

BCS 311: Land and Environments of the Circumpolar World I

Module 3: Geological Processes

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Overview

Constant interaction of geological processes that contribute to mountain building and the weathering and erosion of rocks combine to shape the earth's surface.

Mountain building is associated with movement of materials within the earth's crust driven by **geothermal energy**. **Igneous rocks** that compose the crust are constantly formed, deformed and melted as part of the **rock cycle**.

The transformation of earth materials from igneous rocks into **sedimentary rocks** and **metamorphic rocks** within the rock cycle is associated with the formation of fossil fuels and mineral ores. The exploitation of fossil fuel and mineral ore deposits is a major source of economic activity in the circumpolar North.

Learning Objectives

Upon completion of this module, you should be able to:

1. Discuss the relationship between the rock cycle and the physiography of continents and ocean basins in the circumpolar North.
2. Discuss the origin and distribution of fossil fuel deposits in the circumpolar North.
3. Discuss the origin and distribution of mineral resources in the circumpolar North.

Required Readings

AMAP Assessment Report: *Arctic Pollution Issues*. 1998. Chapter 2: Physical/Geographical Characteristics of the Arctic. pp.13-16.

Lindström, M. 2000. Chapter 1. The Geological Development of the Arctic. In: Nuttall, M. and T.V. Callaghan ed. *The Arctic: Environment, People, Policy*. Amsterdam, the Netherlands: Harwood Academic Publishers. pp.3-26.

A bedrock geology map of the region where you live for Learning Activities 1 and 2.

Key Terms and Concepts

- Aluminosilicate Minerals
- Continental Shield
- Denudation
- Endogenic Processes
- Exogenic Processes
- Ferromagnesian Minerals
- Geothermal Energy
- Mid-oceanic Ridges
- Oceanic Trenches
- Orogenic Mountains
- Rock Cycle
- Sedimentary Platforms
- Volcanism

Learning Material

3.1 Introduction

Variations in the topographic relief of the earth's surface reflect constant interaction of **exogenic** and **endogenic processes**. Endogenic processes are responsible for creating topographic relief, i.e., variations in elevation of land surface relative to sea level. These processes include **volcanism**, earthquakes, and folding and faulting of rocks in the earth's crust. Exogenic processes operate to reduce topographic relief by means of weathering of rock and subsequent redistribution of weathering products, sediments and dissolved minerals across the earth's surface. The processes of weathering, erosion, transport and deposition are collectively referred to as **denudation**.

The transformation of earth materials from igneous rocks into sedimentary rocks and metamorphic rocks within the rock cycle is associated with the formation of fossil fuels and mineral ores. Exploitation of these non-renewable resources constitutes a major economic activity within the circumpolar North.

3.2 The Geologic Framework

Earth's Crust

The outermost layer of the solid earth is the crust. Rock-forming minerals that compose the crust represent naturally occurring inorganic compounds that possess a specific chemical composition and crystalline structure. The three most common rock-forming minerals present in the earth's crust are quartz (SiO_2), which usually occurs as a six-sided prism, feldspar ($\text{NaAlSi}_3\text{O}_8$, $\text{CaAl}_2\text{Si}_2\text{O}_8$), which occurs as a six-sided rhombus, and mica ($\text{K}(\text{Mg},\text{Fe})_3\text{AlSi}_3\text{O}_{10}(\text{F},\text{OH})_2$), which occurs as thin sheets of prismatic crystals. Rocks are defined as mineral aggregates. Rocks are constantly formed, deformed and melted within the crust, and weathered and eroded at the earth's surface under the influence of variations in regional climates over geological time-scales.

Rock Classification

Geologists arrange the rocks that compose the earth's crust into three major classes: igneous, sedimentary and metamorphic. **Igneous rocks** are derived from molten rock or **magma**, which originates beneath the earth's crust. **Sedimentary rocks** are derived from the weathering and erosion of pre-existing rocks or formed by chemical precipitation in aquatic environments, e.g., lakes and oceans. **Metamorphic rocks** are formed of igneous and sedimentary rocks that have been changed physically and chemically by the application of heat and pressure during mountain building periods.

Igneous Rocks

The earth's crust consists largely of igneous rocks derived from magma beneath the crust. As magma rises through the crust it cools and mineral crystals grow through the process of crystallization. Felsic igneous rocks consist largely of minerals composed of silicon (Si) and oxygen (O) atoms, combined with a variety of metallic elements such as sodium (Na), potassium (K), calcium (Ca), magnesium (Mg) and aluminum (Al). These minerals are known as **aluminosilicate minerals**. Mafic igneous rocks consist largely of minerals composed of silicon and oxygen atoms combined with metallic elements such as iron (Fe) and magnesium (Mg). These minerals are known as **ferromagnesian minerals**.

The continental crust consists largely of granite, a felsic igneous rock, and gneiss, a metamorphic rock derived from granite. Rocks of the continental crust exhibit an average density of $2,700 \text{ kg/m}^3$. Oceanic crust consists largely of the mafic igneous rocks basalt and gabbro. Rocks of the oceanic crust exhibit an average density of $3,000 \text{ kg/m}^3$. The crust is much thicker beneath continents than beneath oceans, approximately 40 km versus 5 km, respectively.

Sedimentary Rocks

Physical weathering serves to break down rock into smaller particles known collectively as clastic sediments. Physical weathering does not alter the chemical composition of the original rock materials. Chemical weathering transforms the original minerals (primary minerals) into a new set of minerals (secondary minerals) of different chemical composition and minerals dissolved in surface and ground waters.

Clastic sediments are eroded and transported from the site where they were produced by mass movement, water, wind and ice, and deposited elsewhere on the earth's surface. Dissolved minerals are transferred in surface and ground waters across hillslopes into stream and river channels and eventually accumulate in lakes and oceans (see Module 7). Through a variety of processes known collectively as **lithification**, sediment grains are welded together to form clastic sedimentary rocks. Conglomerate (composed of gravel), sandstone (composed of sand), and shale (composed of mud) are examples of these rocks.

Chemical sedimentary rocks are formed by chemical and/or biochemical precipitation of dissolved minerals in aquatic environments, e.g., lakes and oceans. These minerals include limestone (CaCO_3), dolomite ($(\text{Ca}, \text{Mg})\text{CO}_3$), rock salt (NaCl) and gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). Iron and aluminum oxides, such as limonite ($2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$) and gibbsite ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$), are produced by intense chemical weathering of igneous rocks and accumulate in soils (see Module 6). Organic rocks originate as organic materials produced by a variety of organisms, both terrestrial and aquatic. Fossil fuels such as coal, natural gas and oil are derived from the decomposition and subsequent transformation of organic materials by heat and pressure within the earth's crust.

Metamorphic Rocks

Processes accompanying mountain building occur at high temperatures and pressures. Under these conditions igneous and sedimentary rocks are altered to form metamorphic rocks. Physical changes in rocks accompanying metamorphism involve the re-arrangement of mineral grains into parallel layers creating a mineral structure known as foliation. Gneiss (coarse texture; large mineral crystals) and schist (fine texture; small mineral crystals) are common foliated metamorphic rocks.

Learning Activity 1

Much of the earth's crust consists of ancient igneous and metamorphic rocks. Examine a geologic map to discover the age of the most ancient rocks in the region where you live. To what rock class do they belong? In what physiographic region are these rocks situated (see Figures 3.1a and 3.1b)?

3.3 Physiography of the Circumpolar North

Continental landmasses of the circumpolar North are divided into several physiographic regions based on bedrock composition, geologic age and variations in topographic relief:

- 1) **Continental Shields** – Canadian Shield, Baltic Shield and Central Siberian Plateau;
- 2) **Sedimentary Platforms** – Interior Plains of Canada, Arctic Islands, excluding Devon, Axel Heiberg and Ellesmere Islands, East European Plain and West Siberian Lowland; and
- 3) **Orogenic Mountain Belts** – Western Cordillera of North America, Axel Heiberg and Ellesmere Islands among the Arctic Islands, Ural Mountains and East Siberian Highlands in Russia (Figure 3.1a).

Some landscapes present within these physiographic regions, as illustrated by examples in northern Canada, are examined below.

Learning Activity 2

Examine a geologic map of the region where you live to discover a variety of rocks present in the local landscape. Consider the types of rocks that underlie mountains and hills versus rocks that underlie valleys. Is there a relation between the types of rocks present and the topography of the local landscape?

Canadian Shield

The Canadian Shield represents the ancient core of the North American continent. The rocks that compose most of the Canadian Shield record several cycles of mountain building over several billion years. Extensive volcanism accompanied deformation and metamorphism of igneous and sedimentary rocks (Figure 3.1b). Granite and gneiss dominate the bedrock geology.

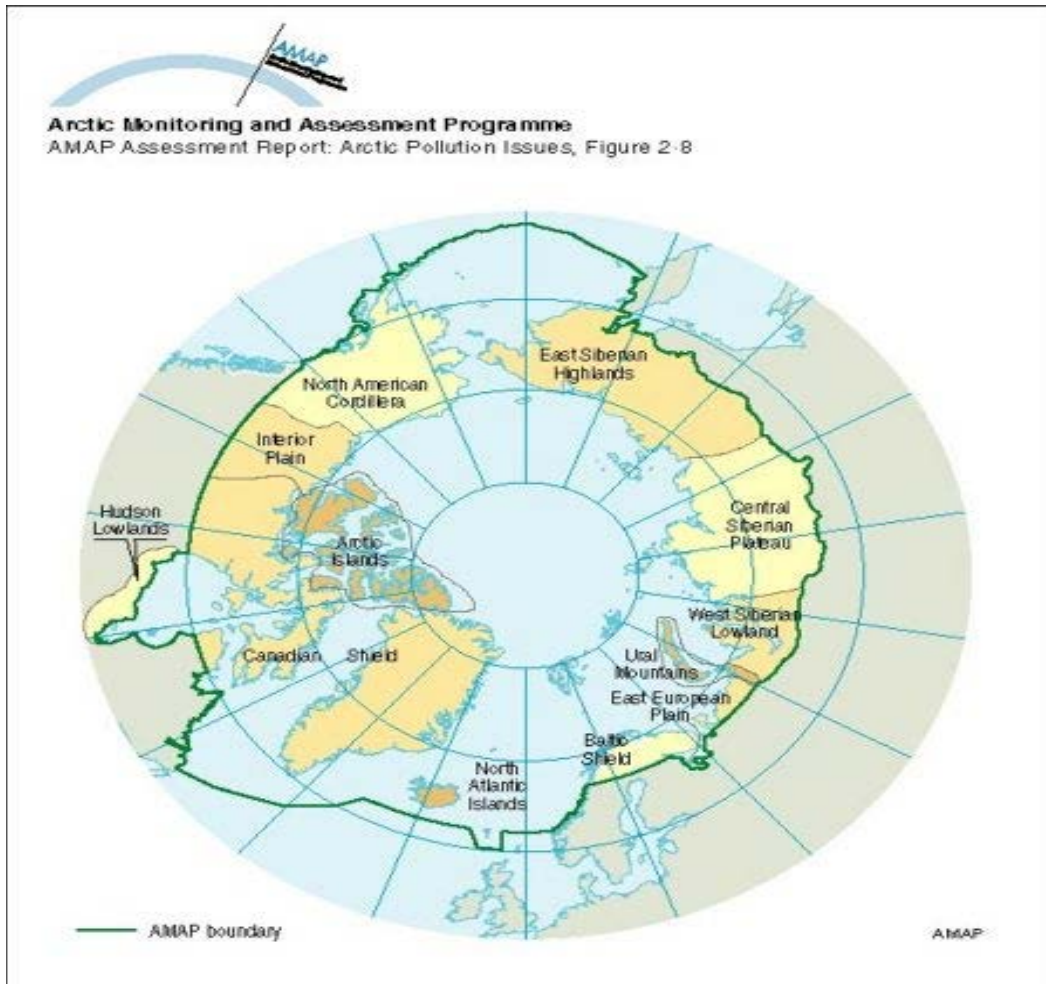


Figure 3.1a. Geologic and physiographic regions of the Arctic. © P. Rekacewicz and E. Bournay (GRID-Arendal). Source: Linell, K.A. and J.C.F. Tedrow, 1981. *Soil and Permafrost Surveys in the Arctic*. Clarendon Press, Oxford.

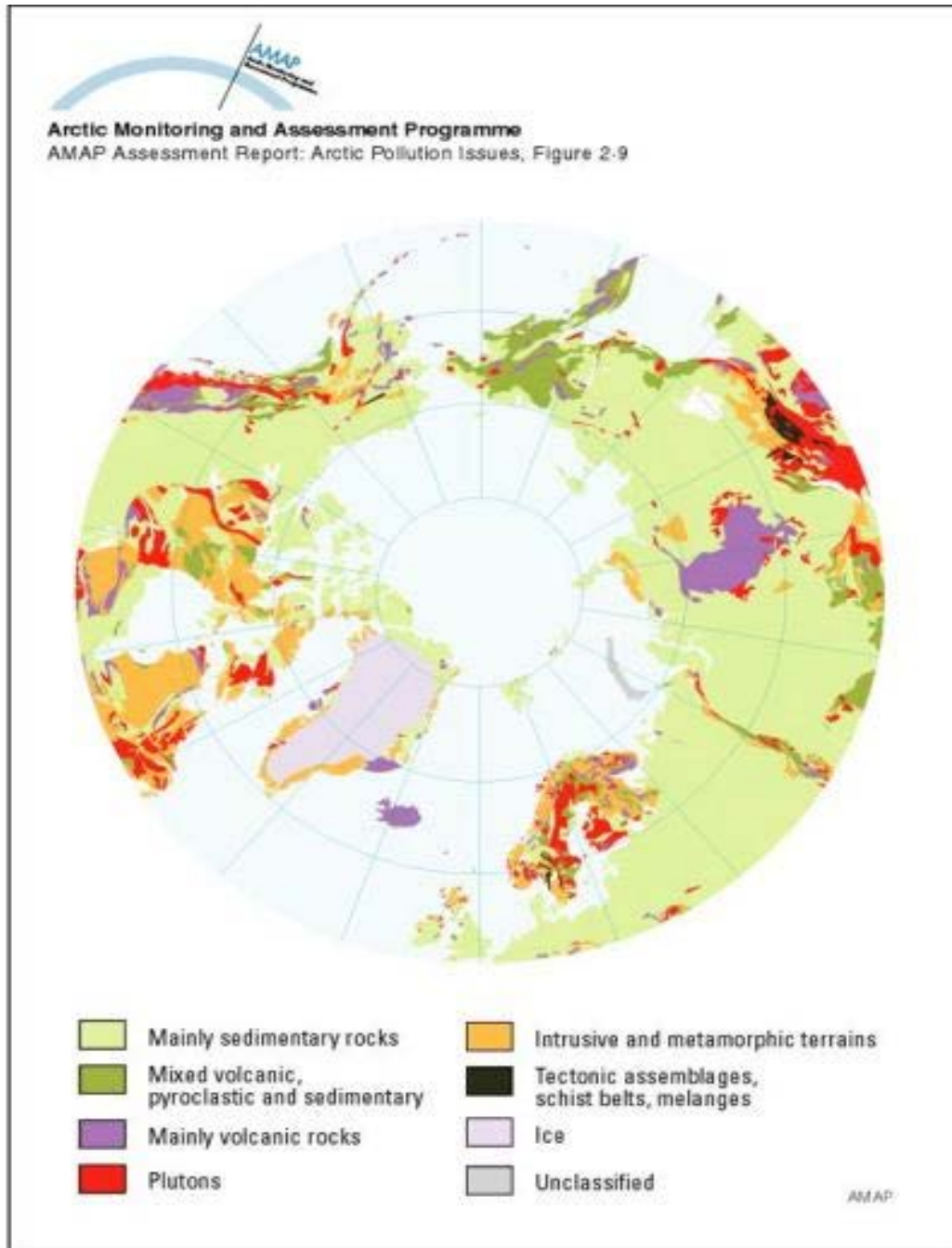


Figure 3.1b. Bedrock geology of the Arctic. © D. Henry, P. Rekacewicz and E. Bournay (GRID-Arendal). Source: Geological Survey of Canada, 1995. Generalized geological map of the world and linked databases. Open File 2915d. Natural Resources Canada (www.nrcan.gc.ca). This map is a copy of an official work that is published by the Government of Canada and has not been produced in affiliation with or with the endorsement of the Government of Canada.

See Glossary for definitions of the terms pyroclastic sediments, plutons, igneous and metamorphic terrains and mélanges.

The Canadian Shield consists largely of a series of broad arches and basins that have been eroded over a vast period of geologic time to create a nearly level surface (Figure 3.2a). In some basins, sandstone and limestone overlie the granite and gneiss. Erosion and deposition of sediments by continental ice sheets over the past two million years have influenced the present morphology of the Canadian Shield.



Figure 3.2a. Glacially eroded landscape in granite, Tree River, Nunavut, Canada. Latitude 67.086°N Longitude 112.346°W GSC Photo Number 2001-235 @ L. Dredge. Natural Resources Canada (www.nrcan.gc.ca). This photo is a copy of an official work that is published by the Government of Canada and has not been produced in affiliation with or with the endorsement from the Government of Canada.

The landscape depicted above is one of glacial erosion. Glaciers have scoured away previously weathered material, leaving a bare granite bedrock surface. Scattered ponds occupy more deeply scoured rock basins. Compare this landscape with the fjord landscape in Figure 3.2b. that follows. Glacial till is virtually absent although boulders carried by glaciers have been deposited on the rock surface.

Mountain ranges are located along the uplifted eastern margin of the Canadian Shield: the Torngat Mountains in Labrador and the Davis Highlands of Baffin, Devon and Ellesmere Islands (Figure 3.2b). These mountains have been eroded by glacier ice to create a fjord coastline (see BCS 100, Module 3). In the photograph below, a large marine embayment lies at the intersection of several major fjords that have been eroded into a 1,000m high plateau by glaciers draining Baffin Island ice caps and continental ice sheets during the last two million years.



Figure 3.2b. Buchan Gulf, Baffin Island, Nunavut, Canada as seen from Baffin Bay. Latitude: 71.755°N; Longitude: 74.022°W. GSC Photo Number: 2002-239 © D. Hodgson. Natural Resources Canada (www.nrcan.gc.ca). This photo is a copy of an official work that is published by the Government of Canada and has not been produced in affiliation with or with the endorsement of the Government of Canada.

South of Hudson Bay and James Bay, the Canadian Shield lies buried beneath a broad, flat clay plain known as the Clay Belt. The land surface in this region is characterized by the presence of poorly drained muskeg (Figure 3.2c). The Clay Belt originated at the end of the last Ice Age (9,000 to 8,000 years ago). Meltwater flowing from the Laurentide Ice Sheet created enormous proglacial lakes known as Glacial Lake Barlow and Glacial Lake Ojibway. Large volumes of silt and clay derived from the glacial erosion of bedrock were deposited on the floors of the proglacial lakes. Subsequent drainage of these lakes exposed the fine-grained sediments as clay plains creating extensive areas of low topographic relief.

The Hudson Bay Lowland is a vast, low-relief wetland called muskeg, which is composed of peat and other organic deposits. The wetland consists of a mosaic of ponds and lakes with forest patches occupying the slightly higher, better-drained parts.



Figure 3.2c. Muskeg, Hudson Bay Lowland, Ontario, Canada.
Latitude: 53.122°N; Longitude: 84.265°W. GSC Photo Number: 2002-387 © H. Thorliefson.
Natural Resources Canada (www.nrcan.gc.ca). This photo is a copy of an official work that is published by the Government of Canada and has not been produced in affiliation with or with the endorsement of the Government of Canada.

Orogenic Mountain Ranges

Innuitian Province

This region of northern Canada includes Axel Heiberg and Ellesmere Islands within the Arctic islands. This region experienced deposition of an immense thickness of sedimentary rocks over hundreds of millions of years (Figure 3.1b). An early episode of mountain building (approximately 540 to 360 million years ago) involved eruption of lava and folding and faulting of the overlying sedimentary rocks. Further uplift of the region was associated with emplacement of large volumes of granite within the crust. Subsequent weathering and erosion (approximately 360 to 66 million years ago) heralded the return of the deposition of great thicknesses of sedimentary rocks along the margin of the Arctic Ocean. Sedimentary rocks in the western region of the province give rise to low-lying terrain usually less than 600 metres above sea level. Sedimentary and igneous rocks in the eastern region form upland terrain more than 1,000 metres above sea level and glacier-capped mountains over 2,000 metres above sea level on Axel Heiberg and Ellesmere Islands (Figure 3.3).



Figure 3.3a. View of the terrain at the head of Whitsunday Bay, Axel Heiberg Island, Nunavut, Canada. Latitude: 79.102°N; Longitude: 86.674°W. GSC Photo Number: 2002-272 © D. Hodgson. This photo is a copy of an official work that is published by the Government of Canada and has not been produced in affiliation with or with the endorsement of the Government of Canada.



Figure 3.3b. View of the terrain at the head of Vendom Fiord, Ellesmere Island, Nunavut, Canada. Latitude: 78.086°N; Longitude: 82.137°W. GSC Photo Number: 2002-268 © D. Hodgson. Natural Resources Canada (www.nrcan.gc.ca). This photo is a copy of an official work that is published by the Government of Canada and has not been produced in affiliation with or with the endorsement of the Government of Canada.

Mountains developed in igneous and folded sedimentary rocks lie adjacent to lowlands developed by erosion of soft sedimentary rocks.

Western Cordillera

The terrain in this region is composed of a variety of igneous, metamorphic and sedimentary rocks (Figure 3.1b) that have experienced folding and faulting. The intrusion of large volumes of granite into the earth's crust and eruption of lavas during construction of volcanoes have contributed to mountain building along the western coastline of Canada over the last two hundred million years. Alpine glaciation has created the rugged topography that characterizes much of this region (Figure 3.4). The highest peaks in Canada, Mount Logan (5,959 metres above sea level) and Mount St. Elias (5,489 metres above sea level), are found in this physiographic region.



Figure 3.4. Alpine glacial landscapes. St. Elias Mountains, Kluane National Park, Yukon Territory, Canada. Latitude: 61.25°N; Longitude: 139.416°W. GSC Photo Number: 2002-678 © R. Bélanger. Natural Resources Canada (www.nrcan.gc.ca). This photo is a copy of an official work that is published by the Government of Canada and has not been produced in affiliation with or with the endorsement of the Government of Canada.

The three alpine glaciers illustrated above are descending through three parallel valleys (glacial troughs). The source of the central glacier is located in the bowl-shaped basin (called a cirque) at the top of the mountain. The valley sides control the flow of these valley glaciers. The morphology of the ridges separating adjacent glaciers (arêtes) are controlled by the structure of the tightly folded sedimentary rocks in the mountains.

Sedimentary Platforms

Sedimentary platforms separate orogenic mountain belts from the Canadian Shield. The oldest sedimentary rocks, consisting of limestone, dolomite and shale, underlie the Hudson Bay Platform (Figure 3.1a). The Interior Platform is developed on sedimentary rocks consisting largely of limestone, dolomite, sandstone and shale (Figure 3.1a). The Arctic Coastal Plain is developed on gravel, sand and silt deposited along the coastline of the Arctic Ocean basin (Figures 3.5a and 3.5b).



Figure 3.5a. A plateau developed in gravel, Prince Patrick Island, Northwest Territories, Canada. Latitude: 76.639°N; Longitude: 119.436°W. GSC Photo Number: 2002-318 © Natural Resources Canada (www.nrcan.gc.ca). This photo is a copy of an official work that is published by the Government of Canada and has not been produced in affiliation with or with the endorsement of the Government of Canada. Open source.

The photograph above clearly shows how gravel caps a plateau and forms a thin blanket over the underlying dark shale bedrock. Streams are cutting into the edge of the plateau isolating extensive patches of gravel.



Figure 3.5b. Coastal lowlands developed from sand and gravel deposits, Prince Patrick Island, Northwest Territories, Canada. Latitude: 77.282°N; Longitude: 119.114°W. GSC Photo Number: 2002-331 © Natural Resources Canada (www.nrcan.gc.ca). This photo is a copy of an official work that is published by the Government of Canada and has not been produced in affiliation with or with the endorsement of the Government of Canada. Open source.

Note the extensive development of patterned ground associated with frost cracking (see Module 4) in beach sediments in the foreground of the photograph above. Coastlines in this region of the Canadian Arctic are presently at risk due to sea level rise (see Modules 8 and 9). Rapid shoreline retreat is associated with melting ground ice and a longer ice-free season that contributes to enhanced wave erosion of coastline sediments (Natural Resources Canada, 2012).

3.4 Plate Tectonics and Volcanism

The earth's crust is fragmented into numerous tectonic plates that move slowly past one another at centimetres per year, and interact along their margins. Tectonic plate motions are associated with volcanism and earthquakes. Tectonic plate margins diverge or move away from one another at mid-oceanic ridges (Figure 3.6). The upward movement of magma through the crust causes the crust to fracture and facilitates eruption of lava onto the ocean floor to construct mid-oceanic ridges. In some places on the ocean floor, the volume of lava erupted along diverging plate margins is so great that the mid-oceanic ridge extends above the surface of the ocean. Iceland was constructed in this fashion along the North Atlantic Mid-oceanic Ridge (North Atlantic Islands on Figure 3.1a).

Tectonic plate margins converge or move towards one another along continental margins. The heavier rocks (3,000 to 3,300 kg/m³) of the oceanic crust are forced to move downwards beneath lighter rocks (2,700 kg/m³) of the continental crust. This downward displacement of the oceanic crust (i.e., subduction) produces a deep depression in the ocean floor known as an **oceanic trench** (Figure 3.6). Shoreward of the trench, magma moves upward through overlying continental crust to erupt as lava

that constructs volcanoes along the continental margin. Rocks of the continental crust experience folding and faulting that contribute to mountain building along the continental margin. Mountains of the Canadian Western Cordillera were built this way.

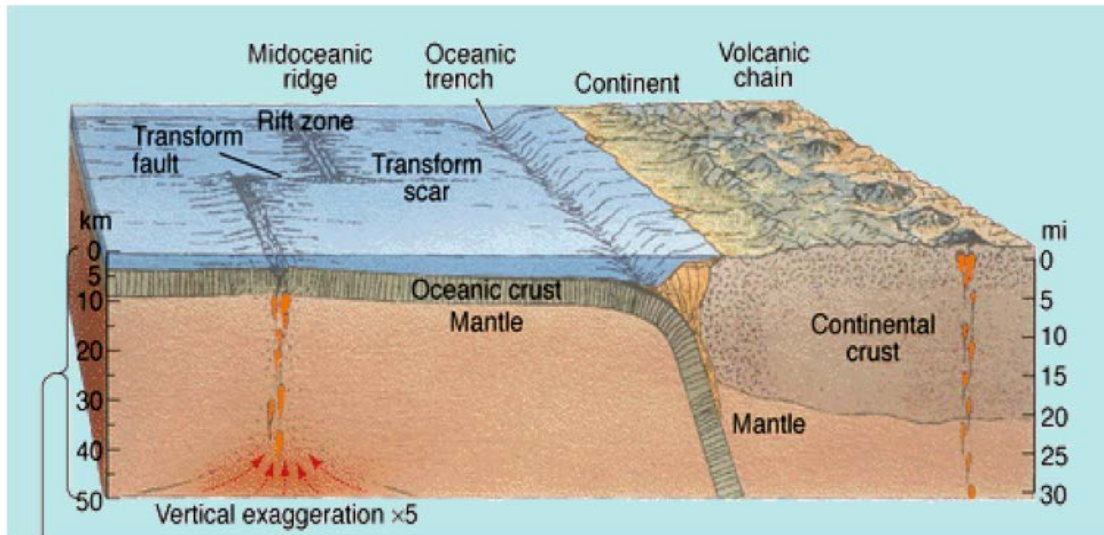


Figure 3.6. Tectonic processes operating at diverging and converging tectonic plate margins. Magma rising beneath the ocean crust erupts onto the seafloor to construct mid-oceanic ridges. Magma rising beneath the continental crust erupts to form volcanoes along the continental margin. Source: A. Strahler and O.W. Archibold. 2011. *Physical Geography: Science and Systems of the Human Environment*. 5th Canadian Ed. Mississauga, Ontario: John Wiley & Sons Canada, Ltd.

Vigorous earthquakes and active volcanoes associated with the Kamchatka Peninsula of eastern Russia and the western coastline of Alaska are associated with converging plate margins that circle the Pacific Ocean to create a “Ring of Fire”. Volcanoes can quickly alter entire landscapes by eliminating existing soil cover and plant and animal life (Figure 3.7).

Learning Activity 3

Plate tectonics and volcanism have been shaping the earth’s surface for billions of years. Research the geology of the region where you live to find evidence of mountain building, volcanic eruptions, lava flows and earthquake activity.



Figure 3.7. A plume of volcanic gas and water vapour rises above the summit crater and growing lava dome at Augustine Volcano in southern Cook Inlet, Alaska, U.S.A. A mantle of light brown ash discolours the snow on the upper flanks of the volcano. Source: Photograph by C. Read, U.S. Geological Survey, January 24, 2006. Alaska Volcano Observatory database image from <http://www.avo.alaska.edu/image.php?id=7051>. Public Domain.

3.5 Origin and Distribution of Mineral Resources

The circumpolar region is rich in natural resources: living and non-living, renewable and non-renewable. Human life and prosperity in the circumpolar North is dependent on the use of these resources for sustenance, export or trade. A renewable resource is a resource that is replaced rapidly by natural processes. Examples of renewable resources are sunlight (non-living) and wildlife (living). Non-renewable resources represent resources that are not replaced or replaced slowly by natural processes. Primary examples of non-renewable resources are mineral ores and fossil fuels such as oil, natural gas and coal. Movement and crystallization of magma and mineral-rich fluids within the earth's crust is largely responsible for the development of commercially exploited mineral deposits. Fossil fuels are continually produced by decaying plant and animal tissues and their transformation by heat and pressure during burial. However, the production rate of fossil fuels is measured in geological time, which is much slower than the rate at which human society consumes them. Once the supply of a non-renewable resource is exhausted it is no longer available for human use.

Fossil Fuels: Oil, Natural Gas and Coal

The circumpolar North holds a significant share of the world's oil and natural gas reserves stored within clastic sedimentary rocks ranging in geologic age from the Carboniferous Period (approximately 354 million years ago) to the Cretaceous Period (approximately 65 million years ago). Depending on oil prices and the supply of oil from existing producing regions, such as the North Sea and the Middle East, there will likely be increasing pressure to develop northern fossil fuel reserves.

Arctic nations, the United States (Alaska), Canada, Denmark (Greenland), Norway, and Russia, are currently engaged in a concentrated effort to map the margins of their continental shelves and slopes, under the auspices of the United Nations Convention on the Law of the Sea, with the view to securing mineral resources beneath the surface of the Arctic Ocean. The Arctic region may become one of the major sources of oil and natural gas in the 21st century.

Within the Arctic region, oil and natural gas are found in several areas:

- Norman Wells (65°17'N, 126°48'W) on the Mackenzie River,
- the Beaufort Sea coast of Alaska and Canada,
- the Sverdrup Basin in the Canadian Arctic Islands,
- the western coast of Greenland,
- the Barents Sea, and
- northwest Russia.

An extensive network of drilling platforms, production facilities and pipelines move petroleum products to markets further south (Figure 3.8).

As was the case for oil and gas deposits in the circumpolar North, coal deposits are associated with clastic sedimentary rocks ranging in geologic age from the Carboniferous Period (approximately 354 million years ago) to the Palaeogene Period (approximately 50 million years ago). Extensive coal deposits occur in central and northern Alaska, on Axel Heiberg and Ellesmere Islands in the Canadian Arctic Islands, on Spitsbergen in the Svalbard archipelago and in the Western Siberian Lowlands in Russia. Coal mining is an important industry in Svalbard and Russia.

Learning Activity 4

Extraction and processing of fossil fuels and minerals significantly contributes to the national economies of several circumpolar states. What are the most important mineral resource industries in your country? What proportion of the Gross Domestic Product (GDP) of your country do these industries contribute?

Minerals

The circumpolar North contains abundant mineral resources. Iron, lead, copper, nickel and zinc are the most abundant and common, but rare minerals such as gold and diamonds are also found within the region. Igneous and metamorphic rocks that compose the Canadian Shield, Baltic Shield and Western Siberian Lowlands (see volcanic rocks, plutons, igneous and metamorphic terrains on Figure 3.1b) host these mineral ore deposits (Figure 3.8). Mineral exploitation continues to be a major source of economic activity across the Arctic region.

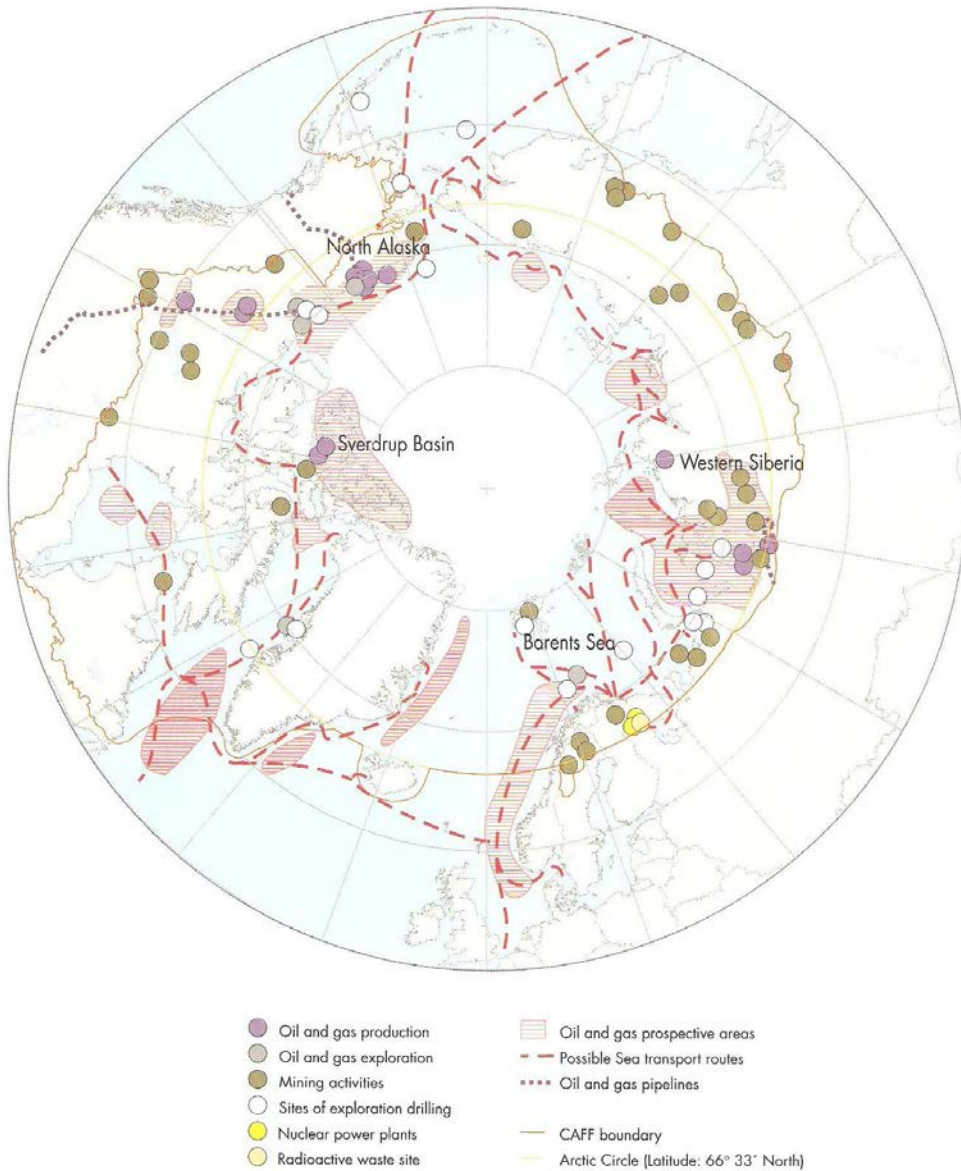


Figure 3.8. Mineral exploration and production activity in the circumpolar North. Source: CAFF, 2001. Arctic Flora and Fauna: Status and Conservation. Edita, Helsinki, Finland. CAFF is a subset of <http://arctic-council.org>. Gov't of Canada partnership initiative to share Arctic information and trends.

Conclusion

Plate tectonics and volcanism have been shaping the earth's surface for billions of years creating volcanic landforms including Iceland and extensive mountain ranges throughout the circumpolar North. Over millions of years rocks exposed at the earth's surface have been subjected to denudation. Transformation of the earth's materials from igneous rocks into sedimentary rocks into metamorphic rocks within the rock cycle is associated with the formation of fossil fuels and mineral ores. Exploitation of these non-renewable resources constitutes a major economic activity within the circumpolar North.

Discussion Questions

1. With reference to the rock cycle and the concept of plate tectonics, describe the processes that contributed to development of the present physiography of circumpolar North continents.
2. Distinguish between mineral resources associated with sedimentary rocks and those associated with igneous and metamorphic rocks.

Study Questions and Answers

1. Describe rock forming materials that compose sedimentary platforms. Identify examples from the region where you live.

Physical weathering serves to break down rock into smaller particles known collectively as clastic sediments. Chemical weathering transforms primary minerals into a new set of minerals (secondary minerals) of different chemical composition and minerals dissolved in surface and ground waters. Clastic sediments are eroded and transported from the site they were produced by mass movement, water, wind and ice, and deposited elsewhere. Dissolved minerals are transferred in surface and ground waters across hill slopes into stream and river channels and eventually accumulate in lakes and oceans. Through a variety of processes, known collectively as lithification, sediment grains are welded together to form clastic sedimentary rocks: conglomerate (composed of gravel), sandstone (composed of sand) and shale (composed of mud) are examples. Chemical sedimentary rocks are formed by chemical and/or biochemical precipitation of dissolved minerals in aquatic environments (e.g., lakes and oceans). These minerals include limestone (CaCO_3), dolomite ((Ca, Mg) CO_3), rock salt (NaCl) and gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). Organic rocks originate as organic materials produced by a variety of organisms, terrestrial and aquatic.

2. Describe processes that contribute to the formation of fossil fuel deposits within sedimentary platforms.

Fossil fuels such as coal, natural gas and oil are derived from the decomposition and subsequent transformation of organic materials by heat and pressure within the earth's crust.

3. Compare and contrast processes that contribute to mountain building along continental margins and volcanic islands such as Iceland.

Magma rising beneath oceanic crust causes the crust to fracture, allowing magma to erupt onto the ocean floor as lava. Lava flows contribute to the development of submarine features known as mid-oceanic ridges. The ongoing flow of magma causes ocean crust to diverge away from mid-oceanic ridges. Oceanic crust collides with continental crust along ocean margins. The more dense rocks of the ocean crust are driven beneath overriding lighter rocks of the continental crust creating a subduction zone. As oceanic rocks slide beneath continental rocks they are heated intensely and melt, generating magma that rises through overlying continental rocks. Magma is eventually erupted as lava on continental surface. Lava flows contribute to the development of explosive volcanoes along the continental margin. Unusually high magma flow rates along a mid-oceanic ridge in the North Atlantic Ocean led to the creation of Iceland.

4. Describe the variety of mineral resources associated with igneous and metamorphic rocks.

Mineral resources associated with igneous and metamorphic rocks consist of metallic ores – iron, lead, zinc, nickel, copper, uranium – and precious minerals such as gold and diamonds. All these materials are non-renewable resources.

5. Distinguish between non-renewable and renewable natural resources.

A renewable resource is a resource that is replaced rapidly by natural processes. Examples of renewable resources are sunlight (non-living) and wildlife (living). Non-renewable resources represent resources that are not replaced or are replaced slowly by natural processes. Primary examples of non-renewable resources are mineral ores and fossil fuels such as oil, natural gas and coal.

Glossary of Terms

Aluminosilicate Minerals: minerals composed of silicon oxides and aluminum oxides combined with a variety of metallic elements such as sodium (Na), potassium (K), calcium (Ca), magnesium (Mg).

Continental Shield: generally a large area of exposed crystalline igneous and metamorphic rocks that form tectonically stable areas. These regions have been affected little by plate tectonic processes since the Precambrian Era more than 570 million years ago.

Denudation: the collective processes of weathering, erosion, transport and deposition.

Endogenic Processes: processes sustained by geothermal heat occurring beneath and within earth's crust that shape the surface of the earth (e.g., volcanism, plate tectonics, folding and faulting of rocks).

Exogenic Processes: processes sustained by radiant energy from the sun occurring at the earth's surface that shape the surface of the earth through the weathering of rock and subsequent redistribution of weathering products, sediments and dissolved minerals across earth's surface.

Ferromagnesian Minerals: minerals composed of silicon oxide combined with metallic elements such as iron (Fe) and magnesium (Mg).

Geothermal Energy: heat generated by the radioactive decay of various elements deep within earth's interior.

Igneous Rocks: rocks derived from molten rock or magma that originate beneath earth's crust.

Lithification: a combination of compaction and cementation that weld sediment grains together to form clastic or chemical sedimentary rocks.

Magma: the high temperature molten state of rocks usually of silicate mineral composition.

Metamorphic Rocks: rocks altered in physical structure and/or chemical composition by the application of heat and pressure deep within the earth during periods of mountain building.

Metamorphism: a change in the mineral composition and structure of pre-existing rocks caused by intense pressure and heat, and/or the injection of hot fluids.

Mid-oceanic Ridge: submarine mountains formed at points where tectonic plate margins diverge or move away from one another; caused by the eruption of lava onto the ocean floor.

Muskeg: an acidic soil type common in arctic and boreal regions of North America; a usually thick deposit of dead plants in various states of decomposition (as peat), ranging from fairly intact sphagnum moss to sedge peat to highly decomposed muck.

Oceanic Trench: a deep depression in the ocean floor caused by tectonic plate movement forcing heavier rocks of oceanic crust downward beneath lighter rocks of continental crust resulting in a downward displacement of oceanic crust.

Orogenic Mountains: regions of high topographic relief that form along continental margins adjacent to converging tectonic plate boundaries; produced by volcanism and the folding and faulting of rocks in the continental crust.

Pluton: a large body of igneous rock crystallized from slowly cooling magma within the crust below the earth's surface.

Pyroclastic sediments: sediments composed solely or primarily of materials ejected from volcanoes; commonly associated with explosive volcanic activity (Figure 3.7 illustrates ash deposits).

Rock Cycle: the cycle in which rocks that compose earth's crust are constantly formed, deformed and melted; transformation of earth materials from igneous rocks into sedimentary rocks into metamorphic rocks within the rock cycle is associated with the formation of fossil fuels and mineral ores.

Sedimentary Platform: a region of a continent covered by flat-lying or gently tilted sedimentary rocks.

Sedimentary Rocks: rocks formed from the accumulation and lithification of sediments.

Tectonic Mélange: a body of deformed and metamorphosed oceanic and continental rocks associated with oceanic trenches.

Terrane (terrain): a fragment of earth's crust formed on or broken off from one tectonic plate and accreted to the crust of another tectonic plate; the terrane preserves its distinctive geologic history, which is different from that of the surrounding areas, and its boundary is usually identifiable as a fault.

Volcanism: phenomena associated with volcanic activity (e.g., eruption of lava).

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