Chapter 21 Geological History of Western Canada

Learning Objectives

After reading this chapter, completing the exercises within it, and answering the questions at the end, you should be able to:

- Describe the general makeup and ages of the provinces of Laurentia, Laurentia's journey over the past 650 Ma, and the processes by which additional rocks were added on its eastern, northern, and western margins during the Phanerozoic to form the continent of North America
- Explain the timing and depositional environments of mid- and late-Proterozoic sedimentary rocks in western Canada
- Describe the depositional environments and types of sedimentary rock that accumulated on the western margin of North America and in the Western Canada Sedimentary Basin (WCSB) during the Paleozoic
- Summarize the extents, geological origins, and migration of the accreted terranes of British Columbia and Yukon
- Explain how terrane accretion on the west coast during the Mesozoic contributed to the formation of the Rocky Mountains and how that in turn provided the source material for a thick sequence of Mesozoic sedimentary rock in the WCSB
- Describe the origins of the Mesozoic intrusive igneous rocks of the Coast Range and other areas within British Columbia
- Describe the geological effects of the accretion of the Pacific Rim and Crescent Terranes, the nature of WCSB deposition in the early Cenozoic, the ongoing volcanism and earthquake activity in western Canada, and the general effects of the Pleistocene glaciation in western Canada

Figure 21.1 Crowsnest Mountain in the southern Alberta Rockies is made up of Paleozoic rocks that were uplifted by continental convergence during the Mesozoic, and then eroded by glaciation during the Cenozoic.

Western Canada has a fascinating geological history with rocks ranging in age from the Archean to the Holocene. Over that time, almost every conceivable geological process has taken place here, resulting in the formation of a wide array of rock types, and some of the most important fossil deposits in the world. The region is also endowed with a range of geological resources, spanning the periodic table from beryllium to uranium, and the geological processes have produced awe-inspiring scenery and world-class recreational opportunities.

This chapter focuses on the important geological history and geological features of western Canada, but includes an overview of Canadian geology as a whole, starting with the development and journey of the ancient continent of Laurentia.

Media Attributions

21.1 Geological History of Canada

Laurentia, which makes up the core of North America, is the largest and arguably the oldest of Earth's **cratons** (regions of stable ancient crust). Some of the rocks are over 4 billion years old, and Laurentia has been together in its present form for the last billion years. Over the past 650 million years, Laurentia has moved along a zigzag path from deep in the southern hemisphere to close to the North Pole (Figure 21.1.1). During that time, it collided several times with other continents and was temporarily part of two supercontinents (Pannotia and Pangea).

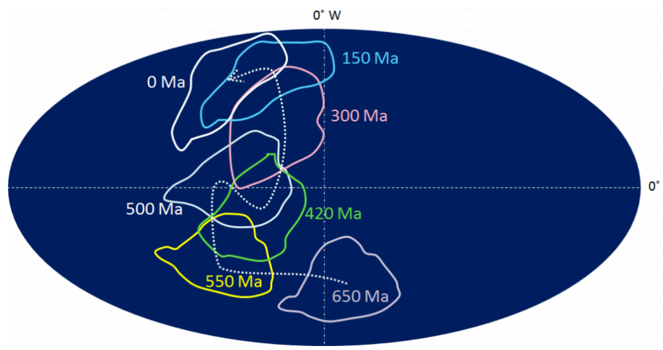

Figure 21.1.1 The path of Laurentia over the past 650 Ma.

Bodies of rock tend to be eroded and recycled through the processes of plate tectonics, including uplift leading to erosion and burial leading to melting, and thus there are very few areas of truly ancient rocks on Earth. The oldest undisputed rocks are those of the Acasta Gneiss from north of Yellowknife, Northwest Territories, aged 4.03 Ga. But there are some rocks that could be even older within the Nuvvuagittuq greenstone belt on the east coast of Hudson Bay, in Quebec. These have been isotopically dated at 4.28 Ga, although the reliability of that date has been questioned. Based on other data, it is acknowledged that the Nuvvuagittuq rocks are at least as old as 3.75 Ga. The Acasta and Nuvvuagittuq rocks are situated within the Slave and Superior Cratons respectively, the oldest parts of Laurentia (Figure 21.1.2). Although not all of the rocks in these ancient cratons are that old, they are generally older than 3 Ga, as is part of the Wyoming Craton. The Hearne and Rae Cratons are older than 2 Ga, while most of the other parts of Laurentia are aged between 1 Ga and 2 Ga. The various provinces of Laurentia were assembled by plate-tectonic processes between 1 Ga and 3 Ga.

The areas of Figure 21.1.2 that are left uncoloured—the Appalachian, Innuitian, and Cordilleran fold belts—are geological regions that have been added to North America since 500 Ma. These are at least partly made up of sedimentary rocks that were deposited along the coasts and then folded, faulted, and uplifted during continental collisions.

The term *Laurentia* is geologically equivalent to the term **Canadian Shield**, although the latter is generally considered to be the area where the ancient Laurentian rocks are exposed at the surface and not covered with younger rocks. That applies to most of the region to the north and east of the red dotted line in Figure 21.1.2.

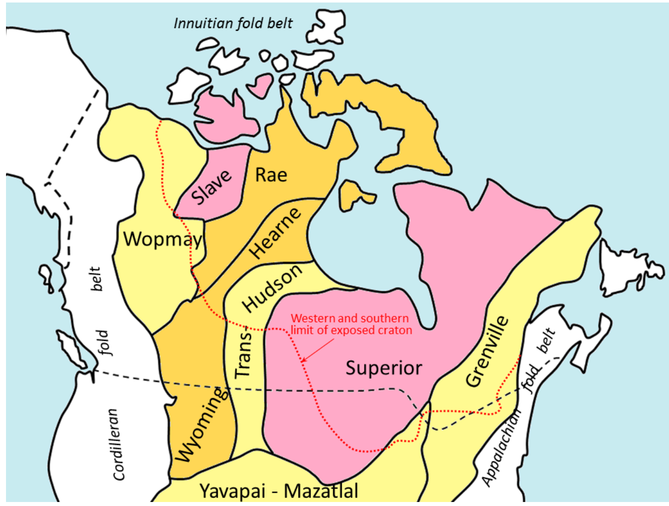

Figure 21.1.2 The main provinces of Laurentia. The pink areas are the oldest; light yellow are the youngest. All of the areas south and west of the dotted red line are now covered with younger rocks. The white areas represent rocks that were added to North America since 700 Ma. *[Image Description]*

Laurentia was part of the supercontinent Rodinia during the period between 1,100 Ma and 700 Ma. As Rodinia started to break up after 700 Ma, sediments derived from the erosion of the interior of the continent began to accumulate along its coasts, initially along the west coast, then the east coast at around 600 Ma, and finally on the north coast by around 550 Ma. This process continued for several hundred million years. By around 450 Ma, large areas of the interior of Laurentia were depressed below sea level—probably because of the downward pull of an underlying subducting plate—and marine sediments were deposited over parts of Quebec, Ontario, Manitoba, Saskatchewan, Alberta, and the Northwest Territories during the Ordovician, Silurian, and Devonian Periods (450 Ma to 350 Ma). These sediments are coloured various shades of blue on the geological map of Canada (Figure 21.1.3).

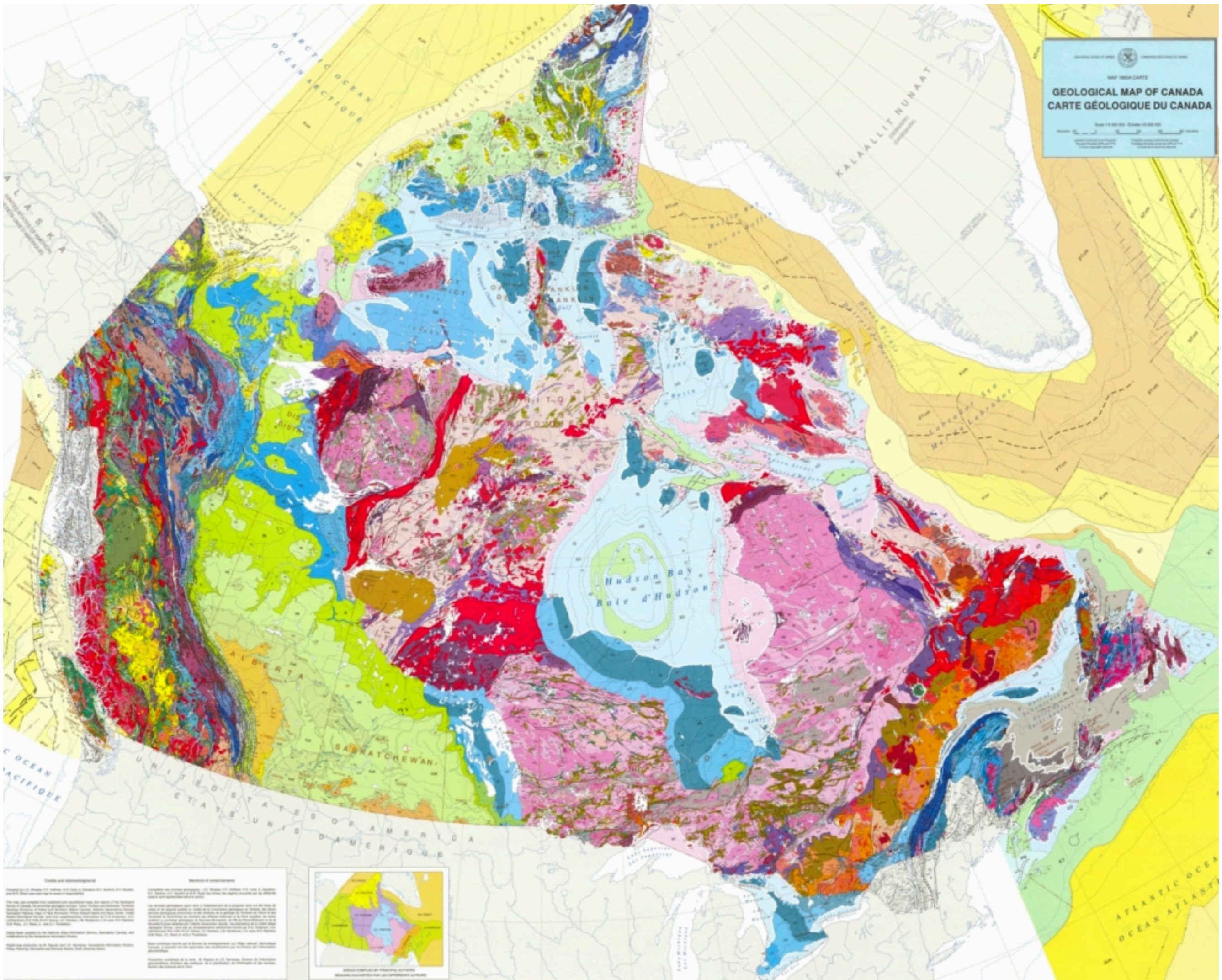

Figure 21.1.3 Geological map of Canada from the Geological Survey of Canada.

At approximately 350 Ma, the part of Gondwana that is now Africa collided with the eastern coast of North America, thrusting volcanic islands and sedimentary layers far inland to become the Appalachian fold belt. The Appalachian Mountains would likely have rivalled the Himalayas in extent and height during the Devonian. At about the same time, a smaller continent, Pearya, collided with the north coast, creating the Innuitian fold belt.

At around 200 Ma, small continents that now make up the interior of B.C. and part of Yukon collided with the west coast of North America, starting the process of thrusting the sedimentary rocks inland and upward to form the Rocky Mountains.

The west-central part of North America subsided once again at around 150 Ma, due to an underlying subducting plate, and this led to the deposition of more marine rocks across Manitoba, Saskatchewan, and Alberta, and north into the Northwest Territories and Yukon (the green areas in Figure 21.1.3).

Finally, at around 90 Ma, more small continents, which now comprise Vancouver Island and Haida Gwaii, collided with the west coast, leading to further uplift of the Rocky Mountains.

Exercise 21.1 Find the geological provinces of Canada

Figure 21.1.3 shows the geology of Canada in some detail, with the colours representing the lithologies and ages of the rocks. Identifying in Figure 21.1.3 some of the major features shown in Figure 21.1.2 will help you understand the distribution of Canada's geological features. Start by outlining the extent of the exposed Canadian Shield (the dotted red line); you might also be able to identify some of the cratons within the Shield. Then look for the limits of the Appalachian and Innuitian fold belts. Finally pick out the extent of the Cordilleran fold belt.

The best way to do this would be to print out a copy of Figure 21.1.3 and draw the boundaries from Figure 21.1.2 on it with a pencil.

If you're interested, you can get your own high resolution copy of the geological map of Canada: http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/fulle.web&search1=R=208175.

See Appendix 3 for Exercise 21.1 answers.

Image Descriptions

Figure 21.1.2 image description: Oldest areas: From Northern Quebec to southern Ontario. Also some land on northern part of the border between and Northwest Territories and Nunavut, including Victoria Island. The next oldest areas include most of central and eastern Nunavut, down through Alberta and Saskatchewan and into the United States. The youngest areas include northeastern British Columbia and up along the Yukon-Northwest Territory border. It also comes down through Manitoba and into the United States. The other youngest area stretches from Newfoundland and Labrador, down through eastern Quebec and into the United States before turning west through the central United States. The eastern and western coastal areas of the United States and Canada have been added in the last 700 Ma. [Return to Figure 21.1.2]

Media Attributions

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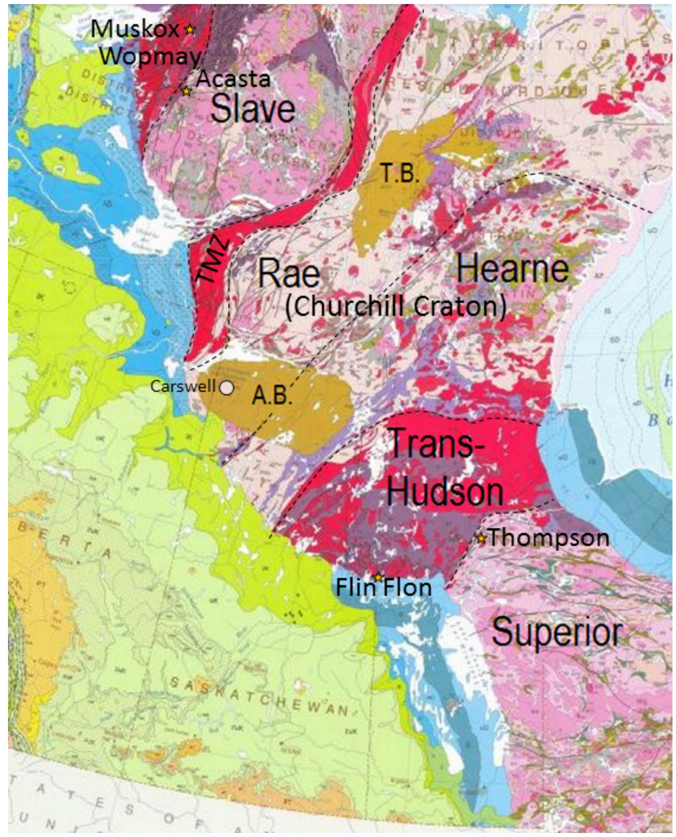
21.2 Western Canada during the Precambrian

Laurentia extends as far west as eastern B.C. (Figure 21.1.2), but the ancient rocks of the craton are almost completely covered by younger rocks in B.C., Yukon, and most of Alberta except the far northeast corner. Laurentia is well represented in northern Saskatchewan and across large parts of Manitoba, the Northwest Territories, and Nunavut (Figure 21.2.1). Where they are exposed, the rocks of the Canadian Shield are highly varied lithologically, typically strongly metamorphosed due to their deep burial at some time in the past, and in some cases, quite different from what could be expected to occur on Earth today.

Starting from the south, in eastern Manitoba and adjacent Ontario, we have the ancient rocks of the Superior Province. On the map the Superior Province, rocks are mostly pink, representing granitic and gneissic rocks, with strips and blotches of green, representing metamorphosed sea-floor basalt and sediments, also known as greenstone belts. These rocks are widely interpreted to have deep crustal origins, and include large areas of granulite facies metamorphic rock formed at high temperatures and moderate to high pressures (see Figure 7.3.7). Superior Province greenstone belts in Ontario and Quebec host some of the world's largest volcanogenic massive sulphide deposits. As described in Chapter 20, the Superior Province in northern Manitoba is host to important nickel deposits at Thompson. These formed from mantle-derived mafic magma that interacted with sulphur-bearing crustal rocks, and within which heavy-metal sulphide minerals formed.



21.2.1 The Trans-Hudson Orogen (THO), as its name implies, extends through Saskatchewan and Manitoba and over to the eastern side of Hudson Bay. It represents the continent-continent collision zone between the Superior Craton to the south and the Churchill Craton (including the Wyoming, Hearne, and Rae Cratons) to the north; thus it's a remnant of the initial formation of Laurentia at around 1.9 Ga. At the time of the collision, the THO would have been a major mountain range, and the rocks that we see there now — which evolved deep beneath those mountains — are highly metamorphosed sedimentary and volcanic rocks intruded by large granitic bodies. The important volcanogenic massive sulphide deposits around Flin Flon are within the THO.

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The Churchill Craton is lithologically similar to the Superior Craton, although not generally as old. It includes two important sedimentary basins: the Athabasca Basin in Saskatchewan and the Thelon Basin in Nunavut, both filled with rocks aged around 1.7 Ga. These consist primarily of sandstones and minor mudstones that are only weakly metamorphosed and essentially undeformed (not folded) because they are situated within a stable craton and so have not been subjected to significant tectonic forces. The Athabasca Basin is economically important for its large and rich unconformity-type uranium deposits (see Chapter 20). At its western end, there is the remnant of a large extraterrestrial impact, the 40 km diameter Carswell Crater. When the meteor struck at this location, at around 115 Ma, the impact and subsequent rebound of the crust was enough to bring metamorphic rock up to surface from beneath about 2,000 m of Athabasca Group sandstone. There is no connection between the Carswell Crater and the much older (~1.2 Ga) uranium deposits.

The Taltson Magmatic Zone (TMZ), which forms the boundary between the Churchill and Slave Cratons, consists primarily of granitic rock. One interpretation is that the TMZ formed along a convergent boundary, although this is not universally accepted.

The Slave Craton is dominated by granitic rocks and metamorphosed clastic sedimentary rocks. On its western edge, there is a large area of very old gneissic rock that includes the Acasta Gneiss, dated at 4.03 Ga, which—for the time being at least—is the oldest rock in the world (Figure 21.2.2).

Figure 21.2.2 A sample of the Acasta Gneiss on display at the Natural History Museum in Vienna.

The Wopmay Orogen, interpreted as the site of another ancient continent-continent collision, lies to the west of the Slave Craton. Although mostly composed of felsic igneous rocks and gneisses, the Wopmay Orogen includes a body of mafic and ultramafic igneous rock called the Muskox Intrusion. Derived from a mantle plume and dated at about 1.1 Ga, the Muskox is comparable to a handful of other mafic and ultramafic intrusions around the world in that it has distinctive repetitive layering caused by settling of heavy metal-rich minerals within the low-viscosity magma. Muskox has high levels of nickel, copper, and chromium, and has the potential to have platinum and palladium like a similar body in South Africa. Ultramafic intrusions like Muskox do not take place on Earth today because the mantle is no longer hot enough.

The oldest rocks in British Columbia are the strongly metamorphosed sedimentary, volcanic, and intrusive rocks of the Monashee Complex, situated to the west of the Columbia River near Revelstoke (Figure 21.2.3). Aged around 2 Ga, these may actually be part of Laurentia.

There are much more extensive Precambrian rocks within the Columbia and Rocky Mountains of southeastern B.C. and the southwestern corner of Alberta. The rocks of the Purcell Supergroup (a **supergroup** comprises more than one group) are present in the extreme southeastern corner of B.C. and adjacent Alberta, and extend well into the United States (as the Belt Supergroup). These are mostly unmetamorphosed clastic rocks deposited in rivers and lakes during the middle Proterozoic, at around 1,400 Ma, while Laurentia was still part of the supercontinent Columbia. When Columbia rifted apart, the division happened within the area of the Purcell/Belt rocks. Similar rocks of the same age are present in Tasmania and Siberia, and it is postulated that they were once part of the same depositional basin.

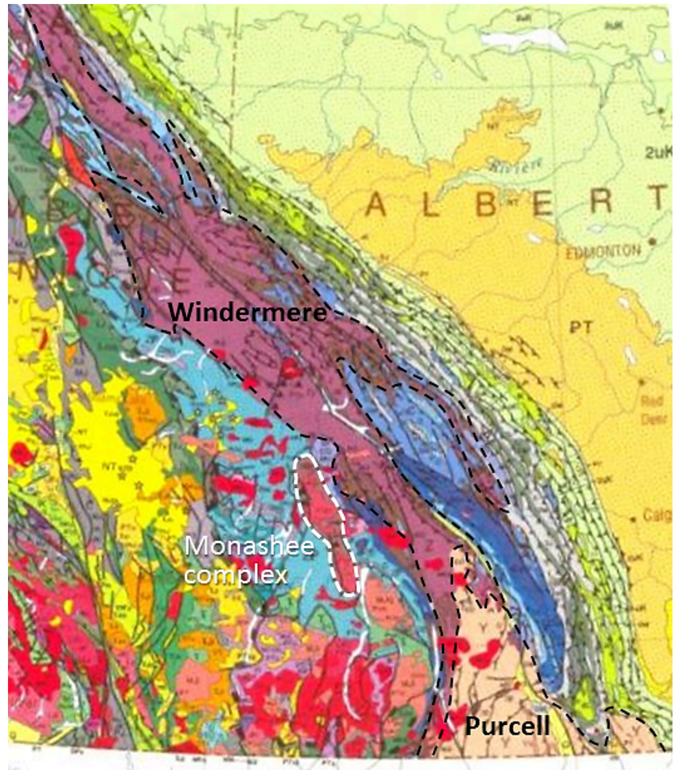

Figure 21.2.3 Precambrian rocks in southern B.C. and Alberta.

Exercise 21.2 Purcell rocks down under?

This map shows the geology of the Australian state of Tasmania. Identify which rocks might be comparable to the Purcell rocks of B.C. and Alberta.

In what way are these rocks different from those in Canada?

See Appendix 3 for [Exercise 21.2 answers.]

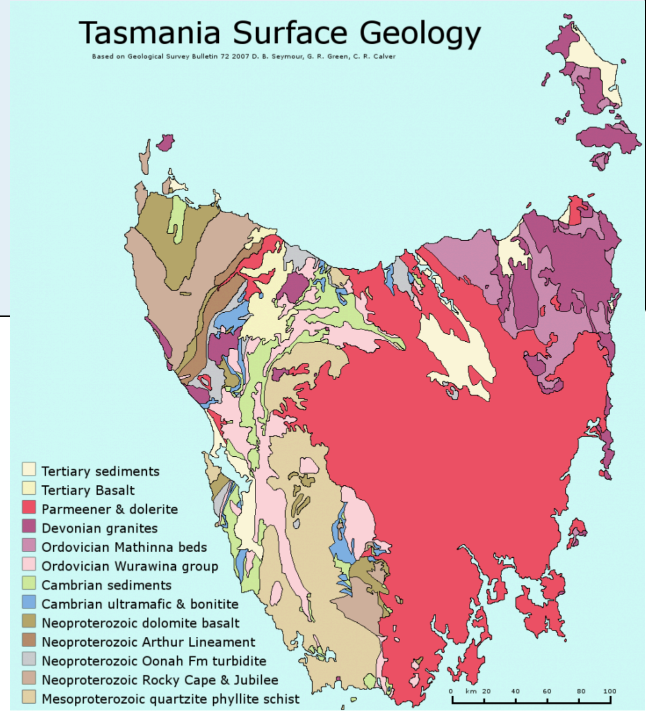

Figure 21.2.4

The Windermere Group rocks—also mostly clastic sedimentary—were deposited in the ocean along the western edge of Laurentia (Figure 21.2.3) in the late Proterozoic (around 700 Ma) after the breakup of Columbia. In fact, sedimentary rocks of this age extend all along the western side of the Rocky Mountains, well into Yukon.

Deposition in this area was taking place during the late Proterozoic Snowball Earth glaciations, as can be seen in Windermere Group rocks of the Toby Formation from the area south of Cranbrook, B.C. (Figure 21.2.5). The Toby Formation is a fine-grained marine rock (mudstone) with numerous large angular clasts of limestone and quartz. The mud was deposited in the quiet water of a continental slope environment, and the large clasts were dropped from floating ice derived from glaciers on Laurentia. The Toby Formation is unique in this area; most of the rest of the late Proterozoic clastic sedimentary rocks in this region do not have glacial dropstones.

Figure 21.2.5 Late Proterozoic Toby Formation mudstone with glacial dropstones, south of Cranbrook, B.C.

Media Attributions

- Figure 21.2.1: "[Geological Map of Canada]" by J. O. Wheeler, P. F. Hoffman, K. D. Card, A. Davidson, B. V. Sanford, A. V. Okulitch, and W. R. Roest. The Government of Canada retains the copyright of this image but allows for reproduction for non-commercial use. Image edited by Steven Earle.
- Figure 21.2.2: "[Acasta gneiss]" © Pedroalexandrade. CC BY-SA.
- Figure 21.2.3: "[Geological Map of Canada]" by J. O. Wheeler, P. F. Hoffman, K. D. Card, A. Davidson, B. V. Sanford, A. V. Okulitch, and W. R. Roest. The Government of Canada retains the copyright of this image but allows for reproduction for non-commercial use. Image edited by Steven Earle.

21.3 Western Canada during the Paleozoic

At the beginning of the Paleozoic (542 Ma), Laurentia was near the equator (Figure 21.1.1) and sedimentation was continuing on all of Laurentia's marine margins, including the passive margin (not tectonically active) on what is now the west coast. The clastic sediments of the Windermere Group are succeeded by mostly limestone beds (represented by the blue areas in Figure 21.2.3) interbedded in some areas with mudstone and sandstone. The most famous Cambrian rocks in the Rockies are those around Field, B.C., within Yoho and Kootenay National Parks. The Burgess Shale of the Stephen Formation is considered by some to be the most important fossil bed in the world because of its spectacular preservation of detail in a wide array of organisms that are ancestors to many of today's organisms and are not present in earlier rocks. The Walcott Quarry, on the pass between Mt. Field and Wapta Mountain has been known and studied for over 100 years (Figure 21.3.1). In 2012 a new Burgess Shale discovery was made at Marble Canyon, about 30 km to the southeast, by a team led by the Royal Ontario Museum (ROM). Fossils with similar levels of preservation are present, and several previously unknown organisms have been found. The ROM continues to work in the Marble Canyon area and some of their discoveries are described and illustrated on their website, such as a discovery of a large Burgess Shale fossil site in 2014. The Paleozoic strata of the Rockies also include Ordovician, Devonian, Carboniferous, and Permian sedimentary rocks. For example, Carboniferous limestone makes up most of the upper part of Crowsnest Mountain in southern Alberta (Figure 21.0.1).

Figure 21.3.1 The Cambrian Burgess Shale at the Walcott Quarry, Yoho Park, B.C., with Wapta Mountain in the upper right.

While clastic and carbonate sediments were accumulating along the western edge of Laurentia, much of the interior of the continent was submerged under inland seas that were connected to ocean most of the time. This region is known as the Western Canada Sedimentary Basin (WCSB). The Paleozoic sediments that accumulated within this basin show up as the blue areas in Figures 21.1.3 and 21.2.1; however, their extent is much wider than that because Paleozoic sedimentary rocks also underly the Mesozoic rocks within most of the areas that are light green on those maps. By way of example, a schematic cross-section through the Paleozoic and Mesozoic rocks of southern Manitoba is given in Figure 21.3.2. The section extends from the Saskatchewan-Manitoba border on the left to just east of Winnipeg on the right, and shows the Paleozoic rocks overlain on the rocks of the Precambrian Superior Craton.

Fifteen different Paleozoic formations, ranging in age from Ordovician to Carboniferous, are shown in Figure 21.3.2. Of these, 11 are dominated by carbonate rocks (limestone or dolomite) that very likely formed in an ocean-connected marine environment. The non-carbonate formations are the lowermost one (resting on Precambrian rocks), which is sandstone of marine origin; the Devonian Prairie Evaporite Formation (in red)—the same formation from which potash is mined in Saskatchewan; and the upper two Devonian formations (in yellow), which are shale. When the Prairie Evaporite formed, the basin was isolated from the open ocean, and the rate of evaporation was greater than the rate of input from precipitation and river inflow. During that time, probably at least several million years, there were numerous changes in sea level or land level that allowed additional ocean water—and therefore additional salt—into the basin.

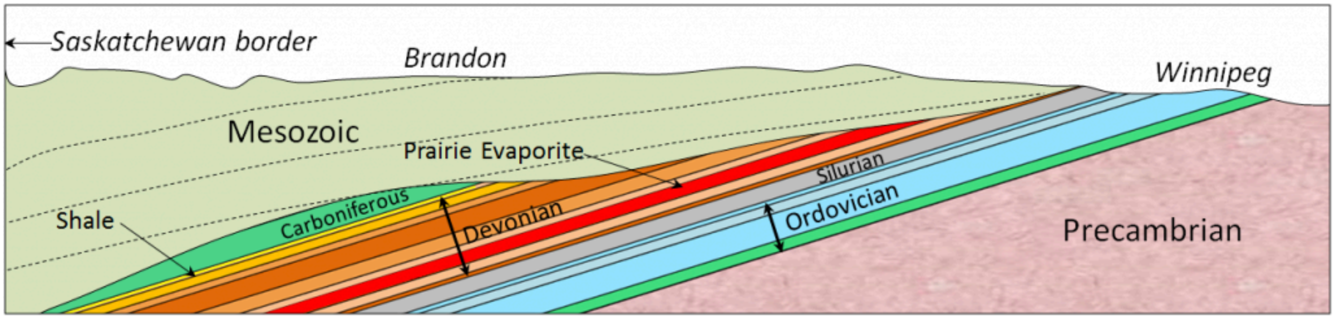

Figure 21.3.2 The Paleozoic sedimentary rocks of southern Manitoba along a section extending from the Saskatchewan border on the left to the Winnipeg area on the right. The section is 400 km wide and 1,800 m high, and the vertical exaggeration is about 100 times. The dip of the beds is also exaggerated by 100 times; their original and current attitudes are close to horizontal.

There are Paleozoic rocks in the central and western parts of British Columbia and Yukon, but they formed far away and did not become part of North America until the Mesozoic. Subduction started along the western edge of Laurentia by the middle Paleozoic. That meant that oceanic crust was moving toward the continent, bringing small segments of exotic continental crust with it (Figure 21.3.3). These crustal blocks along western North America are called **terranes**, indicating that they are sections of the continent that have an exotic origin (Figure 21.3.4). Most of British Columbia is made up of terranes that include sedimentary rocks with fossils that imply an origin south of the equator, or volcanic rocks with magnetic orientations that indicate a southern-hemisphere origin.

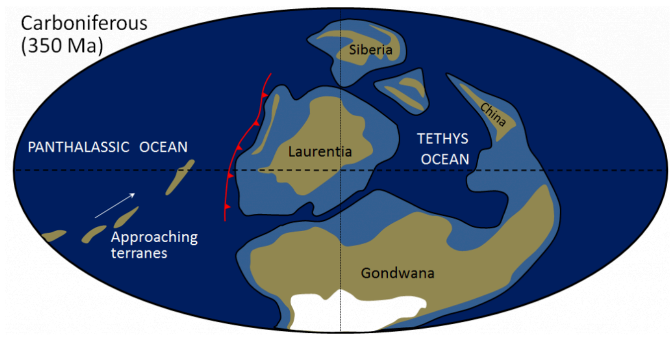

Figure 21.3.3 The distribution of continents in the early Carboniferous, showing the terranes that later became attached to the west coast of North America. The light blue areas are continental shelves, the white is ice of the Karoo Glaciation, and the red line shows subduction of oceanic crust beneath Laurentia. Panthalassic is the name for the huge ocean that preceded the Pacific Ocean.

Figure 21.3.4 The Carboniferous Mt. Mark Formation on Vancouver Island is part of the Wrangellia Terrane, which arrived on the edge of North America during the Cretaceous.

Exercise 21.3 What is Vancouver Island made of?

This map shows the main geological features of the Wrangellia Terrane rocks that were present when Vancouver Island arrived on the coast of North America.

1. Roughly what percentage of Vancouver Island is underlain by Paleozoic rock?
2. What is the most common age and type of rock on Vancouver Island?

To answer these questions, you might find it useful to fill in each rock type area using coloured pencils.

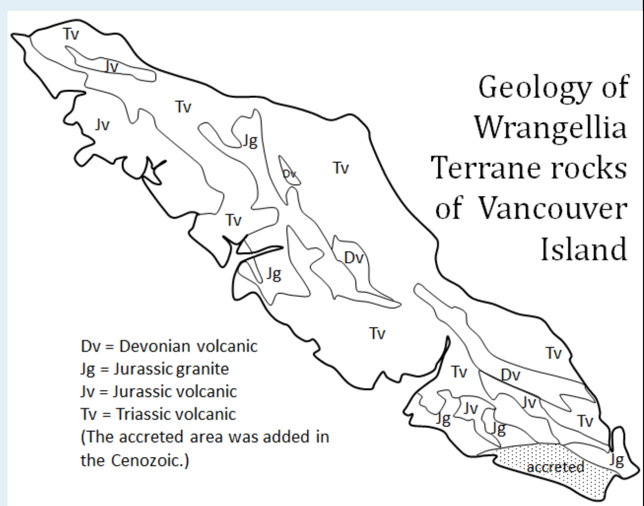

Figure 21.3.5 Rocks of Vancouver Island: Triassic volcanic, Devonian volcanic, Jurassic granite, and Jurassic volcanic.

See Appendix 3 for [Exercise 21.3 answers.]

Media Attributions

- Figure 21.3.3: © Steven Earle. CC BY. Based on information from Christopher Scotese.

21.4 Western Canada during the Mesozoic

The Mesozoic extends over 187 million years from the beginning of the Triassic (252 Ma) to the end of the Cretaceous (65.5 Ma). It was a particularly important period for the geology of western Canada. During this time, several continental collisions occurred along the west coast, resulting in the formation of the Rocky Mountains and the **accretion** (addition) of much of the land mass of British Columbia, and continuing deposition within the WCSB.

Terrane Accretion in British Columbia and Yukon

Continued subduction along the western edge of North America carried a number of continental terranes toward the coast, with the first collisions taking place in the early part of the Triassic, as the Quesnel, Cache Creek, and Stikine Terranes combined to form the Intermontane Superterrane, so named because it forms the interior plateau of British Columbia, between the Rockies to the east and the Coast Range to the west (Figure 21.4.1).

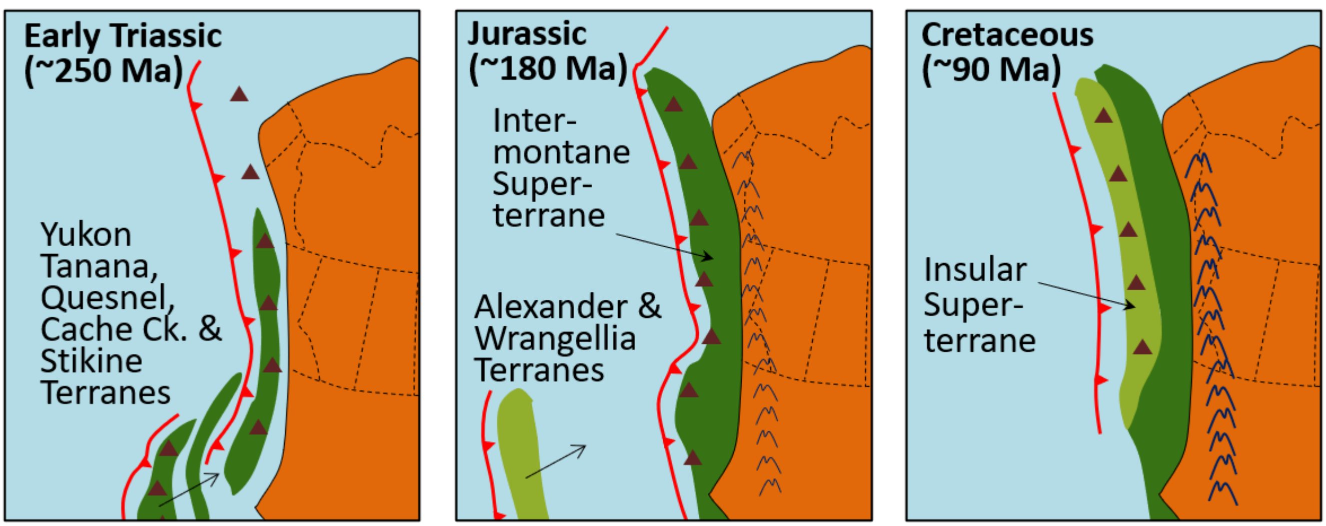

Figure 21.4.1 Model of the accretion of the Intermontane and Insular Superterranes to the west coast of North America during the Mesozoic. Subduction zones are the red-toothed lines. The dark-red triangles represent volcanoes. [Image Description]

Approximately 100 million years later, another pair of terranes—Alexander and Wrangellia—collided to form most of Vancouver Island and Haida Gwaii, plus a significant part of Alaska. During the Cenozoic, additional terranes (the Outboard terranes) were added to the western edge of North America. An overview of the accreted terranes of B.C., Yukon, and Alaska is given in Figure 21.4.2.

During the Jurassic, the Intermontane Superterrane acted like a giant bulldozer, pushing, folding, and thrusting the existing Proterozoic and Paleozoic west coast sediments eastward and upward to form the Rocky Mountains (Figure 21.4.3). The same process continued into the Cretaceous as the Insular Superterrane collided with North America and pushed the Intermontane Superterrane farther east. Folding in Rocky Mountain rocks, like that shown in Figures 21.4.4 and 21.4.5, is one of the results of this process.

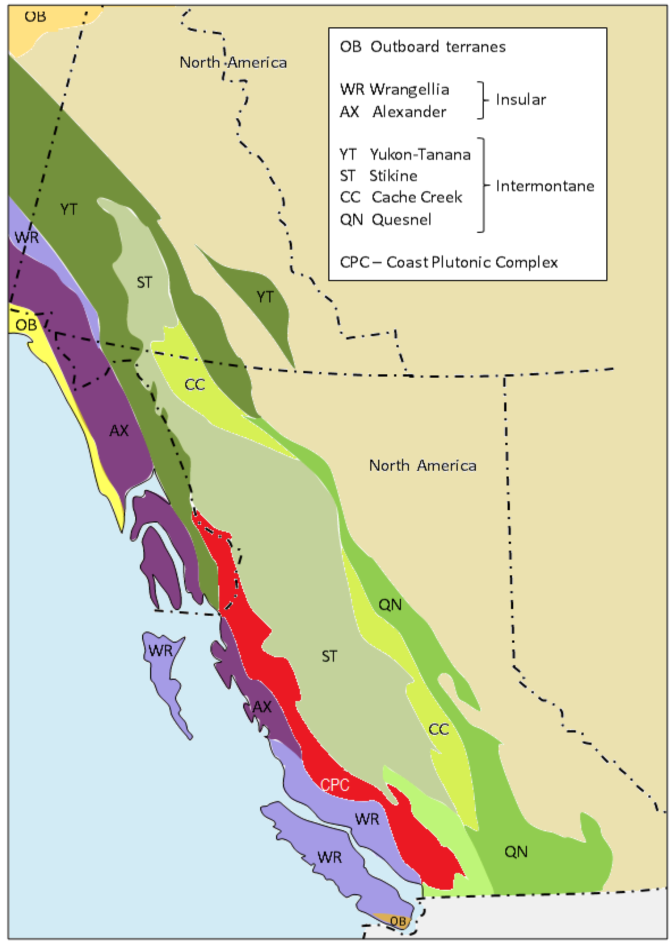

Figure 21.4.2 A generalized overview of the accreted terranes of B.C., Yukon, and Alaska. The Intermontane terranes are in green, the Insular terranes in purple, and the Outboard terranes in yellow. The Coast Plutonic Complex (CPC) formed in situ and is not a terrane. [Image Description]

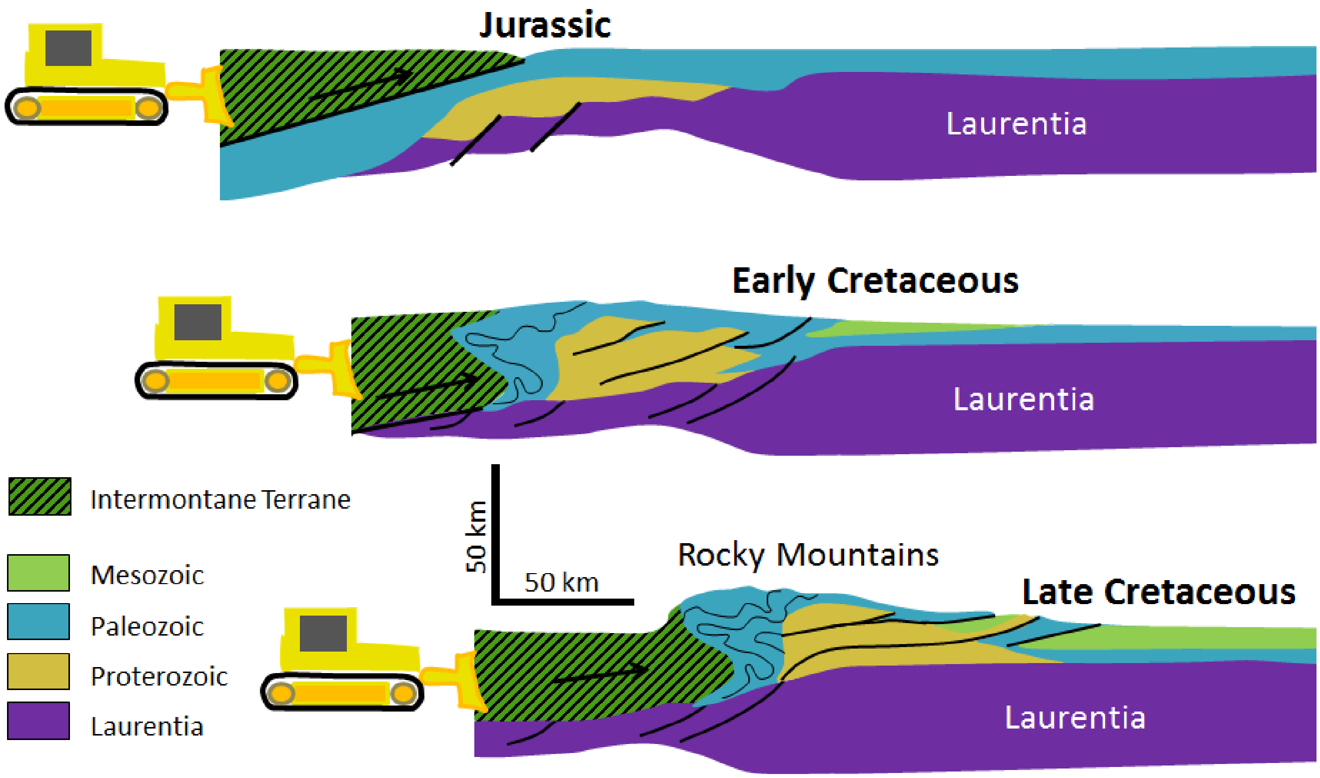

Figure 21.4.3 Cross-section of the accretion of the Intermontane Superterrane to the west coast of North America and the resulting compression, folding, and thrusting of North American sedimentary rocks. In the Late Cretaceous, it was the accretion of the Insular Superterrane pushing against the Intermontane Superterrane that did most of the work.

Figure 21.4.4 Tight folds in sedimentary rocks of the Rocky Mountains near Field, B.C.

Figure 21.4.5 Folding of sedimentary rocks at Mt. Rae, Alberta.

Thrusting is another important process in the formation of fold-belt mountains, as described in Chapter 12. During plate convergence, entire sheets of sedimentary rock are slowly pushed over top of other sheets, resulting in situations where older rocks lie on top of younger ones. One of the best known examples of this is at Mt. Yamnuska, near Exshaw, Alberta (Figure 21.4.6), where the older Cambrian rocks were pushed east by a total of 40 km, over top of younger rocks.

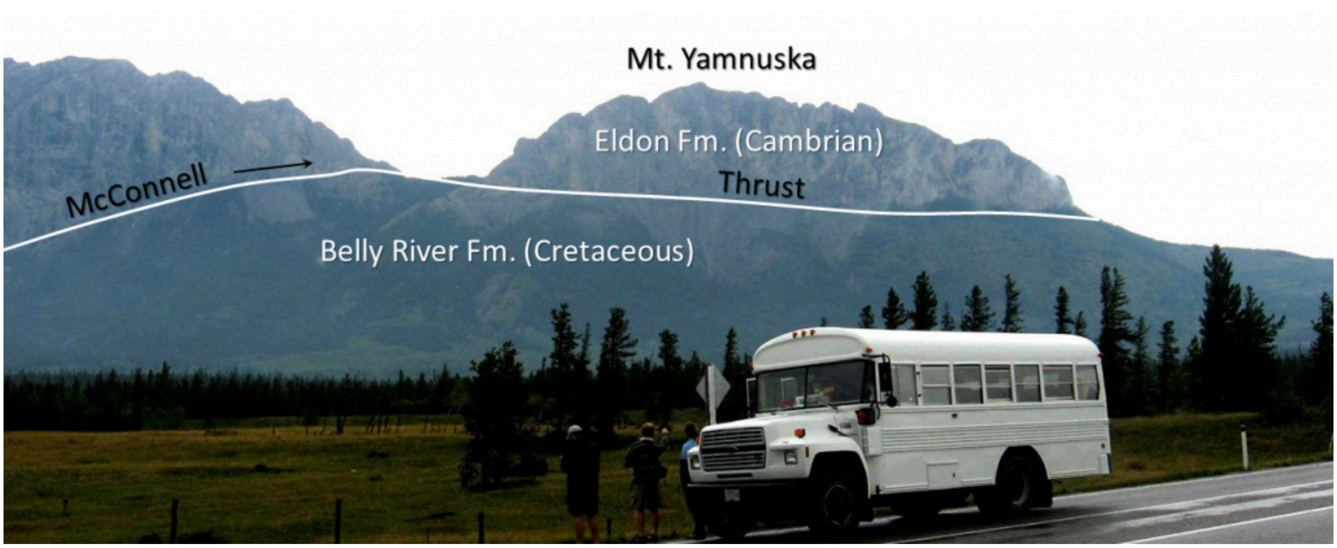

Figure 21.4.6 The McConnell Thrust at Mt. Yamnuska near Exshaw, Alberta. Carbonate rocks of Cambrian age have been thrust over top of Cretaceous mudstone.

In the area near the U.S. border, within B.C., Alberta, and Montana, a sheet of Paleozoic rocks has been thrust about 80 km east over top of Cretaceous rocks along the Lewis Fault (Figure 21.4.7).

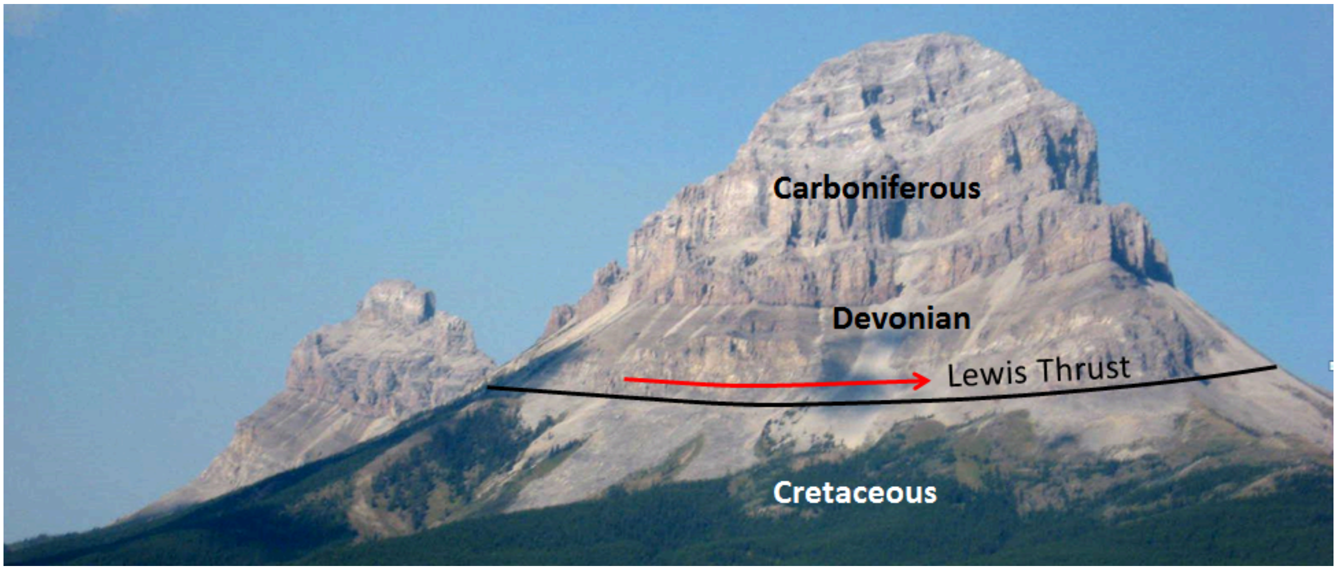

Figure 21.4.7 The Lewis Thrust at Crowsnest Mountain near Frank, Alberta. Carbonate rocks of Devonian and Carboniferous age have been pushed 80 km to the east and thrust over top of Cretaceous mudstone.

Not only did the subduction of oceanic crust beneath North America during the Mesozoic deliver geologically exotic terranes to the western edge of the continent, it also resulted in massive amounts of volcanism along the boundary (Figure 21.4.1). The upper-crustal magma chambers that fed those now-eroded volcanoes slowly cooled into granitic and dioritic stocks, and those stocks gradually coalesced into batholiths that extend from the southwest corner of B.C. all the way into Yukon and Alaska (Figures 21.4.8 and 21.4.9). Most of the granitic rocks of this region fall into two main age ranges: many are middle-Jurassic to early Cretaceous in age (~ 170 Ma to 140 Ma), while others are late Cretaceous to Paleogene (~50 Ma to 90 Ma). Many of the older bodies intruded into the terranes they are on before they arrived on the North America coast. This applies to those on Vancouver Island and Haida Gwaii. Some of the older ones formed in situ when the subduction zone was farther east (see Figure 21.4.1). Most of the younger bodies formed in situ when the subduction zone was close to where it is now (west of Vancouver Island) or slightly to the east.

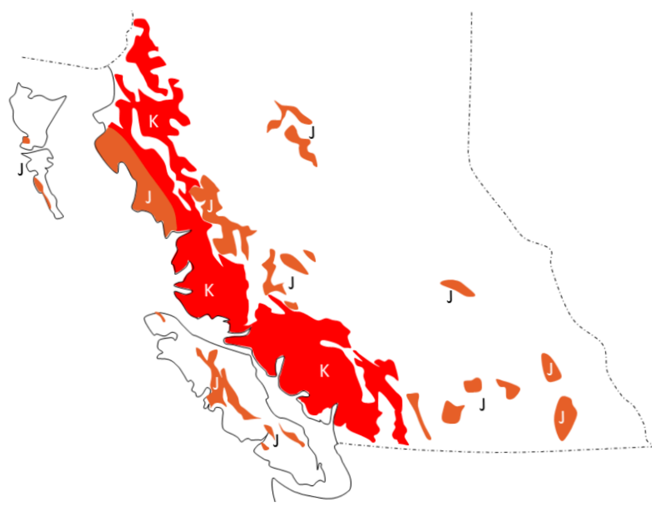

Figure 21.4.8 Jurassic (J) and Cretaceous (K) granitic bodies in south-central B.C. [Image Description]

Although these intrusive igneous rocks cooled at depth in the upper crust, they now form some of the highest peaks in Canada, many of them hundreds of metres higher than those of the Rocky Mountains (including Mt. Waddington, the highest peak entirely within British Columbia at 4,091 m). It is estimated that over the past 100 million years some of these igneous bodies have been uplifted in the order of 8,000 m. Much of that uplift is a result of the relative low density of the granitic rocks compared with the surrounding rocks.

Figure 21.4.9 Jurassic-Cretaceous granite adjacent to the Coquihalla Highway, north of Hope, BC. (The dark streaks are water from melting snow.)

The Western Canada Sedimentary Basin during the Mesozoic

The construction of the Rocky Mountains during the Jurassic and Cretaceous—and their ensuing erosion—created a significant new source of sediments for the WCSB. Based on the ages, distributions, and thicknesses of the sedimentary layers (Figure 21.4.11), it is evident that the greatest volumes of sediment were produced in the Upper Cretaceous (100 Ma to 65 Ma) and into the Paleocene (65 Ma to 55 Ma). The sediments accumulated in a basin that is thought to have been at least partly formed by the presence of a subducting slab of oceanic lithosphere underneath this part of North America. However, the ongoing uplift of the Rockies through this time period also led to isostatic depression of the crust. The western edge of the basin, which has about 4,500 m of Mesozoic rock alone, is a foreland basin. (See Chapter 6 for more on the origins of basins.)

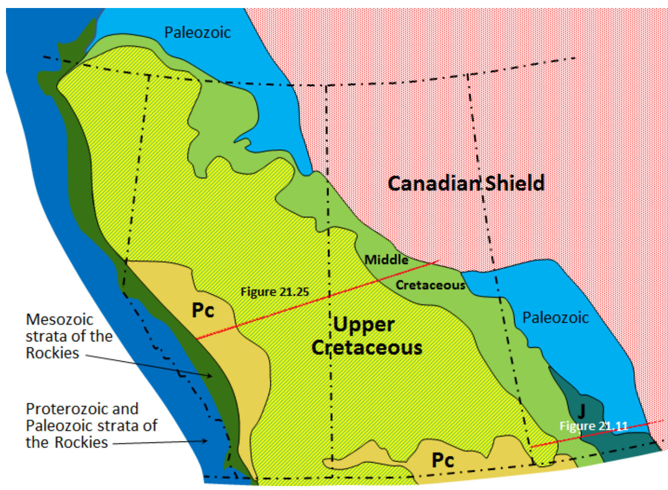

Figure 21.4.10 The distribution of Mesozoic sedimentary rocks in the Western Canada Sedimentary Basin. J stands for Jurassic and Pc for Paleocene. The lines of the cross-sections of Figures 21.3.2 and 21.4.11 are shown. [Image Description]

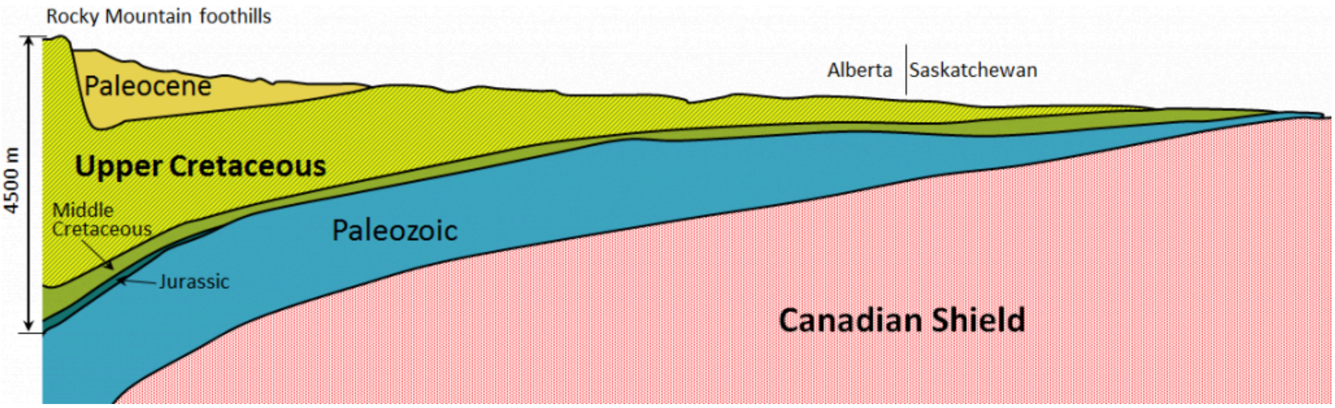

Figure 21.4.11 A cross-section showing the Mesozoic sedimentary rocks in the WCSB from the Rocky Mountain foothills to north-central Saskatchewan. [Image Description]

From time to time during the Mesozoic, the WCSB was filled to varying degrees with marine water. The Jurassic rocks at the base of the sequence are marine in origin, although the Jurassic sequence in Manitoba also includes evaporite layers. Most of the Middle Cretaceous rocks across the basin are marine, but the majority of the Upper Cretaceous rocks are of terrestrial origin, deposited within the flood plains and deltas of rivers. Some of these terrestrial sediments include coal layers; as described in Chapter 20, there are significant coal deposits in central Alberta.

The Paleozoic sediments within the WCSB were buried deeply beneath the Mesozoic sediments and were heated enough to form both oil and gas. There are large petroleum resources in reservoir rocks of various ages extending from northeastern B.C. to southwestern Manitoba.

Figure 21.4.12 The Horseshoe Canyon Formation near Drumheller, Alberta.

Several of the terrestrial Cretaceous formations in the WCSB are host to important dinosaur fossils. Some are within B.C. and Saskatchewan, but the most famous are in Alberta, including the Dinosaur Park Formation (Figure 6.0.1), the Scollard Formation, and the Horseshoe Canyon Formation (Figure 21.4.12). The Dinosaur Park Formation has one of the greatest concentrations of dinosaur fossils of any rock on Earth, with at least 50 genera of dinosaurs represented, ranging from tiny *Hesperonychus* to giant *Albertosaurus.* The Hilda Bone Bed, situated about 80 km to the east of Dinosaur Park, is estimated to have the remains of approximately 1500 ceratopsians, all of which are interpreted to have died in a flood related to a tropical storm. A few of the larger herbivorous dinosaurs found at Dinosaur Park are illustrated in Figure 21.4.13.

Figure 21.4.13 Depiction of some of the large herbivorous dinosaurs from the upper part of the Dinosaur Park Formation. Left to right: the ceratopsian Pentaceratops , the hadrosaur Lambeosaurus eating from a tall tree, the ceratopsian Styracosaurus, the ankylosuar Scolosaurus, the hadrosaur Prosaurolophus (in the distance), the ankylosaur Panoplosaurus, and a herd of Styracosaurs in the background.

Exercise 21.4 Dinosaur country?

The photo is from the Cretaceous Dinosaur Park Formation in Alberta. What characteristic of this rock tells you that it might be suitable for the discovery of the fossils of dinosaurs or other terrestrial organisms?

Figure 21.4.14

See Appendix 3 for Exercise 21.4 answers.

Several important depositional basins existed in British Columbia during the Mesozoic, including the large Jurassic-aged Bowser Basin north of Terrace, and the smaller late-Cretaceous Nanaimo Basin between Vancouver Island and the mainland. In both cases, the rocks are mostly clastic, with both terrestrial and marine deposition.

Image Descriptions

Figure 21.4.1 image description: During the early Triassic period (around 250 Ma), subduction along the west coast of North America caused the Quesnel, Cache Creek, and Stikine Terranes to collide with the continent. By the Jurassic persion (180 Ma), the collision had caused the formation of mountains along the coast and the creation of the Intermontane Superterrane, the present interior plateau of British Columbia. The Alexander and Wrangellia Terranes were also pulled towards the coast and by the Cretaceous period (around 90 Ma), they had formed the Insular Superterrane. [Return to Figure 21.4.1]

Figure 21.4.2 image description: This image shows two groups of terranes, the Intermontane terranes and the Insular terranes. The Intermontane terranes make up the interior portions of present-day British Columbia and the Yukon. The Yukon-Tanana terrane in the Yukon and the Quesnel terrane in BC are the farthest inland. As you move closer to the coast, there is the Cache Creek terrane and the Stikine terrane. Then comes the Insular terrane group. This includes the Alexander terrane and the Wrangellia terrane, which make up the coast and islands of British Columbia. [Return to Figure 21.4.2]

Figure 21.4.8 image description: Cretaceous rocks cover a lot of the southwest coast of BC and a bit in the north. Jurassic rocks can be found on the northwest coast of BC, scattered sparsely through the interior, and a bit on Haida Gwaii, and Vancouver Island. [Return to Figure 21.4.8]

Figure 21.4.10 image description: The age and location of sedimentary rocks in the Western Canada Sedimentary Basin

Period/Era/ Epoch	**Age (Ma)**	**Location of sedimentary rocks**
Paleozoic Era	540 to 251	• southern part of Northwest Territories • northeast corner of Alberta • central Manitoba
Jurassic Period	202 to 146	• a small strip in southwest Manitoba
Middle Cretaceous Period	145 to 100	• a thin strip that runs from the south of Northwest Territories down to southwest Manitoba
Upper Cretaceous Period	100 to 66	• runs from the north east corner of BC, down through most of Alberta, to central and southern Saskatchewan
Paleocene Epoch	65 to 55	• southwest parts of Alberta • along the Saskatchewan-United States border

[Return to Figure 21.4.10]

Figure 21.4.11 image description: At the Rocky Mountian foothills, the Paleozoic sedimentary rocks are buried over 4500 metres under Mesozoic sedimentary rocks. At the Alberta-Saskatchewan border,

the Mesozoic layers are much thinner, so the Paleozoic sedimentary rocks are much nearer to the surface.
[Return to Figure 21.4.11]

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- Figure 21.4.14: © Steven Earle. CC BY.

21.5 Western Canada During the Cenozoic

Two additional relatively small terranes collided with North America early in the Cenozoic. At around 55 Ma metamorphosed sedimentary and volcanic rocks of the Pacific Rim Terrane were forced a few tens of kilometres underneath the west coast of Vancouver Island (Figure 21.5.1).

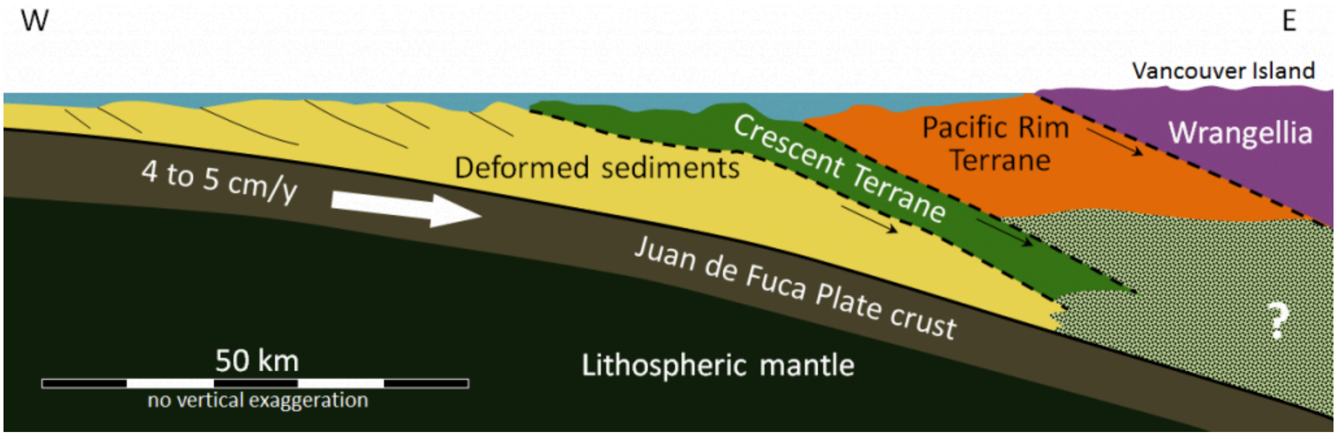

Figure 21.5.1 East-west cross-section showing the accretion of the Pacific Rim and Crescent Terranes beneath Vancouver Island, and the ongoing subduction of the Juan de Fuca Plate. The dashed lines are inactive faults.

These rocks are distributed along the west coast of the island and in the area around Victoria (Figure 21.5.2). At around 42 Ma, sea-floor pillow basalt and gabbro of the Crescent Terrane was accreted to the southern margin of Vancouver Island and also to the adjacent part of Washington State (Figuer 21.30). These two terranes are shown as “Outboard terranes” in Figure 21.4.2.

The accretion of the Pacific Rim and Crescent Terranes had the effect of pushing Vancouver Island closer to the North American mainland, resulting in the uplift of the sediments deposited within the Nanaimo Basin to form islands in the Strait of Georgia (Figure 21.5.3) and mountains on Vancouver Island.

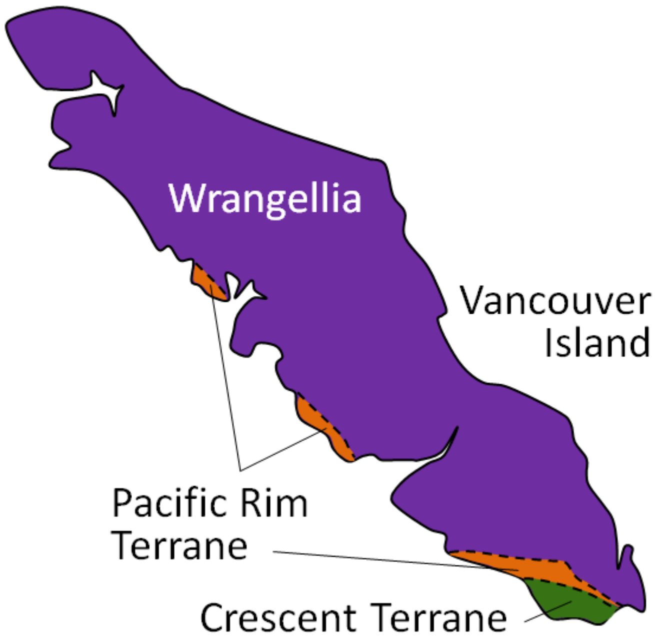

Figure 21.5.2 The distribution of Pacific Rim and Crescent Terrane rocks on Vancouver Island.

Figure 21.5.3 The Geoffrey Formation of the Nanaimo Group on Ruxton Island, B.C.

Following these events, the subduction of the Juan de Fuca Plate, which is a remnant of the former, much larger, Farallon Plate, was re-established at its current location farther to the west of Vancouver Island. This subduction—and that of the North America Plate beneath Alaska—has produced recently active volcanoes in Alaska, and all along the west coast from southwestern B.C. to northern California (Figure 21.5.4). In southwestern B.C. there are several dormant volcanoes of Pleistocene age (including Garibaldi and Meager) that trend along a line that also passes through Mt. Baker in Washington State. About 40 km to the east is a trend of slightly older igneous complexes (Pliocene to Oligocene). The displacement between these belts could be explained by a westward shift in the position of the subduction zone over that time period. The subduction and transform boundaries along this coast also generate relatively frequent earthquakes throughout this region, as illustrated in Exercise 11.1.

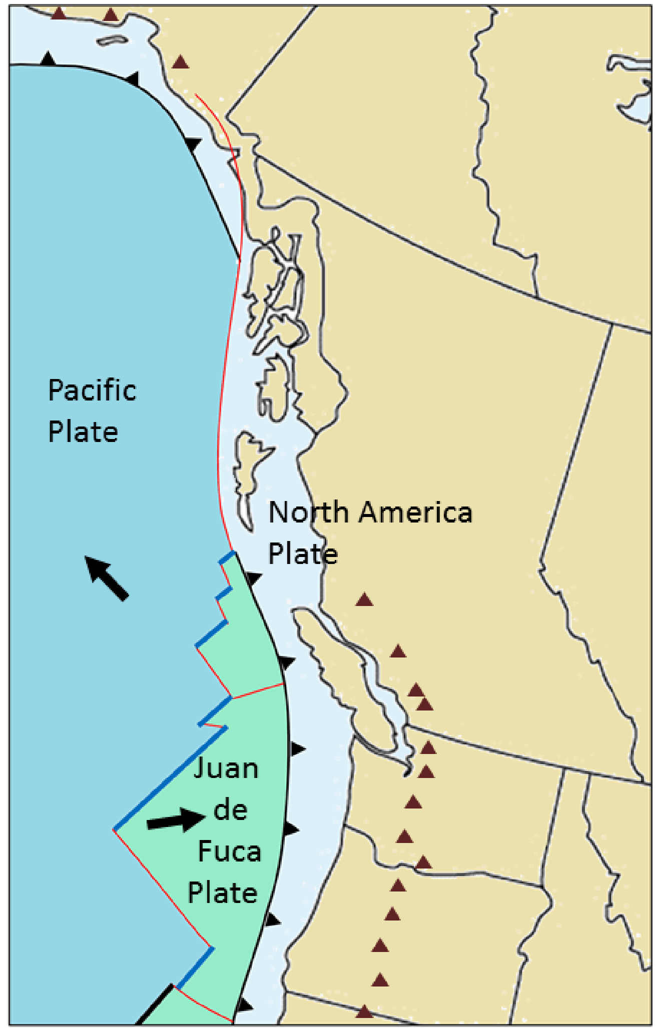

Figure 21.5.4 The current plate situation along the western edge of northern North America. Blue lines are divergent boundaries, red lines are transform boundaries, and black lines with teeth are subduction boundaries. The dark red triangles are volcanoes. [Image Description]

Sedimentation in the Western Canada Sedimentary Basin continued into the Cenozoic (Figure 21.4.10) with deposition of the Paskapoo Formation adjacent to the Rockies in Alberta (Figure 21.5.6), the Ravenscrag Formation in the Cypress Hills of southern Alberta and Saskatchewan, and the Turtle Hills Formation in southern Manitoba. All of these strata were deposited in terrestrial fluvial and deltaic environments, and all of them include coal deposits. Numerous mammalian (and other) fossils have been found in these rocks in Alberta and Saskatchewan. The mammals include primitive ungulates (ancestors to the deer and their relatives), a type of pangolin, a colugo (a gliding mammal that was possibly a primate ancestor), and some true primates in the suborder Plesiadapiformes, which became extinct and are not ancestors to any modern primates.

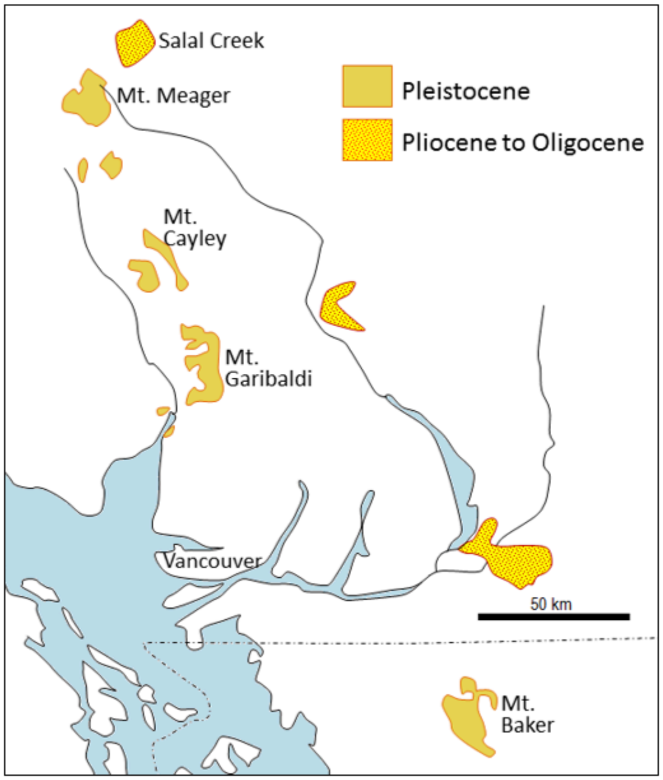

Figure 21.5.5 Oligocene to Pleistocene igneous complexes and volcanoes in southwestern B.C. and adjacent Washington.

Figure 21.5.6 The Paskapoo Formation exposed on the banks of the Red Deer River, Alberta.

Exercise 21.5 The volume of the Paskapoo Formation

The area underlain by the Paleocene Paskapoo Formation is outlined in yellow on the map shown here. The Paskapoo ranges up to about 1,000 m thick, and contours of its thickness (known as isopachs) are shown. The average thickness is about 500 m, and the area covered by the formation is about 90,000 km^2. This means that the rock has a volume of about 45,000 km^3. The sediments of the Paskapoo were derived from the Paleocene Rocky Mountains, within the area shown in blue, which is about 60,000 km^2.

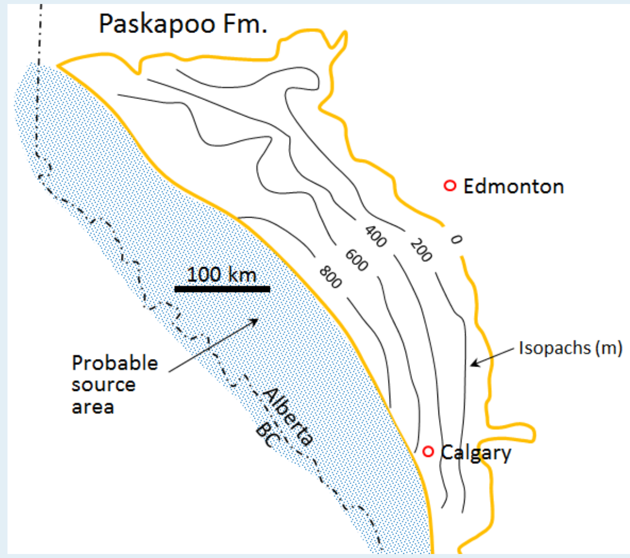

Figure 21.5.7

1. What average depth of erosion would have been required within the source area to produce the 45,000 km^3 of sediment, assuming that all of the eroded sediment ended up in the Paskapoo Formation?
2. The Paskapoo was deposited over a period of 4 million years from 62.5 Ma to 58.5 Ma. Assuming an average thickness of 500 m, what was the average rate of deposition (in mm/year) over that period?

See Appendix 3 for [Exercise 21.5 answers.]

Rocks younger than Paleocene (i.e., younger than 55 Ma) are relatively rare across the prairies, but there are widespread Eocene-aged volcanic and sedimentary rocks in central and southern B.C. The Kamloops Group includes the Tranquille Formation, made up of lacustrine (lake deposited) sediments, overlain by the Dewdrop Flats Formation of basaltic and andesitic volcanic flows and breccias. The Tranquille Formation includes the McAbee Beds and a number of other important sites with Eocene fossils (Figure 21.5.8).

Figure 21.5.8 The Tranquille Formation at the McAbee fossil site west of Kamloops, B.C.

The earliest Pleistocene glaciation in Canada started at about 2.64 Ma (late Pliocene) in the Klondike area of Yukon. This was part of the Cordilleran Ice Sheet. The Laurentide Ice Sheet started to form shortly afterward, and within 200,000 years had covered a large part of Canada and extended well into the United States. The Pleistocene glaciations had a major impact on the topography and geology of western Canada, creating extraordinary glacial erosion features in the mountainous regions of the west (Figure 21.5.9), and leaving enormous volumes of glacial sediment and glacial depositional features throughout the region (Figure 21.5.10).

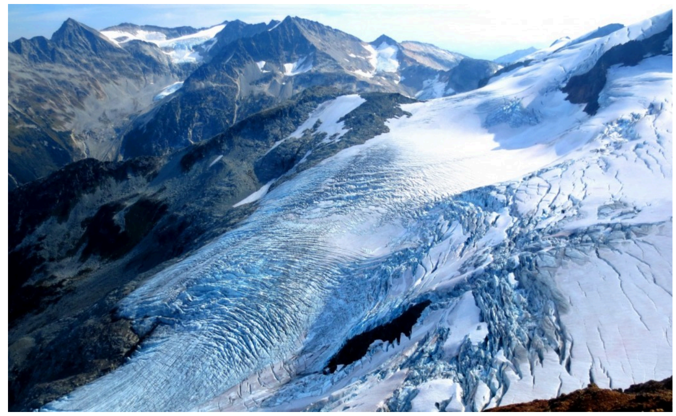

Figure 21.5.9 Various glacial erosion features (top left) and glaciation at the Overlord Glacier, Coast Mountains, B.C.

Figure 21.5.10 A drumlin field with an esker (centre) in the Cree Lake area of northern Saskatchewan.

Image Descriptions

Figure 21.5.4 image description: The Juan de Fuca Plate lies between the Pacific and the North America plates along the south coast of British Columbia and the northwest coast of the United States. It is subducting beneath the North America Plate to form mountains along the west coast of North America. The Pacific Plate and the Juan de Fuca Plate are pulling apart to create divergent and transform boundaries. The Pacific Plate and the North America Plate have a transform boundary along the north coast of British Columbia, but the Pacific Plate is subducting beneath the North America Plate along the Alaskan coast. [Return to Figure 21.5.4]

Media Attributions

Summary

The main topics of this chapter can be summarized as follows:

Section	Summary
21.1 Geological History of Canada	The continent Laurentia, which includes what is now the Canadian Shield, was formed through the assembly of a number of smaller continents over the period from around 4 Ga to 1 Ga. Over the past 650 Ma, Laurentia moved north from deep within the southern hemisphere. During that time, a number of important plate-tectonic events have taken place, including formation of the Appalachian and Innuitian fold belts, sedimentation within the interior of the continent, and terrane accretion and mountain formation along the west coast.
21.2 Western Canada during the Precambrian	The two oldest parts of the Canadian Shield in western Canada are the Slave and Superior Cratons, and both include some of Earth's oldest rocks. During the formation of Laurentia, these cratons were combined with the Rae and Hearn Cratons, with the collision zones now represented by the Trans-Hudson Orogen and the Taltson Magmatic Zone. Continental sediments accumulated in Saskatchewan and Nunavut at around 1,700 Ma and in the area of the southern B.C.-Alberta border at around 1,400 Ma. This region was rifted apart during the breakup of the supercontinent Columbia, after which sedimentation continued on the western margin of Laurentia with the deposition of the Windermere Group.
21.3 Western Canada during the Paleozoic	Sedimentation on the west coast of North America continued into the early Paleozoic, and by the Ordovician, the Western Canada Sedimentary Basin (WCSB) had developed, extending from southern Manitoba to the northern Northwest Territories. Most of the Paleozoic rocks in this basin, which range in age up to the Carboniferous, have marine affinities, although there are important evaporites as well. Sedimentation continued on the west coast through this time, but by the late Paleozoic, a subduction boundary had developed along the coast and small continents were moving toward North America.
21.4 Western Canada during the Mesozoic	The various parts of the Intermontane Superterrane began colliding with the west coast of North America during the Jurassic (~180 Ma). This started the building of the Rocky Mountains by the thrusting of existing sedimentary rocks toward the east. The arrival of the Insular Superterrane during the Cretaceous (~90 Ma) contributed to further thrusting and uplift of the Rockies, creating a significant source of sediments for the WCSB. The greatest volume of Mesozoic rocks in the basin are of Upper Cretaceous age, and that likely coincides with the period of maximum collision-related uplift of the Rockies. Subduction of oceanic crust at various locations along the west coast and within the accreted terranes prior to their arrival has produced massive volumes of intrusive igneous rocks within the Coast Range.
21.5 Western Canada During the Cenozoic	The Pacific Rim and Crescent Terranes were added to the western edge of Vancouver Island during the Paleogene, pushing the island closer to the mainland and forcing recently deposited Nanaimo Group rocks onto the island. Continuing subduction along the coast has generated ongoing volcanism and earthquake activity in southwestern B.C. Sedimentation continued in the WCSB into the Cenozoic, especially in the Paleocene with deposition of the terrestrial Paskapoo Formation in Alberta and similar rocks in southern Saskatchewan.

Questions for Review

See Appendix 2 for answers to Review Questions.

1. What are the oldest parts of Laurentia?
2. The five main geological regions of Canada are shown on Figure A. Name the regions A through E.
3. Which ancient continent collided with North America to form the Innuitian fold belt, and when did that take place?
4. Explain why the ancient sedimentary rocks of the Athabasca and Thelon Basins are generally unmetamorphosed and undeformed.
5. Explain why ultramafic intrusions, like those of the Muskox Intrusion, are relatively common in Archean rocks, but rare in Phanerozoic rocks.
6. Use the Internet to find out why Cambrian marine organisms are so well preserved in the rocks of the Burgess Shale of British Columbia.

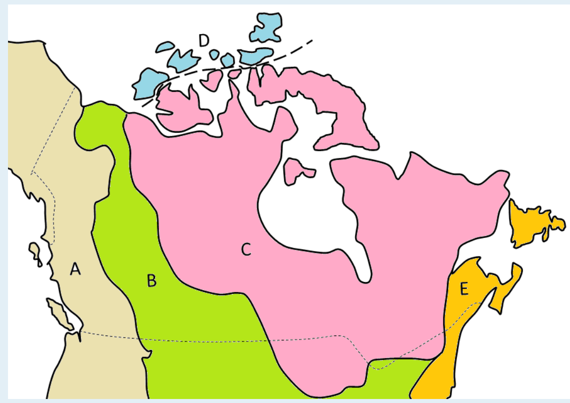

Figure A

7. The Prairie Evaporite Formation overlies marine carbonate rocks of the Winnipegosis Formation and is overlain in turn by marine carbonate rocks of the Dawson Bay Formation. What type of changes might have led to the accumulation of evaporites during this period of marine deposition?
8. What features of the Intermontane Superterrane have been used to indicate that these rocks formed south of the equator?
9. What is the connection between terrane accretion on the west coast and the relatively rapid accumulation of sediments within the WCSB?
10. Why is the WCSB considered to be a foreland basin during the Mesozoic?
11. The four main terranes of the Intermontane Superterrane are Cache Creek, Quesnel, Stikine, and Yukon-Tanana. Referring to Figure 21.4.2, determine the order in which these terranes are likely to have reached North America.
12. The presence of Nanaimo Group sedimentary rocks far inland and at relatively high elevations on Vancouver Island is attributed to the accretion of the Pacific Rim and Crescent Terranes. What is the likely connection?
13. Referring to the diagram in Exercise 21.5, explain why the Paskapoo Formation gets thinner toward the northeast.

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