

Geology of the Canadian Rockies and Columbia Mountains

Summary by Ben Gadd

1. Basic geological history of western Canada

The evidence reposes in four great layers, each thousands of metres thick. These four great layers (I call them the **ancient sediments**, the **old clastics**, the **middle carbonates** and the **young clastics**) show **two main phases** in the geological history of western Canada. First came a long period of **sediment deposition**, followed by a shorter period of **mountain-building**. Throughout this time—1.7 billion years altogether—the movement of the world’s crustal plates played a key role.

- *See last page for the currently accepted geological time scale, with period names and dates.*

First phase: deposition of most of the rock. About 1.7 billion years ago, part of what is now North America was imbedded in a **supercontinent** (amalgamation of continents) called **Columbia** (no relation to the Columbia Mountains). The oldest sedimentary rock in the Rockies was deposited about this time in an inland sea on Columbia. This rock is mostly **argillite**—very hard mud—and it is now found at the northern end of the Rockies. It is not found in ranges west of the Rockies.

The supercontinent of Columbia broke up about 200 million years later. While North America was drifting free some 1.5 billion years ago, a **second batch** of ancient argillite, with additional limestone and dolostone—more on dolostone in a minute—was deposited in another inland sea, this time at the southern end of the Canadian Rockies in the Waterton area, and to the west in what are now the **Purcell Mountains**, one of the ranges in the Columbia Mountains (Purcells, Selkirks, Monashees and Cariboos). These are the oldest sedimentary layers in the Columbia Mountains. I think of these layers, plus the similar but even older rock at the northern end of the Rockies, as western Canada’s **ancient sediments**, the oldest of the four great layers. It is eight to nine kilometres thick.

The fragments of Columbia drifted back together, rotating somewhat and moving into different positions. By one billion years ago they had formed a new supercontinent: **Rodinia**. Western Canada was part of Rodinia.

By 800 million years ago Rodinia was **splitting up**. One of the pull-apart zones lay pretty much where the Rockies and Columbias are now, and a lot of coarse sedimentary rock—mostly **gritstone** (evidence of undersea landslides), sandstone and shale—was deposited in the widening sea produced by the pulling apart. I think of the gritstone, sandstone and shale as the next great layer, the **old clastic unit**, also eight to nine kilometres thick. (“Clastic” just means rock made of particles eroded from one place and transported to another by water, gravity, glacial ice or wind.) Some of these deposits are glacial, because the world was undergoing its **greatest ice age**. This very cold period lasted 220 million years. At times, all the continents were covered by glaciers and the sea may have been frozen over entirely. Viewed from space, our planet would have been blindingly white. Geologists have given it the nickname “**Snowball Earth**.”

Over the next 625 million years, North America drifted slowly **southeastward**. As the great ice age ended, the glaciers melted and sea level rose. By 513 million years ago the shore had moved thousands of kilometres inland, and the Rockies/Columbias area was a **continental shelf** under shallow seawater. This shelf was like the Grand Banks of Newfoundland, but it was on the western side of North America instead of the eastern side. And it was much wider. **Limestone, dolostone** (similar to limestone but with the magnesium-bearing mineral **dolomite** in it as well as lime) and **shale** were deposited on the shelf. I think of this third great layer, 6.5 km thick, as the **middle carbonate unit**. “Carbonate” refers to CO₃, the chemist’s “carbonate ion,” with its negative-two electric charge. The carbonate ion is found in both lime—proper mineral name **calcite**—and dolomite.

Unlike clastic rock, which is made of particles that have travelled before settling and hardening to rock, carbonate rock is made mostly of particles that have **formed in place**, usually in the sea. These particles began as tiny crystals of calcite, or of a similar mineral called **aragonite**, produced inside **cyanobacteria**, also known as “blue-green algae.” Whether floating at or near the surface, or growing in colonies on the seabed, countless tiny cyanobacterial cells released their calcite/aragonite crystals as they died. The crystals accumulated and intergrew to become limestone. Over time, magnesium that was dissolved in the seawater worked its way into some of the calcite in the limestone, changing the calcite to dolomite and thus turning some of the limestone to dolostone.

Meanwhile the world’s continents were slowly drifting together again to form yet another supercontinent, **Pangea**. Pangea was fully assembled by 300 million years ago. It straddled the equator and was home to the **dinosaurs**.

Second phase: mountain-building. Around 210 million years ago, Pangea began to split up. The Atlantic Ocean opened. North America changed its direction of drift and began to move **northwestward**, over-riding the denser rock making up the floor of the Pacific Ocean, which was still moving northeastward. The oceanic floor had large chains of islands riding on it, most of them made of relatively light volcanic rock. Rather than slipping under the edge of the continent, the islands stuck themselves onto North America. Much of western British Columbia is made up of these **terrane**s.

The force of the collisions built the **Canadian Cordillera**, the mountains of western Canada. “Cordillera” is from Spanish and should be pronounced “core-dee-YAIR-uh,” not “core-DILL-er-uh.” The Columbias were the first to rise, at about 185 million, along with the **Cassiars** and **Ominecas**, which are similar ranges west of the Rockies and north of the Columbias. The Rockies are the easternmost, youngest part of the cordillera, last to rise, which stood above sea level by 100 million. **Thrust-faulting** (more on that on the next page) is a Rockies hallmark. The **Coast Mountains** of western B.C., also part of the cordillera, are on the terranes and intermediate in age between the Rockies and the Columbias.

Out in front of the growing Rockies, along their eastern edge, lay a long, shallow **seaway** that at times connected the Gulf of Mexico to the Arctic Ocean. Coarse sediment—mostly river silt, sand and gravel—was eroded from the Rockies, Columbias, Ominecas and Cassiars and carried eastward into the seaway. Later on, these deposits were themselves caught in the mountain-building as it kept working its way northeastward. They became the rest of the rock in the Rockies, an upper and last great layer I think of as the **young clastic unit**. It is about five kilometres thick.

By 60 million years ago the mountain-building period was winding down. At 55 million, the horizontal compression caused by the terrane collisions was replaced by stretching and San-Andreas-style **transcurrent faulting** (major sideways slippage). The result was the **Rocky Mountain Trench**. This long valley now divides the Rockies on the eastern side of the trench from the Columbias, the Ominecas and the Cassiars on the western side. Were it not for the Rocky Mountain Trench, the entire region would still be one continuous mountain range—which it is south of the trench, in Montana, Idaho and northeastern Washington. There the whole works is referred to as the **Northern Rockies**.

2. Key concepts of Canadian Rockies and Columbia Mountains geology

Here are the three main things to keep in mind about this great mountain region.

1. Old rock. Overlying the **basement** (the ancient gneiss and granite of the North American continental crust, up to 3.3 billion years old in western Canada) are the four great sedimentary layers of the Rockies and Columbias. As described already, these are the **ancient sediments** (age 1200–1700 million, thickness 8–9 km), the **old clastic unit** (age 513–780 million, thickness 8–9 km), the **middle carbonate unit** (251–513 million, 6.5 km) and the **young clastic unit** (1.8–251 million, 5 km).

2. Middle-aged mountain-building. A simple analogy for mountain-building in western Canada is to imagine a rug lying on a hardwood floor. If you push on one side of the rug with your foot, wrinkles form in the rug ahead of the place you are pushing. The rug contracts there, losing width.

Imagine that the flat-lying sedimentary rock of western Canada is the rug, and the underlying metamorphic rock of the basement is the hardwood floor. Shoved northeastward by terranes colliding with North America, the rug-like sedimentary layer slides along over the floor-like basement. The sedimentary layer contracts and wrinkles into folds. In places it breaks (it **faults**), and slabs of rock kilometres thick and many kilometres in size slide up and over one another, a process known as **thrust-faulting**. The basement under the Rockies is generally not folded or thrust-faulted. Under the Columbia Mountains it is.

The Columbia Mountains and the Rockies were built from **southwest to northeast**, beginning about 185 million years ago in the western Columbias and ending about 55 million years ago in the eastern foothills of the Rockies. The basement was upthrust extensively in the Columbia Mountains. You see banded black-and-white basement **gneiss** (pronounced “nice”) along the Trans-Canada Highway around Revelstoke, for example, and along Highway 5 southwest of Valemount. But in the Rockies the basement is exposed at the surface only at a few spots along the Rocky Mountain Trench. In the Columbia Mountains you also find younger gneiss and **granite** (igneous rock crystallized from deeply buried areas of magma) produced during the plate collision. There is no granite in the Canadian Rockies.

In contrast, within the American Rockies large areas of basement gneiss and granite moved upward along thrust faults, carrying the overlying sedimentary rock with them. These sediments were stripped away by erosion, leaving the granite and gneiss exposed. This is what you see in the Rockies of Colorado, for example. Another difference is that the southern part of the American Rockies was built twice: once from 325 million to 280 million (the **ancestral Rockies**, worn down flat) and again when the entire modern American Rockies rose, from 90 million to the present. But the essential mountain-building mechanism—terrane/continent collision—was similar.

The three main east-west divisions of the central Canadian Rockies, meaning the section between Crowsnest Pass and the Peace River, correspond roughly to the distribution of three of the four great layers. The old clastics are found mostly along the continental divide in the **main ranges**, above sea level by 100 million. The middle carbonates are found mostly east of the divide in the **front ranges**, present by 75 million. And the young clastics are found mostly farther east in the **foothills**, present by 70 million.

The ancient sediments lie at each end of the Canadian Rockies. North of the Peace River, the ancient sediments are found in the front ranges at the far northern end. There are no main ranges here. The ancient sediments also form the southern end of the region, in the Waterton area and along the eastern wall of the Rocky Mountain Trench south of Radium. This area is mostly front ranges, but there are some main-range ancient sediments here, too.

The Columbia Mountains have four sub-ranges: **Cariboos, Monashees, Selkirks** and **Purcells**. The Cariboos are nearly all old clastics. Basement rock makes up the northern part of the Monashees, while the old clastic unit makes up most of the southern part. The Selkirks have a lot of young-granite areas, plus some middle carbonates in the northern part. Ancient sediments and old clastics make up much of the Purcells, plus some young-granite areas with impressive spire-like peaks such as the Bugaboos. What you don't see in the Columbia Mountains are the young clastics. They are absent. However, the nearby Rocky Mountain Trench is filled with them.

Mountain-building in the Rockies and neighboring ranges was mostly finished by 60 million, but **block faulting** (this occurs when stretching breaks the rock and blocks slip downward to fill the gap) and transcurrent faulting still continue today west of the Rockies.

3. Young landscape. It is unlikely that the Columbias and the Rockies ever reached Himalayan heights, but they might have stood six kilometres above sea level. It's important to understand that **erosion occurred during mountain-building as well as after.** (The rate of mountain-building must exceed the rate of erosion, or no mountains will be built, right?) In all, a thickness of up to **10 km** of rock has been eroded away in the region during and after its 125 million years of mountain-building activity. So the landscape we see now—the positions of the ridges and the valleys, the heights of the peaks, the depths of the valleys—is quite different than it was 60 million years ago. At that time the area probably resembled today's **Tibet**, a huge, hilly highland elevated several kilometres above sea level.

The modern landscape developed through **differential erosion.** The rock lay in parallel bands of hard and soft layers. The soft layers were worn down more quickly than the hard layers. So the hard layers became the ridges, and the soft layers became the valleys. The valleys deepened faster than the ridges could be eroded, producing greater **topographic relief** (elevation difference between ridges and valleys) as time went by.

Herein lies a wonderful paradox. The Rockies and Columbias have steadily lost elevation, but because the valleys have deepened faster, the ridges and summits lie farther above the valley floors now than they once did. The Rockies are grander and more rugged today than they were when they were young.

Today's landscape is glacial, carved over the last 2.9 million years, during which there have been many ice advances and retreats. The most recent major glacial-sculpting episode was the **Late Wisconsinan Glaciation**, which began about 31,000 years ago and ended about 14,000 years ago. (You may see this as 25,000–12,000 B.P., where “B.P.” means “before present” and refers to uncalibrated radiocarbon years.) That's not very far in the past, when you consider the great lengths of time we have been considering. In geological terms, this is a very young landscape.

A minor glacial advance called the **Little Ice Age** began about A.D. 1200 and reached its maximum in the mid-1840s, building the fresh-looking moraines seen at higher elevations all over the Rockies and Columbias today. The **Milankovitch cycle**—a complex interaction among regular changes in the Earth's orbit, the tilt of its axis and the wobble in its rotation, all affecting the planet's climate—indicates that another minor advance should be occurring now. But **global warming** from rapidly increasing levels of CO₂ in the atmosphere (main cause: our own burning of fossil fuels) is overcoming this natural cooling trend. The glaciers of the Rockies and the Columbias are melting.

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- You can find out more about the geology of the Rockies, including what you see along the region's highways, in two of Ben's books: *Canadian Rockies Geology Road Tours* (Corax Press, 2008) and *Handbook of the Canadian Rockies* (Corax Press, 2009).
- For yet more information, check Ben's website, www.bengadd.com.

Geological time scale 2013, in millions of years

This scale is by the **International Commission on Stratigraphy (ICS)**. It is based on the ICS *International Chronostratigraphic Chart*, which is the standard time scale used by the Geological Survey of Canada, the Geological Society of America and most other geological organizations worldwide.

PHANEROZOIC EON 541–Present

Cenozoic Era 66.0–Present

Quaternary Period 2.59–Present

Holocene Epoch 13,500*–Present

Pleistocene Epoch 2.59–13,500*

Neogene Period 23.0–2.59

Pliocene Epoch 5.33–2.59

Miocene Epoch 23.0–5.33

Paleogene Period 66.0–23.0

Oligocene Epoch 33.9–23.0

Eocene Epoch 56.0–33.9

Paleocene Epoch 66.0–56.0

Mesozoic Era 252–66.0

Cretaceous Period 145–66.0

Late 101–66.0

Early (no middle) 145–101

Jurassic Period 201–145

Late 164–145

Mid 174–164

Early 201–174

Triassic Period 252–201

Late 237–201

Mid 247–237

Early 252–247

Paleozoic Era 541–252

Permian Period 299–252

Lopingian (Late) 260–252

Guadalupian (Mid) 272–260

Cisuralian (Early) 299–272

Carboniferous Period 359–299

Pennsylvanian Epoch 323–299

Mississippian Epoch 359–323

Devonian Period 419–359

Late 383–359

Famennian Age 372–359

Frasnian Age 383–372

Mid 393–383

Early 419–393

Silurian Period 443–419

Late (Pridoli) 423–419

Mid (Wenlock and Ludlow) 433–423

Early (Llandovery) 443–433

Ordovician Period 485–443

Late 458–443

Mid 470–458

Early 485–470

Cambrian Period 541–485

Furongian 497–485

Epoch 3 509–497

Epoch 2 521–509

Terreneuvian 541–521

PROTEROZOIC EON 2500–541

Neoproterozoic Era 1000–541

Ediacaran Period 635–541

Cryogenian Period 850–635

Tonian Period 1000–850

Mesoproterozoic Era 1600–1000

Stenian Period 1200–1000

Ectasian Period 1400–1200

Calymmian Period 1600–1400

Paleoproterozoic Era 2500–1600

Statherian Period 1800–1600

Orosirian Period 2050–1800

Rhyacian Period 2300–2050

Siderian Period 2500–2300

ARCHEAN EON 4000–2500

Neoproterozoic Era 2800–2500

Mesoarchean Era 3200–2800

Paleoarchean 3600–3200

Eoarchean Era 4000–3600

HADEAN EON 4567–4000

No eras or periods are defined in the Hadean. Scale begins when Earth and the other planets were fully formed from the pre-solar nebula, which took only about ten million years.

*In calendar years. Same as 11,800 BP, where “BP” stands for “Before the present,” meaning radiocarbon years.