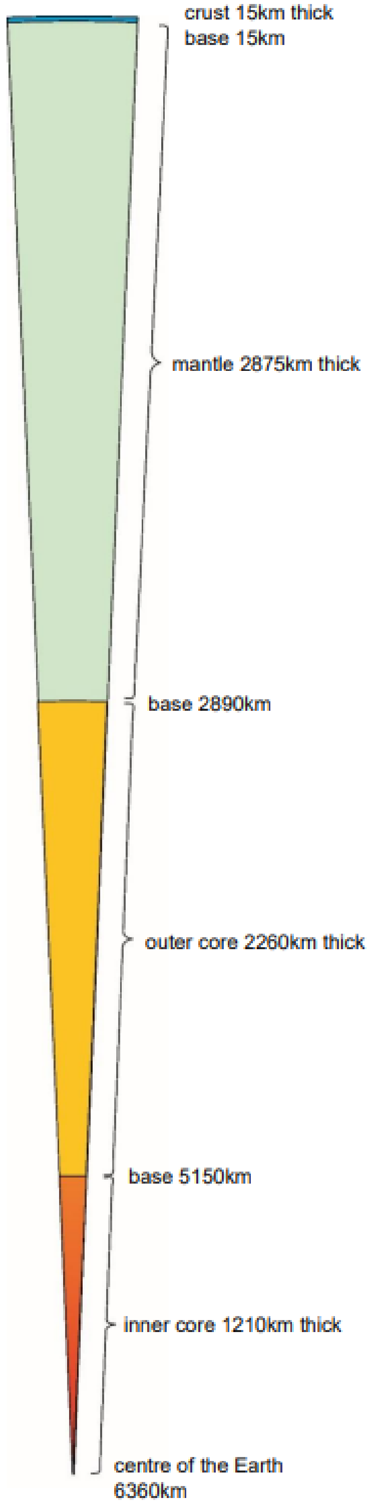


The evidence shows how new oceanic crust is formed at divergent plate margins. Magma from local partial melting of the mantle rises at oceanic ridges. There it collects and solidifies below the surface, forming coarse-grained gabbro. If it rises through vertical fractures to the surface, it erupts as lava on the ocean floor, often with characteristic pillow lava shapes, and solidifies quickly into fine-grained basalt. Meanwhile the magma in the vertical fractures solidifies more slowly into medium-grained dolerite. Each time a fracture opens, a new sheet forms, producing more and more sheets of dolerite dykes.

4.1.3 Structure of the Earth and evidence

4.1.3.1 Evidence

Figure 4.9. Cross-section of the Earth

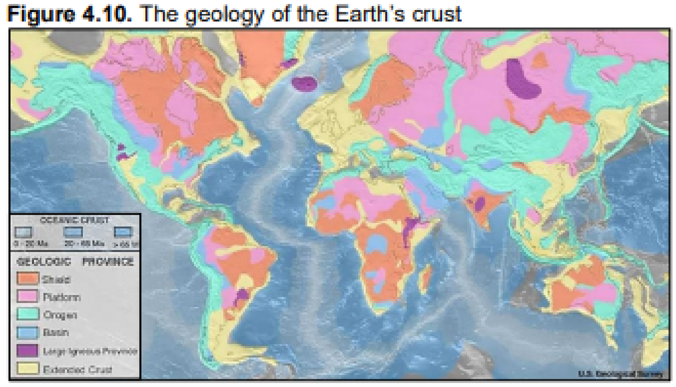


4.1.3.2 Crust

Figure 4.9 shows that the crust is very thin, when compared with the distance to the centre of the Earth. A good model of the crust's thickness is a postage stamp stuck onto a football. There are two sorts of crust: the continental crust found beneath continents and continental shelves, and the oceanic crust under the oceans.

The geological map in Figure 4.10 shows that the crust of the continents is much more complex than the crust of the oceans. This is because the continental crust is generally much older than the oceanic crust and some areas have been involved in several cycles of the rock cycle. The oldest rocks so far found on Earth are more than 4000 million years old, and form part of the continental crust in Australia. Meanwhile, the oldest parts of the oceanic crust are rarely more than 200 million years old and have a much simpler history.

Figure 4.10. The geology of the Earth's crust

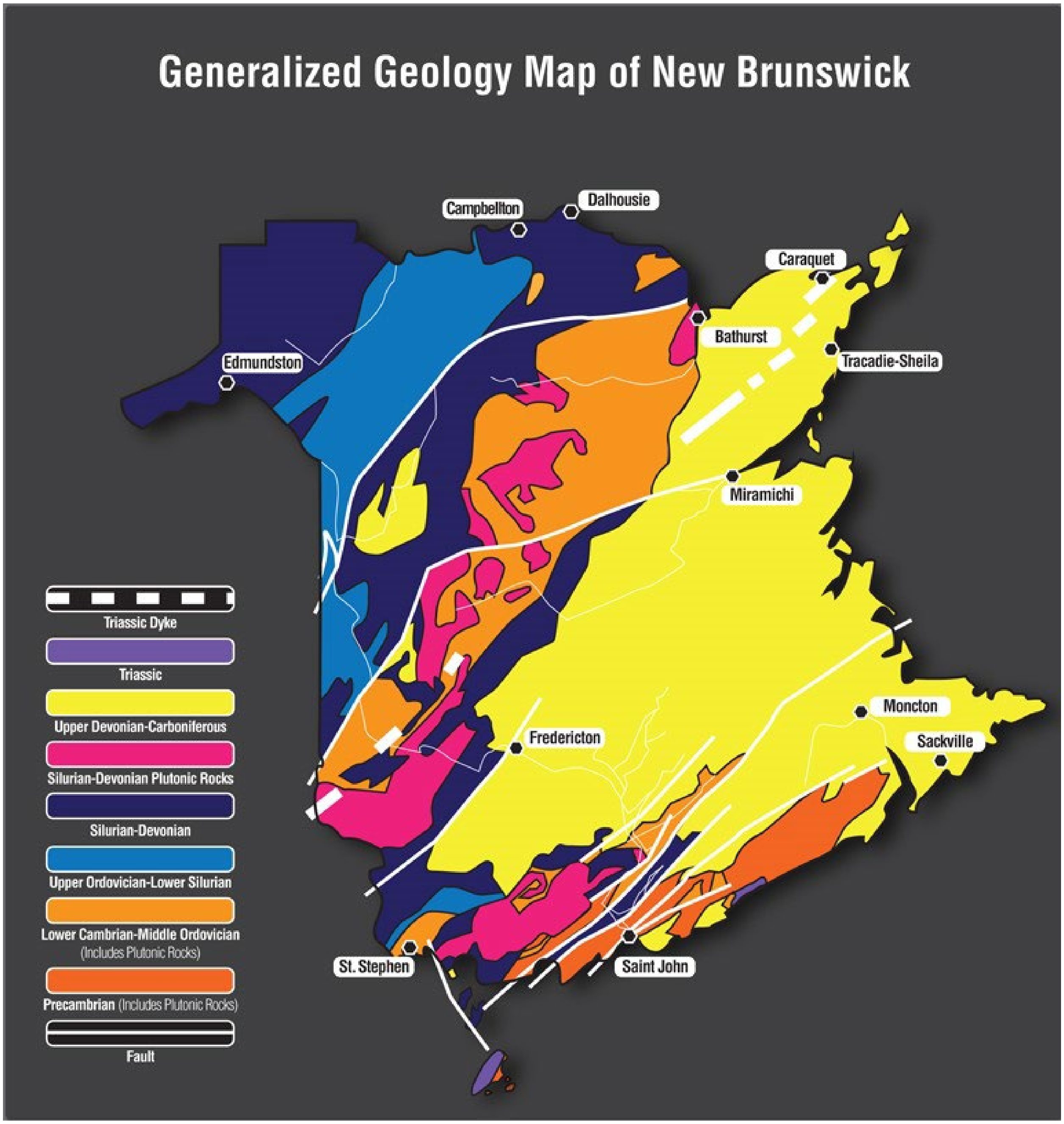


The continental crust that we live on ranges in thickness from around 25 to 70 km. Although sedimentary rocks are only about 5% of the volume of the whole crust, they cover 75% of the continental crustal surface, about three quarters of the brightly-coloured area of Figure 4.10. Estimates suggest that these continental sedimentary rocks are about 79% mudstone, 13% sandstone and 8% limestone. Most of the volume of the continental crust is formed of igneous rock like granite, and metamorphic rock like gneiss (Figure 4.11). All these rocks have been formed by normal rock-cycle processes, even though some of the materials in them have been around the rock cycle several times.

The evidence for the structure and rocks of the oceanic crust includes seismic data, data from deep sea drilling and information from places like Cyprus, where a plate collision has forced old oceanic crust up onto the continent. This evidence shows that oceanic crust has four main layers. On top is a layer of deep sea sediments that are not found at ocean ridges, but become thicker and thicker moving away from the ridges. Beneath the sediments is a layer of fine-grained basalt, often in pillow lava form. The basalt overlies a layer made up of many vertical sheets of medium-grained dolerite dykes. Under that is a thick layer of coarse-grained gabbro, before the bottom of the oceanic crust and the top of the mantle are reached (Table 4.19).

Journey Through Time: Places of geological significance in New Brunswick and Prince Edward Island

Note to students – This is a brief summary of the geological history. It is not important to remember names etc. although supercontinents have cool names. It is important to get a picture of the complexity, processes, and the diversity of lithologies which resulted from this and created what we now know as New Brunswick.

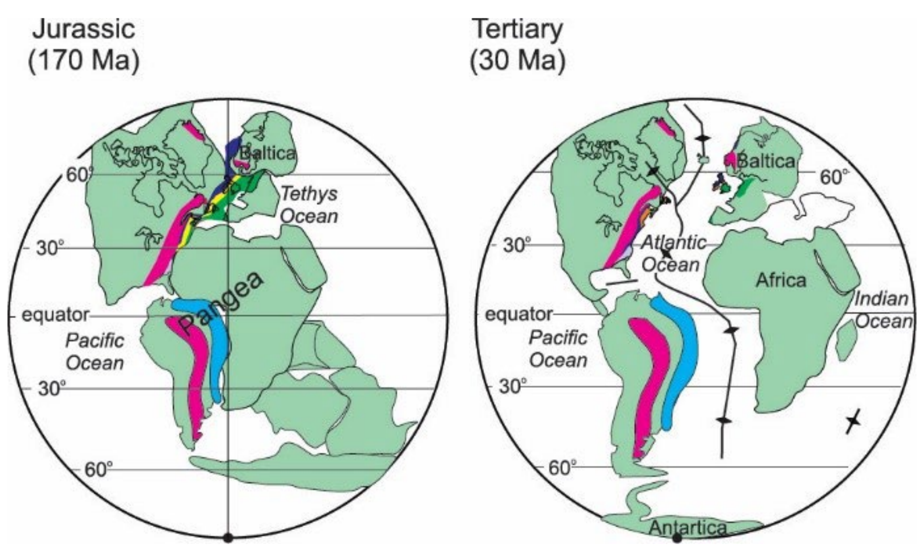


New Brunswick's geology reflects a complex history of repeated cycles of ocean opening and closing, accretion of crustal blocks, mountain building (orogenesis), and glaciations. These processes are part of the supercontinent cycle, whereby continents as we know them today are slowly being rearranged throughout Earth's history. Continental rifting brought on by a build--up of heat and convection in the Earth's mantle triggers supercontinent break-up. Most, but not all, of the rocks in New Brunswick are related to the accretion of fragments of continental and oceanic rocks to the margin of Laurentia (ancestral North America), during closure of the Iapetus and Rheic oceans in the Paleozoic, leading ultimately to the amalgamation of the most recent supercontinent, Pangea. This history is responsible for the great diversity of New Brunswick's landscape and of its mineral resources.

The bedrock of New Brunswick is divided into a series of northeast-trending tectonic zones, each a crustal fragment that contains rocks related by age and tectonic history and accreted to the continental margin during a specific orogenic event. The tectonic zones are overlain by cover sequences that are dominated by sedimentary rocks that commonly form in basins lying between uplifted areas such as active orogenic zones. These sedimentary rocks may themselves be deformed and uplifted during later tectonic events. The following description of the geologic evolution of New Brunswick is divided by geologic Period, and the accompanying paleo-geographic reconstructions illustrate the relative position of the crustal blocks (terranes) through time.

The presence of volcanic and uplifted sedimentary rocks are a reflection of an active continental margin, whereas today in New Brunswick we are on a passive margin. Presently, active margins are on the west coast of North America and the mid-Atlantic Ridge.

The Break-up of the most recent super continent Pangea



Late Permian to Present

At the close of the Permian, continental rifting initiated the break-up of Pangea beginning with continental separation in what is now the Central Atlantic Ocean and thence the South Atlantic. This led to the development of extensive rift basins in the latest Permian to earliest Jurassic. These same tensional forces resulted in the formation of a rift valley in what is now the

Bay of Fundy. Fluvial and aeolian sedimentary rocks were deposited at the base of these rifts. Subsequently, upwelling magma erupted along basin-bounding faults forming extensive basalt flows of the Late Triassic (ca. 200 Million years) Central Atlantic magmatic province, which is exposed on both sides of the bay, and in New Brunswick are best exposed on Grand Manan Island. The Caraquet and Ministers Island dykes that cross New Brunswick from northeast to southwest formed in response to the same tensional forces. Spreading in the Fundy rift ceased in the Early Jurassic and the axis of spreading stepped to the east of Nova Scotia in the Late Cretaceous (ca. 80 Ma) with the initial opening of the North Atlantic Ocean and has been ongoing since that time. New Brunswick has since remained relatively quiet tectonically; however, erosion and deposition related to continental glaciations over the last 2.5 million years have had significant effects on the landscape.

Glacial Geology of New Brunswick

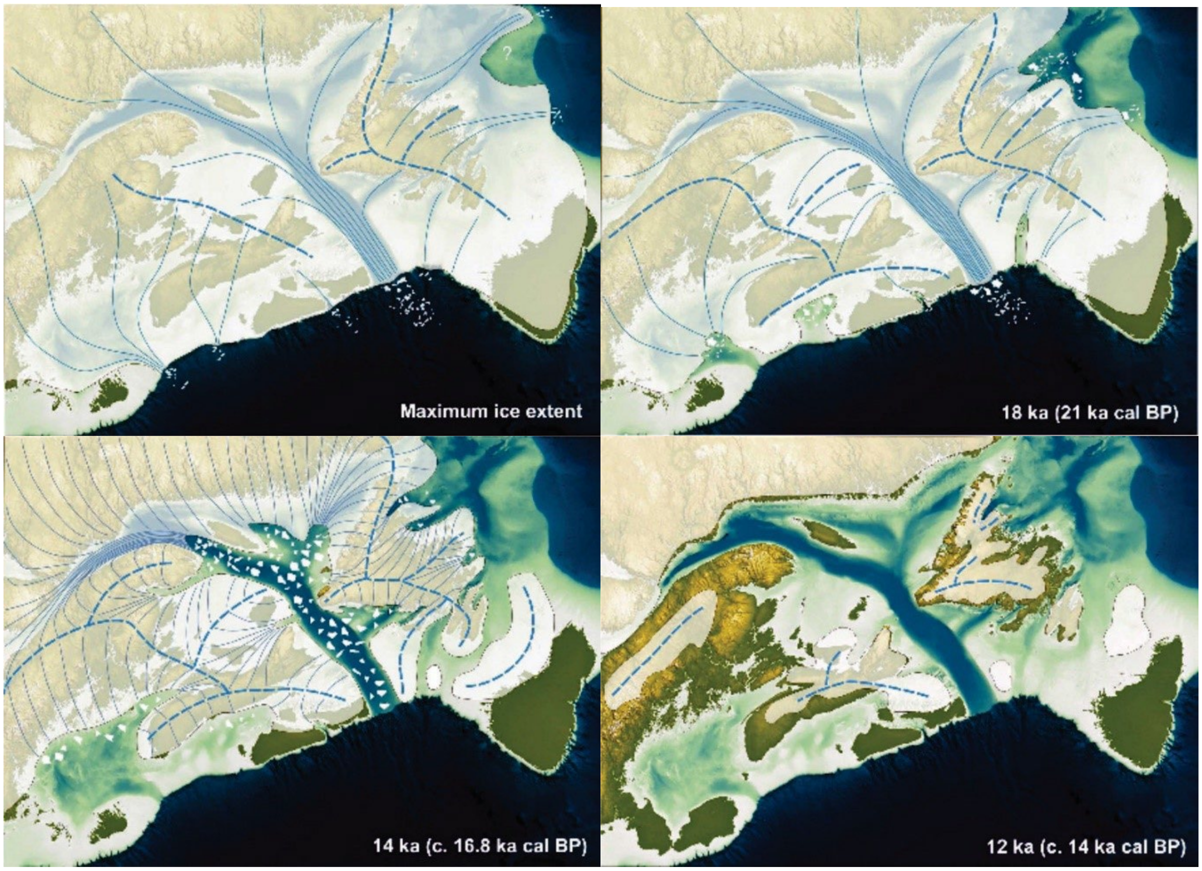
Around two and a half million years ago, Earth entered its most recent glacial era. As the result of climatic changes triggered by the rearrangement of the continents and ocean currents, in combination with the reduced influx of heat from the sun, ice caps expanded at both the north and south poles and, locally, glaciers formed and spread. In this context, it is important to note that continent-sized ice sheets covered almost all of Canada and adjacent parts of the United States. Peripheral to this were regional ice sheets like the Cordillera (Rockies) and Greenland sheets, as well as local glacier complexes like the Appalachian and Newfoundland ice caps. New Brunswick was completely or partially covered in ice several times during the Pleistocene. However, the last glacial period (the Wisconsinan) eroded almost all signs of earlier glaciations and glacial deposits. The oldest confirmed glacial deposit in New Brunswick is a clay that contained a fossilized mastodon (found in a sinkhole near Hillsborough), which lived during a colder phase of the last interglacial stage (the Sangamonian), approximately 80,000 years ago. A replica of this mastodon is on display in the entry hall of the New Brunswick Museum in Saint John.

New Brunswick's glacial deposits are between 100,000 and 10,000 years old (Sangamonian to Wisconsinan). The dominant accumulation is a blanket of moraine deposits, which are typically on the order of one to a few metres thick; however, significantly thicker deposits exist within some valleys. These moraine deposits are composed of local and far-travelled materials and are distinguishable by grain size, compactness, sorting, etc.

Additional accumulations of sediment were deposited under, next to, and in front of the ice masses by meltwaters that drained into large glacial lakes and the sea. These deposits provide sources of sand and gravel for construction projects, like road building. Because these materials were moved by and deposited in water, most of the fine particles (silt and clay) were washed farther into the lakes and sea. Eskers (ridges of sand and gravel), terraces along river valleys, and deltaic sediments that were deposited into lakes and the sea are recognizable at different elevations in the landscape today.

In many parts of the province, exposed bedrock surfaces are very smooth, having been glacially scoured and scratched by sand, gravel, and boulders as they were pushed along the interface between the bedrock and the ice. These glacial striations reveal a lot about the flow directions of the ice (ice flows much like thick molasses, both under the influence of gravity and by internal deformation under its own weight) and understanding flow directions can be helpful in mineral exploration. In New Brunswick, ice generally flowed from northwest to southeast, but during the different stages of the glaciations, ice masses took many different paths. At times, large ice streams developed in major valleys like the Saint John (Wolastoq), Nepisiguit, Upsalquitch, Miramichi, and Petitcodiac rivers. At one time, ice flowed through deep glacial valleys in the

Gaspé's Chic-Choc mountains and glacial erratics following this route from the Saguenay region of Québec can be found as far south as the Grand Lake area of New Brunswick.



Ice cover, ice divides, flow lines, ice streams, and calving bays in the Maritime provinces during the last glacial period from about 30,000 to 12,000 years ago. People moved into the ice-free area very soon after the ice left at around 11,500 years.

As the ice expanded, its weight depressed the Earth's crust; as the ice melted, sea level rose quickly while the crust slowly began to rebound. As a result, the sea flooded low-lying areas of New Brunswick, in some places rising to around 90 m above present-day sea level. As the crust continued to rebound, sea level dropped. When the crust finally came to rest, sea level slowly rose again (globally), influenced by the melting of ice in other areas of the world.

Just as the start of ice ages involves interplay between the global distribution of the continents and the intricate cycles of the earth-sun system (Milankovitch cycles), the end of glacial periods is also triggered by changes in these cycles. When Earth receives and holds more solar heat, it warms, and ice sheets start to melt; when it receives and holds less solar heat, it cools, and ice sheets begin to grow. These climatic variations are recorded in ice layers, by tree rings, and in sediments and components thereof, like pollen. A rapid climate reversal (in this case, a very rapid cooling phase while the world in general was warming up), known as the Gerzensee-Killarney Oscillation (from 11,160 to 10,910 years BP), was first recorded at Killarney Lake in Fredericton by a University of New Brunswick graduate student studying sediment cores from the lake.

Bay of Fundy & Grand Manan

The Bay of Fundy has long been recognized as a rift valley that formed about 250 million years ago as a result of tensional forces, which eventually led to the breakup of the supercontinent Pangea. The water that now fills the Bay of Fundy is a result of the rise in sea level after the last glaciation, about 10,000 years ago. The Bay of Fundy is sometimes called a 'failed rift' because complete separation of the continents that eventually opened the Atlantic Ocean did not occur here, but some distance to the east. The tensional stresses from stretching of the crust caused one fault block to go down relative to the other resulting in the formation of a half-graben (Fundy Basin). The rift valley eventually became filled with sediments eroded from the surrounding Appalachian Mountains. In the Late Triassic, around 200 Ma, the rifting process eventually stretched the crust enough to allow up-welling basaltic magma to erupt from basin-bounding faults. Huge volumes of basalt were extruded over once contiguous parts of eastern North America, Europe, Africa, and South America. Some speculate that these large eruptions may have caused, or at least contributed to, a global extinction at the end of the Triassic.

Grand Manan Island, the largest island in the Bay of Fundy, is surrounded by an archipelago of smaller islands (each with spectacular and varied geology) and is unique as it contains some of the oldest and youngest rocks in the province. The main island is transected by a north-trending normal fault that brought Cambrian and older rocks in the east against much younger Triassic basalts of the Fundy Basin in the west. At Southwest Head, these basalts exhibit well-developed columnar jointing, which was created when lava slowly cooled to form closely-spaced 5- or 6-sided columns. Basalt on Grand Manan is the same age as, and likely co-magmatic with the North Mountain Basalt, which forms the linear volcanic ridge on the south side of the Bay of Fundy in Nova Scotia. Cavities within the basalt commonly contain well-formed crystals of amethyst, agate, or zeolite minerals.

In contrast, the eastern side of Grand Manan Island is much older, mainly consisting of deformed Ediacaran and Cambrian volcanic and sedimentary rocks. On the north end of Ross Island near The Thoroughfare, and on White Head Island, there are quartz-rich sandstones (quartzites) that are among some of the oldest rocks in New Brunswick. Recent data hints at an ancient origin for these quartzites and associated carbonaceous shale, which may be as old as 1.8 billion years.

Photo: Quartzites from White Head Island, New Brunswick

Our Landscape Heritage: Chapter 3
New Brunswick Physiography and Superficial Geology

New Brunswick lies in the Appalachian physiographic region of Canada. Bostock (1970) reported that New Brunswick is composed of three physiographic regions; Rampton et al. (1984) reported six regions subdivided into 42 sub-regions (Fig 1). The Appalachians consist of a complex belt of folded mountains composed largely of flat-topped rolling uplands and highlands.

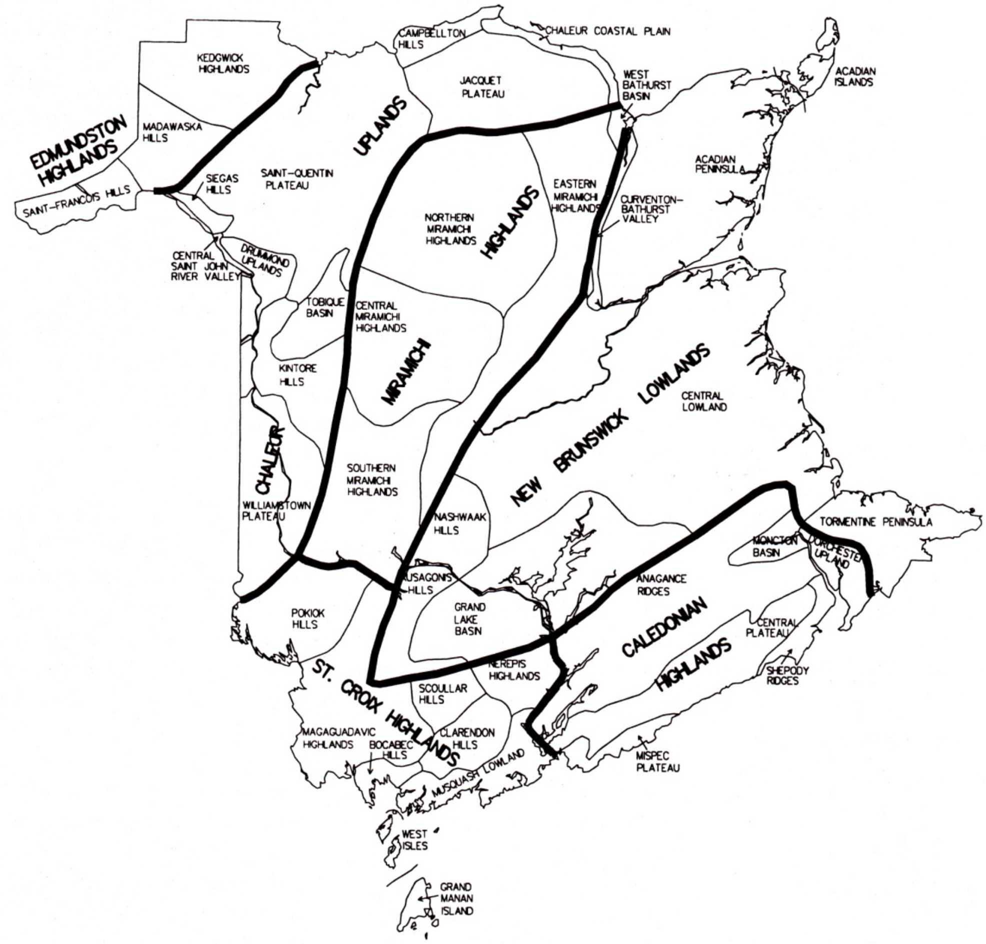


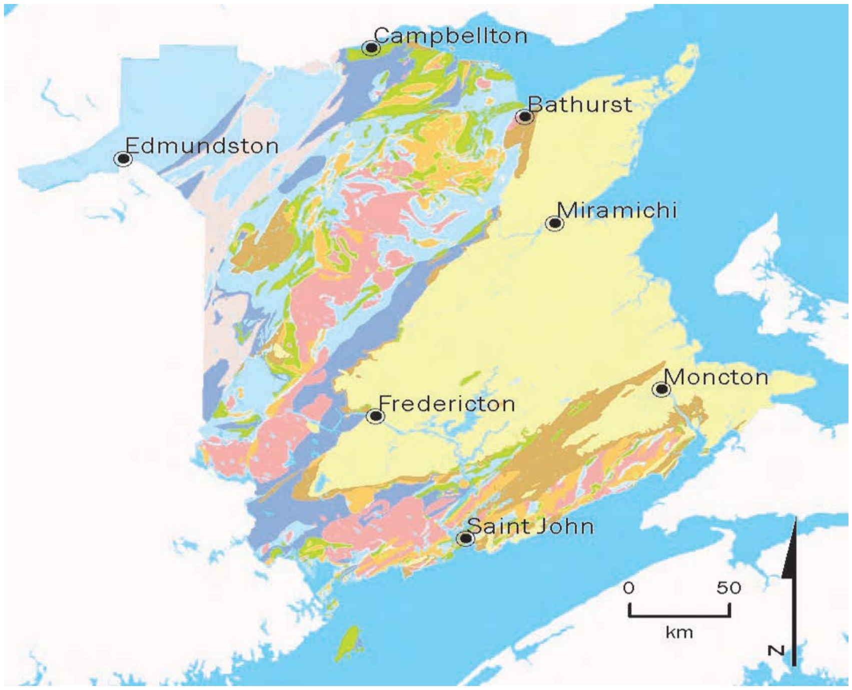
Figure 1. New Brunswick Physiographic regions Map (Rampton et al., 1984)

In New Brunswick, differential erosion has left a northeast-southwest trend of physiographic units composed of highlands and uplands, separated by valleys, and broad lowland areas developed on less resistant Paleozoic sedimentary rocks. The Highlands and Uplands form a semicircle about the vast New Brunswick Lowland, or Maritime Plain. The Maritime Plain is for the most part, below 120 m in elevation, while the surrounding uplands range between 150 and 820 m. Mount Carleton in the Northern Miramichi highlands sub region is New Brunswick's highest peak at an elevation of 820 m.

The Chaleur Uplands are thought to be the remnants of a peneplain which has since been uplifted and heavily dissected. In general, the peneplain is southeastwardly sloping with long, flat-topped or gently rounded ridges and uplands formed on folded Paleozoic strata. The area is drained by either the Restigouche River into the Bay of Chaleur or the St. John River into the Bay of Fundy. Elevations range from 240 to 300 m. On their eastern boundary, the Chaleur Uplands gradually merge into the Central Highlands.

The U-shaped central highlands have been heavily dissected by rivers. The St. John River has divided the highlands into the Miramichi Highlands to the northeast, the St. Croix Highlands to west, and the Caledonian Highlands to the east. In the north-eastern and western sections of the highlands, large granite batholiths rise above the softer slates, conglomerates and sandstones to provide the basis for a more rugged relief, reaching elevations in excess of 610 m in the Miramichi Highlands. Elevations in the St. Croix and Caledonian Highlands tend to be in the 300 m range. East of the central highlands is the triangular Maritime Plain, which extends under the Northumberland Strait. The plain is composed of flatlying Permian and Carboniferous rocks comprised of shale, sandstones, and conglomerates.

Clayton et al. (1977) reported that all of the Appalachian Region was glaciated during the Pleistocene period and much of the pre-glacial surface has been scoured and subsequently covered with a layer of till deposits of different thickness. Granitic rock fragments originating from the Precambrian shield are found in the St. John River Valley and Chaleur Uplands, indicating that the Laurentide Ice Sheet reached the uplands. But the pattern of de-glaciation reveals that there may have been a separate center of ice dispersion over the southern part of the province forming part of the Appalachian Glacier complex. The disintegration of the ice sheets and subsequent changes in sea level has had a significant effect on the coastal regions. The most extensive areas of marine submergence occur on the east coast of the province where thin deposits of marine sediments are scattered along the coastline. However, many of these deposits have been eroded away or incorporated into soil profiles. Very stony sandy till deposits occurring frequently with rock outcrops are found in the New Brunswick Highlands, with the exception of the southwest, where deep gravely tills have smoothed the rough topography into a more rolling upland terrain. In contrast to this, the Chaleur Uplands are considered to have a more rugged deeply dissected topography with very shallow, stony to very gravelly till deposits. On the Maritime plain region of the province, sandy tills are only found within the Miramichi watershed. Elsewhere the till is a deep red brown loamy material of local origin. Alluvial plains and terraces are found along the valleys of most of the main rivers. Thin layers of marine sediments cover extensive areas within the plain, especially along the coast, these alluvial and marine deposits range from fine sands and silts to coarse sands and gravel.



Highly calcareous sedimentary rocks
Calcareous sedimentary rocks
Non-calcareous sedimentary rocks
Early Carboniferous sedimentary rocks
Late Carboniferous sedimentary rocks
Mafic volcanic rocks
Felsic volcanic rocks
Granites and granodiorites

Geomorphological Regions of New Brunswick, after Bostock (1970)

Classification of Soils

The overall philosophy of soil classification is to deal with the systematic categorization of soils based on distinguishing characteristics as well as criteria that dictate choices in its use. The Canadian System of Soil Classification 1998 has five categorical levels: Order, Great group, Subgroup, Family, and Series. The three highest categories: The Order, Great group, and Subgroup, deal specifically with concepts and variations of kinds of profiles, relating in particular to the recognition of soils having morphological features that reflect similar pedo-genetic environments.

1) The Order level: Reflect the broadest influences of the active environmental factors in soil genesis (the soil forming factors) of: the parent material, vegetation, climate, and activity of living organisms in relationship to time.
2) The Great group level: Are subdivisions of each order group; they are based on properties that reflect differences in the strengths of dominant processes and / or of a major

contribution of a process; i.e. in the luvic gleysol; gleying is the dominant process. Clay translocation is also considered a major process in formation of the Bt horizon in the luvic gleysol great groups.

3) The Subgroup level: Are subdivisions of great groups. They are differentiated on the basis of the kind and arrangement of horizons that indicate: conformity to the central concept of the soil great group (e.g. Orthic); intergrading towards soils of another order (e.g. Gleyed, Brunisolic); or additional special features within the control section (e.g. Ortstein).

All three categories are largely conceptual in nature and correlate generally to similar concepts of pedon classification as defined in other world classifications. They are not; therefore, dependent on localized mapping characteristics. The two lower categories: of Family and Series are no less important than the higher categories and are in fact the groupings that are essential to soil mapping. It is at these levels that the profile characteristics classified in the subgroup level come down to earth and become related to the individual pedons reflecting features of parent material and texture, and the polypedons that form mapping units with position and extent within the soil landscapes. In this respect, the soil series is the basic unit of soil mapping and is defined as a group of soils pedons (polypedons) that are essentially alike in all major profile characteristics including kind of parent material (i.e. each having limits and a central concept for their characteristics).

4) The Family level: Is the fourth level in the Canadian System of Soil Classification, it is defined as a group of soil series within a taxonomic subgroup that are uniform enough in their horizon development and physical and chemical composition to be relatively homogeneous with respect to soil environment and interpretive relationships.
5) The Soil Series level: Is the link between the conceptual entity (the soil series) with defined limits and real bodies of soils (the pedons), i.e. a soil series is many pedons within set limits, they are 16 subdivisions of soil families based upon relatively detailed properties of the pedon within the depth of the control section (1 meter). They cannot transgress climatic, particle-size, or other boundaries recognized in family separations. The significance of differences in properties of the kinds of pedons that fall within a soil family depends on the combinations of these properties.

No specific property or group of properties has been assigned limits and used consistently from family to family and within families to define series. Each potential soil series is treated as an individual case and the decision on whether or not it should be recognized as a separate taxon involves a judgment based on the following guidelines:

1) The properties that distinguish a particular series from other series must be sufficiently recognizable that qualified field pedologists can identify the series consistently.
2) The properties used to differentiate series must be within the control section (4 & 5 below)
3) Soils of a series must occupy at least a few hundred hectares. The establishment of a series to classify a few pedons occupying a few hectares is not justified even if the pedons have unique properties.

4) Soil series within families of mineral soils are usually differentiated on the basis of the following properties:
    a. Color, including mottling
    b. Texture
    c. Structure
    d. Consistence
    e. Thickness and degree of expression of horizons and of the solum
    f. Abundance of coarse fragments
    g. Depth to bedrock, permafrost, or contrasting material.
5) Soil series within families of soils of the Organic order may be differentiated on the basis of the following properties:
    a. Parent material: botanical origin of fibres and nature of terric layer, if any
    b. Absence or Presence of logs and stumps and its abundance.
    c. Calcareousness
    d. Bulk density
    e. Mineral content of organic material
    f. Soil development in the terric layer
    g. Mineralogy of terric or cumulo layers
    h. Texture of cumulo layers, thickness, pH, degree of decomposition, and layers arrangement.

2023 NCF-Envirothon New Brunswick

Soils and Land Use Study Resources

Key Topic #2: Soil Structure and Function

5. Identify different types of parent material and how they are formed (such as residual material, alluvial and marine deposit, volcanic deposits, glacial deposits, and organic deposits).
6. Define the five soil-forming factors and describe their influence on a particular soil.
7. Describe how different soil components (mineral composition, organic matter, particle size, etc.) affect the properties of a soil including pore space/soil density.
8. Describe what factors influence soil structure and explain the impact of soil structure on soil properties.
9. Describe what factors influence available water capacity in a soil, and how this affects vegetation growth.
10. Describe the following soil properties and their importance: a. Density, b. Porosity, c. Permeability, d. Cation exchange capacity (CEC), e. Salinity.

Study Resources

Resource Title	Source	Located on
Earth's Critical Zone	*National Research Council, 2001*	Page 35
REQUIRED VIDEO: Frontiers in the Exploration of the Critical Zone	*WSKG Public Media, 2017*	Page 36
Soil Classification Canadian System	*Government of Canada-Soil Drainage Class, 2013*	Pages 37
Soil Erosion	*Government of Canada-Soil Drainage Class, 2013*	Pages 38-42
New Brunswick Soils	*Soils of New Brunswick: The Second Approximation, Fahmy et al., 2010*	Pages 43-44
Soil Forming Factors	*Canadian Society of Soil Science, 2020*	Pages 45-47
Importance of Soils - Soil Structure and Function	*Agriculture and Agri-Foods Canada, 2023*	Pages 48-58
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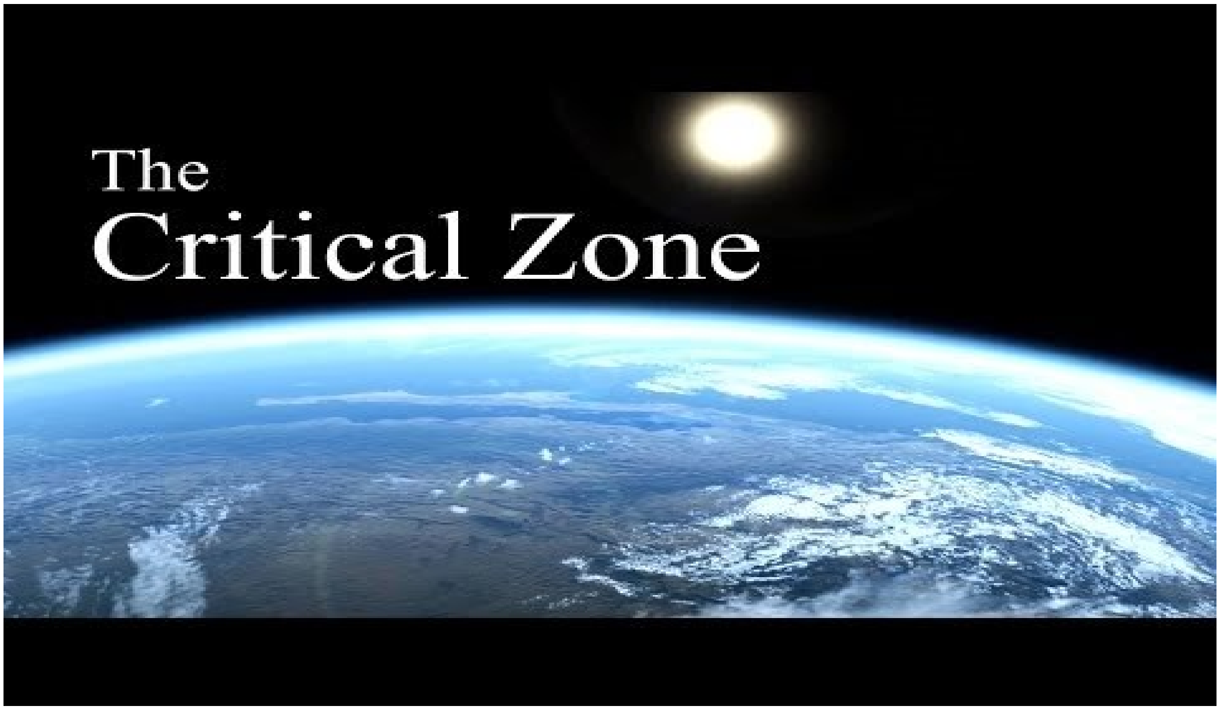
Study Resources begin on the next page! ➡

Earth's Critical Zone

Earth's critical zone is the "heterogeneous, near surface environment in which complex interactions involving rock, soil, water, air, and living organisms regulate the natural habitat and determine the availability of life-sustaining resources" (National Research Council, 2001).[1] The Critical Zone, surface and near-surface environment, sustains nearly all terrestrial life.[1] The critical zone is an interdisciplinary field of research exploring the interactions among the land surface, vegetation, and water bodies, and extends through the pedosphere, unsaturated zone, and saturated groundwater zone. Critical Zone science is the integration of Earth surface processes (such as landscape evolution, weathering, hydrology, geochemistry, and ecology) at multiple spatial and temporal scales and across anthropogenic gradients. These processes impact mass and energy exchange necessary for biomass productivity, chemical cycling, and water storage.

REQUIRED VIDEO: Frontiers in the Exploration of the Critical Zone Explore the Critical Zone:

https://youtu.be/8gW-Vy7zFdU



Soil Classification Canadian System of Soil Classification

There are 10 classes of soil orders in the Canadian system:

1) Brunisolic Order – Soils formed under forests and have brownish-colored B horizons; they lack the degree or kind of horizon development specified for soils of other orders.
2) Chernozemic Order – Soils formed under grassland communities and have surface horizons darkened by organic matter.
3) Cryosolic Order – Soils formed where permafrost exists.
4) Gleysolic Order – Soils that have properties that indicate prolonged periods of saturation with water. The soils found in this order will have grey coloring.
5) Luvisolic Order – Soils that have an increased accumulation of silicate clay in the B horizons.
6) Organic Order – Soils composed largely of organic materials (bogs, peat and swamp soils).
7) Podzolic Order – Soils that have B horizons that are enriched with an accumulation of organic matter combined with Al and Fe.
8) Regosolic Order – Soils that do not contain a B horizon and are referred to as weakly developed. Imperfect to Poorly drained
9) Solonetzic Order – Soils that are identified by the presence of columnar or prismatic structure within the B horizons.
10) Verisolic Order – Soils that occur in heavy textured materials and have shrink-swell characteristics.

Soil Erosion

Definition – The processes by which soil is removed from one place by forces such as wind, water, ice or gravity and eventually deposited at some new place. There are two basic types of erosion:

1. Natural Erosion – Erosion that occurs under natural conditions (without the aid of human interaction).
2. Accelerated Erosion – Erosion that occurs more rapid than normal, primarily as a result of human activities. Accelerated erosion is often 10-1000 times more destructive than natural erosion.

Water Erosion

Wind Erosion

When soil erosion occurs, the soil that is eroded away is almost always more valuable than what is left behind. Erosion removes organic matter, fine particles (such as clay) and essential nutrients (such as nitrogen, phosphorous and potassium). The soil that is left behind usually has lower water-holding capacity, less biological activity and a reduced supply of nutrients. These factors limit the plant growth for the remaining soil. Sediment and nutrients get transported to streams, lakes and rivers where they can have a huge impact on the stream ecosystem. The nutrients impact water quality by increasing the concentration of nitrogen and phosphorous in streams. Erosion can also pollute streams by transporting toxic metals and organic compounds (such as pesticides). The control of soil erosion is detrimental to ensuring that there is a lucrative soil resource for future generations.

Some examples of ways to control soil erosion in an agricultural setting are as follows:-

Conservation Tillage – Conservation tillage is used to minimize the effects of soil erosion on agriculture areas. It produces equal or higher crop yields while saving time, fuel, money and soil.

Vegetative Barriers – Rows of vegetation planted on the contours of the land can be used to slow down run-off, trap sediment, and eventually create natural terraces.

Some examples of ways to control soil erosion in a forestry setting are as follows:

Intensity of Harvest – Selective cutting on steep slopes and soil with a high erosion potential minimize surface runoff.

Method of Tree Removal – Skidding trails should be cushioned with bows and tops to minimize soil compaction and mineral soil exposure which will maintain soil porosity.

Schedule of Harvest – Forests located on heavy soils should not be harvested during wet conditions because damage to the forest floor occurs more readily when the soil is wet.

Forest Roads – Building roads with proper materials, drainage and minimizing mineral soil exposure helps control the rate of soil erosion.

Buffer Strips – Leaving vegetation strips along streams protect them from soil sediment and nutrient inputs which can cause water pollution.

Plant Nutrients
Sixteen chemical elements are known to be important to a plant's growth and survival. The sixteen chemical elements are divided into two main groups: non-mineral and mineral.

Non-Mineral Nutrients
The Non-Mineral Nutrients are hydrogen (H), oxygen (O), & carbon (C). These nutrients are found in the air and water. In a process called photosynthesis, plants use energy from the sun to change carbon dioxide (CO_2 - carbon and oxygen) and water (H_2O- hydrogen and oxygen) into starches and sugars. These starches and sugars are the plant's food. Since plants get carbon, hydrogen, and oxygen from the air and water, there is little farmers and gardeners can do to control how much of these nutrients a plant can use.

Mineral Nutrients
The 13 mineral nutrients, which come from the soil, are dissolved in water and absorbed through a plant's roots. There are not always enough of these nutrients in the soil for a plant to grow healthy. This is why many farmers and gardeners use fertilizers to add the nutrients to the soil. The mineral nutrients are divided into two groups: macronutrients and micronutrients.

Macronutrients
Macronutrients can be broken into two more groups: primary and secondary nutrients. The primary nutrients are nitrogen (N), phosphorus (P), and potassium (K). These major nutrients usually are lacking from the soil first because plants use large amounts for their growth and survival. The secondary nutrients are calcium (Ca), magnesium (Mg), and sulfur (S). There are usually enough of these nutrients in the soil, so fertilization is not always needed. Also, large amounts of Calcium and Magnesium are added when lime is applied to acidic soils. Sulfur is

usually found in sufficient amounts from the slow decomposition of soil organic matter, an important reason for not throwing out grass clippings and leaves.

Micronutrients

Micronutrients are those elements essential for plant growth which are needed in only very small (micro) quantities. These elements are sometimes called minor elements or trace elements, also known as micronutrients. The micronutrients are boron (B), copper (Cu), iron (Fe), chloride (Cl), manganese (Mn), molybdenum (Mo) and zinc (Zn). Recycling organic matter such as grass clippings and tree leaves is an excellent way of providing micronutrients (as well as macronutrients) to growing plants.

Macronutrients

Nitrogen (N)

- Nitrogen is a part of all living cells and is a necessary part of all proteins, enzymes and metabolic processes involved in the synthesis and transfer of energy.
- Nitrogen is a part of chlorophyll, the green pigment of the plant that is responsible for photosynthesis.
- Helps plants with rapid growth, increasing seed and fruit production and improving the quality of leaf and forage crops.
- Nitrogen often comes from fertilizer application and from the air (legumes get their N from the atmosphere, water or rainfall contributes very little nitrogen)

Phosphorous (P)

- Like nitrogen, phosphorus (P) is an essential part of the process of photosynthesis.
- Involved in the formation of all oils, sugars, starches, etc.
- Helps with the transformation of solar energy into chemical energy; proper plant maturation; withstanding stress.
- Effects rapid growth.
- Encourages blooming and root growth.
- Phosphorus often comes from fertilizer, bone meal, and superphosphate.

Potassium (K)

- Potassium is absorbed by plants in larger amounts than any other mineral element except nitrogen and, in some cases, calcium.
- Helps in the building of protein, photosynthesis, fruit quality and reduction of diseases.
- Potassium is supplied to plants by soil minerals, organic materials, and fertilizer.

Calcium (Ca)

- Calcium, an essential part of plant cell wall structure, provides for normal transport and retention of other elements as well as strength in the plant. It is also thought to counteract the effect of alkali salts and organic acids within a plant.
- Sources of calcium are dolomitic lime, gypsum, and superphosphate.

Magnesium (Mg)

- Magnesium is part of the chlorophyll in all green plants and essential for photosynthesis. It also helps activate many plant enzymes needed for growth.
- Soil minerals, organic material, fertilizers, and dolomitic limestone are sources of magnesium for plants.

Sulfur (S)

- Essential plant food for production of protein.
- Promotes activity and development of enzymes and vitamins.
- Helps in chlorophyll formation.
- Improves root growth and seed production.
- Helps with vigorous plant growth and resistance to cold.
- Sulfur may be supplied to the soil from rainwater. It is also added in some fertilizers as an impurity, especially the lower grade fertilizers. The use of gypsum also increases soil sulfur levels.

Micronutrients

Boron (B)

- Helps in the use of nutrients and regulates other nutrients.
- Aids production of sugar and carbohydrates.
- Essential for seed and fruit development.
- Sources of boron are organic matter and borax

Copper (Cu)

- Important for reproductive growth.
- Aids in root metabolism and helps in the utilization of proteins.

Chloride (Cl)

- Aids plant metabolism.
- Chloride is found in the soil.

Iron (Fe)

- Essential for formation of chlorophyll.
- Sources of iron are the soil, iron sulfate, iron chelate.

Manganese (Mn)

- Functions with enzyme systems involved in breakdown of carbohydrates, and nitrogen metabolism.
- Soil is a source of manganese.

Molybdenum (Mo)

- Helps in the use of nitrogen
- Soil is a source of molybdenum.

Zinc (Zn)

- Essential for the transformation of carbohydrates.
- Regulates consumption of sugars.
- Part of the enzyme systems which regulate plant growth.
- Sources of zinc are soil, zinc oxide, zinc sulfate, zinc chelate.

In general, most plants grow by absorbing nutrients from the soil. Their ability to do this depends on the nature of the soil. Depending on its location, a soil contains some combination of sand, silt, clay, and organic matter. The makeup of a soil (soil texture) and its acidity (pH) determine the extent to which nutrients are available to plants. Soil Texture (the amount of sand, silt, clay, and organic matter in the soil), affects how well nutrients and water are retained in the soil. Clays and organic soils hold nutrients and water much better than sandy soils. As water drains from sandy soils, it often carries nutrients along with it. This condition is called leaching. When nutrients leach into the soil, they are not available for plants to use. An ideal soil contains equivalent portions of sand, silt, clay, and organic matter. Soils can vary in their texture and nutrient content, which makes some soils more productive than others. Sometimes, the nutrients that plants need occur naturally in the soil. Other times, they must be added to the soil as lime or fertilizer.

Soil pH (a measure of the acidity or alkalinity of the soil)
Soil pH is one of the most important soil properties that affect the availability of nutrients.

- Macronutrients tend to be less available in soils with low pH.
- Micronutrients tend to be less available in soils with high pH.

Lime can be added to the soil to make it less sour (acid) and also supplies calcium and magnesium for plants to use. Lime also raises the pH to the desired range of 6.0 to 6.5. In this pH range, nutrients are more readily available to plants, and microbial populations in the soil increase. Microbes convert nitrogen and sulfur to forms that plants can use. Lime also enhances the physical properties of the soil that promote water and air movement.

NEW BRUNSWICK SOILS

In this publication; "The Soils of New Brunswick: The Second Approximation", all available soil information was collected, compiled and interpreted from several sources. These included both published and in-house reports as well as other documents and field checks. The end result of these efforts is summarized in tables and figures reported in the publication. Absence of the information is reported as blank spaces or NA which represents gaps in the data base. Hopefully these gaps will be filled sometime in the future when the information becomes available. General Descriptions of New Brunswick Soils Table 2 reports the general description and morphology of New Brunswick Soils. It characterizes New Brunswick soil series in terms of their important properties concerning: mode of deposition, surface expression, slope, depth to contrasting layer, petrology, surface texture, parent material, texture, color, pH and consistence, drainage, catena head and soil classification.

Mode of deposition

In New Brunswick, only small hectarages of soils have developed in sites from the underlying bedrock (residual deposit). Most mineral soils have developed on parent materials that have been transported into place such as compacted and non-compacted tills (morainal deposits), colluvial, glaciofluvial, eolian and fluvial sediments. These are subdivided according to the mode of transportation such as gravity, water, ice, or wind. Although such groupings are very general, the characteristics of parent material strongly influence the kinds of soils that developed from that material. Where soils have developed in "layered" deposits; two or more parent materials, a slash "/ "is used to separate these parent materials.

Surface Expression: Is defined according to the Canadian System of Soil Classification (1998). In New Brunswick, nine categories are identified as: domed and horizontal for organic deposits; hummocky, level, ridged, rolling, steep, terraced, undulating, and veneer for mineral deposits

Depth to contrasting layer: In this context a contrasting layer is defined as having a significant difference in one of the following: mode of deposition (one or more parent material), consistency (compaction) of the parent material, and / or total thickness of the soil (over bedrock) or over a different parent material (different deposit contrasting with the deposit above it).

Petrology: Used here, petrology refers to the classification of the coarse fragments of geologic origins within the control section of the soil matrix. By definition these are rock or mineral particles that are greater than 2.0 mm in diameter, they include gravels (0.2-0.5, 0.5-2, and 2-7.5 cm in diameter, for fine medium and coarse), channers (flat gravels 0.2-15 cm long), cobbles (7.5-25 cm in diameter), stones (25- 60 cm in diameter or 15-38 cm long for flag stones or 38-60 cm long for other flat stones), and boulders (> 60 cm in diameter or length).

Texture: Soil texture refers to the relative proportions of the various soil separates (sand, silt and clay) in a soil. The names of textural soil classes are modified by adding suitable adjectives where coarse fragments are present in substantial amounts as a modifier to this texture, for example, gravely sandy loam. The texture is provided for: (1) the surface layer of 0-25 cm; the plow layer Ap, and (2) for the Parent Material (PM); the C horizon, which is the more or less weathered material from which the soil has developed. Soil textures are described first in terms of fine, medium, and / or coarse classes (family classes) and in terms of the series classes, using the actual soil texture names, i.e. clay loam, loam, loamy sand, etc.

Organic soils are described in terms of degree of decomposition i.e. Fibric, Mesic and / or Humic. Parent material color: The in-ped reading of soil colors of Hue, Value and Chroma; under moist conditions, are determined using the Munsell Color Chart. Parent material pH or reaction: The degree of acidity or alkalinity of a soil is expressed in terms of the reaction class of a soil rather than the determined pH (Day 1983).

Consistence of parent material or rubbed fibres: Soil consistence is the property of soil materials that relates to the degree and kind of cohesion and adhesion or to the resistance to deformation and rupture (soil strength), and the percentage of rubbed fibre describes its content in organic soils (Day 1983). Drainage: The soil drainage classes used here are defined in terms of (1) actual moisture content in excess of field moisture capacity and (2) the extent of the period during which such excess water is present in the plant-root zone (Day 1983).

Soil Forming Factors

Hans Jenny suggested a slightly different way of considering the factors of soil formation and their effects, in his 1941 book "Factors of Soil Formation". Jenny's model (idea) is consistent with others in that it indicates five factors of soil formation: (1) climate (cl); (2) organisms (o); (3) topography (r); (4) parent material (p); and (5) time (t). Because the factors define the state and the history of soil systems, they are referred to as state factors, and the whole idea is called the state factor approach. Jenny considered that soil systems could be described mathematically by the following expression:

$$\mathbf{S = f\,(cl, o, r, p, t....)}$$

where the....(dots) are additional unspecified factors that may be unique to a particular soil, S= a measurable soil property, and f means "is a factor of".

Later, Jenny suggests that the model is best used in a conceptual way to understand and study soil formation by considering that changes in the soil system that are the result of regular variations in one factor, with all other factors more or less constant. For example, the effect of topography can be evaluated by studying related groups of soils where topography varies, as in a hillslope, and the other variables (parent material, organisms, climate and time) are similar.

Climate as a soil-forming factor

- Water is the solvent, reaction environment, and transport medium for nearly all reactions/processes in soil.
- Temperature determines the rate of chemical reactions and the intensity of biological activity. Also freeze-thaw processes.
- Wind influences soil directly (erosion or deposition) and by influencing the effectiveness of precipitation.

Organisms/vegetation as a soil-forming factor

- Vegetation helps to hold parent material in place, allowing time for soil formation to occur. Plant roots bind soil particles together and increase the entry of water (infiltration) into the soils, reducing runoff and erosion.
- Plant roots growing in cracks and fissures break apart rocks, speeding up soil formation. Similarly, lichen on rock surfaces increases weathering.
- Plants produce weathering agents that increase rates of chemical weathering of soil minerals by releasing acidic components such as organic acids and carbon dioxide. The result is faster breakdown of the minerals and release of nutrients required by the plants and other biota.
- Vegetation is the initial source of the carbon fixed by photosynthesis that becomes organic matter in the soil. Plants that fix atmospheric nitrogen in symbiotic association with Rhizobacter bacteria are an important means by which nitrogen is added to the soil system.

- Vegetation modifies microclimates by: slowing wind speeds, shading the soil surface, and retaining snow, resulting in cooler and more moist soil environments, as well as less variation in soil-forming environments with topography.

Topography (relief) as a soil-forming factor

- The shape of the land surface influences the redistribution of the water received as precipitation. As a general rule land surfaces that are higher in landscapes, particularly sloping or convex surfaces lose water by runoff: and lower surfaces, particularly those that are concave or depressional receive extra water. The net result, is drier, less developed soils on the convex and sloping surfaces, and deeper, more strongly developed soil profiles in the more moist lower areas. Poorly drained or Gleysolic soils often occur where the amount of water received results in water ponded on the soil surface for a significant period of time.
- The climate becomes cooler, and more moist with increase in elevation, which coupled with related changes in vegetation results in regular changes in the soil. This is a good example of the interrelations among factors.
- In the northern hemisphere, slopes with south-facing aspects receive more solar radiation (insolation) than north-facing slopes, so south-facing slopes are warmer and less moist. The differences in soil temperature and soil moisture are not great (perhaps about 2 degrees cooler on average, and just a bit more soil moisture) but the net result over time is deeper, more strongly leached, more acidic soils on the north slopes, and drier, shallower and less well-developed profiles on the south-facing slope.

Parent material as a soil-forming factor

The initial stage of soil formation is the accumulation of the parent materials - the sediments or rocks in which the soils will form. The vast majority of the Canadian land mass was glaciated during the last glacial episode, and hence the majority of parent materials in Canada are of glacial origin and (by the standards of geological time) are relatively young. The nature and properties of the parent materials exert a very strong subsequent control on the pathways of soil genesis. The categories of major parent materials in Canada are shown in the table below. The initial stage of soil formation is the accumulation of the parent materials - the sediments or rocks in which the soils will form. The vast majority of the Canadian land mass was glaciated during the last glacial episode, and hence the majority of parent materials in Canada are of glacial origin and (by the standards of geological time) are relatively young. The nature and properties of the parent materials exert a very strong subsequent control on the pathways of soil genesis. The categories of major parent materials in Canada are shown in the table below.

Parent Material	Brief Description
Residual	Bedrock weathered in place; common in non-glaciated areas; soils reflect characteristics of parent rocks Lacustrine Sediments which have been deposited in still, fresh-water lakes; commonly well sorted sands, silts, and clays; deposits associated with glacial episodes called glacio-lacustrine
Fluvial	Sediments deposited in flowing water environments (rivers); commonly well sorted sands and gravels; deposits associated with glacial episodes called glacio-fluvial

Glacial Till	Sediments deposited directly beneath, within, or on top of glacial ice; commonly poorly sorted mixture of gravel, sand, silt, and clay
Eolian	Sediments moved and deposited by the wind; commonly consist of well-sorted sand and silt (loess)
Colluvial	Sediments moved and deposited by unchannelized flow on slopes. Properties reflect sediments from where it was derived
Marine	Sediments originally deposited on the ocean floor and then exposed due to rebound of the land surface
Lacustrine	Parent materials deposited in lakes. Most lacustine parent materials in Canada were deposited in lakes that existed during the glacial periods and are called glacio-lacustrine sediments. Lacustrine sediments are typically well- sorted sands, silts, and clays. Well-sorted means that one particle size (e.g. clay) is dominant in the texture.

Parent material influences:

- Soil texture, which influences the entry of water (infiltration) into the soil and its transmission in the soil are related to texture. The depth of leaching is related to the average depth to which water penetrates the soil. Other factors being equal, clayey soils take in water more slowly and, because the moisture storage capacity for a given depth is greater, are less leached, resulting in shallower soil profiles, whereas sandy soils are leached to greater depth
- Clay content also affects the soil's ability to retain cations, or the cation exchange capacity (CEC) and organic matter content generally increases with clay content - due to the higher plant production on the more clayey soils, and the formation of clay humus complexes that stabilize humus and slow its decomposition.
- Soil mineralogy: minerals vary in their resistance to weathering, and therefore the degree to which elements are made soluble and soils change during soil formation. Some minerals are important stores of nutrients (such as phosphorus, potassium and calcium), which are released slowly as soils weather. Some minerals are characteristic of an Order (for example, the smectite content in Vertisolic soils).
- Buffering capacity, which is the ability of a soil to resist changes in pH. The content of calcium carbonate is important to buffering, in that $CaCO_3$ is able to neutralize soil acidity. Clay and organic matter contents are also important to buffering capacity.

Importance of Soil – Soil Structure and Function

"Soil is the essence of life"; most life on earth depends on soils as a direct source of food, water and shelter. Soil quality determines the nature of plant ecosystems and the capacity of land to support animal life and society. Soil is home to billions of organisms; these organisms aid and assist in the breakdown of organic material which improves soil quality. The ability to preserve and manage the soil resource is instrumental to continue to support life.

Functions of Soil

The many functions of soil can be grouped into five crucial ecological roles:

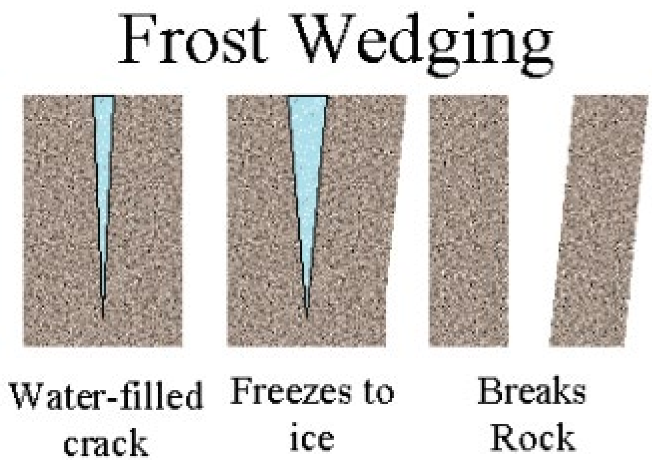
1) Medium for plant growth – Soil is a source of macro (nitrogen, phosphorous, potassium, etc) and micronutrients (iron, manganese, zinc, copper, etc). Soil provides ventilation for plants root systems; allowing CO_2 to escape and fresh O_2 to enter the root zone. Soil pores absorb rainwater and hold it where it can be used by the plant's roots. A deep soil may store enough water to allow plants to survive long periods without rain. Soil also moderates temperature fluctuations; the insulating properties of soil protect the deeper portion of the root system from extreme hot and cold temperatures.
2) Regulator of water supplies – Soil plays a vital role in the cycling of freshwater. Soil filters and regulates water supply by storing water after a precipitation event. Nearly every drop of water in our rivers, lakes, estuaries, and aquifers has either travelled through soil or flowed over its surface.
3) Habitat for organisms – Soil is home to billions of organisms, belonging to thousands of species. Small quantities of soil are likely to contain predators, prey, producers, consumers, and parasites. These organisms decompose organic matter and convert minerals and nutrients into forms that are available to plants and animals.
4) Recycler of raw materials – Soil has the capacity to assimilate great quantities of organic waste, turning this waste into humus. Soil also converts the mineral nutrients in the wastes into forms that can be utilized by plants and animals. Soil also returns the carbon to the atmosphere as carbon dioxide, where it will again become a part of living organisms.
5) Engineering medium – Soil is used for structures such as roads, causeways and as the foundation for buildings and bridges. Soil is also used for the establishment of forestry and agriculture crops.

Soil Forming Processes

The soil forming processes include:

1. Chemical weathering – Chemical weathering is also known as decomposition. It is caused by the chemical action of water, oxygen and organic acids. Decomposition occurs when the chemical makeup of the soil or rock particles change; but the physical size of the particles do not. One example of chemical weathering is oxidation.

2. Physical weathering – Physical weathering is also known as disintegration. It is caused when the size of the rock or soil particles is reduced without changing the chemical makeup of the soil or rock particles. One example of physical weathering would be frost wedging.

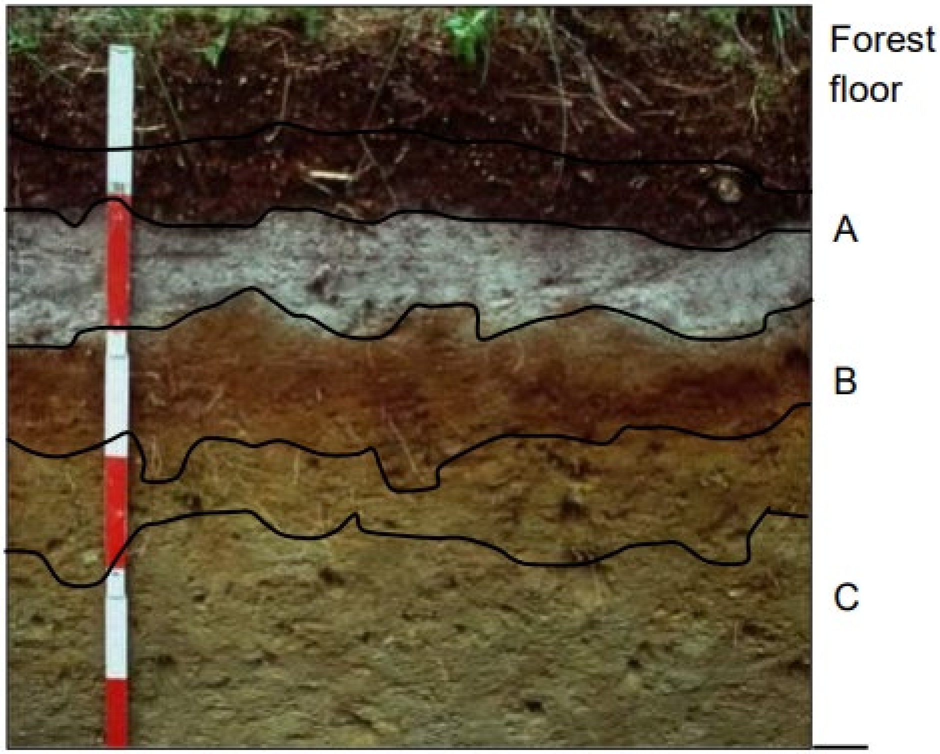


3. Biological weathering – Biological weathering occurs when organisms assist in the breakdown and formation of sediment and soil. This type of weathering can react with particles to change the physical size as well as the chemical composition.

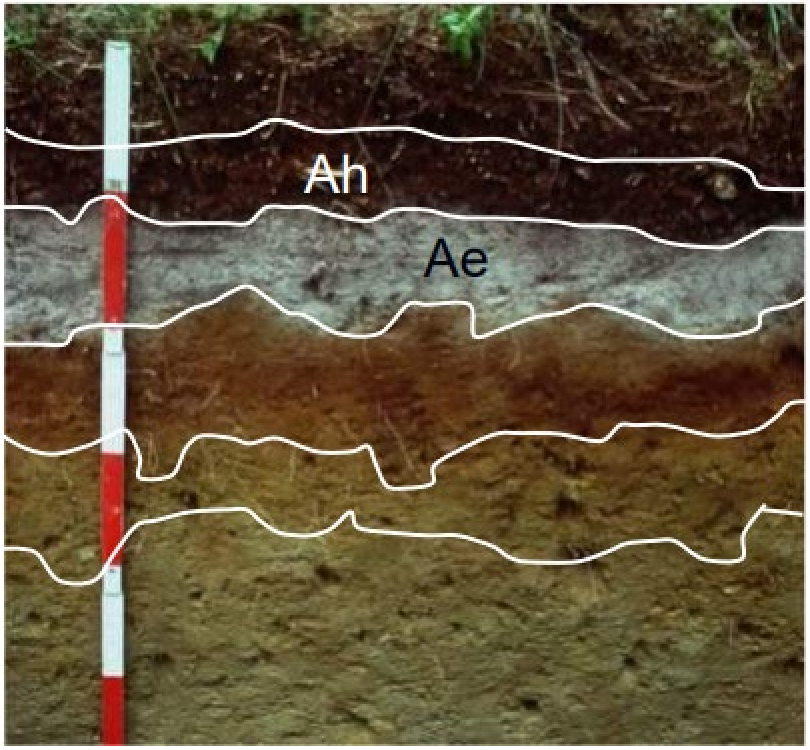
Soil Horizons

Based on the Canadian System of Soil Classification, soil may consist of five horizons. These horizons are as follows:

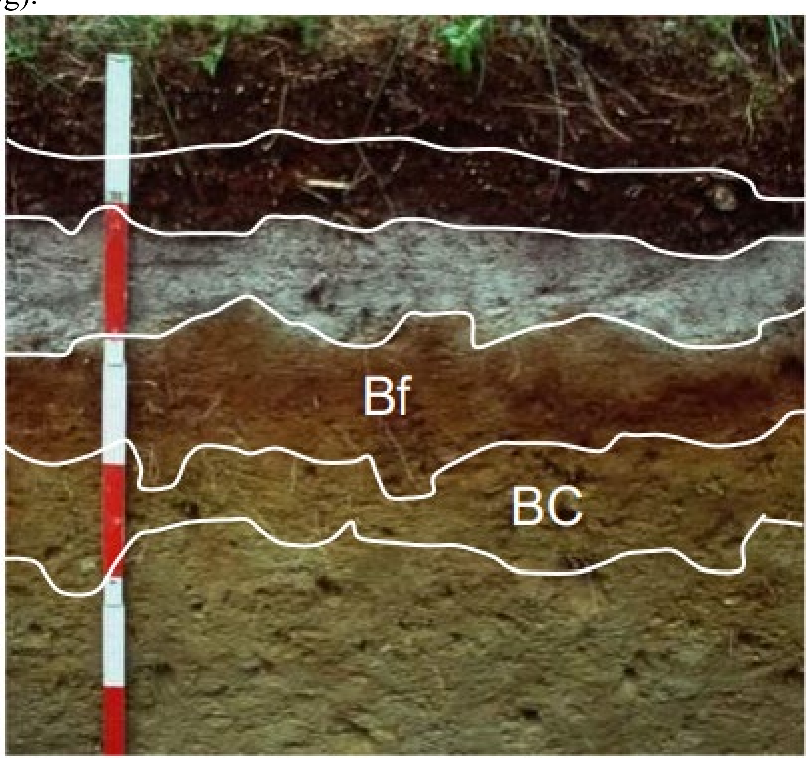
1. Forest Floor
2. A – Horizon
3. B – Horizon
4. C – Horizon
5. R – Bedrock



1. Forest floor - The forest floor consists of primarily organic material. The forest floor horizon can be separated into three layers:
    1. L (Litter layer) – Found on the ground's surface and is composed of needles, leaves, twigs and other organic materials.
    2. F (Fermented layer) – Partially decomposed organic materials such as needles, leaves and twigs.
    3. H (Humus layer) – Further decomposed amorphic organic material
    4. A Horizon – The A horizon is the first mineral horizon; it can be identified by three of the following examples.
        - Ah (humus) – Due to biological activity, organic matter has accumulated in this horizon.
        - Ae (eluviation) – Identified by the absence of clay, iron, aluminum and organic matter (grey to white color).
        - Ap (plow) – Horizon that has been disturbed by cultivation, logging and habitation.



1. B Horizon – The B horizon is also known as the zone of accumulation. This horizon is characterized by enrichment in organic matter (Bh), iron and aluminum (Bf), or enriched with silicate clays (Bt). This horizon may also be characterized by grey colors and/or mottling (Bg).

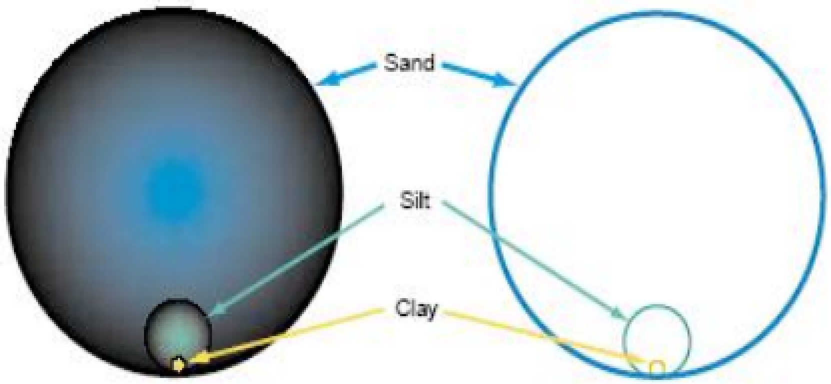


2. C Horizon – The C horizon is characterized as parent material that is relatively unaffected by the soil forming processes. An example of a C horizon that is located in poorly drained areas is characterized by grey colors and/or mottling is denoted as Cg.
3. R - Bedrock

Soil Properties

There are seven major soil properties: texture, organic matter, color, structure, pH, bulk density, and porosity. A brief description of each of the soil properties as well as any possible soil field test are described below.

1. Texture – The knowledge of the proportions of different sized particles in soil is critical for understanding soil behavior and management. Soil texture is a measure of the proportions of sand, silt, and clay in any given soil. A representation of each soil texture/ particle separated along with its diameter ranges as found below:

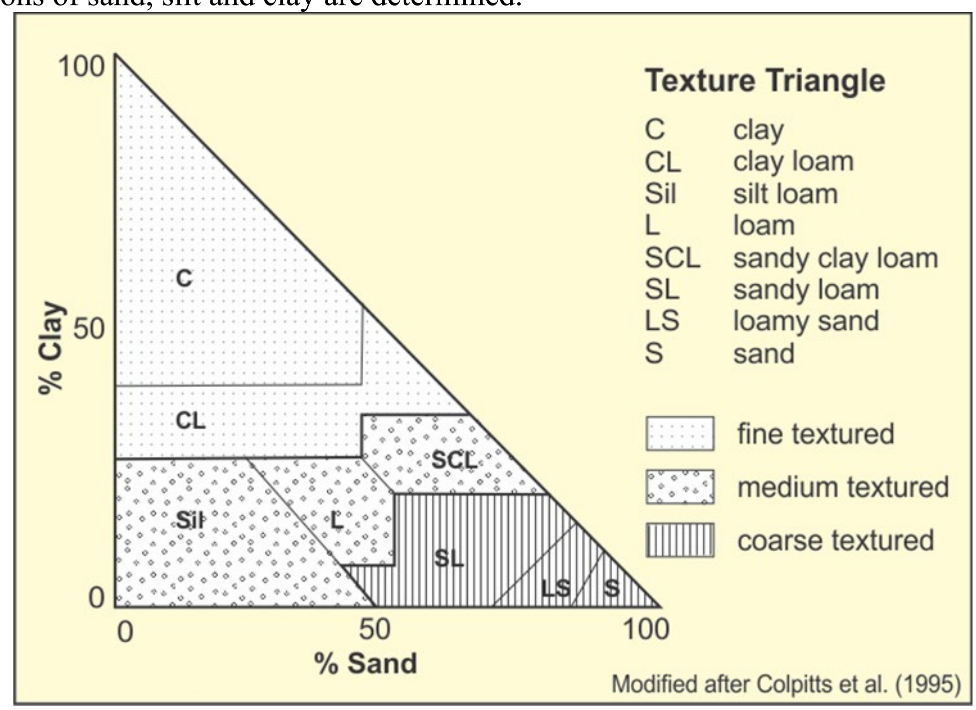


Soil Separate	Diameter (mm)
Sand	2.0 - 0.05
Silt	0.05 - 0.002
Clay	< 0.002

Different combinations of sand, silt, and clay gives rise to soil texture classes. There are eight texture classes in the Canadian System of Soil Classification:

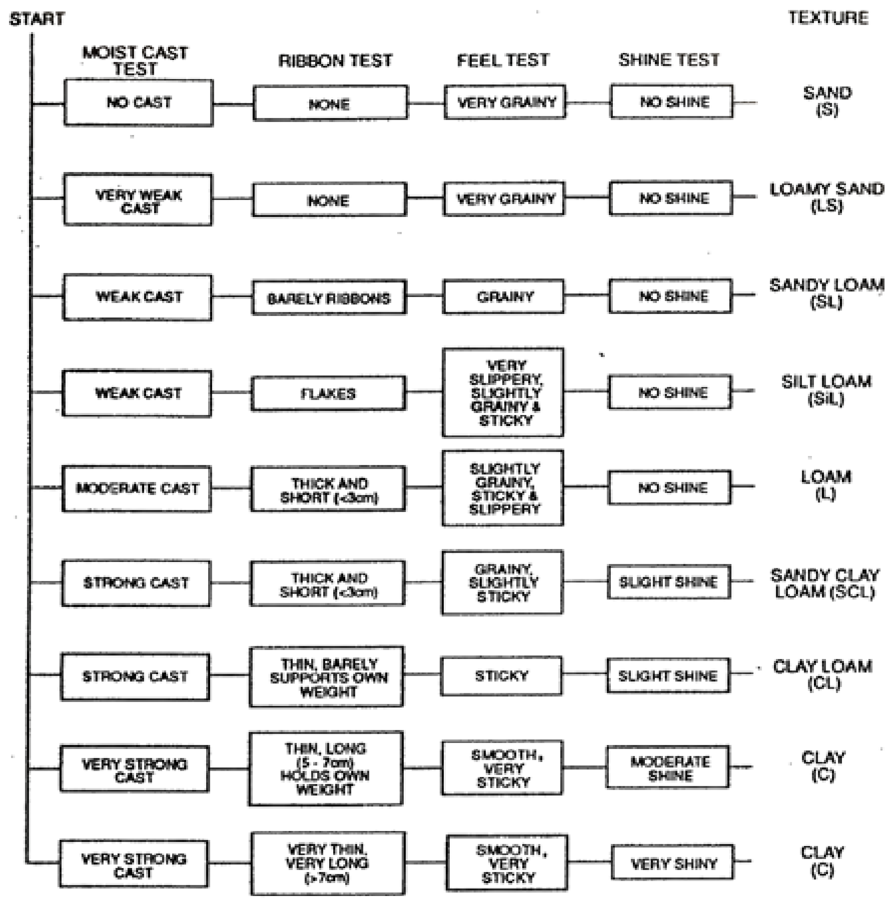
Texture Class	Description
S	Sand
LS	Loamy Sand
SL	Sandy Loam
L	Loam
SiL	Silty Loam
SCL	Sandy Clay Loam
CL	Clay Loam
C	Clay

The soil texture triangle (as seen below) can be used to determine soil texture when the proportions of sand, silt and clay are determined.



If the proportions of sand, silt and clay are not determined; then a soil texture field test can be used to determine which texture class a given soil belongs.

SOIL TEXTURE ASSESSMENT GUIDE*



* modified from Jones *et al*. 1983

2. Organic Matter - Soil organic matter has many beneficial effects to soil. It has the ability to increase the soil's infiltration rate as well as increases the water holding capacity and nutrient holding capacity. Organic matter has the ability to change the structure of the soil by affecting the pore size. Organic matter helps reduce the plasticity, cohesion and stickiness of heavy soils. Generally organic matter content in soil decreases with soil depth. Generally, productivity increases as organic matter within the soil increases.

3. Soil Color – Soil color provides valuable clues to the nature of other soil properties and conditions, such as parent material of the soil, soil drainage, amount of iron and organic matter in soil. Generally, soils with rapid, well, and moderately well drainage have bright colors. Soil that has dark brown or black colors suggests high levels of organic matter. Soil color is described by using the Munsell color charts. These charts describe soil by its Hue, Value and Chroma. An example of a soil color would be 10YR 5/6, where 10 YR is the hue, 5 is the value, and 6 is the chroma.

4. Structure – Soil structure relates to the arrangement of primary soil particles called "Aggregates" or "Peds". Soil structure greatly influences water movement, heat transfer, aeration, and porosity of soil. Structure is characterized in terms of shape, size, and distinctness. There are four principal shapes of soil structure:
    i. Spheroid (Granular)
    ii. Plate-like (Platy)
    iii. Block-like (Blocky)
    iv. Prism-like (Columnar and Prismatic)

Soil structure can be identified in the field by using the following soil structure identification sheet.

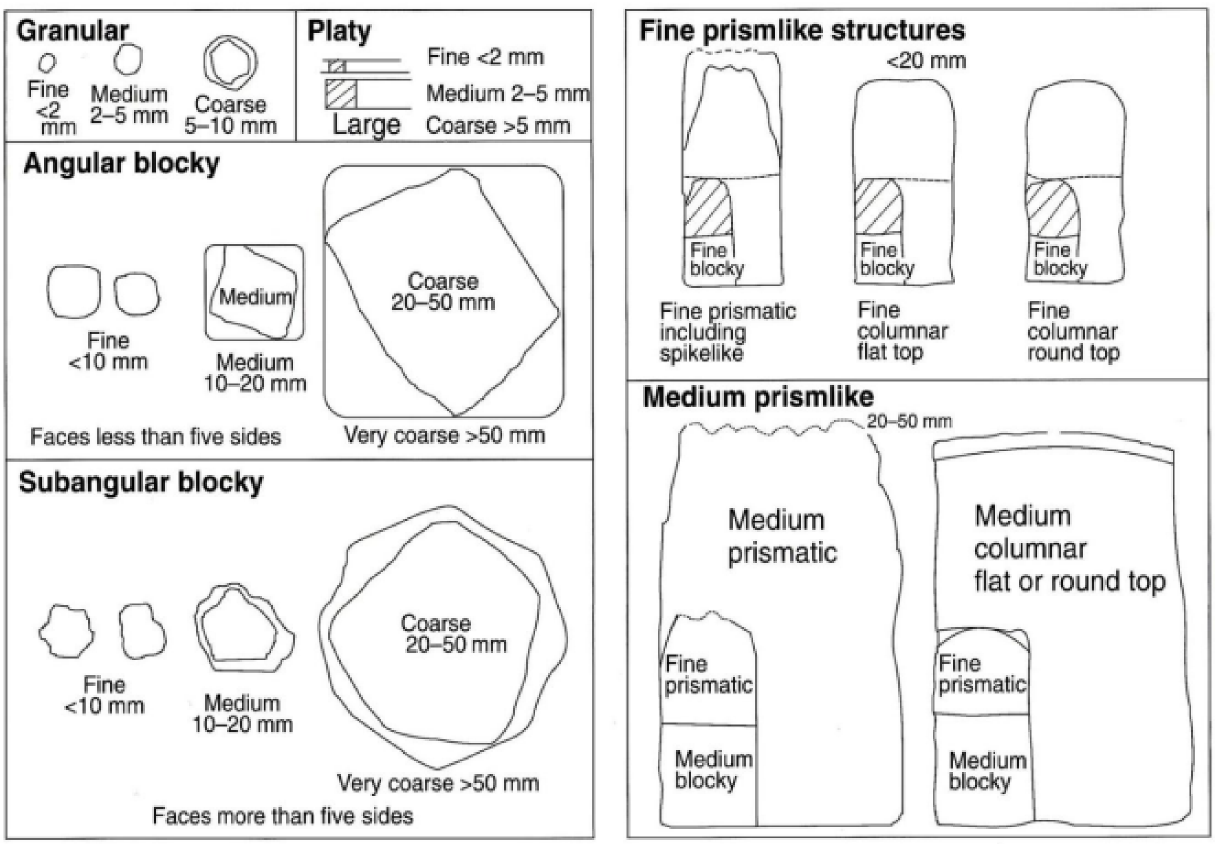


Figure 43 Types, kinds, and classes of soil structure.

5. Soil pH – pH is the degree of acidity or alkalinity of soil and is a key variable that affects all soil properties (chemical, physical and biological). The solubility of minerals and nutrients as well as microbial activity in soil is highly dependent on pH. Microbial activity tends to decrease when pH reaches below 5.5. Nutrients such as Ca and Mg become more soluble and therefore available once pH reaches 7. The following is a representation of soil pH and the zones of microbial activity and the availability of nutrients.

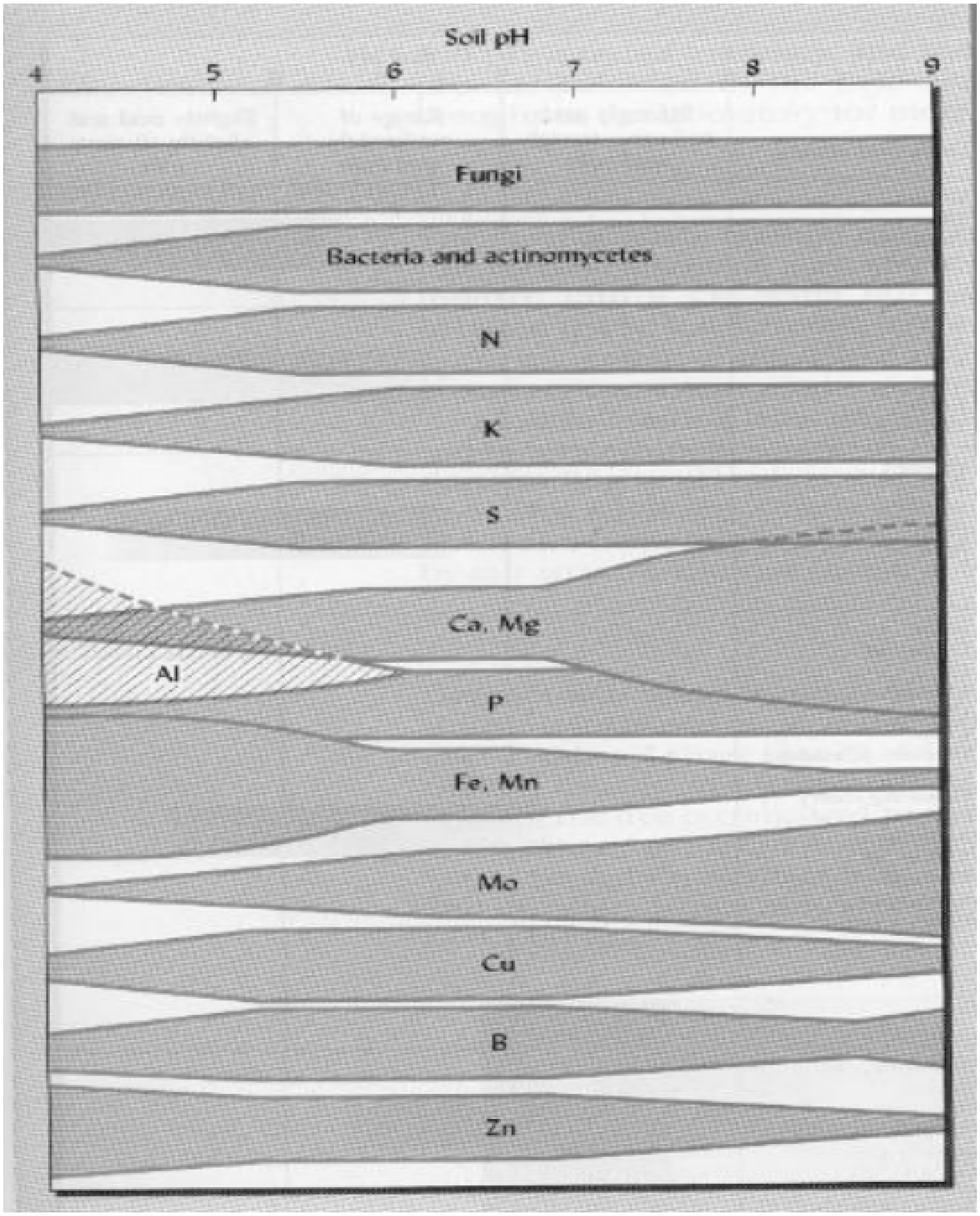


Figure: Representation of soil pH and the zones of microbial activity and the availability of nutrients

6. Bulk Density – Soil bulk density is a measure of the mass of a unit volume of dry soil. Bulk density is directly related to pore space; the more pore space present in a soil, the lower the bulk density. The presence of organic matter will decrease the bulk density. Soil that is deep in the profile will tend to have higher bulk density as a result of lower organic matter content, less aggregation, fewer roots and compaction. Soils with higher

bulk density usually indicate a poorer environment for root growth, reduced aeration and reduced water infiltration.

7. Porosity – One of the main reasons for measuring bulk density is to calculate pore space. Soil pore space or porosity serves a number of functions in soil such as: allowing the movement of air within the soil; allowing drainage of water in soil; accommodating plant roots and root hairs; accommodating the soil organisms that are present. The lower the bulk density in a soil the higher the percent pore space.

Soil Drainage Colours
Soils with Rapidly, Well and Moderately Well drainage tend to have bright colors; soils with Imperfectly, Poorly and Very Poor drainage tend to have a grayish color

Imperfectly drained

Poorly drained

.


Imperfect to Poorly drained


Imperfect to Poorly drained

Soil Drainage

Soil drainage is defined by the length of time it takes water to be removed from the soil in relation to the supply. Soil drainage is affected by two groups of factors:

1. **Soil External Factors**

- Position on the slope – Soils in upper positions tend to be better drained than those in the lower slopes.
- Aspect – Southern aspects are warmer than northern aspects; therefore, southern aspects will have less soil water and better drainage.
- Climate – Areas that receive high amounts of rainfall will have poorer drainage than those that receive low amounts.
- Bedrock – The presence and type of bedrock can affect the rate and flow direction of soil water.

2. **Soil Internal Factors**

- Soil texture – Coarse to medium textured soils will tend to have better drainage.
- Stoniness – Soils with gravels and cobbles have better drainage.
- Bulk density – Soils with high bulk density tend to be more poorly drained than those with low bulk density.

Drainage – Soil Drainage Class – Removal of water from the soil profile

Very rapidly drained – Water is removed from the soil very rapidly in relation to supply. Excess water flows downward very rapidly if underlying material is pervious. There may be very rapid subsurface flow during heavy rainfall provided there is a steep gradient. Soils have very low available water storage capacity (usually less than 2.5 cm) within the control section and are usually coarse textured, or shallow, or both. Water source is precipitation.

Rapidly drained – Water is removed from the soil rapidly in relation to supply. Excess water flows downward if underlying material is pervious. Subsurface flow may occur on steep gradients during heavy rainfall. Soils have low available water storage capacity (2.5-4 cm) within the control section, and are usually coarse textured, or shallow, or both. Water source is precipitation.

Well drained – Water is removed from the soil readily but not rapidly. Excess water flows downward readily into underlying pervious material or laterally as subsurface flow. Soils have intermediate available water storage capacity (4-5 cm) within the control section, and are generally intermediate in texture and depth. Water source is precipitation. On slopes subsurface flow may occur for short durations but additions are, equaled by losses.

Moderately well drained – Water is removed from the soil somewhat slowly in relation to supply. Excess water is removed somewhat slowly due to low perviousness, shallow water table, lack of gradient, or some combination of these. Soils have intermediate to high water storage capacity (5-6 cm) within the control section and are usually medium to fined textured. Precipitation is the dominant water source in medium to fine textured soils; precipitation and significant additions by subsurface flow are necessary in coarse textured soils.

Imperfectly drained – Water is removed from the soil sufficiently slowly in relation to supply, to keep the soil wet for a significant part of the growing season. Excess water moves slowly downward if precipitation is the major supply. If subsurface water or groundwater, or both, is the main source, the flow rate may vary but the soil remains wet for a significant part of the growing season. Precipitation is the main source if available water storage capacity is high; contribution by subsurface flow or groundwater flow, or both, increases as available water storage capacity decreases. Soils have a wide range in available water supply, texture, and depth, and are gleyed phases of well drained subgroups.

Poorly drained – Water is removed so slowly in relation to supply that the soil remains wet for a comparatively large part of the time the soil is not frozen. Excess water is evident in the soil for a large part of the time. Subsurface flow or groundwater flow, or both, in addition to precipitation are the main water sources; there may also be a perched water table, with precipitation exceeding evapotranspiration. Soils have a wide range in available water storage capacity, texture, and depth, and are gleyed subgroups, Gleysols, and Organic soils.

Very poorly drained – Water is removed from the soil so slowly that the water table remains at or on the surface for the greater part of the time the soil is not frozen. Excess water is present in the soil for the greater part of the time. Groundwater flow and subsurface flow are the major water sources. Precipitation is less important except where there is a perched water table with precipitation exceeding evapotranspiration. Soils have a wide range in available water storage capacity, texture, and depth, and are either Gleysolic or Organic.

2023 NCF-Envirothon New Brunswick

Soils and Land Use Study Resources

Key Topic #3: Soil Ecology

11. Describe the cycles of essential elements (such as nitrogen, phosphorus, and carbon) as they relate to soil, nutrient availability, and plant growth.
12. Explain the interactions of soil with the water cycle, including infiltration, runoff, and reservoirs such as aquifers.
13. Describe the ecosystem services provided by soil, such as water filtration, carbon sequestration, nutrient cycling, et cetera.
14. Define the soil-forming factors and describe their influence on a particular soil.

Study Resources

Resource Title	Source	Located on
Our Landscape Heritage- Chapter 3: Enduring Features: Geology and Topography, Climate and Soil	*Our landscape Heritage Zelazny V. (ed) 2007 New Brunswick Department of Natural Resources (Chapter 3)*	Pages 62-69
Hydric Soils	*Agriculture Canada Internal, 2022*	Page 70
Digging into Canadian Soils	*Digging into Canadian Soils-An Introduction of Soil Science: from Soils & Land Use | Envirothon NB, 2022*	Pages 71-72

Study Resources begin on the next page! ➡

Our Landscape Heritage - Chapter 3
Enduring Features: Geology and Topography, Climate and Soil

The enduring features of a landscape — geology and topography, climate and soils — lend themselves readily to sensory impression. A person can feel hard bedrock underfoot, smell damp forest soil on an upturned tree root, or sense an icy wind or warm rain on the face. A practical aspect of ecological land classification is that it uses tangible physical features and measurable climatic phenomena to describe ecosystems.

Each enduring feature melds into the other in a continuum of interaction. Soils are derived partially from the action of climatic elements upon rock as the sun, wind, ice, and water take their toll on stone, hastening its physical and chemical degradation into soil particles. Geology and glaciation help to sculpt the topography of a landscape. Topography is decisive in creating climate through such factors as the relationship between temperature and elevation.

The relative influence of these enduring features depends upon the geographic scale of observation. Together, the enduring or non-living features provide the more or less stable environment in which the biotic elements of fauna and flora exist.

Geology and Topography

Geology is arguably the most fundamental of all the enduring landscape features. Bedrock creates the structure beneath the countenance of landscape, although weathering and glaciation do much to soften and alter its face - that is, to modify its physiography or topography.

The rocks of New Brunswick belong to the Appalachian Mountain Range, which borders the Canadian Shield that forms the core of North America. The Appalachians reach from central Alabama northeast to Newfoundland and were continuous with the Caledonides Mountain Range in northwest Europe until the two ranges became severed with the opening of the present Atlantic Ocean some 200 million years ago. As an example of this ancient marriage, a person walking in areas of west Saint John will encounter outcrops that belong to the same volcanic rock sequence as those seen by a hiker on the cliffs of St. David’s Head in southwest Wales.

Geology with a Past

The rocks of New Brunswick cover a time period of about one billion years between the oldest rocks around Saint John and the youngest strata on Grand Manan Island. The time spans involved in geological reckoning have led to the development of a time scale with eras and periods covering millions of years. New Brunswick’s geological evolution has involved turbulent episodes of volcanism, tectonic rifting, continental collision, and mountain building, interspersed with unimaginably lengthy interludes of relative quiescence, drifting sedimentation, and gradual erosion. Current geological thinking suggests the story began about one billion years ago when the world was already 3.6 billion years old, and the continents as we know them did not exist. Instead, there appears to have been a giant supercontinent that shifted about the planet before slowly breaking into tectonic plates or proto-continents around 600 million years ago. These plates can be thought of as rock islands floating on a sea of molten rock inside the earth’s crust. For another several hundred million years, the plates skimmed the globe, driven by intense heat and convection currents beneath earth’s crust. Their movements resembled a very slow geological dance in which the plates repeatedly drifted apart and then collided with each other over time. The boundaries of plate separation changed with each opening and closing so that the resulting continents, including the region we now call New Brunswick, became a geo-montage of rocks of varying ages and type. As the continental plates separated, whole oceans developed between them, and sediments eroding from the continents filled huge valleys beneath the expanding sea. In places where the plates merged together and the oceans closed, volcanoes erupted, and buckling mountains formed at plate margins. The mountainous edge of the west coast of the Americas is relatively youthful geologically, and reflects this process. Ordovician volcanic rocks from an early episode of ocean closure can be seen near Bathurst, where they are mined for their base-metal deposits. The earth of one billion years ago was a younger, internally hotter, more volcanic place than it is today.

The Fossil Record

Some of the oldest known rocks in New Brunswick are Late Precambrian limestones that were deposited during an early period of ocean opening. These rocks occur near Saint John and hold ancient fossils known as stromatolites, remnants of algal reefs that lived some 980 million years ago. During the Late Cambrian, New Brunswick's fossil record reveals evidence of more advanced life forms, including oval-shaped creatures called trilobites that resembled horseshoe crabs, and brachiopods that looked somewhat like bivalve molluscs. When the ancient oceans closed yet again during the Devonian, about 400 million years ago, molten rock that would later become massive bodies of granite called plutons intruded the older rocks. The resistant granitic plutons were less easily eroded than some of the surrounding rock types and today form areas of high elevation, such as the Christmas Mountains. Devonian granites in New Brunswick have been quarried for dimension stone and aggregate material and contain significant metallic minerals. Elsewhere in Devonian New Brunswick, future uplands were being deposited on the ocean floor from older, eroded material. These sedimentary rocks preserved the oldest vertebrate fossil in the province: a jawless fish, *Yvonaspis campbelltonensis*, so-named for its discovery location in northern New Brunswick near Campbellton. This extinct fish lived about 350 to 400 million years ago, had one central nostril between its eyes, and featured a protective sensor zone along the edge of its head shield.

About 370 million years ago, the nearly half a billion years of tectonic jostling subsided into a relatively tranquil era that spanned much of the Carboniferous and Permian. The land that became New Brunswick lay near the present-day equator at this time, and a shallow sea invaded the land. Terrestrial or land-based plants, which had first appeared in the Silurian, came into their own during this humid time and grew in profusion across the Carboniferous landscape. One of the most interesting was a huge tree-like plant called Calamites. The Carboniferous also saw massive volumes of sediment eroded from mountain ranges to the west and transported by river systems to form huge deposits of sand, gravel, and clay. The sediments eventually consolidated into the sandstones, conglomerates, and shales that comprise the huge wedge of Carboniferous strata blanketing central and eastern New Brunswick. A final episode of continental rifting began in the Late Triassic with the opening of the present Atlantic Ocean, which is still widening today at a speed of about 4 cm to 5 cm per year, the growth rate of a fingernail. As the plates split apart, volcanic rocks called basalts filled the fractures caused by rifting. Such rocks can be seen in several New Brunswick locales, including Grand Manan Island where they contain rare minerals called zeolites that attract collectors from across the continent. These Jurassic basalts, along with some Triassic sandstones found along the Bay of Fundy coastline, constitute the youngest rocks in the province.

Recent Geological Events

The beginning of the Tertiary around 65 million years ago marks the start of what is known as the Cenozoic Era in geological time. The end of the Tertiary coincides with what many scientists believe was a collision between the earth and an asteroid, a catastrophe that led, among other things, to the extinction of dinosaurs. New Brunswick rocks during this period became increasingly weathered and eroded down to a fairly level landscape surface that bore little resemblance to the contrasting highlands and lowlands of today. The terrain appears to have remained gently undulating until the late Tertiary, when the entire area experienced another episode of broad regional uplift and tilting. This initiated a new cycle of erosion, during which the unsolidified sedimentary material and less resistant (mainly younger) rocks were worn down into valleys and lowlands. The deep stream dissection and incision of such waterways as the Upsalquitch River and much of the Saint John River apparently took place around this time. The more resistant, older granitic and volcanic rocks gradually emerged from their weaker cover rocks to become highlands and uplands. The Pleistocene ice ages constitute the most recent major episode in the geological history of the Maritimes. They laid a heavy hand on New Brunswick, as the province became inundated by glaciers that in places reached more than 2 km thick. Advancing ice sheets scraped up surface soil and plucked gravel and boulders from the surface and dropped them again, sometimes several kilometres away. Pebbles embedded in the base of the ice scoured and gouged the bedrock, leaving features such as glacial striations. When the glaciers paused or retreated, they laid down thick deposits of silt, sand, and gravel that disrupted drainage patterns, blocked streams and lakes, led to the formation of ponds and bogs, and gentled bedrock contours. The glaciation events that essentially defined the surface of modern-day New Brunswick commenced about 100,000 years ago, waxed and waned, then ended about 11,000 years ago. Sometime in those distant icy millennia, the first human inhabitants arrived in North America. Scientists are still debating where they came from, when they arrived, and how they got here. The prevailing wisdom is that they crossed between Siberia and Alaska at least 12,000 years ago, or perhaps much earlier, across Beringia, a vast plain that once connected the two landmasses when sea levels were lower. We do know that, as the glaciers eroded and disappeared around 11,000 years ago, the first post-glacial boreal forest gradually expanded over the land, and the earliest Paleo-Indians ventured into the Maritime region. Their arrival on the heels of the retreating ice signifies the tantalizing but hazy origins of the Early Period in Maritime human history.

A Coastline in Flux

One of the more intriguing aspects of the Pleistocene glaciations has been their effect upon sea levels. The colossal weight of ice warped and depressed the earth's crust by perhaps 100 m in places. At the same time, the ice sheets tied up massive volumes of water, causing the sea level to fall by more than 100 m below present levels. When the glacial ice began to melt, sea levels rose and partially flooded the land, then retreated again as land gradually lifted up from the loss of the ice's weight. The dynamic interplay between glacial rebound (also called isostatic rebound) and increased meltwaters entering the ocean (called eustatic change) caused shorelines to shift back and forth for several millennia.

Since about 3,000 years ago, the net effect has been a creeping rise in sea levels, such that our coastlines in most places are gradually submerging at a rate of several centimetres a year. The drowned forests in salt marshes at the head of the Bay of Fundy testify to a time of lower sea levels. Many of the oldest Paleo-Indian sites, too, are believed to rest beneath the ocean adjoining the present shoreline, hiding unknown relicts of an ancient people who once dwelled close by the sea.

The Geological Picture Today

The foregoing events have combined to create the geological patchwork quilt of New Brunswick. It is a mosaic composed of tectonic units, microcontinents, and rock terranes all stitched together along faults and other geological features, and then modified by recent tectonic and erosional forces to create the landscape we see today. The results of past geological events and processes are summarized by the bedrock geology map of New Brunswick (See *Geomorphological Regions of New Brunswick, after Bostock (1970), Page 31 of this document)*. It depicts an extensive wedge of low-lying Carboniferous sedimentary rocks bordered on one side by the Northumberland Strait, and on the two remaining sides by areas of higher elevation composed of mainly older igneous, sedimentary, and metamorphic rocks. When bedrock geology is considered together with elevation and relief (topography), New Brunswick falls naturally into six geomorphologic regions. Each region delineates an area that differs from adjoining regions on the basis of bedrock type, relief, and elevation. This is the simplest depiction of the variety of landscapes in the province.

The significance of geomorphology to ecological land classification becomes apparent when we correlate geology and elevation with climate. As described in detail in the next section, New Brunswick's abrupt changes in elevation are partly responsible for its variable climate and, hence, for the diversity in natural vegetation that characterizes the landscape.

What Affects Our Climate?

Most of New Brunswick possesses a singularly un-maritime climate, despite its geographic placement in Maritime Canada. No part of the province lies more than 200 km from the ocean, yet its climate is distinctly continental, with hot summers and cold winters. The climate of the province reflects an amalgam of three basic factors: latitude, proximity to large bodies of water, and elevation. The most significant of these is latitude, which determines the amount of radiation received from the sun. New Brunswick lies at approximately the same global latitude as Bordeaux, France, and Venice, Italy; however, their climates are quite unlike our own, being much warmer. Obviously, other climatic factors must come into play. We will examine these factors in the sections below.

Large Bodies of Water

The Bay of Fundy, Chaleur Bay and the Northumberland Strait embrace the south, north and east coastlines of New Brunswick, respectively. Yet, despite sharing a common association with the Atlantic Ocean, these large expanses of water exert substantially different effects upon the landscape. Bodies of water that remain unmixed tend to become stratified, with the warmest layer on top in summer and the coldest layer on top in winter. The Bay of Fundy, however, undergoes daily mixing when incoming ocean tides from the southwest strike underwater reefs at the mouth of the bay and bring its bottom waters to the surface. The bay thus remains cold in summer and unfrozen in winter. This has a strongly moderating effect upon the climate of adjacent land areas and supports a distinctive red spruce-dominated forest, as well as wetlands that are home to a number of regionally rare plant species. Tidal mixing also causes fog development along the Bay of Fundy, especially in spring and summer when the cold waters contact the warm, humid air from the interior regions. The fog increases moisture levels and decreases summer temperatures by masking the sun. Springs and summers along the Fundy coast, therefore, see cool temperatures that are more typical of those felt in the northern highlands. By way of compensation, the warmer winter ocean gives the south shore a frost-free period that is equal to, or longer than, anywhere else in the province. The shallower waters of the Northumberland Strait and Chaleur Bay, on the other hand, are often frozen by mid-January, then grow as balmy in August as the sea off Virginia. They tend to warm the adjacent land areas during winter, but their moderating effect is less noticeable in summer, partly because prevailing winds are offshore. Indeed, the Northumberland coast experiences some of the highest summer temperatures and lowest summer precipitation amounts in the province.

Elevation

Elevation, together with the maritime effects of the Bay of Fundy, is a major influence on New Brunswick's regional climatic variation. Elevations shift from sea level at the coast up to more than 800 m in the northwest and central regions. The accompanying temperature drop with elevation rise produces variations in temperature and precipitation. Where elevation is more uniform from north to south, as along the Northumberland Coast, the climate remains relatively consistent. Yet, where it increases substantially such as rising from sea level at Kouchibouguac National Park up to 820 m at Mount Carleton, climatic differences are dramatic. Because air temperatures normally decrease at a rate of 0.4° C for every 100m gain in elevation, an increase in elevation is comparable, temperature-wise, to an increase in latitude. When moist air of the prevailing westerlies meets elevated land, it cools as it flows upwards, causing its water to condense and fall as rain or snow. This is nowhere more apparent in New Brunswick than in the northwest and north-central highlands. There, the western slopes receive extremely high precipitation amounts, leaving rain shadows on the adjoining eastern flanks. Lower lying areas, such as the Northumberland coast, gain less precipitation than the higher, inland locations. Air masses arriving at the coast from the uplands already will have dropped some moisture, but also are able to retain more water because they are descending and have become warmer.

Soils

Soil is regarded as one of the three enduring features, but, in fact, embodies the interface between the organic and non-organic worlds. It straddles and links the living world of micro-organisms, bacteria, fungi and plants, and the non-living world of humus, mineral grains, bedrock, atmosphere, and precipitation. Soil also represents the dynamic interplay between climate and geology, as it manifests the action of climate upon rock through the phenomena of erosion and weathering in soil formation. Soil is used in ecological land classification to delineate the boundaries of ecosections and ecosites, two levels in the New Brunswick Ecological Land Classification (NBELC) structure.

Glacial Processes and Soil Deposits

The landscape of New Brunswick is covered with a relatively fresh mantle of soil material composed of rock and mineral fragments that have been influenced by the crushing, grinding, washing and sorting processes associated with advancing and retreating glaciers. The mantle is 'fresh' in the sense that the glacial activity which ended 11,000 years ago exposed much unweathered rock and minerals to weathering and soil formation, whereas areas outside the farthest southern extent of the Laurentide ice sheet (Connecticut and points south) are covered by relatively old soils that have been in place for a much longer period of time.

Basal Till Deposits

We must now imagine an advancing glacier as it gathers together soil, gravel, and boulders into its mass. It then grinds it into paste, and smears this crushed rock and mud mixture over bedrock beneath the glacier, not unlike peanut butter spread over a cracker with a knife.
Soil deposited in this type of environment is known as basal till; it is relatively fine textured and compact below the rooting zone, a legacy of the huge weight of the ice bearing down on the material at its base. Basal till tends to conform to the shape of the underlying bedrock. It may be between 0.5 m to 20 m or more in depth, but is, on average, about two metres thick in New Brunswick. This is the predominant type of glacial deposit covering the hilly uplands of the province. Compared with other types of glacial deposits, basal tills have good nutrient-holding capacity related to their higher silt and clay content. Soils that are high in silt and clay and low in sand and gravel have a greater total surface area per volume of soil to which nutrient molecules may adhere. Soil nutrient content has important implications for vegetation.

Ablation Till Deposits

Ablation tills are formed as glaciers melt and retreat. As the late Pleistocene sun beat down on the tops of the glaciers, it exposed some of the rocks and rubble tied up in the glacier's mass. Exposed rocks absorbed heat from the sun and accelerated the process of melting around them, making holes in the glacier into which more and more gravel, sand, and mud would fall. With continued melting, the holes in the ice containing this debris would become inverted, the debris coming to rest as mounds on the earth's surface once the melting was completed. Today, well developed or typical ablation deposits appear to be dumped mounds of boulders, stones, cobbles, gravel, and coarse soil, the tops of which are separated by distances of perhaps 100 to 200 metres. The intervening hollows between the mounds are typically poorly drained forest or wetland. In some circumstances, drainage of the land is impeded to the extent that lakes or ponds form behind ablation deposits. Due to washing of the material as a glacier melts, ablation till lacks the silt and clay content of a basal till, is coarser-textured, and tends to support plant communities tolerant of nutrient-poor, acidic soil conditions.

Glaciofluvial Deposits

Glaciofluvial deposits are typically well sorted deposits of silt, sand, and gravel. These deposits formed in the rush of water while the great continental glaciers were melting. They are the ancient fans, beaches, and gravel bars that formed in proximity to immense rivers that drained meltwater from the retreating ice sheets. A unique form of glaciofluvial deposit is an esker, which is typically deposited in a meltwater tunnel inside a melting glacier. Eskers are long, snake-like ridges of sand and gravel.

Organic Deposits

Organic, or peat, soils have formed since the retreat of the glaciers in cool, poorly drained, acidic environments where the growth and accumulation of (typically) sphagnum moss exceeds its rate of decay. The thickest peat deposit on record in New Brunswick is at Gallagher Ridge and measures 9.9 m thick. The average depth of the larger peatlands is between 2 m and 3 m.

Recent Soil Deposits

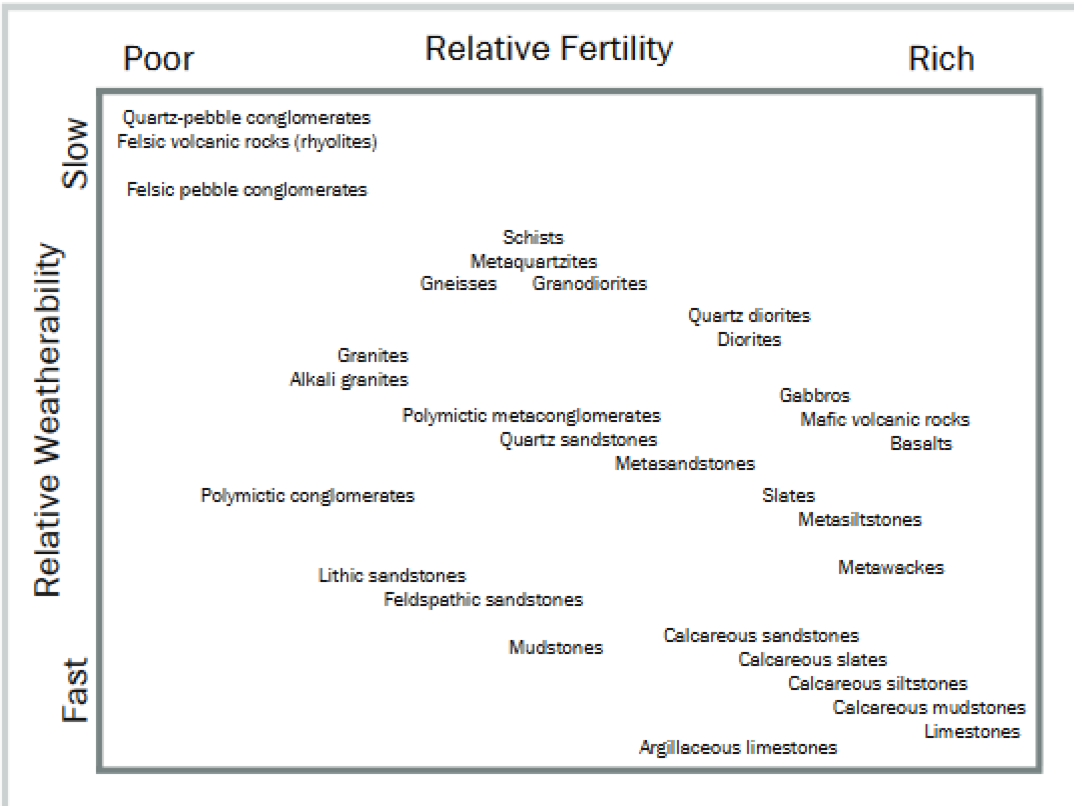
Other soils have formed in relatively recent, post-glacial time. These include the intervale soils found along the major river valleys and the tidal soils that underlie the brackish estuaries where rivers meet the sea. Both soil types are formed when silt-laden water settles over the land during high-water times that coincide with the seasons or the tides. The soils are favoured for agriculture because they are virtually stone-free, moist, and enriched by seasonal floodwaters carrying silt, clay, and other organic materials.

Lithology and Fertility

Rock types containing minerals with elevated concentrations of calcium, magnesium, and potassium generally weather into less acidic soil types than do rocks containing minerals low in these elements. In New Brunswick, the best lithological sources of calcium, magnesium, and potassium include limestone, calcareous sedimentary rocks, feldspathic sedimentary rocks, and mafic igneous rocks. Limestone and calcareous sedimentary rocks contain relatively high concentrations of calcium and/or magnesium carbonate. Feldspathic sedimentary rocks contain some calcium, potassium or sodium, and can yield moderately fertile soils, whereas siliceous or quartzose sedimentary rocks are high in quartz, but low in nutrient elements. Felsic igneous rocks, such as granites and rhyolites, have a high quartz content, but a relatively low percentage of minerals containing the nutrient elements. They often weather very slowly.
Mafic igneous rocks, however, contain minerals that are rich in iron, calcium, and magnesium, and consequently can yield moderately fertile soils.

Weatherability

Relative weatherability is an important factor in assessing the potential fertility of a forest soil unit. Rocks that weather or break down readily yield more nutrients than do rocks that resist weathering. Among the sedimentary rocks, calcareous sedimentary rocks and limestone weather the most rapidly of all rock types under moist conditions, as they react chemically with the carbonic acid often found in precipitation and groundwater. Next in weatherability are the non-calcareous sedimentary rocks with a significant clay component, such as greywackes, mudstones, and siltstones. Clay particles resemble tiny, loosely connected mineral wafers and have an extremely high surface area relative to their volume (not unlike a stack of soda crackers). Water and acids are able to penetrate deeply into the interior of the grains to pry loose essential nutrients. The exposure of such a large surface area to the weathering agents of water, wind, sun and ice can result in rapid weathering. Sandstones are less easily weathered, because sand grains display low surface area relative to volume (a sand grain as a solid glass ball comes to mind). Water and acids may pluck nutrients only from the outer surface of the grain. Feldspar grains, also a constituent of many types of sandstone, are more susceptible than quartz grains to chemical weathering; feldspathic sandstones therefore disintegrate more quickly than quartzose sandstones. Mineral grains in sedimentary rocks essentially are ‘glued’ together by a cementing matrix. Igneous and metamorphic rocks, in contrast, are “fused” together in an interlocking pattern that makes them less easily weathered than sedimentary rocks. Mafic igneous rocks generally contain minerals bearing calcium, iron, and magnesium. These minerals undergo chemical weathering more quickly than do the siliceous minerals in felsic igneous rocks. The weatherability of metamorphic rocks varies with their relative content of mafic and felsic minerals. The highly foliated, intensely compressed rock types, such as schist, tend to weather more slowly than do the less foliated types, such as slates.



Rock types shown here are plotted according to their relative fertility and weatherability. Rock types producing nutrient-poor soils appear in the upper left, and rock types associated with rich soils are in the lower right.

Hydric Soils

In order to fully understand the legal definition of wetlands, one must examine the major attributes of the definition. Hydric soil is the first attribute. A hydric soil is a soil that is, "formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part" (Federal Register July 13, 1994). Although hydric soils are typically organic soil types such as peats or mucks, several mineral soil types, including sandy ones, may also be classified as hydric.

Although the process of identifying soil type can be very technical, there are some relatively simple ways an individual can tell whether or not a soil may be hydric. Due to the ionic reducing conditions caused by long periods of inundation, most hydric soils have some very distinguishing characteristics. The following is a list of some common characteristics of hydric soils:

- excessive moisture
- a "rotten egg" odor of hydrogen sulfide present within 12 inches of the surface
- a predominance of decomposed plant material (peats or mucks)
- reddish or dark-colored mottles or streaks
- stratified layers in the top 6 inches
- a 12 inch or thicker layer of decomposing plant material on the surface, or is sandy with a layer of decomposing plant material near the surface
- either a gleyed coloring (a bluish-gray or gray color) below the surface, or the major color of the soil at this depth is dark (brownish-black or black) and dull (U.S. Department of Commerce and U.S. Army Crops of Engineers,1987).

This list does not contain guidelines to identify every type of hydric soil. It only lists a few of the most common test-positive indicators and is intended to inform individuals of some of the general characteristics of hydric soils. Consequently, an absence of these indicators does not necessarily mean a soil is not hydric.

The National Technical Committee for Hydric Soils (NTCHS) has developed a detailed list of all the hydric soil types in the United States and a list of their characteristics. Both of these lists, entitled Hydric Soils of the United States and Field Indicators of Hydric Soils of the United States respectively, are important tools used by federal and state entities to make wetland determinations and/or delineations.

Digging Into Canadian Soils

1. Introduction

Soil and Ecosystem Services

Beyond defining soil as a physical entity as described above, soil also can be defined based on the ecosystem services it provides and supports. Ecosystem services are the benefits that humans derive directly and indirectly from ecosystems. Although the notion of ecosystem services has long been recognized by scientists, particularly those working in the area of sustainability science, the concept was formalized in a report of the Millennium Ecosystem Assessment (MEA) (MEA, 2005), an initiative conducted under the auspices of the United Nations, and called for by then Secretary-General Kofi Annan in 2000. The MEA report defined an ecosystem as "a dynamic complex of plant, animal and microorganism communities and the nonliving environment interacting as a functional unit" (2005, p. v). The report grouped ecosystem services into four main categories: (1) provisioning services; (2) regulating services; (3) supporting services; and (4) cultural services. Soils provide and contribute to many functions within ecosystems, and humans derive many benefits from soil, both directly and indirectly (Figure 1.1), all of which fall within one or more of these four main categories.

Provisioning services of soil are perhaps the easiest to recognize. Our relationship with soil is very direct: we grow more than 95% of our food, animal feed, fibre and, in some instances, our fuel in soil. Soils provide these goods and play a crucial role in ecosystem functioning (Adhikari and Hartemink, 2016). The sustained provision, or flow, of these goods or products from soil is dependent on the health of the soil and its ability to support plant growth now and for future generations. It follows that provisioning services are dependent both on the intrinsic chemical, physical, and biological properties of the soil as well as those properties that can be managed to improve or sustain the productivity of the soil (Dominati et al., 2010). Equally, soil degradation processes, such as soil erosion or soil salinization, can reduce soil quality and hence its capacity for provisioning services.

The regulating services that soils provide are many and easily overlooked. For example, we know that the levels of atmospheric carbon dioxide, an important greenhouse gas, are increasing. Soils can sequester, or retain, carbon from the atmosphere. Specifically, through the process of photosynthesis, atmospheric carbon dioxide is transformed, or "fixed" by plants into simple carbon molecules that are incorporated into structures within the plant. A similar transformation occurs within photosynthetically active soil microorganisms. These organic components, when returned to the soil, contribute to the soil organic matter thereby "sequestering" carbon that originated in the atmosphere as carbon dioxide. When this occurs, the soil is effectively a sink for carbon but when this same organic matter decomposes soils also can be a source of carbon either as carbon dioxide or methane. The degree to which soils act as either a sink or source of these greenhouse gases can be controlled, to some degree, by appropriate management strategies such as minimum tillage practices. Similarly, the degree to which soils emit nitrous oxide, another very powerful greenhouse gas, is directly dependent on soil mineral nitrogen in the soil, which is a manageable soil property in agroecosystems. Other regulating services provided by soils include water management and flood mitigation, biological control of pests and diseases, and detoxification of unwanted substances, to name a few. These examples of the regulating services that soils provide are not exhaustive, and other soil functions occurring at both the micro and macro scales—some of which have yet to be explicitly identified—are likely to fall within the category of regulating services.

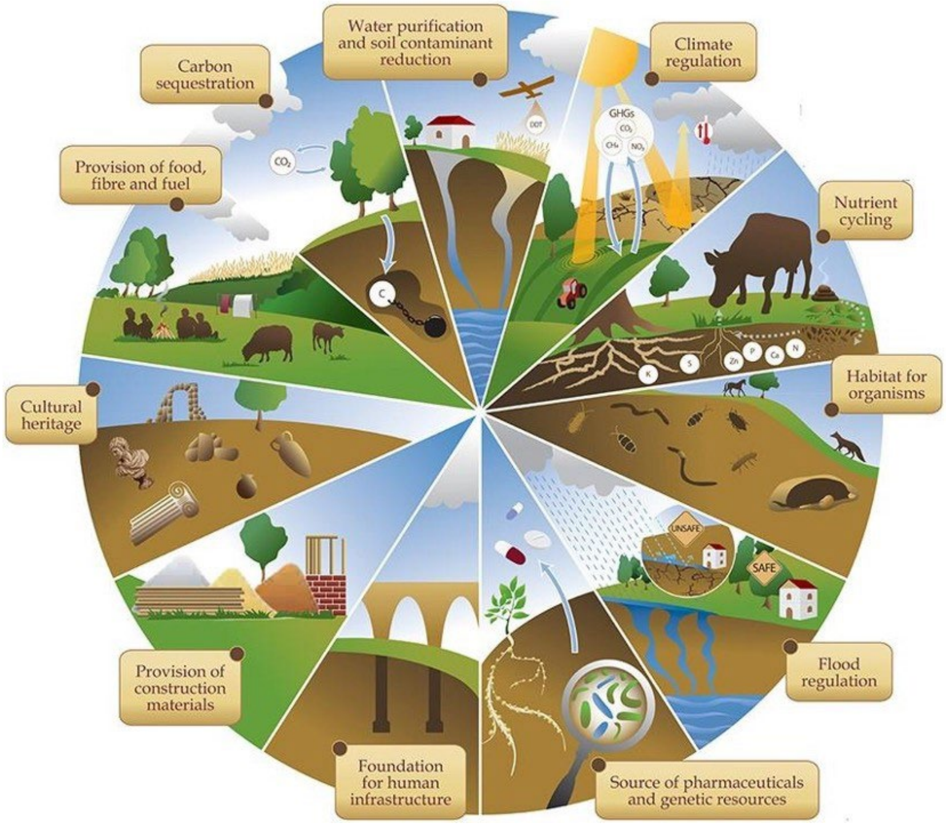


Figure 1.1 Schematic diagram representing some of the many functions that soils deliver. These functions contribute to ecosystems services, categorized as provisioning, regulating, supporting and cultural services. To which of these ecosystem service categories would you assign each of the above functions? © Food and Agriculture Organization of the United Nations. Reproduced with permission. Licensed under a CC BY-NC (Attribution NonCommercial) license.

Cultural services include the many non-material benefits derived from soils, such as spiritual enrichment, knowledge, sense of place, and connection to the land that soils provide. Many people and communities feel a deep connection to the land and the soil of their homeland. Clearly soil and the notion of soil matters at many levels. For many, the soil of their homeland represents them and who they are as a people—its colour or its smell after a rain, for example, reminds them of home and provides a sense of place.

Finally, supporting services provide support for the production of all other ecosystem services. Soil formation is an example of a supporting service that ultimately must take place to support all other ecosystems services. Other examples of supporting services include nutrient cycling, water cycling and soil biological activity, without which the other ecosystem services would not be achievable.

2023 NCF-Envirothon New Brunswick

Soils and Land Use Study Resources

Key Topic #4: Soils, Land Use, and Society

15. Explain how human development on floodplains impact the soil formation and ecology around streams and rivers.
16. Describe the impact changes in climate have on soil ecology.
17. Explain the principles of regenerative agriculture in the context of a changing climate.
18. Describe the significance of the land to New Brunswick First Nations communities.

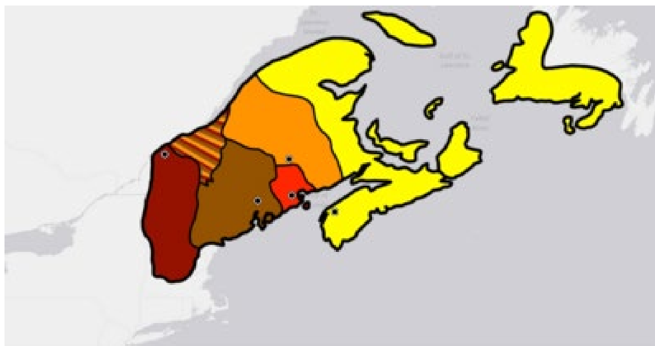
Study Resources

Resource Title	Source	Located on
The Story of Turtle Island	*The Canadian Encyclopedia, 2018*	Pages 74-75
Why is Soil Important	*Soil Science Society of America Agency, 2021*	Pages 76-77
The Original Principles of Regenerative Agriculture	*The Original Principals of Regenerative Agriculture, 2017*	Page 78
Soil Health Management (Natural Resource Conservation Service)	*USDA, 2022*	Pages 79-80
Soil Organic Matter	*Cornell University: Department of Crop and Soil Sciences, 2008*	Pages 81-82
A Perspective On Time	*Maliseet Mi'kmaq: First Nations of the Maritimes, Robert M. Leavitt, 1995*	Pages 83-88
Excerpt: Scientific Statement on Climate Change – Canadian Federation of Earth Sciences Amplification Of GHG Effects By Other Earth Processes	*The Canadian Federation of Earth Sciences Scientific Statement on Climate Change –It's Impacts in Canada, and the Critical Role of Earth Scientists in Mitigation and Adaptation, Burn et al., 2021*	Pages 89-90

<u>Study Resources begin on the next page!</u> ➡

Story of Turtle Island

New Brunswick First Nations are part of the Wabanaki (children of the light, or dawn) Confederacy, the four principal eastern Algonquin nations: Penobscot, Passamaquoddy, Mi'kmaq, and Maliseet.



Yellow – Mi'kma'ki; Orange – Wolastokuk; Red – Peskotomuhkatik; Brown – Panawahpskewahki; Burgundy – Ndakinna
The dots are the listed capitals, being political centers in Wabanaki.
The mixed region is territory outside of the historic ranges of the five tribes. It was acquired from the St. Lawrence Iroquois between 1541-1608 with Abenaki peoples having moved in by the time Samuel de Champlain came to the region establishing Quebec City.

"The story of Turtle Island varies among First Nation communities, but by most accounts, it acts as a creation story that places emphasis on the turtle as a symbol of life and earth. The following versions are brief reinterpretations of stories shared by Indigenous peoples. In no way do these examples represent all variations of the tale; they merely seek to demonstrate general characteristics and plots of different stories.

In some Ojibwe oral traditions, the story of Turtle Island begins with a flooded Earth. The Creator had cleansed the world of feuding peoples in order to begin life anew. Some animals survived the flood, such as the loon, the muskrat and the turtle. Nanabush, a supernatural being who has the power to create life in others, was also present. Nanabush asked the animals to swim deep beneath the water and collect soil that would be used to recreate the world. One by one the animals tried, but one by one they failed. The last animal that tried — the muskrat — was underwater for a long time, and when it resurfaced, the little animal had wet soil in its paws. The journey took the muskrat's life, but the creature did not die in vain. Nanabush took the soil and put it on a willing turtle's back. This became known as Turtle Island, the centre of creation. Many versions of the tale start in the Sky World — a land in the heavens where supernatural beings existed. One day, a pregnant Sky Woman fell through a hole under the roots of a tree and descended to Earth. Gently guided down by birds that saw her falling through the sky, she was placed safely onto a turtle's back. Sky Woman was grateful to the animals for helping her. In some versions, her appreciation was so powerful that the earth began to grow around her, forming Turtle Island. In other versions, the animals brought forth mud from the bottom of the water, which grew on top of turtle's back and formed a new land for Sky Woman and her descendants — Turtle Island.

Scholars tend to describe tales like Turtle Island as "earth-diver myths" — stories that in some way connect the origin of the world to beings (often animals) that dove into ancient waters to retrieve soil used to create (or recreate) the world as we know it. Such tales also often involve the presence of supernatural beings and a Creator."

Note to students:

In relation to geology, a water-dominated earth and accretionary terrain, and land added to a core continent, seems a very accurate description. Flood stories are found in many traditions. Geologically floods bring sediments, nutrients, and thus new life. Throughout the Maritime Provinces, geo-archeology and oral First Nation traditions combine to unravel the story of how the land was first settled after the ice disappeared from the land around 12,000 years ago.

In northern Canada, the Dene First Nation has a motto they try to live by: "We take care of the land, the land takes care of us". In a later part of this document in section "Soil and Ecosystem Services" there is mention of our sense of place and connection to the land. This connection is still very strong with First Nations.

Why is Soil Important?

Soil provides ecosystem services critical for life: soil acts as a water filter and a growing medium; provides habitat for billions of organisms, contributing to biodiversity; and supplies most of the antibiotics used to fight diseases. Humans use soil as a holding facility for solid waste, filter for wastewater, and foundation for our cities and towns. Finally, soil is the basis of our nation's agroecosystems which provide us with feed, fiber, food and fuel.

SSSA Members & Professionals

SSSA members are researchers, educators, extension agents, consultants and industry advisers. Our members, along with practicing Certified Professional Soil Scientists (CPSSc) and Certified Professional Soil Classifiers (CPSC), advise land managers in decisions that meet our nation's modern agricultural, water quality, land management, and environmental challenges. SSSA members educate, train, and mentor the future workforce of scientists, science educators, and extension agents to ensure the availability of expertise in soil science for sustainable agricultural production, natural resource management, and environmental protection.

Ecosystems Services

Advances in watershed, natural resource, and environmental sciences have shown that soil is the foundation of basic ecosystem function. Soil filters our water, provides essential nutrients to our forests and crops, and helps regulate the Earth's temperature as well as many of the important greenhouse gases. As our awareness of the value of natural and managed ecosystems services grows, new biodiversity, carbon, and water markets are emerging, such as the Chicago Climate Exchange, and the nutrient trading programs under the new Executive Order on the Protection and Restoration of the Chesapeake Bay. These markets place an economic value on management practices which increase those ecosystem services, producing goods that enhance human and environmental health.

Environmental & Human Health

Industrial, household, and non-point source pollution jeopardizes the health of the environment and humans. Over the past several decades, soil scientists have identified new practices which limit the mobility of contaminants and rehabilitate polluted land. As a result, land managers now have access to new, innovative soil management strategies that can mitigate soil, water, and air pollution, while also enhancing ecosystem performance.

Food Security

We must develop new technologies and techniques to produce more feed, fiber, food and fuel with less— less land, less water, less energy, and fewer nutrient inputs. Achieving this will require improved crops and novel soil management strategies that can only be accomplished through investment in interdisciplinary research and development.

"To Forget how to Tend the Soils is to Forget Ourselves"
- Mahatma Gandhi

Climate Change

Almost 35% of all greenhouse gases (GHG) released into the atmosphere due to anthropogenic activities since 1850 are linked to land use changes. Crop, grazing, and forest lands, as well as wetlands, all have the potential to contribute to or, through sound management strategies, mitigate GHG emissions through soil carbon sequestration, while also enhancing ecosystem services. Soil stores carbon dioxide (CO_2) and other GHGs in soil organic matter. Soil organic matter offers several added benefits: it filters and cleans water, enhances water retention and storage, mitigates the impacts of extreme weather events, improves soil structure, reduces soil erosion, provides microbial habitats, and serves as a source of long-term, slow-release nutrients.

Science & Education Workforce Development

Funding for science education and workforce development must, in addition to other important disciplines, include soil science. Research, education and training provided through the U.S. Department of Agriculture's National Institute of Food and Agriculture (NIFA) and Land-Grant University System (LGU), as well as the U.S. Environmental Protection Agency (EPA), National Science Foundation (NSF), U.S. Department of Energy (DOE), and U.S. Geological Survey (USGS), are essential to prepare the next generation of interdisciplinary soil scientists. Only with adequate investment in soil science will the nation have the workforce (educators, researchers, and land managers) necessary to safeguard this irreplaceable resource and ensure ecosystem health as well as the continued sustainable production of feed, fiber, food and fuel.

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Soils Sustain Life

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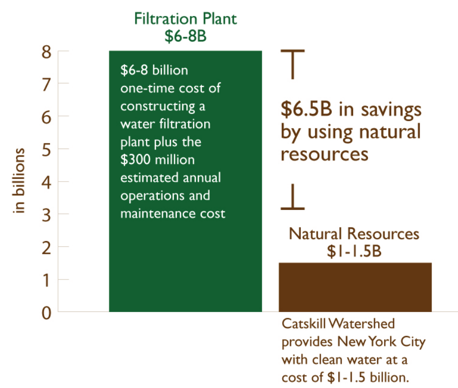
Soil science integrates scientific principles from physics, biology, and chemistry to elucidate how soils provide these essential services. Soil science provides an understanding of how soil properties relate to and can be managed for optimal agricultural production, forest, range, and wetland management, urban land use, waste disposal and management, and reclamation of drastically disturbed sites, such as mines. Soil science addresses nutrient management, sustainable agriculture, global biogeochemical cycles and climate change, ecosystem structure and function, or nuclear waste disposal and management, among many others.

Soil scientists research soil biogeochemical and physical processes, map soil characteristics, and teach aspiring scientists about soil processes. Soil scientists perform soil surveys, develop land use plans, conduct site evaluations for septic systems or storm water facilities, examine soil function and health, identify optimal food production methods, develop climate change mitigation strategies, and develop new approaches for clean water and resource management at many spatial scales.

Important Facts about Soil

- Wetlands deliver a wide range of ecosystem services that contribute to human well-being, such as fish and fiber, water supply, water purification, climate regulation, flood regulation, coastal protection, recreational opportunities, and, increasingly, tourism. Despite these important benefits, the degradation and loss of wetlands is more rapid than that of other ecosystems.
- Through natural processes, such as soil adsorption, chemical filtration and nutrient cycling, the Catskill Watershed provides New York City with clean water at a cost of $1-1.5 billion, much less than the $6-8 billion one-time cost of constructing a water filtration plant plus the $300 million estimated annual operations and maintenance cost.



- U.S. agriculture produces about 500 million tons of crop residue annually, most of which contributes to maintaining soil organic matter. Plans to use crop residues for bioenergy production could deprive agroecosystems of important inputs for future soil productivity, potentially upsetting existing agroecosystem balances.
- Arsenic from smelter emissions and pesticide residues binds strongly to soil and will likely remain near the surface for hundreds of years as a long-term source of exposure.
- Archaeologists have determined that the demise of many sophisticated civilizations, such as the Mayans of Central America and the Harappan of India, resulted directly from the mismanagement of their soils.
- Covering just 6% of Earth's land surface, wetlands (including marshes, peat bogs, swamps, river deltas, mangroves, tundra, lagoons and river floodplains) currently store up to 20% (850 billion tons) of terrestrial carbon, a CO_2 equivalent comparable to the carbon content of today's atmosphere.

Soil Trivia

- Did you know that there are more living individual organisms in a tablespoon of soil than there are people on the earth?
- Did you know that almost all of the antibiotics we take to help us fight infections were obtained from soil microorganisms?
- Did you know that agriculture is the only essential industry on earth?
- Did you know that soil is a non-renewable natural resource?
- Did you know that the best china dishes are made from soil?
- Did you know that about 70% of the weight of a text book or glossy paged magazine is soil?
- Did you know that putting clay on your face in the form of a "mud mask" is done to cleanse the pores in the skin?

Please visit us at www.soils.org

The Original Principles of Regenerative Agriculture

Beyond Sustainable

Robert Rodale, Rodale Institute, championed regenerative agriculture before the USDA organic standards and certification even existed.

Regenerative as we know it today applies specifically to measures of soil health, animal welfare, and social fairness. But Bob's original philosophy of regenerative encompassed a broader spectrum of human values. Together with his daughter, Maria Rodale, Bob penned the 7 principles of regenerative as he saw them, outlined below.

Seven Tendencies Toward Regeneration

1. Pluralism

- Increase in diversity of plant species
- Increase in diversity of business, people, and culture

2. Protection

- More surface cover of plants, ending erosion and increasing beneficial microbial populations near the surface
- More resistance to economic and cultural fluctuations because of quantity and variety of businesses and people, which increases overall employment and community stability

3. Purity

- Without chemical fertilizer and pesticide use, a greater mass of plants and other life exists in the soil.
- Without pollution of the environment, more people can exist in better health.

4. Permanence

- More perennials and other plants with vigorous root systems begin to grow.
- As businesses and individuals become successful and stable, they can contribute more to the community.

5. Peace

- Past patterns of weed and pest interference with growing systems are disrupted
- Former patterns of violence and crime are reduced, improving overall security and wellbeing.

6. Potential

- Nutrients tend to either move upward in the soil profile or to accumulate near the surface, thereby becoming more available for use by plants.
- "Trickle up" economics – more resources and money accumulate and are more available to more people

7. Progress

- Overall soil structure improves, increasing water retention capacity
- Overall community life improves, increasing the health and wealth of its inhabitants

Soil Health Management (Natural Resources Conservation Service)

"A very important land use function of soils is its role as a growing medium for food production and agriculture. Proper soil management within agriculture is a necessity to ensure that soils remain productive, fertile, and effective at producing edible food crops and forages for human and animal consumption. There are many best management practices that can be used on farm to help maintain soil productivity and reduce the risk of environmental risks associated with agriculture, such as soil loss to erosion, and/or nutrient loss due to leaching or overaccumulation.

Many of these beneficial management practices listed below are based on building and maintaining soil organic matter, which can contribute to the functioning of soil in many ways. Soils high in organic matter generally have better nutrient availability, higher cation exchange capacity, greater water holding capacity as well as water infiltration, a greater buffering capacity on soil acidity, and better aggregate stability and porosity."

Managing for soil health (improved soil function) is mostly a matter of maintaining suitable habitat for the myriad of creatures that comprise the soil food web. This can be accomplished by disturbing the soil as little as possible, growing as many different species of plants as practical, keeping living plants in the soil as often as possible, and keeping the soil covered all the time.

Manage More by Disturbing Soil Less

Soil disturbance can be the result of physical, chemical or biological activities. Physical soil disturbance, such as tillage, results in bare and/or compacted soil that is destructive and disruptive to soil microbes, and it creates a hostile environment for them to live. Misapplication of farm inputs can disrupt the symbiotic relationships between fungi, other microorganisms, and plant roots. Overgrazing, a form of biological disturbance, reduces root mass, increases runoff, and increases soil temperature. All forms of soil disturbance diminish habitat for soil microbes and result in a diminished soil food web.

Diversify Soil Biota with Plant Diversity

Plants use sunlight to convert carbon dioxide and water into carbohydrates that serve as the building blocks for roots, stems, leaves, and seeds. They also interact with specific soil microbes by releasing carbohydrates (sugars) through their roots into the soil to feed the microbes in exchange for nutrients and water. A diversity of plant carbohydrates is required to support the diversity of soil microorganisms in the soil. In order to achieve a high level of diversity, different plants must be grown. The key to improving soil health is ensuring that food and energy chains and webs consist of several types of plants or animals, not just one or two.

Biodiversity is ultimately the key to the success of any agricultural system. Lack of biodiversity severely limits the potential of any cropping system and increases disease and pest problems. A diverse and fully functioning soil food web provides for nutrient, energy, and water cycling that allows a soil to express its full potential. Increasing the diversity of a crop rotation and cover crops increases soil health and soil function, reduces input costs, and increases profitability.

Keep a Living Root Growing Throughout the Year

Living plants maintain a rhizosphere, an area of concentrated microbial activity close to the root. The rhizosphere is the most active part of the soil ecosystem because it is where the most readily available food is, and where peak nutrient and water cycling occurs. Microbial food is exuded by plant roots to attract and feed microbes that provide nutrients (and other compounds) to the plant at the root-soil interface where the plants can take them up. Since living roots provide the easiest source of food for soil microbes, growing long-season crops or a cover crop following a short-season crop, feeds the foundation species of the soil food web as much as possible during the growing season.

Healthy soil is dependent upon how well the soil food web is fed. Providing plenty of easily accessible food to soil microbes helps them cycle nutrients that plants need to grow. Sugars from living plant roots, recently dead plant roots, crop residues, and soil organic matter all feed the many and varied members of the soil food web.

Keep the Soil Covered as Much as Possible

Soil cover conserves moisture, reduces temperature, intercepts raindrops (to reduce their destructive impact), suppresses weed growth, and provides habitat for members of the soil food web that spend at least some of their time above ground. This is true regardless of land use (cropland, hayland, pasture, or range). Keeping the soil covered while allowing crop residues to decompose (so their nutrients can be cycled back into the soil) can be a bit of a balancing act. Producers must give careful consideration to their crop rotation (including any cover crops) and residue management if they are to keep the soil covered and fed at the same time.

Soil Organic Matter

Soil organic matter is the fraction of the soil that consists of plant or animal tissue in various stages of breakdown (decomposition). Most of our productive agricultural soils have between 3 and 6% organic matter.

Soil organic matter contributes to soil productivity in many different ways. In this fact sheet, we describe the various components of organic matter and the different roles organic matter plays in soil productivity. We also discuss field management practices that will help preserve or increase soil organic matter levels over time.

What is Soil Organic Matter?

Organic matter is made up of different components that can be grouped into three major types:

1. Plant residues and living microbial biomass.
2. Active soil organic matter also referred to as detritus.
3. Stable soil organic matter, often referred to as humus.

The living microbial biomass includes the microorganisms responsible for decomposition (breakdown) of both plant residues and active soil organic matter or detritus. Humus is the stable fraction of the soil organic matter that is formed from decomposed plant and animal tissue. It is the final product of decomposition.

The first two types of organic matter contribute to soil fertility because the breakdown of these fractions results in the release of plant nutrients such as nitrogen, phosphorus, potassium, etc.

The humus fraction has less influence on soil fertility because it is the final product of decomposition (hence the term "stable organic matter"). However, it is still important for soil fertility management because it contributes to soil structure, soil tilth, and cation exchange capacity (CEC, see Agronomy Fact Sheet #22). This is also the fraction that darkens the soil's color.

Benefits of Stable Soil Organic Matter

There are numerous benefits to having a relatively high stable organic matter level in an agricultural soil. These benefits can be grouped into three categories:

Physical Benefits

- Enhances aggregate stability, improving water infiltration and soil aeration, reducing runoff.
- Improves water holding capacity.
- Reduces the stickiness of clay soils making them easier to till.
- Reduces surface crusting, facilitating seedbed preparation.

Chemical Benefits

- Increases the soil's CEC or its ability to hold onto and supply over time essential nutrients such as calcium, magnesium and potassium.
- Improves the ability of a soil to resist pH change; this is also known as buffering capacity (see Agronomy Fact Sheet #5).
- Accelerates decomposition of soil minerals over time, making the nutrients in the minerals available for plant uptake.

Biological Benefits

- Provides food for the living organisms in the soil.
- Enhances soil microbial biodiversity and activity which can help in the suppression of diseases and pests.
- Enhances pore space through the actions of soil microorganisms. This helps to increase infiltration and reduce runoff.

Organic Materials

Over time, the application and incorporation of organic materials can result in an increase in stable soil organic matter levels. Sources of organic materials include:

- Crop residues.
- Animal manure.

- Compost (Figure 1).
- Cover crops (green manure)
- Perennial grasses and legumes.

The quickest increases are obtained with sources that are high in carbon such as compost or semi-solid manure.

Figure 1: Compost application can increase soil organic matter levels over time.

Organic Matter Management

Farm practices that help to maintain or increase soil organic matter levels:

- Use of conservation tillage practices (for example zone tillage or no-till). Tillage exposes the organic matter to air and will result in the lowering of stable organic matter due to increased mineralization rates and erosion losses.
- Rotation of annual row crops with perennial grass or legume sods will reduce erosion and build up organic matter as a result of the decomposition of the rootmass.
- Establishment of legume cover crops will enhance organic matter accumulation by providing the nitrogen (N) needed for decomposition of freshly added organic materials, especially those with a high C to N ratio (corn stover, cereal straw, heavily bedded manure, etc.).
- Avoiding soil compaction which increases waterlogging, and maintaining proper pH to enhance microbial activity and decomposition of freshly added materials.

Actual buildup of stable organic matter will, in addition to the amount and source of organic material added, and tillage and rotation practices, also depend on**:**

- Soil temperature.
- Precipitation and soil moisture holding capacity.
- Soil type and drainage class.
- Existing microbial community.
- Soil fertility status and soil pH.

Monitoring Soil Organic Matter

To get an idea of the effect of farm management practices on soil organic matter buildup or decrease, soil samples should be taken over time. Consistency in sampling time is important to build records for fields over time (see Agronomy Fact Sheet #1). Although other tests are available, most laboratories will do a loss-on-ignition (LOI) test to estimate the organic matter content of the soil. At Cornell University, soil is exposed to 105°C (221°F) for 1.5 hours to remove soil moisture and then to 500°C (932°F) for 2 hours to determine LOI. Not all laboratories us the same method so for accurate records over time, it is important to consistently use the same laboratory service.

In Summary

With careful management the preservation and accumulation of soil organic matter can help to improve soil productivity resulting in greater farm profitability.

Additional Resources

- Cornell University Agronomy Fact Sheet series: nmsp.css.cornell.edu/publications/factsheets.asp.

Disclaimer

For more information

Cornell University Cooperative Extension

Nutrient Management Spear Program
http://nmsp.css.cornell.edu

Megan Fenton, Carl Albers, Quirine Ketterings

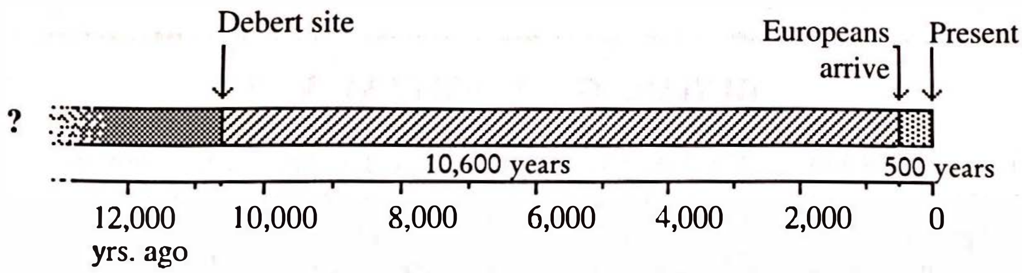
2008

3.2. A PERSPECTIVE ON TIME

- The Maritime region has been *occupied by people* for at least 10,600 years.
- People of European ancestry have lived here for *less than five percent of that time.*

MORE THAN 10,000 YEARS OF HISTORY

According to archaeological investigations, people are known to have been living in the Maritime region of Canada for at least 10,600 years. No doubt there were people here earlier than that, but no physical traces of their presence have yet been found. (Before 13,000 years ago no one could have been living in the Maritime region, because according to geological evidence almost all the land was covered by ice.) The earliest known inhabitants were making weapons, butchering game animals, cleaning hides and cooking meat about 10,600 years ago at a campsite discovered near Debert, Nova Scotia. Even at the time of those hunters, small ice-caps remained in the nearby mountains. Later, this ice disappeared, the climate gradually became warmer, different kinds of forests and animals appeared (and some died out), and even the shape of the land itself changed, until the environment of the Maritime provinces came to be as we know it today.



THE HUMAN PRESENCE IN THE MARITIME REGION

Although people have lived in the Maritime region for more than 10,000 years, those from Europe and other continents have been here for less than 500 years — or less than five percent of that time. It is easy to identify the enormous changes introduced into the region by European settlement and colonization, and by the technology of the twentieth century. Such changes also occurred in the distant past. During those thousands of years, local initiatives and communication and trade with other peoples resulted in significant developments in the Maritime way of life — in technology, design and religious practices.

• Much cultural development occurred before the arrival of the Europeans.

In spite of all the historical and contemporary changes, there are still distinct traces of the distant past to be found in the Maritimes today — in the languages spoken by Native people and familiar to everyone in geographical place-names, in the oral tradition and in other characteristics of Micmac and Maliseet culture (skill in the use

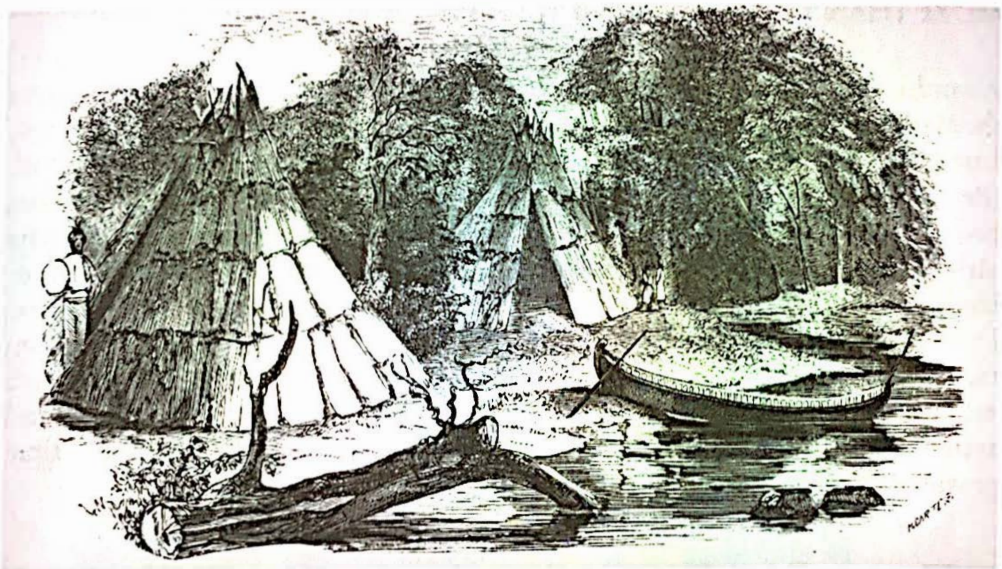
• Daily life in the Maritimes is still shaped in part by the ideas, events and knowledge of ancient times.

of herbal medicines, for example) which are retained by both the Native and non-Native people of the region as part of a common Maritime heritage.

WIGWAMS THEN AND NOW: KNOWLEDGE FROM MANY SOURCES

Wigwams — the birchbark houses of the Micmacs and Maliseets, observed by European visitors 500 years ago — had been built in the region for thousands of years before that. They were such an ideal solution to the need for housing in the Maritime region that they remained essentially unchanged into the 1900s. Our knowledge of wigwam form and construction comes from archaeological sites, written records, oral history, paintings, drawings and photographs.

Sketch of wigwams and canoe (1847) by Abraham Gesner. PANB



NICOLAS DENYS

• Wigwam construction as it was when Nicolas Denys visited the Maritimes in 1672.

BUILDING A WIGWAM

HAVING ARRIVED at the place where they wish to remain, the women must build the camp. Each one does that which is her duty. One goes to find poles in the woods; another goes to break off branches of Fir, which the little girls carry. The woman who is mistress, that is, she who has borne the first boy, takes command and does not go to the woods for anything. Everything is brought to her. She fits the poles to make the wigwam and arranges the Fir to make a place for each person. This is their carpet and the feathers of their bed....

They lined all the inside of the wigwam to four fingers' depth, with the exception of the middle, where the fire was made, which was not so lined. They arranged it so well that it could be raised all as one piece. It served them also as a mattress and as a pillow for sleeping...

If the family is a large one they make [the wigwam] long enough for two fires; otherwise they make it round, just like military tents, with only this difference that in place of canvas they are of barks of Birch. These are so well fitted that it never rains into their wigwams. The round kind holds ten to twelve persons, the long twice as many. The fires are made in the middle of the round kind, and at the two ends of the long sort.

–Nicolas Denys, 1672,
The Description and Natural History..., pp. 405-406, 423.

Section 3.3

3.3. THE MARITIME ENVIRONMENT: 13,000 YEARS OF CHANGE

- *Knowledge of changes in the ancient environment* is important to the understanding of Maritime history.

- *Land in the Maritime region has been sinking* very gradually for approximately the last 10,000 years.

- *Tides in the Bay of Fundy,* now the highest in the world, did not develop until the offshore banks began to sink, allowing ocean currents to enter the bay. The increasing tides lowered the water temperature, resulting in a more abundant fishery; they also created extensive mudflats along the coast.

- In general, *the climate in the Maritime region* grew steadily warmer after the ice retreated, until about 4,000 years ago; since then it has cooled slightly.

- For a few hundred years after the retreat of the glaciers, the Maritime region was covered by tundra. Since then, *the region has been continuously forested.*

- *The fish and game species* living in the region have changed as the climate, water temperatures, tide levels and forest cover have changed.

KNOWING THE ENVIRONMENT

• The Native people of the Maritimes saw the land repopulated with animals and plants after the Ice Age.

Native people were the first people to live in the Maritime region. At first they lived on the open tundra, but within a few hundred years the land was covered with forest. The people watched all these changes happen. They saw new kinds of herbs and trees begin to grow. They encountered new species of ducks and saw the first moose and beaver. They discovered each new type of fish that made its way into the fresh and salt water. They witnessed the development of the first clam-flats and the disappearance of the last swordfish as the pattern of ocean currents changed in the Bay of Fundy.

For the environment was not always the same as it is today. About 13,000 years ago, most of the land was still covered by ice — the last of several "Ice Ages." We can still see where glaciers scraped away the surface of the earth and left deposits of gravel and enormous boulders — like those found in the Spednik Lake region of western New Brunswick. The sea, too, once came far in over the land, so that seashells and walrus bones are found today in high places, such as the upper St. John River Valley, many kilometres from the ocean.

The Native people of the Maritime region knew their environment very well. Their knowledge was based on lifelong observation. They responded to the gradual changes in food resources by adapting their technology. They were always able to tap the most plentiful species of fish and game, grains and seeds, fruits and vegetables. Sometimes they had to adapt quickly — when it was a bad year for duck-hunting, for example. But they also changed their way of life gradually, over thousands of years, as the climate changed and the general environment no longer supported animals that had once been important for food. Animals which are now extinct used to live in the Maritime region. Mastodons and woolly mammoths were found here just after the last Ice Age, perhaps at the same time as the earliest people. Swordfish were once caught in the Bay of Fundy, but the water is too cold for them now.

• The people of the Maritime region lived off the land oll year round.

The people of the Maritime region were fishermen, hunters and gatherers. To early European visitors, the abundance of fish and game in the Maritime region was incredible. Again and again they commented on it in their diaries and letters home. The Micmacs and Maliseets used all the great variety of resources in the woods, lakes, rivers and ocean around them. They chose to settle in places near the animals and plants they depended upon for food — good hunting or fishing spots. If one resource failed — if, for example, there weren't enough salmon one spring — they turned to something else. In this way, they lived through hard times to times of plenty again.[1] There isn't even a word for "scarcity" in Micmac or Maliseet!

• The Micmacs and Maliseets lived in such harmony with their environment that they even lack a word for "scarcity."

THE SHAPE OF LAND AND WATER

The Maritimes and Maine form a long peninsula, surrounded by the St. Lawrence River, the Gulf of St. Lawrence, the Atlantic Ocean, the Bay of Fundy and the Gulf of Maine. For as long as people have lived here, these waters have provided natural travel routes — to and from the west by way of the St. Lawrence and along the seacoast to points north and south.

• The people of ancient times could travel easily on the waterways of the Maritime region.

At different times, people and ideas from other places have made their way to the Maritime region via these routes. About 2,400 years ago, for example, travellers from the Ohio River Valley brought the idea of building a burial mound to the people living along the Miramichi River. The idea of making pottery first came to the Maritimes from people living in the St. Lawrence River Valley. Later, pottery refinements and innovations moved from here into Maine. There were many cultural exchanges like this during ancient times.

Along the Atlantic coast of New England and the Maritimes there is a series of parallel river systems (each consisting of a river and all the streams flowing into it) — the Merrimack, Saco, Androscoggin, Kennebec, Penobscot, St. Croix and St. John rivers; and there are the Miramichi and Restigouche river systems in northern New Brunswick. Each of these watersheds formed a natural living area for a group of related people. The Miramichi, in particular, is rich in archaeological sites dating back over 3,000 years. Living along the estuary at the mouth of the river, people could easily fish in both salt and fresh water and hunt in the surrounding forests. At the end of the last Ice Age, these estuaries ran much further inland than they do today; the head of tide on the St. John River, for instance, was at Grand Falls, far upstream from its present location, just above Fredericton.

• What routes might they have taken from the Ohio River to the Miramichi?

[1] There is no archaeological evidence (in the form of tools or plant remains) that the ancient people in the Maritime region grew crops. Food was so abundant in the environment that there was no need for them to do so; it was far more efficient to gather wild fruits, grains and vegetables, and to hunt and fish. The nearest farmers seem to have been in southern Quebec and southern New England.

• People followed routes which disturbed the environment as little as possible.

Even in Nova Scotia, Prince Edward Island and southeastern New Brunswick, which do not have such large river systems, people took advantage of the same abundant resources, inland and along the coasts. In Nova Scotia, there are many sites where people lived on the shores of rivers and lakes in ancient times. These waterways offered the best travel routes throughout the region. Using them meant that people could disturb the forest as little as possible. Even the trails they used may have been kept up from the time when the land was open tundra.

Although it has been a peninsula during all the time people have lived here, the exact shape of the land in the Maritime region has changed. Many places are now under water that were once dry land.

The ice sheet that once covered the Maritime region was so heavy that it actually pressed the land down. The sea came far inland, creating inlets and estuaries in what would later be river valleys. As the ice melted and disappeared northward, beginning about 13,000 years ago, the land began to rise. Of course, it rose very slowly — only a few centimetres per century — but after several thousand years, it was so high out of the water that places like Cobequid Bay and the Northumberland Strait were dry. Prince Edward Island was connected to the mainland; it was not an island at all.

• The coastline of the Maritimes has been sinking for thousands of years.

As time went on, the ice sheet melted farther and farther to the north and west, and the land there began to rise, too. When this happened, the land to the south and east — in the Maritime region — stopped rising and began to sink instead, just as one end of a see-saw goes down when weight is taken off the other end. At the same time, the oceans were filling up again with the water melting from the glaciers, making it seem as if the land were sinking even faster. Today, the Maritime provinces are still sinking, at an average rate of about fifteen centimetres per century. Areas around the Bay of Fundy are sinking more rapidly than those in the Gulf of St. Lawrence.

THE HIGHEST TIDES IN THE WORLD

Just as the land in the Maritime region has been sinking, so have the offshore banks. These banks are high places on the floor of the ocean off the Nova Scotia and New England coasts. They cover enormous areas, and the ocean water above them is relatively shallow. In fact, 13,000 years ago, some of the land in what is now the Georges Bank and the Browns Bank lay above the water as islands. Fishermen sometimes haul up the bones and teeth of mammoths and mastodons, which once lived there on dry land.

When the banks were above water or, later, just below the surface, they blocked ocean currents from flowing strongly in and out of the Bay of Fundy. This had two effects: (1) the water in the bay stayed warm because there was nothing to stir up cold water from deep below the surface; and (2) there was little, if any, tide.

• The water in the Bay of Fundy grew cooler, creating an abundant fishery.

As the offshore banks sank lower, however, ocean currents began to enter the bay. The water grew steadily cooler as the deeper layers were stirred up and mixed with the surface. Even though it eventually became too cold for the warm-water species, such as swordfish, that people had once fished there, the Bay of Fundy became a very productive source of food, because cold ocean water is generally far richer in fish and other animal life than warm water.

At the same time that the water was cooling, the action of the tide was increasing. Today the difference in depth between high and low tide in the Bay of Fundy is greater than anywhere else in the world, almost twenty metres in Minas Basin.

Along the coast in certain areas the action of the tide has created mudflats — broad, flat, sandy areas — as it erodes the coastline. As the tide rises, water flows in, bringing nourishment to the clams, mussels and other species there. (Outside the Bay of Fundy, where the tides are smaller, extensive mudflats are not as common.) People living along the coast near mudflats learned to take advantage of shellfish and the inshore fishery. They settled along the shore above the beaches, where their *shell-middens* can still be seen today. These are places where people left deep accumulations of clam, mussel, sea urchin and other shells, sometimes representing an occupation that lasted for hundreds of years.

THE 10,000-YEAR-OLD FOREST

Twelve-thousand five hundred years ago, the average temperature in the Maritime region was ten to fifteen degrees Celsius cooler than its present value. Winters were much colder and longer and even the summers were quite cold. By 11,000 years ago, there were no glaciers left, except perhaps in a few high places in the Gaspé and central Nova Scotia. The climate grew steadily warmer from then on, until about 4,000 years ago, when it was actually somewhat warmer than it is today. After that, the climate cooled slightly. By 2,500 years ago, weather conditions were much as they are today.

Excerpt: Scientific Statement on Climate Change – Canadian Federation of Earth Sciences
Amplification Of GHG Effects By Other Earth Processes

Anthropogenic greenhouse gas emissions warm the climate, but the resulting adjustments in temperature, evaporation, and precipitation cause additional modifications at the Earth's surface that amplify or exacerbate climate change. An immediate amplifying effect is that evaporation and the potential amount of atmospheric water vapour, also a greenhouse gas, increases with temperature. Since water vapour cycles quickly through the atmosphere, its concentration is a response to temperature and its effect is not to drive climate change but to amplify it (Maslin 2014).

A second effect of global warming is the wasting of ice sheets in Greenland and Antarctica and of ice caps and glaciers in mountains worldwide (Hugonnet et al. 2021). This is apparent in the western mountains and Arctic islands of Canada, where glaciers are shrinking and ice shelves are collapsing (Marshall et al. 2011; Fig. 9). The loss of ice cover lowers surface reflectivity, so that more solar radiation is absorbed and the surface warms further. Reduction in the Arctic Ocean ice cover also reduces reflection of solar radiation from the polar regions and, in turn, contributes to the greater warming observed and expected in the North (Serreze et al. 2007). A similar reduction in reflectivity and enhanced warming occurs in the spring when seasonal snow cover melts earlier or is less extensive across Canada (Zhang et al. 2019).

A third effect follows the thawing of near-surface permafrost, with emissions of CO_2 and methane from the decay of soil organic matter formerly entombed in frozen ground (Schuur et al. 2015; Fig. 10). It is particularly relevant for Canada because, after Russia, we have the largest area of permafrost enriched in carbon, particularly in the Mackenzie River valley, NT, and the Hudson Bay Lowlands of Manitoba, Ontario, and Quebec (Fig. 11). Canada has about 400 billion tonnes of soil organic carbon in the uppermost 3 m of the ground in the permafrost regions (Hugelius et al. 2014). Worldwide, the quantity of carbon in the top 3 m of permafrost terrain, some 1000 billion tonnes (Tarnocai et al. 2009), is about 100 times greater than annual industrial emissions (EPA 2021), so the release of even a small fraction of the permafrost carbon will counteract governments' efforts to limit emissions (Natali et al. 2021). Methane emissions from permafrost sources are of particular concern because CH_4 has greater warming potential, about 30 times higher per tonne than CO_2 over 100 years (EPA 2020). Thawing of permafrost beneath lakes and in the continental shelves of the Arctic Ocean also leads to release of deeply stored geological methane (Walter Anthony et al. 2012; Kohnert et al. 2017).

Two further amplifying effects stem from the increase in area burned by wildfires as summers become drier in a warming climate (Wang et al. 2017). First, a reduction of forest cover reduces evapotranspiration and more of the available solar energy warms the soil and atmosphere. Second, tundra and peatland fires add to atmospheric concentrations of greenhouse gases. These fires have more net emissions than forest fires because burned forests commonly regrow and recapture their lost carbon over a few decades whereas peat takes hundreds to thousands of years to re-accumulate (Zoltai 1993).

Consequences of climate change for Canadian society

Some of the immediate consequences of climate change stem from the increasing frequency and intensity of unusual and, at times, extreme weather events (Vincent et al. 2018). These lead to flooding, especially in spring, as in Calgary (2013), Saskatchewan (2014 and 2016), eastern Ontario and Quebec (2017), and New Brunswick (2018 and 2019) (e.g. Pomeroy et al. 2016; Fig. 12). In addition, the frequency of hurricanes and other major storms making landfall has increased, with 16 of these events battering Canada in the 45 years between 1950 and 1994, and, more recently, 25 hurricanes in the 25 years since 1995. Excessive precipitation and thawing permafrost also promote the conditions for landslides (Patton et al. 2019). Data published by both the federal Climate Disaster Database and the Insurance Bureau of Canada track increasing numbers of weather-related disasters over the last 50 years: the federal data show a doubling of events in 1970–2019, and the Insurance Bureau a tripling in 1983–2019 (Sawyer et al. 2020).

More frequent drought is anticipated with climate change. Many rivers of western Canada depend on runoff from glaciers in the mountains and are now facing reduced flow or drought in the summer as these ice fields melt away and snowmelt occurs earlier in the year (Dierauer et al. 2019). Acute summer drought in the interior of British Columbia is already a regular occurrence due to shifts in timing of spring melt of mountain snowpacks and high water use for irrigation. These factors lead to increased water shortages for municipal use and affect stream flows (Polar Geoscience Ltd. 2012). Reductions in the thickness of mountain snowpacks are leading to reduced replenishment of surface water reservoirs during spring melt, exacerbating water shortages (Schindler and Donahue 2006). Drought in the Prairies, like that in 1999– 2004, is similarly expected to increase. However, in areas where recharge of aquifers mainly occurs in summer, more extreme rainstorms may benefit the water supply (Bonsal et al. 2019).

Sea level has risen and fallen over the last few million years, largely in response to glaciation. Current melting of ice sheets and glaciers and warming of the oceans is causing sea level to rise between 3 and 4 mm per year (Dangendorf et al. 2017), increasing the risk of flooding and destructive storm surges for communities near sea level. About 40% of the increase is due to expansion of the oceans as their temperature rises and most of the rest from melting of ice on land. The increase in sea level by the end of this century is projected to be between 0.5 and 1 m, with a further metre possible if melt of the Greenland ice sheet accelerates (Maslin 2014). In the long term, losses from the Greenland and West Antarctic ice sheets are expected to raise sea level significantly, because the level was 6–20 m higher the last time atmospheric greenhouse gas concentrations were similar to present values (Foster and Rohling 2013). Cities such as Charlottetown, PE, and Richmond, BC, will eventually become submerged if the ice caps respond fully to climate warming, but the time at which this may happen is not clear. Sea level also depends on long-term effects associated with movement of Earth's crust, especially continuing relaxation from the loss of the ice that formed during the last glaciation. The east coasts of Canada may experience over 1.5 m of sea level rise before 2100, but less is anticipated on the west coast (James et al. 2021). This century, the near-sea-level transportation corridor between New Brunswick and Nova Scotia, which includes the Trans-Canada Highway and the CN Railway, will become increasingly vulnerable and need protection by dykes or to be relocated (Fig. 13).

The effects of sea-level rise will be exacerbated by increased storm damage due to the loss of protective winter ice along shorelines of the Great Lakes, the coasts of eastern Canada, and in the Arctic (Lemmen et al. 2016). The longer open water season and greater area of open water increasing storm wave power has already led to more rapid coastal erosion, threatening Arctic settlements such as Hall Beach, NU, and Tuktoyaktuk, NT (Lim et al. 2020; Fig. 14). Erosion is prevalent along the coast of Prince Edward Island and the depositional shorelines of the Great Lakes (Genest and Joseph 1989; Keillor 2003).

2023 NCF-Envirothon New Brunswick

Soils and Land Use Study Resources

Key Topic #5: Field Skills

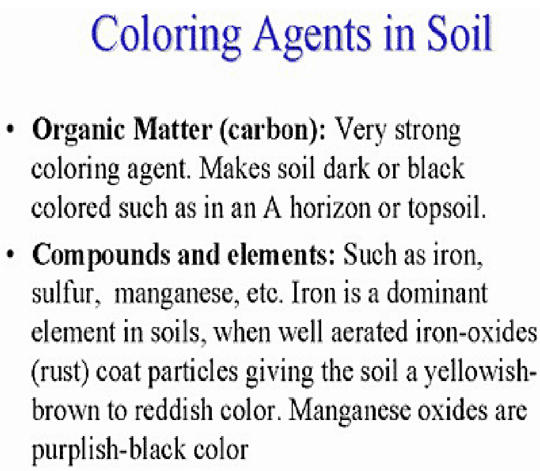
19. Identify characteristics of a soil pit or soil sample, including horizons, colour, structure, texture, and special features.
20. Use a soil triangle to evaluate the texture of a soil.
21. Read and interpret a topographic/LiDAR map.
22. Utilize field tools to provide on-site soil analysis, including:
    a. Auger,
    b. Munsell soil colour chart,
    c. compass,
    d. particle sieve,
    e. GPS (or field tablet with integrated GPS)

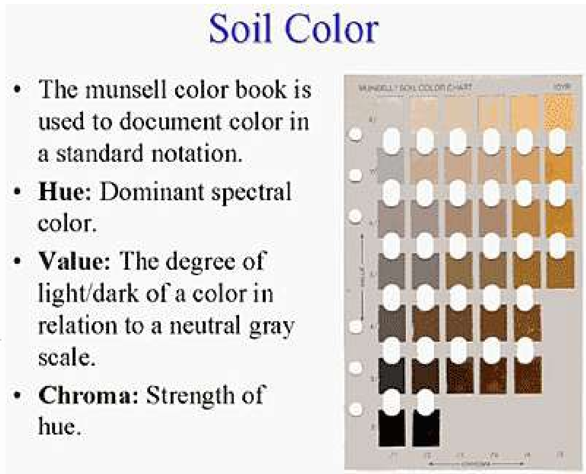
Study Resources

Resource Title	Source	Located on
Describing and Interpreting Soil Profiles	*Agriculture and Agri-Foods Canada, 2023*	Page 92

<u>Study Resources begin on the next page!</u> →

Describing and Interpreting Soil Profiles





Gray colors will exist in soils that are not well drained. These gray colors are developed by the reduction and movement of iron in wet areas of the soil. As iron moves, the reddish or brownish color disappears, leaving behind gray colors. In general, these spots of gray color are called Mottles. The hue is determined by the numbers and letters in the upper right-hand corner of the page. The page given above represents hue 10YR. The value is represented by the numbers given on the left side of the page, and they are read vertically. Chroma is given across the bottom of the page and is read horizontally. So, an example of a proper Munsell designation is 10YR 5/6.