Geology Teacher Guide to Rocky Mountain National Park

Figure 1: summit of Emerald Peak in late February, 2012 14ers.com

Kellyn Griffin
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Contents

Introduction 3
Acknowledgments 3
Setting and Overview 4
Geographic Setting of Rocky Mountain National Park 4
Geologic Setting of Rocky Mountain National Park 5
Precambrian Era: 3800-543 million years ago 6
Paleozoic Era: 543-248 million years ago 6
Mesozoic Era: 248- 65 million years ago 7
Cenozoic Era: 65 million years ago- present day 8
Tectonics of Rocky Mountain National Park 9
Tectonic Principles relevant to Rocky Mountain National Park 9
Plate Tectonics 10
The Great Unconformity 12
Plate tectonics of the Paleozoic Era 12
Plate Tectonics of the Mesozoic Era 13
Plate Tectonics of the Cenozoic Era 14
Glaciers of Rocky Mountain National Park 15
Pre-Bull Lake- 1.2 million years ago 16
Bull Lake glaciation- 300,000-127,000 year ago 16
Pinedale glaciation- 30,000-12,000 years ago 17
Post- Pleistocene Glaciation 18
Rock Glaciers 19
Erosion History of Rocky Mountain National Park 20
Foothills just outside of Rocky Mountain National Park 21
Climate and Ecology of Rocky Mountain National Park 21
References 24
Lesson Plans 24
Making a Geologic Time Scale Lesson 25
The Mystery of the Valley Lesson 30
Rocks of the Alluvial Fan Lesson 40
Foothills Geology Lesson 44
Appendix 53
Geologic Time Scale 53
Common Rocks and the Rock Cycle 55
Formation Properties of Rocky Mountain National Park 57
Foothills Formations 58
Vocabulary 59

Introduction

Dear Teachers-

Rocky Mountain National Park is a unique and beautiful place. The park is made up of several geologic processes working together for billions of years creating the dynamic beauty you see today. This teacher guide is intended to give an overview of all the geologic history with details to the key events of Rocky Mountain National. The goal is to use this teacher guide as a resource to the geology of Rocky Mountain National Park and take the information back to the classroom, or better yet, in the field at Rocky Mountain National Park.

This geology teacher guide of Rocky Mountain National Park includes the geologic history starting 1.7 billion years ago and details key geologic events that have profoundly shaped the park. The geologic history of Rocky Mountain National Park includes several of examples of mountain building, inland sea advancement, erosion, and glaciers. In the teacher guide you will discover why the crystalline basement rock is so important to the stability of the Rocky Mountains, how glaciers have shaped the Continental Divide alpine and everything in between. Geology is the backbone to the climate and ecosystems of Rocky Mountain National Park and without all the geologic history Rocky Mountain National Park would not be what it is today.

In the teacher guide there are lessons to be used both in the classroom and on-site at Rocky Mountain National Park. It is important to remember when visiting Rocky Mountain National Park the high elevation dehydrates you quicker, gives you more exposer to UV rays and causes the weather to change quickly. Remember to come prepared and bring lots of water, sun screen, and plan accordingly for the weather. Beyond the geology of Rocky Mountain National Park, the park is also a great place to see diverse wildlife, colorful flowers and the experience of being on top of the world high in the alpine tundra. Regardless if you are visiting Rocky Mountain National park for an education experience or personal pleasure, always remember to follow park rules, leave no trace and be respectful to the wildlife and other visitors enjoying the park.

Acknowledgments

Special thanks to Mark DeGregorio, Caroline Smith, Nick Voegtly, and the Geological Society of America for their support of this teacher guide.

Setting and Overview

Geographic Setting of Rocky Mountain National Park

Rocky Mountain National Park is part of the Colorado Front Range. The Front Range rises west of Boulder, Denver and Colorado Springs and is the easternmost mountain range of the southern Rockies. The Rocky Mountains run from northern New Mexico with a northwest trend to British Columbia, Canada as part of the Continental Divide of North America. Throughout the Rocky Mountains there are 54 peaks that exceed 14,000ft and Longs Peak is the only "fourteener" within Rocky Mountain National Park. In Rocky Mountain National Park you find a range of geologic evidence that includes erosion, inland sea, mountain building and glaciations. The climate and ecosystems of Rocky Mountain National Park are a direct outcome from the geology. The altitude of the Continental Divide creates a rain shadow effect for the eastern side of Rocky Mountain National Park and the change of elevation with in the park allows for four different ecosystems to thrive. All aspects of Rocky Mountain National Park are a result of the geology that has sculpted the park today.

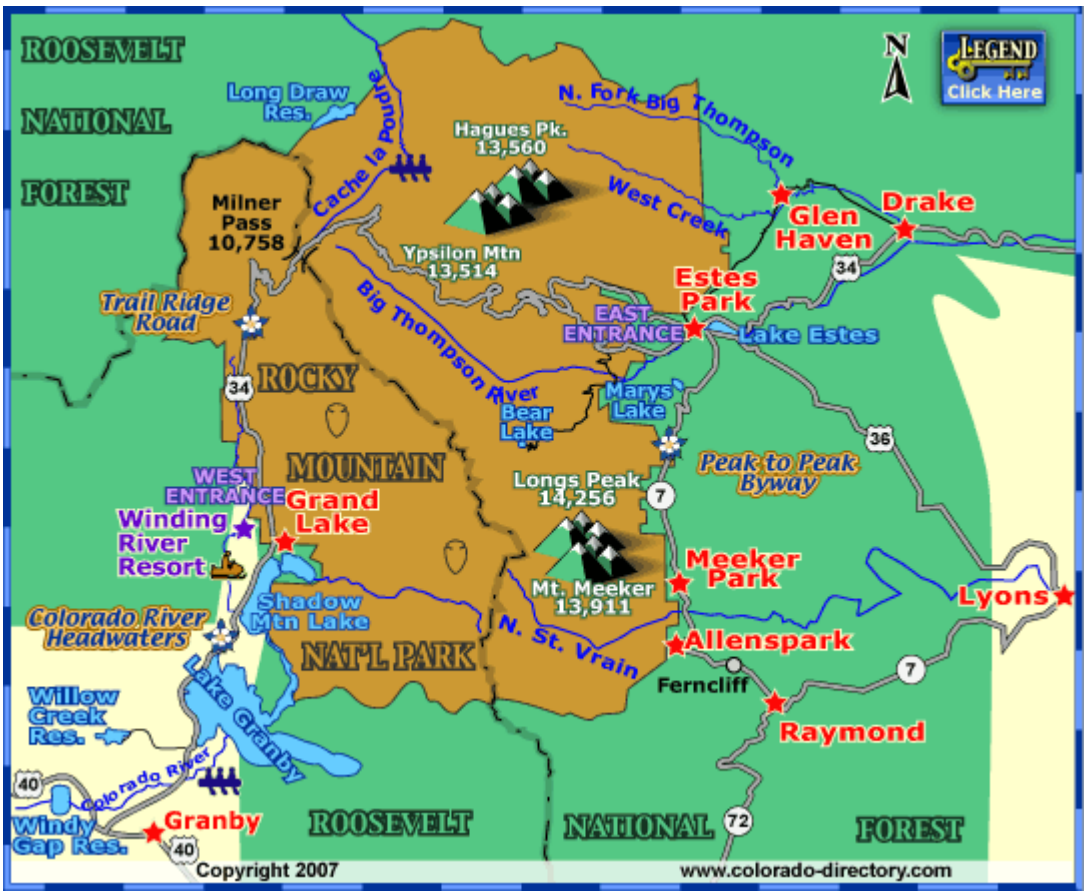

Figure 2: colorado-directory.com

Geologic Setting of Rocky Mountain National Park

The geologic history of Rocky Mountain National Park includes three orogenic events, erosion and uplifting, faulting, inland seas, and three major glaciations. Evidence of each geologic event can be found within Rocky Mountain National Park.

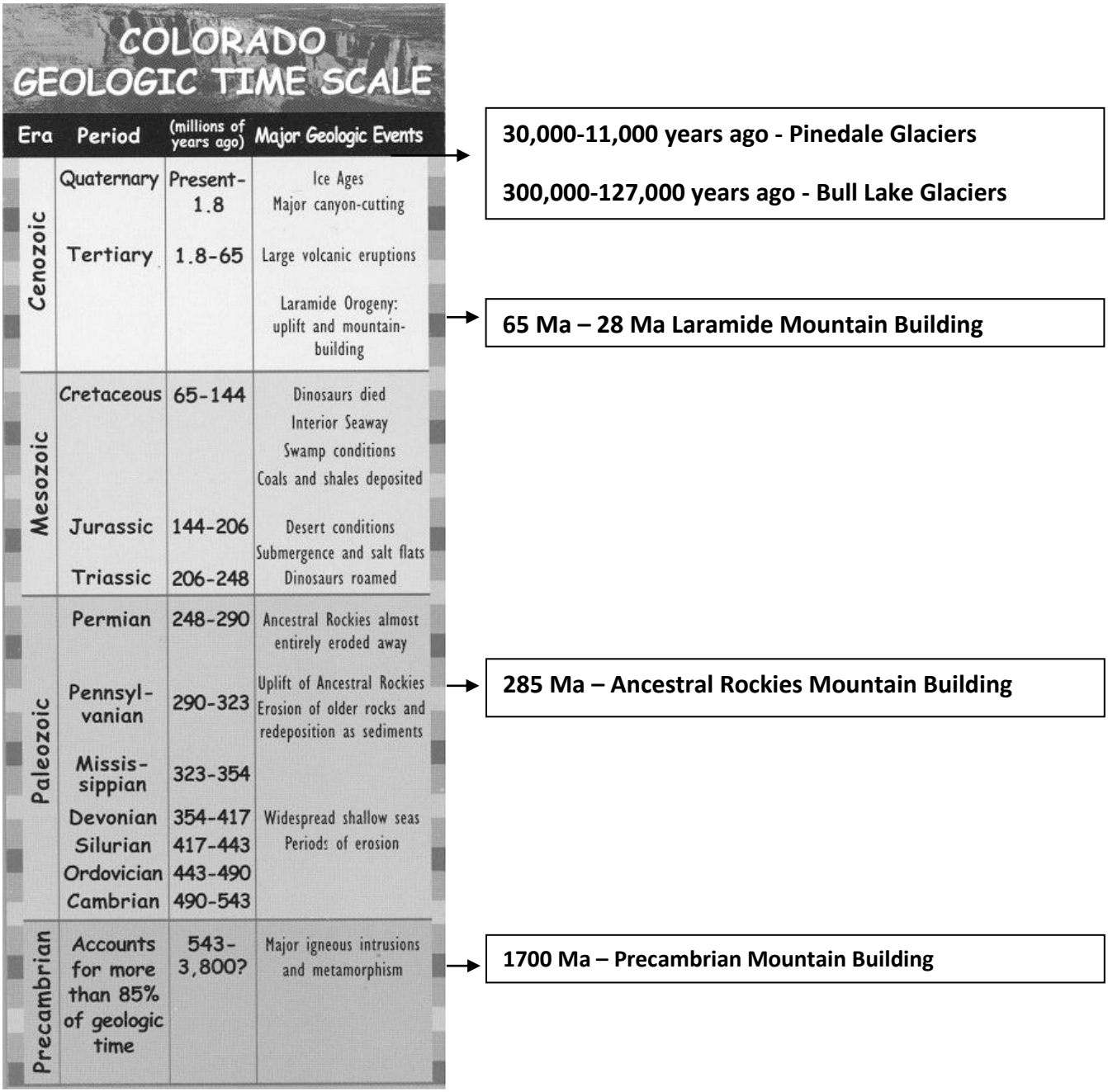

Figure 3: NPS

Precambrian Era: 3800-543 million years ago

The Precambrian Era, 3800-542 million years ago, is about 88% of earth‟s history. There is not a major extinction event that ends the era, but an explosion of the first life 3.5 billion years ago starting to develop from the single celled organisms.

Geologic Era	Time Period	Rocky Mountain National Park Evidence
Precambrian	3800-543 million years ago	- Crystalline basement rock created - Ancient Rockies Orogeny - Major igneous intrusions and metamorphism • Boulder Creek Batholith • Silver Plume Granite intrusion

Several events happened in the Precambrian Era to create the rock formations seen in Rocky Mountain National Park. The oldest rocks in Rocky Mountain National Park come from the Precambrian Era and date back 1.7 billion years. The parent rocks include sedimentary shale, sandstone interbedded with volcanic granites. The Precambrian orogeny that created the Ancient Rockies increased tectonic activity, compressed, folded, uplifted and metamorphosed the parent rocks into a variety of metamorphic schist and gneiss rocks. The metamorphosed rocks can be seen along the Continental Divide and Trail Ridge Road. The schist and gneiss of Rocky Mountain National Park show evidence the tectonic activity occurred repeatedly during the Precambrian Era. The tectonic activity also created major faults that are significant to the Rocky Mountains you see today. About 1.6 billion years ago a massive igneous intrusion known as the Boulder Creek Batholith pushed into the schist and gneiss basement rock creating regional metamorphism. The batholith extended about 30 miles across Rocky Mountain National Park. Contacts between the granitic intrusions and metamorphic rock can be seen on canyon walls east of the Continental Divide. This event is separate from the worldwide intrusion 1.4 billion years ago that is evident in Rocky Mountain National Park.

Paleozoic Era: 543-248 million years ago

The Paleozoic Era occurred 542- 251 million years ago. The prefix *paleo* means past and this era encompasses the first land plants, first fish, organisms with shells, insects, amphibians, and the dominate trilobites. The major extinction that ended the Paleozoic Era is the Permian- Triassic extinction. During the extinction 50% of all animal families went extinct, and 95% of all marine species went extinct.

Geologic Era	Time Period	Rocky Mountain National Park Evidence
Paleozoic	543- 248 million of years ago	- Inland sea advancement and retreats - Ancestral Rockies Orogeny - Ancient Rockies eroded away

After the Ancient Rockies formed1.7 billion years ago, Rocky Mountain National Park was covered with sediment from inland seas for about 200 million years in the Early Paleozoic. Erosion and the Ancestral Rockies orogeny took the bedrock away creating a major unconformity. About 300 million years ago in the Late Paleozoic Era, the Ancestral Rockies formed west of the Front Range today. The Ancestral Rockies were about 2,000 feet high and extended from Boulder to Steamboat Colorado. The Ancestral Rockies orogeny was elevated along faults in the Precambrian crystalline basement rock. There is little evidence of the Paleozoic Era within Rocky Mountain National Park and what is known is from studying the upturned layers of sedimentary rock just outside the park.

Mesozoic Era: 248- 65 million years ago

The Mesozoic Era occurred 251- 65 million years ago. The prefix *Meso* means middle and this era is also known as the time of dinosaurs. During the Mesozoic Era the first flowering plants and birds appear on earth. The extinction event that ended the Mesozoic Era is known at the Cretaceous- Tertiary. During this extinction event 50% of marine and land life forms died out, including the dinosaurs.

Geologic Era	Time Period	Rocky Mountain National Park Evidence
Mesozoic	248-65 million years ago	- Ancestral Rockies erosion - Western Interior Seaway Advancement and retreat - Beginning of Laramide Orogeny

By the beginning of the Mesozoic Era most of the Ancestral Rockies eroded away and Rocky Mountain National Park slowly became covered by water and sediment from the advancement and retreatment of the Western Interior seaway. In the Late Mesozoic Era, Cretaceous Period 100 million years ago, the Western Interior seaway advanced to completely cover Rocky Mountain National Park accumulating several hundred feet of sediment. This is evident in Rocky Mountain National Park east of Lead

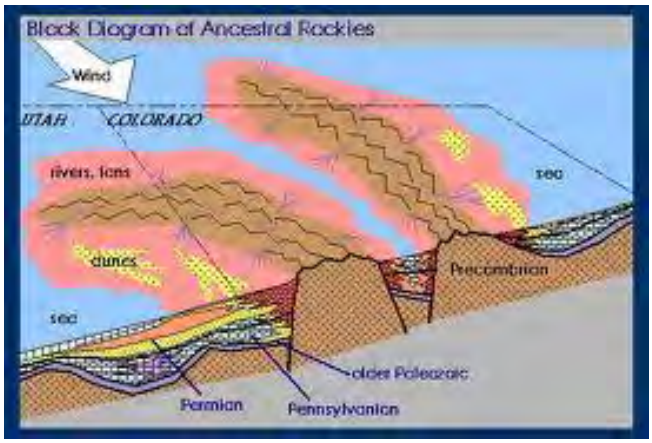

Figure 4: jan.ucc.nau.edu

Mountain, and on summits of Howard Mountain and Mount Cirrus in the Never Summer Mountains. The inland sea was followed by the Laramide orogeny beginning about 70 million years before present.

Cenozoic Era: 65 million years ago- present day

The Cenozoic Era, 65 million years- present day, is the era of today. The prefix *ceno* means current. We are still in the Cenozoic Era because the earth has not experienced a mass extinction event.

Geologic Era	Time Period	Rocky Mountain National Park Evidence
Cenozoic	65 million years ago- present	- Continuation of Laramide Orogeny - Volcanism - Glaciation events • Bull Lake Glaciation • Pinedale Glaciation • Satanta Peak advance - Mass wasting and erosion

Tertiary Period: 65-2.6 million years ago

The first and most significant geologic event that shaped Rocky Mountain National Park in the Tertiary Period is the Laramide orogeny. The Laramide orogeny started in the Mesozoic Era 70 million years ago but the majority of the event occurring in the Tertiary Period until 28 million years ago. The Laramide orogeny involved block fault mountain building controlled to the north-northwest by the preexisting Precambrian faults. After the initial uplift there was extensive volcanism in Rocky Mountain National Park. Evidence of mudflows, ash falls, pyroclastic flows, as well as intrusive igneous rocks and extrusive igneous rocks are evidence of volcanism found in the Never Summer Mountains of Rocky Mountain National Park. The most recent Tertiary event is a combination of erosion and faulted uplifting. The uplift

occurred in a series of steps on older Precambrian faults and is responsible for the Rocky Mountains modern height. The uplift disrupted the older drainage patters and created the modern drainage patters of today. The new drainage patterns removed as much as 5000 feet of sedimentary rocks from earlier inland seas deposits. This erosion exposed the basement rock of the Ancestral Rockies. Evidence of the uplifting and erosion can be found on the way to Rocky Mountain National Park in the hogbacks of the Front Range foothills.

Quaternary Period: 2.6 Million years ago- present

The major geologic process that shaped Rocky Mountain National Park in the Quaternary Period was glaciers. The first glacial event is the Bull Lake that occurred 300,000- 127,000 years ago. Bull Lake is further broken down into the Early Bull Lake, 300,000- 200,000 years ago, and Late Bull Lake, 200,000- 127,000 years ago. Evidence of Bull Lake can be found within Rocky Mountain National Park at Bierstadt Lake, west of the Beaver Meadows entrance, south of Sandbeach Lake, and east of Copeland Mountain. The second glacial event in Rocky Mountain National Park is the Pinedale glaciation. Pinedale occurred 30,000- 12,000 years ago, reaching a maximum 23,500 years before present. Pinedale is the last true valley glaciation to affect the Front Range. Evidence within Rocky Mountain National Park of the Pinedale glaciation can be found at Moraine Park and Horseshoe Park, as well as Wild Basin and Kawuneeche Valley. In the Late Pleistocene a minor glaciation event called the Satanta Peak advance occurred about 10,000 years before present. The most recent geologic activity in Rocky Mountain National Park is stream erosion starting 3,800 years before present. Evidence of stream erosion is seen throughout Rocky Mountain National Park by the v- shaped valleys. The best recent example of stream erosion in Rocky Mountain National Park is the alluvial fan that was deposited in the Lawn Lake Flood of 1982.

Tectonics of Rocky Mountain National Park

Tectonic Principles relevant to Rocky Mountain National Park

There are some important tectonic principles to know in order to understand the process of building the Rocky Mountains. First, it is important to recognize the difference between the hard basement layer of crystalline rock, and the easily erodible cover layer of sedimentary and igneous rocks. The mechanical strength of the crystalline basement rock is directly proportional to how much the Earth crust can support a geologic feature. The mechanical strength of the Rocky Mountain crystalline basement is particularly strong because it supports a geologic feature as big as the Rocky Mountains. The basement rock has planes of weaknesses in faults and shear zones that influence building of the current Rocky Mountains.

Second, isostasy is the ideal balance of large portions of Earth‟s crust. It controls the regional elevations adjacent to Rocky Mountain National Park by elevating the area on east and west of the mountains to account for the weight of the Rocky Mountains. Without the strength of the basement crystalline rock and isostasy the Earth‟s crust would not be about to support the Rocky Mountains.

Plate Tectonics

The plate tectonics of Rocky Mountain National Park started 1.7 billion years before present and include mountain uplifting, erosion, inland seas and localized deformation. The current Rocky Mountains can be explained by plate tectonics as intraplate deformation by a combination of low angle subduction of the Farallon Plate to the west, and regional uplift and extension to the south-southwest by the Rio Grande Rift.

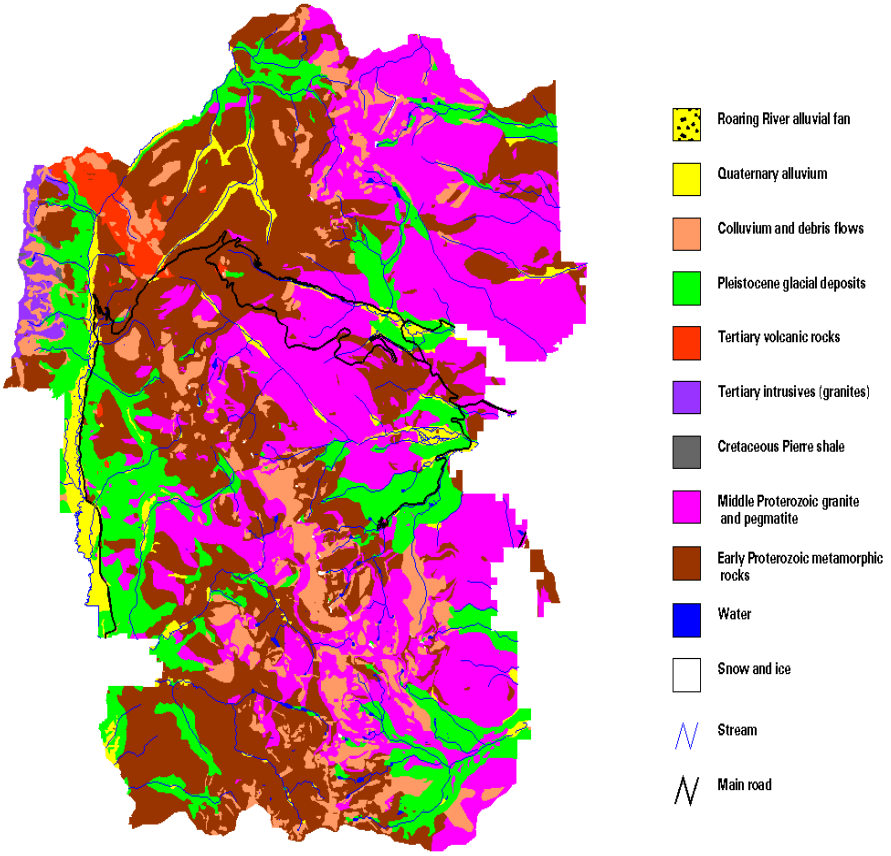

Figure 5: RMNP geologic map
geo.arizona.edu

Plate tectonics of the Precambrian Era
1.8 billion years ago- 570 million years ago
Building of the basement rock and more… that eventually becomes less

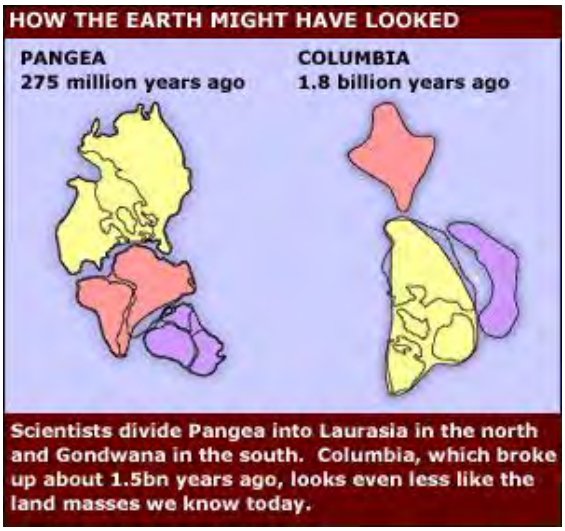

Figure 6: http://www.altacolumbia.com

1.8 billion years before present in the Precambrian Era the Colorado orogeny created the crystalline basement rock of Rocky Mountain National Park. A subduction zone collision with pieces of Wyoming cratons increased the pressure and temperature to create the metamorphic rocks that formed the crystalline basement rock of gneiss and schist. The Colorado orogeny was not the only event to create the crystalline basement of the Rocky Mountains. The Berthoud orogeny, 1.4 billion years before present, was the second step in creating the crystalline basement of Rocky Mountain National Park. A subduction zone to the south created a ductile shear zone and numerous plutons in the Rocky Mountain chain. Known as the Berthoud orogeny, these plutons make up of 20-30% of the basement rock and extend far beyond Rocky Mountain National Park. The specific type of Berthoud granite that is exposed in Rocky Mountain National Park is the Silver Plume granite. The Silver Plume granite was brought the surface by continental rifting and uplifting that ended in the Late Proterozoic 600 million years ago. The Silver Plume granite can be seen throughout Rocky Mountain National Park by the rounded granite tops of Lumpy Ridge. Other intrusions of the Berthoud orogeny in Rocky Mountain National Park are Hagues Peak granite found in the Mummy Mountains, multiple mafic dikes and pegmatite throughout the park, the Iron Dike near Mount Chapin and Storm Pass north of Trail Ridge Road.

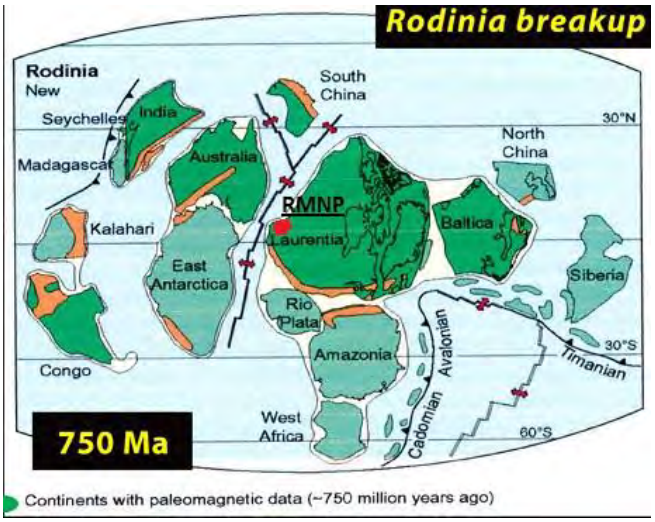

Figure 7: © Snowball Earth.org.

At the Precambrian-Cambrian boundary Rodinia broke apart re-assembled to form Pangaea. Geologist further divide Pangae into Lauurasia to the north, and Gondwana to the

south. The coast of western North America was created when Gondwana rifted away from Rodinia's southwest margin around 750 million years before present. The rifting created low lying mountains, mass wasting and erosion, with the eventual formation of shallow inland seas. The rifting ending about 600 million years ago but the faults created define the Rocky Mountains millions of years later.

The Great Unconformity

Figure 8: I-70 and Glenwood Canyon, Colorado. Steven Dutch, Natural and Applied Sciences, University of Wisconsin- Green Bay

After the creation of the crystalline basement and before the rifting away of Gondwana the Rocky Mountains are a mystery. Known as the Great Unconformity, Earth‟s history from 1.4 billion years to 600 million years is missing from the stratigraphic column of the Rocky Mountains. Any surface deposited in Colorado before 600 million years before present, except the crystalline basement, has been erased by erosion to create the Great Unconformity. The Great Unconformity leaves unanswered questions of the plate tectonics of the Rocky Mountains in the Precambrian Era.

Plate tectonics of the Paleozoic Era
570-290 million of years ago
Build it up and break it down

Before the Cambrian period, all the evidence of Rocky Mountain National Park is lost in the Great Unconformity. The Rocky Mountains history begins to show record again in the Late Cambrian, 510 years ago. Shallow tropical seas spread over Rocky Mountain National Park and 6,000-12,000 feet of marine sediments accumulated over the eroded surface of the Precambrian crystalline rocks. The sediment accumulated continued into the early Pennsylvanian 300 million years ago. In the Devonian, 360 million years before present, the eastern margin of Lauurasia collided with a microcontinent Avalonion and created the Application

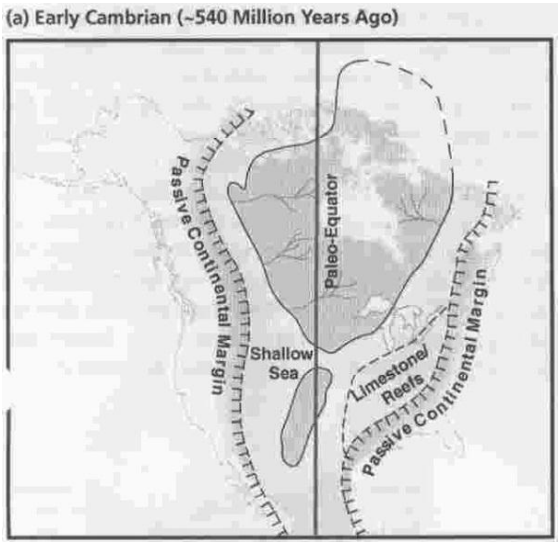

Figure 9: shallow Sea advancing over the North American Craton 540 million years before present (Robert J. Lillie)

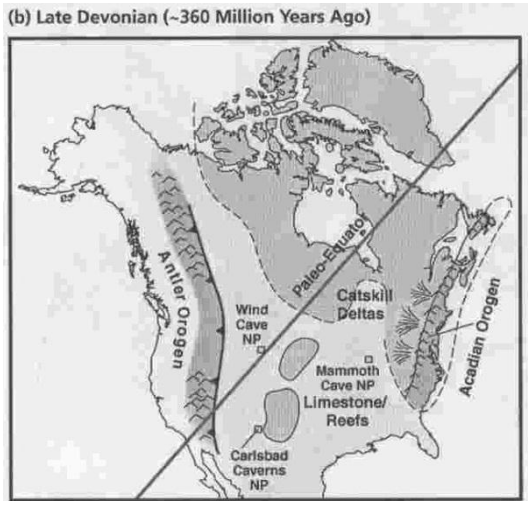

Figure 10: shallow sea advancing over the North American Craton 360 million years before present (Robert J. Lillie)

Mountains in the Alleghenian orogeny. The effects of the Alleghenian orogeny caused a massive uplift of the Colorado region that impacted the Rocky Mountains. The impact was strong enough to activate the Precambrian faults in the crystalline basement and uplifted the Ancestral Rocky Mountains. The Ancestral Rocky Mountains are broken down to Frontrangia to the east, and Uncompahgria in southwestern Colorado. The Ancestral Rocky Mountains uplifted with a northwest- southeast trend by faulted anticlines and steep reverse faults set by the Precambrian crystalline basement. Erosion eventually removed the sediment cover and part of the basement rock. Sediments were transported east of Frontrangia and accumulated in central and eastern Colorado. Sediments from Uncompahgria washed the west and accumulated in southwestern Colorado. By the end of the Permian, 248 million years before present, the Ancestral Rockies were almost eroded away and the evidence is now found in the foothills just east of Rocky Mountain National Park.

Plate Tectonics of the Mesozoic Era
248- 65 million years ago
Some like it warm and tropical

In the early Triassic, 248 million years before present, the Ancestral Rocky Mountains were almost eroded away completely. Colorado was above water in the Triassic but there was little surface relief left from the Ancestral Rocky Mountains. The low lying relief was covered when the climate changed to warm tropical. As a result Rocky Mountain National Park, and most of Colorado, was a desolate mudflat area. In the early Jurassic, 206 million years before present, there was another change from mudflats to desert dune fields, back to mudflats, and back again to a desert environment. By the end of the Jurassic Pangaea had broken apart and plate tectonics moved Colorado to its present latitude. Colorado was flat and

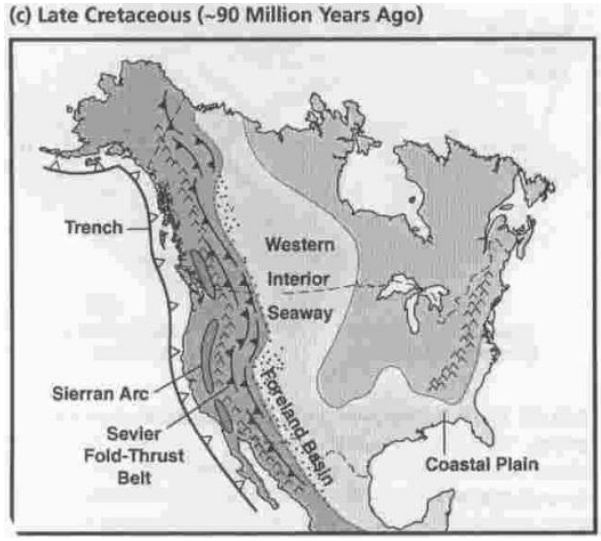

Figure 11: Western Interior seaway (Robert J. Lillie)

barely above sea level as the climate became moist again. The Western Interior seaway started its advancement in the early Cretaceous and reached its maximum about 90 million years ago in the Mid Cretaceous. The Western Interior seaway stretched west to central Utah and reached east to the Appalachians, extended north to the Arctic and south to the Gulf of Mexico. During this time Rocky Mountain National Park was covered by at least 600 feet of water. The Late Cretaceous was the last time Rocky Mountain National Park was covered with as much water and sediments because 70 million years ago the Laramide Orogeny started and uplifted the Rocky Mountains as we know them today.

Plate Tectonics of the Cenozoic Era
65 million years ago- Today
Oh My! What big mountains you have!

Starting in the Late Cretaceous, 70 million years before present, the Laramide orogeny did a majority of work in the Tertiary Period of the Cenozoic Era lasting until 35 million years before present. The origin of the Laramide orogeny is from low angle, flat slab subduction of the Farallon Plate under the North American Plate. Prior to the Laramide orogeny, the Farallon plate was subducting at a typical angle of 30 degrees. The crustal plate changed to flat slab subduction of an angle less than 10 degrees. Geologist theorized the reason for the change of subduction angle is to account for a change in rate of subduction, and/or change to a more buoyant plate material. The result is the Rocky Mountains building 500-700 miles inland, not the 100-250 miles normally seen at subduction zones. The Rocky Mountain chain is located in the central part of the continent because of the flat slab subduction and a weakness in the crust extending the North American continent. The rift section directly affecting Rocky Mountain National Park is known as the Rio Grande Rift. The current rift is a result of the extension and stretching to the west in the Basin and Range area and originated near the end of the Laramide orogeny in the Mid Tertiary about 28 million years ago.

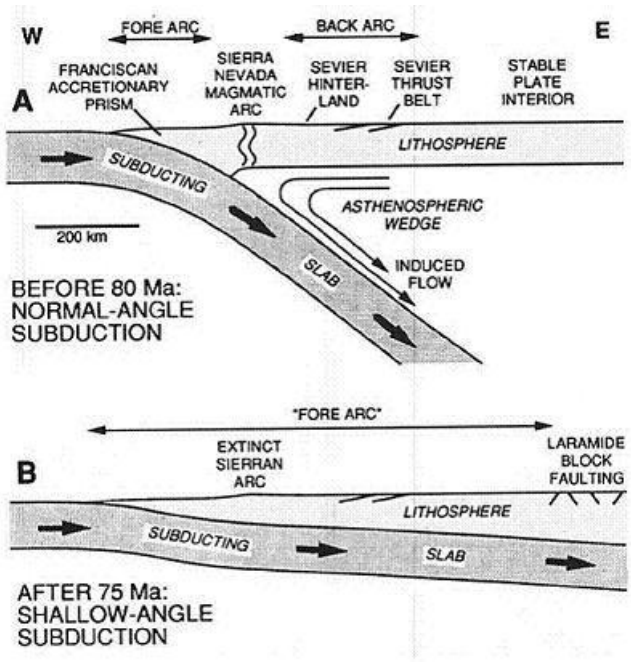

Figure 12: Dumitru et al., 1991

Before the Laramide orogeny uplifted the current Rocky Mountains there was low relief thousands of feet of sedimentation. When the Laramide orogeny uplifted the Rocky Mountains the sediment had to go

somewhere. The somewhere is the hogbacks of the foothills of Rocky Mountain National Park. The hogbacks are clearly seen driving east out of Rocky Mountain National Park from Loveland on U.S. 34. Rock descriptions of the foothill formations can be found in the appendix.

The Laramide orogeny not only removed the sediment from Rocky Mountain National Park but also produced a volcanic event that started 30 million years before present. Lava flows at Mt. Richthofen are evidence of the first part of the volcanic event. The later volcanic event occurred 27 million years before present and is preserved in Rocky Mountain National Park near Specimen Mountain as mudflows, lava flows and obsidian. A layer of volcanic ash and rhyolite tuff can be seen near Iceberg Lake along Trail Ridge Road. After the Laramide orogeny and the volcanic intrusions, another uplift event occurred. Erosion eventually removed most of the volcanic and all of the sedimentation evidence in Rocky Mountain National Park.

The most recent tectonic history of Rocky Mountain National Park is the uplifting of the Front Range. The Precambrian faults activated again to raise Rocky Mountain National Park 4000-6000 feet and drop areas like Estes Park 1000 feet. This last uplifting event began 2.6 million years ago and is responsible for the current drainage patters of the Continental Divide. This uplifting, along with worldwide climate change, was also responsible for glaciation events that sculpted Rocky Mountain National Park.

Glaciers of Rocky Mountain National Park

Glacier history is evident everywhere in Rocky Mountain National Park. Glaciers are responsible for how Rocky Mountain National Park is sculpted with meadows and mountains. Glaciations are a response to the climate and tectonic processes, without both aspects working together glaciers cannot exist. Glaciations of Rocky Mountain National Park are: Bull Lake glaciation, 300,000-127,000 year ago, Pinedale glaciation, 30,000-12,000, Satanta Peak glaciation, 14,400-10,000 years ago and the current Neoglaciation which started 3,800 years ago.

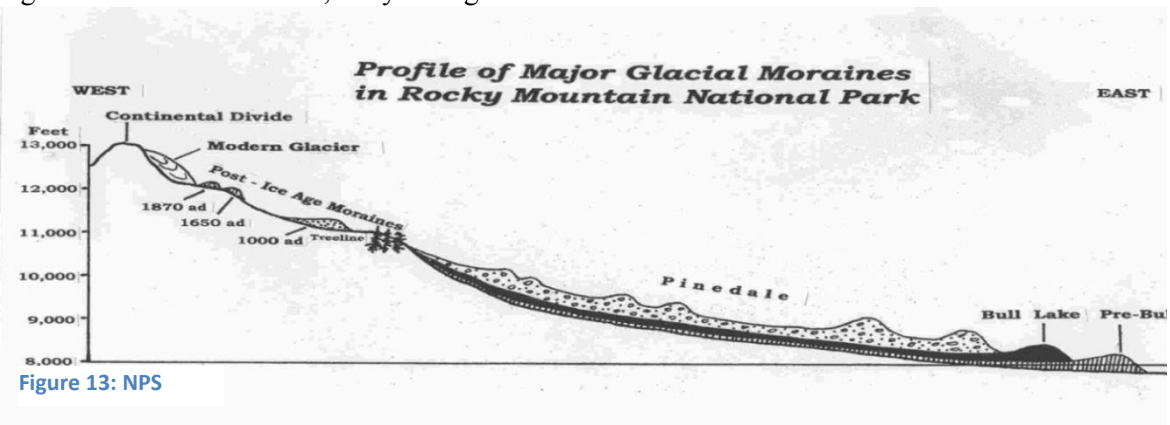

Figure 13: NPS

Pre-Bull Lake- 1.2 million years ago

The Pre-Bull glaciation occurred before the Bull Lake glaciation starting 1.2 million years ago. Pre Bull Lake had 2 major advances; however most of the Pre-Bull glaciation evidence was removed by later glaciations. Some deposits are found outside the eastern boundary of Rocky Mountain National Park along highway 7 near the Fall River entrance. Most evidence found in Rocky Mountain National Park is evidence from later glaciation events.

Bull Lake glaciation- 300,000-127,000 year ago

The Bull Lake glaciation is broken down in the early Bull Lake that occurred 300,000-200,000 years ago and the late Bull Lake occurred 200,000-127,000 years ago. Bull Lake glacier tributaries started high in the Rocky Mountains and joined together in lower elevations to create large massive glaciers that sculpted Rocky Mountain National Park. Both advances of the Bull Lake glaciation sculpted the same cirque basins and canyons leaving behind similar moraine evidence. To distinguish between the late Bull Lake and early Bull Lake glaciation geologists use degree of weathering and different moraine features.

The terminal moraines of the early Bull Lake glacial advance consist of brown, silt and sand deposits containing pale-gray stones. The deposits of the late Bull Lake advance overlie the weathered deposits of the early Bull Lake advance. These deposits also contain pale brown silty sand with stones of different sizes and degrees of rounding. Some of the rocks in the moraines show glacial striations, however, boulders are usually not found with these moraines.

Figure 14: 14ers.com

On the west side of the park, Bull Lake glaciers occupied the Colorado River Valley and deposited a terminal moraine directly south of Shadow Mountain Lake. This terminal moraine has a high degree of weathering and is consistent with other Bull Lake evidence. The Shadow Mountain moraines contain

large amounts of volcanic rock carried down by the glacier from the Never Summer Mountains. The glaciers from the Never Summer Mountains merged with the glaciers in the Colorado River Valley to reach 20 miles long, extending from the La Poudre Pass to Shadow Mountain Lake. Other evidence of Bull Lake can be seen in east side of Rocky Mountain National Park at Aspenglen Campground and near the Beaver Meadows entrance.

Pinedale glaciation- 30,000-12,000 years ago

The Pinedale glaciation occurred 30,000-23,500 years ago and makes up the majority of glacial evidence in Rocky Mountain National Park. Not as extensive as Bull Lake, the Pinedale glaciation reached a maximum 23,500- 20,000 years ago; then between 15,000- 12,000 years ago the glaciers started to recede. By 10,000 years before present all Pinedale glaciers were melted.

The Pinedale glaciation sculpted the alpine and large flat valleys in Rocky Mountain National Park. Pinedale moraines evidence shows less weathering and erosion with sharper and predominate ridges. The Pinedale glaciers also have more boulders scattered along the moraine surface.

Figure 15: rmnp.com Moraine Park view from Many Parks Curve

There are more boulders on the Pinedale moraines because the glaciers used preexisting valleys carved by Bull Lake. The Pinedale glaciation started in the alpine and gouged out mountain peaks creating cirque headwalls and vertical faces like the diamond of Longs Peak. The alpine glaciers also created rock basin lakes seen in Tyndall Gorge and Loch Vale. The boulders were carried down to the valley floor and deposited in the moraines. On the west side of Rocky Mountain National Park a glacier 20 miles long extended west of Le Poudre pass south to the morainal islands of Shadow Mountain Lake. Ice 1,000 feet deep formed the Fall River glacier that sculpted the u-shaped valley of Horseshoe Park and the 13 mile long Thompson glacier occupied Big Thompson valley and carved Moraine Park. Enclosed by the lateral moraines and terminal moraines, ice started to melt creating glacial lakes that filled the valley floors with small sediment. The different terrain and vegetation of the moraines compared to the valley floor is a result of the glacier lake. Grasses grow on the valley where the sediment is fine because of the lake and while bigger trees prefer the moraine terrain with a courser soil that is able to support their root system.

There are several other glacier features found in Rocky Mountain National Park created by the Pinedale glaciation. Lake features associated with glaciers found in Rocky Mountain National Park are cirque lakes like Chasm Lake and Lake Mills. Sheep Lakes in Horseshoe Park are a good example of kettles and kettle ponds. Several Mountains top horns, cols and arête are seen high in the alpine. The best example of a horn is the Little Matterhorn in Glacier Gorge and cols can be found above Andrew Glacier in Loch Vale. A roche moutonnee is evident in the Glacial Knobs area and Moraine Park. Erratics are abundant at boulder field and along Cub Lake trail. Glacial pavement and striations are seen near North Inlet and along Fall River Road. Everywhere you look in Rocky Mountain National Park you can find evidence of the Pinedale glaciation.

Post- Pleistocene Glaciation
Satanta Peak glaciation, 14,400-10,000 years ago
Neoglaciation, 3,800 years ago

Today there is not extensive glaciation in Rocky Mountain National Park and post- Pleistocene ice accumulation is only found within cirques. The evidence of post- Pleistocene glaciations is easier to identify because the weathering is less extensive than older glacial evidence. The evidence is also found high in the alpine because the glaciers do not advance very far due to the warmer climate.

The Satanta Peak advance began to about 14,400 years ago and ended about 10,000 years ago. The Satanta Peak advance was a cirque- glacier advance with the furthest advancement occurring after the large valley Pinedale glaciers disappeared. Evidence in Rocky Mountain National Park of the Satanta Peak glaciation advance can be seen at Sky Pond and the moraine in Loch Vale.

Ice accumulation during Holocene time was given the name Neoglaciation meaning “Little Ice Age” because the ice advancement was not extensive enough to be considered an ice age. The ice deposits found in Rocky Mountain National Park record four intervals of ice accumulation. The ice accumulations are the Ptarmigan, 7,250–6,380 years ago, Triple Lakes, 5,200–3,000 years ago, Audubon, 2,400–950 years ago, and Arapaho Peak 350–100 years ago.

The Ptarmigan advance represents a brief reversal of the warming trend that had begun about 10,000 years ago. The Triple Lakes accumulation was the most extensive. Like modern glaciers, Audubon and Arapaho Peak glaciers depended on wind- drifted snow for their existence.

Currently there are 34 snow banks and ice masses near Rocky Mountain National Park. Fourteen of the ice masses are located in Rocky Mountain National Park: Rowe Glacier, located between Rowe Peak and Hagues Peak, Sprague Glacier, at Irene Lake in Spruce Canyon, Tyndall Glacier placed at the head of Tyndall Creek, Andrews Glacier which can be seen east of Andrews Pass, Taylor Glacier, at the head of Icy Brook, Chiefs Head Peak Glacier above Frozen Lake, Mills Glacier on the east side of Longs Peak, Moomaw Glacier on the south of The Cleaver. There are six St. Vrain Glaciers located outside of the park at the head of Middle St. Vrain Creek.

Figure 16: protrails.com Andrews Tarn and Andrews Glacier

Only the ice mass above Murphy Lake near Snowdrift Peak is on the east side of the Continental Divide and all but one ice mass occur on north or east facing cirques. The exception is the large snow bank northeast of Rowe Mountain. Some of the ice masses, such as Andrews Glacier, are actively moving and can be considered actual glaciers. Winter winds blow snow over the Continental Divide where the snow drifts into cirques. The process of snow deposition gives these “wind drift glaciers” their name and is the majority of modern glaciers in Rocky Mountain National Park.

Rock Glaciers

Rock glaciers are left by retreating ice glaciers. The rocks contain enough ice to still be affected by freezing and thawing, pushing the rock glacier down slope over time. Rock glaciers are hard to recognize on the ground because they look like a rock field or talus slope. Rock glaciers flow downhill at speeds up to 1-2 m/year, however, rock glaciers in Rocky Mountain National Park have been clocked at 13-20 cm/year Rock glaciers exist below Taylor and Tyndall glaciers, as well as other locations without glaciers

Erosion History of Rocky Mountain National Park

Erosion processes are a direct response to the tectonic and glacial history of Rocky Mountain National Park. Without erosion removing thousands of feet of sediment the Rocky Mountains would look dramatically different than what you see today.

Figure 17: rmnp.com View from Rainbow Curve looking at Horseshoe Park.

Before the Ancestral Rockies could finish rising, erosion began to change the growing topography of Rocky Mountain National Park. During the Mesozoic Era the major advancement of the Western Interior seaway accumulated about 10,000 feet of sedimentary rock in Rocky Mountain National Park. The sediments washed away with the uplift of the modern Rocky Mountains during the Laramide orogeny 70 million years before present. The crystalline basement rock was uncovered and v- shaped valleys were carved by mountain streams. The sediment was displaced and is now the foothills of Rocky Mountain National Park.

Remnants of Cenozoic Era, Tertiary period erosional surfaces are preserved in the level tops of mountains above timber line in Rocky Mountain National Park. The erosion surface forms the top of Flattop Mountain and the entire rolling upland has been named Flattop peneplain, meaning almost a plain. The erosion surface now stands 11,500 to 12,000 feet in elevation and was raised by a series of uplifts which did not fold or distort them. The summits of Deer Mountain and The Needles are another example of an erosion surface that now stands about 10,000 feet. The granite in Rocky Mountain National Park is susceptible to exfoliation joint weathering, creating exfoliation domes that can be seen on McGregor Mountain and throughout Lumpy Ridge. The last uplifting event was before the last glaciation event, resulting in the terrain of Rocky Mountain National Park returning v-shaped valleys with u-shaped valleys remaining on the low lying areas of Horseshoe Park and Moraine Park.

Foothills just outside of Rocky Mountain National Park

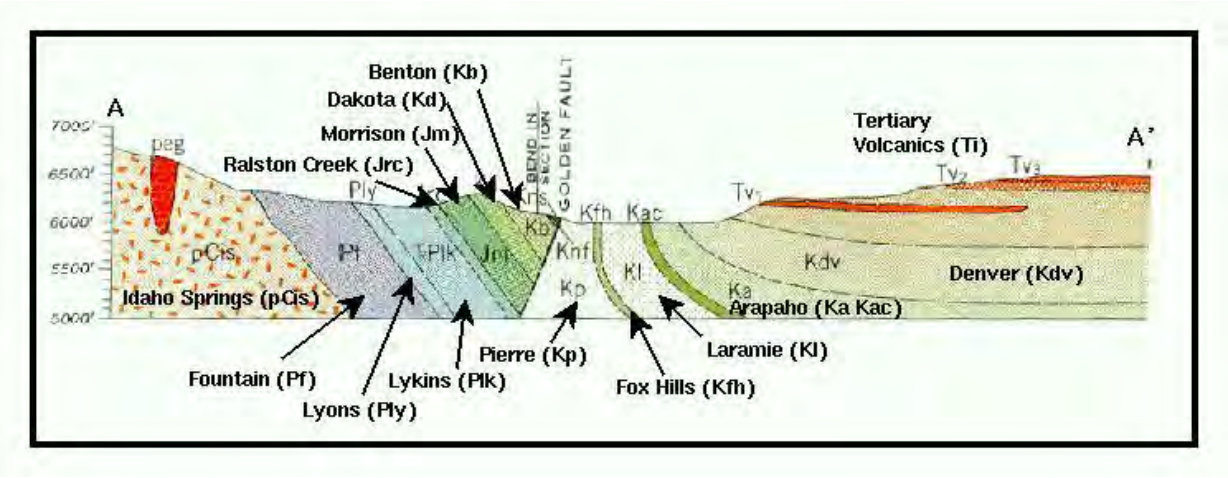

Figure 18: Amuedo and Ivey, 1978

Most of the sediments in the foothill formations east and west of Rocky Mountain National Park are from the Western Interior seaway of the Mesozoic Era. The same formations are on the east and west side of the Rocky Mountain National Park indicating there were no mountains when the sediments were accumulating by the Western Interior seaway. Deposited with the principle of horizontality, the sediments now make up the hogbacks of the foothills of the Front Range just outside Rocky Mountain National Park. Though the foothills formations are outside Rocky Mountain National Park, they are an important piece of geologic history of Rocky Mountain National Park. Rock descriptions of the foothill formations can be found in the appendix.

Climate and Ecology of Rocky Mountain National Park

The climate and ecosystems of Rocky Mountain National Park is a bi product of the geology in the park. Rocky Mountain National Park ranges from 7,860- 14,259 feet, and it is the range of altitudes within the park that is responsible for the different climates and ecosystems. Increase in elevation results in a decrease of temperature and a change of the environment. The Continental Divide creates a rain shadow effect that influences the climate in Rocky Mountain National Park. The east side of Rock Mountain National Park is referred to as the dry side, where the west side is referred to as the wet side of the park. The latitude position of Rocky Mountain National Park also affects the climate. The north side of the park receives more snow then the south side of the park. A weather pattern that does not follow these general climate boundaries is known as the Albuquerque low. A low pressure system sits above New Mexico creating more snow fall in southern and eastern Rocky Mountain National Park.

Climate is also related to the ecology of Rocky Mountain National Park. Climate and elevation control what plants and animals can survive. As you increase in elevation you decrease in temperature and oxygen levels. Rocky Mountain National Park has four ecosystems intertwined together in a delicate balance with the climate and geology. The four ecosystems give home to a variety of plants and animals that are dependent of the climate of their particular ecosystem.

The base ecosystem in Rocky Mountain National Park is the montane and occurs until 9,500 feet. The montane has a combination of dense forest and parks to support both large trees and grasses. The difference in vegetation is a result of soil content and what direction the slope is facing. The montane ecosystem in Rocky Mountain National Park is molded by large glacier moraines. The moraine soil can support the large evergreen trees, however the valley parks cannot. The soil found in the valleys tends to be of finer grained material and support grasses with some aspen and willow trees. The Subalpine Ecosystem occupies elevations between 9,500 and 11,000 feet. The lower elevation of the Rocky Mountain National Park subalpine forest consists mostly of subalpine fir and engelmann spruce. As you climb higher the trees start to change to limber pine and whitebark pine. Huckleberry and other shrub plants live in the subalpine and are vital to forest restoration after a fire. The geology of the subalpine allows for the tress to dig through roots into soil that will support them from the winds. The higher you go in elevation the oxygen become thinner and so do the trees. The subalpine ecosystem reaches the tree line and gives way to the alpine ecosystem on Rocky Mountain National Park. The alpine ecosystem of Rocky Mountain National Park occurs around 11,000 and higher. Frequent strong winds and cold temperatures limit what plants can grow is the alpine ecosystem. Cushion plants, looking like ground-hugging clumps of moss, escape the strong winds blowing a few inches above them. Many flowering plants of the tundra have dense hairs on stems and leaves to provide wind protection. Where the tundra soil is well-developed, grasses and sedges are found. Non-flowering lichens cling to rocks and soil and only photosynthesize at a temperature above 32 F. The adaptations for survival of drying winds and cold may make tundra vegetation seem very hardy, but in

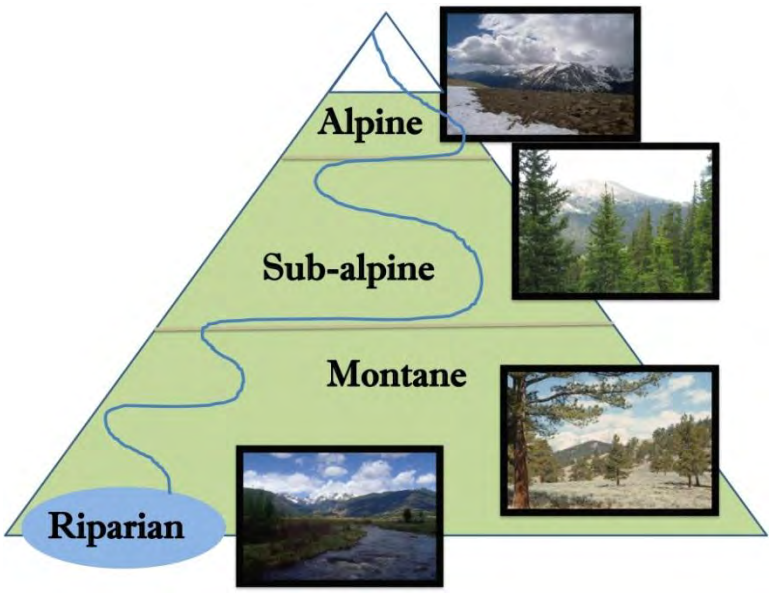

Figure 19: Alpine Sub-alpine Montane and Riparian (Image created by Jon Nicholson).

some respects the tundra is very fragile. Repeated footsteps often destroy tundra plants, leaving exposed soil to blow away, and recovery may take hundreds of years. The geology of the alpine is important because without the rich soil and rocks for moss and lichen to cling to, the ecosystem would not exist as it does today. The last ecosystem in Rocky Mountain National Park is the riparian. The riparian ecosystem stretches through all other ecosystems in Rocky Mountain National Park. This ecosystem is vital to the geology by creating v-shaped valleys and other erosional features.

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Lesson Plans

The following lesson plans are designed to teach students geologic processes using Rocky Mountain National Park. The lessons are better taught on-site in Rocky Mountain National Park but can be adapted for a classroom. If you would like to bring your classroom outdoors to Rocky Mountain National Park visit The Heart of the Rockies website to learn more http://www.heartoftherockies.net/welcome.html and then contact Mark De Gregorio at (970) 586-3777 or Mark_De_Gregorio@nps.gov to schedule a field trip.

Theme

RMNP has some of the oldest geologic evidence dating back 1.7 billion years ago, but is nothing compared to the beginning of the geologic time scale.

Goals

To understand how long the earth has been around

SWBAT categorize the evolution of geologic and life events within each time period

Objectives

SWBAT break down each geologic time period in relation to one another by illustrating the size ratio of each time period.

SWBAT interpret dominate geologic and life event of each time period.

Time

30 min

Location

RMNP
Classroom or outside

Grade Level

All grade levels

Materials

1 inch of stacked paper per group
40 feet rope/ string/ wood
25+ foot measuring tape
Timeline markers
Label stickers
Calculator
List of geologic events of RMNP

Making a Geologic Time Scale Lesson

Introduction
Give the students an introduction of the lesson, the goals and objectives, and final outcome of the assignment. Remind the students of geologic time. Relative dating, absolute dating, millions of years verse billions of years, how the geologic time scale is read and interpreted. Lead the students into the idea that geologic time is a long time and this assignment is going to help them conceptualize the concept.

Talk to the students about the geologic history of RMNP. Students should know about how there have been several mountain building events, and the inland seas that covered the area. Talk to the students about the faulting and glacier history of RMNP. If you are doing this assignment in RMNP give the students a few minutes to observe the environment around them.

Engage
Give the students a warm up to start conceptualizing the length and size of the geologic time scale. The warm up can be any metaphor of your choice.

Example:
Dollar bill: Have the students stack paper, dollar bills, anything of your choice, 1 inch high. Have the students count how many items it to make 1 inch. Remind the students the earth is 4.6 billion years old. Tell the students 1 billion dollars stacked would be 20 times higher than Longs Peak. (14,256 x 20= 285,120) Next have the students do the math and work out how high a billion dollar bills would be. Connect the billion dollars to being less than ¼ of the earth‟s history and if the students wanted to represent the full length of the geologic time scale using dollar bills the students would need a lot more space.

After the students are familiar with RMNP geologic history, give the details of the timeline activity.

- Explain students are going to represent the time scale using ratios.
  - The time scale can be hard to comprehend because it is dealing with a large amount of time. A better way to conceptualize the length of time is with ratios
    - 1 inch= 10 million years
  - Remind students that geologist always use millions of years to keep everything organized in the time scale.
    - 2.5 billion years is represented as 2500 million years.
- Use the Quaternary period as an example
  - 1.8 million years = 0.17 inches (~1/8 inch)

Explore
The students will now complete the timeline activity using the materials and worksheets.

Explain
After the students have completed labeling their timeline regroup back together and discuss. Explain to the students how most of the world‟s history came towards the end of geologic time. Point out how in the Precambrian there wasn‟t much going on but it is the longest time length on the time scale. Show the students how life grows exponentially once life started.

Elaborate
After the timeline activity has been discussed. Share with the students another example of how geologic time can be interpreted. Bring this section back to RMNP by using the length of a year as a reference.

Year example of RMNP:
If the span of Earth‟s history was compressed into one calendar year

- Earth would form on January 1st.
- August 15 the metamorphic rocks of RMNP form
- The granites would intrude around September 3rd
- The first shell-bearing animals appear November 16th.
- Between December 12th and 27th dinosaurs would roam the planet. Between December 20th and 25th current Rocky Mountains form
- At 5:00 PM on December 31st the ancestors of man would appear The Last Ice Age was at 11:58 PM
- At 11:59:58 modern technology would make its way to the stage.

Evaluate
Your explanation in the year example did not cover all the geologic events of RMNP. Have the student put the remainder of RMNP geologic history in the correct calendar day.

Conclusion
Sum up the activity by relating back to geologic time and how life has grown exponentially. Pose the question of how the time scale might look in the near and distance future.

Table 1-1. Geologic events and deposits in Colorado through time.

Era	Period	Millions of Years Ago	Events and Geologic Deposits	Features
Cenozoic (Age of Mammals)	Quaternary	1.8	Development of present topography: Neoglaciation (small cirque glaciers); Altithermal phase (warming); Ice Age (large valley glaciers in mountains) Dune, wind, landslide, glacial deposits	Great Sand Dunes; widespread faulting
	Tertiary	65	Uplift (to present elevations) and mountain-building; Laramide Orogeny (major canyon cutting); San Juan and Thirty Nine Mile Volcanic Fields White River Formation (ash and many mammal fossils), Denver Formation, Arapahoe Conglomerate, Dawson Arkose (delta and river sediments)	Florissant fossil beds; San Juan Mtns. (largest volcanic area in Colorado); rich mineral deposits;
	(K-T boundary)		**Asteroid impact causes worldwide extinction of plants and animals**	**End of dinosaurs**
Mesozoic (Age of Reptiles)	Cretaceous	144	Deep and shallow marine and swamp conditions Laramie Formation (interbedded sands and coal), Pierre Shale (fine gray muds), Niobrara Limestone, Benton Shale (black muds), Dakota Formation (beach and sand bars)	Oysters; oil in eastern Colorado; coal in western Colorado
	Jurassic	206	Desert conditions; intermittent streams; Brief submergence and "salt" flats Morrison Formation (streams), Ralston Creek Formation ("salt" flats), Navajo Sandstone (dune), Carmel Formation (stream), Entrada Sandstone (dune)	Dinosaurs; vanadium, radium, and uranium concentrations in organic materials
	Triassic	248	Desert conditions; mudflats; alluvial plains, dune fields Coastal plain, dune, or delta deposits; Lykins Formation	Early dinosaurs
Paleozoic (Age of Fishes)	Permian	290	Deep basins and deserts; Ancestral Rockies almost entirely removed by erosion Maroon Formation (red bed deposits)	Tracks of early reptiles in Lyons Formation
	Pennsylvanian	323	Uplift of Ancestral Rockies; Erosion of older sediments; shallow seas and evaporite basins Fountain, Hermosa, and Minturn Formations	Flatirons and Red Rocks Park
	Mississippian	354	Widespread open ocean then withdrawal of the sea Leadville Limestone, Molas Formation (soil/pebbles/chert)	Brachiopods, corals
	Devonian	417	Embayments of western sea covering much of Colorado; Deposition of marine limestone; Intrusion of kimberlite volcanics Parting Sandstone, Dyer Dolomite	Fossil fish, algae, brachiopods, mollusks, corals
	Silurian	443	Shallow seas and marine deposition	Corals, brachiopods
	Ordovician	490	Deepening and widening of sea; Deposition of limestone and dolomite Manitou Formation, Harding Sandstone, Fremont Limestone	Earliest known vertebrate, agnathids (jawless fish)
	Cambrian	543	Invasion of the sea from the west and east Sawatch Quartzite (e.g., Glenwood Canyon)	First hard-shelled animals, e.g., trilobites
Precambrian	Accounts for more than 85% of geologic time	4,600	"Lipilian Interval" (long period of erosion) Pikes Peak Granite (pink, coarse-grained), Silver Plume Granite (light pinkish gray, fine-grained), Boulder Creek Granite (dark gray, faintly banded), Red Creek Quartzite	Front Range "core"; Early soft-bodied marine organisms

from *Ground Water Atlas of Colorado,* Colorado Geological Survey Special Publication 53

Geologic Time Period History

Name_____

The beginning of the ____ was ____ millions of years before present, which is ____ inches from the end.

1 inch= 10 million years

Time Era	Time Period	Millions of years go	Inches from end	Rocky Mountain National Park Geologic History	World Wide Geologic History
Cenozoic	Current	0		Look around!	Look around!
	Quaternary	1.7		Mass wasting, stream erosion, interglacial	Ice ages, mammoths, sea level changes
	Tertiary	65		Pinedale Glaciation, Bull Lake Glaciation, Volcanism, start of Laramide Orogeny.	First grasses, modern mammals
Mesozoic	Cretaceous	140		Laramide Orogeny, Western Interior Seaway advancement & retreat	First flowers, dinosaurs mass extinction
	Jurassic	210		Desert conditions.	First bids & mammals, dinosaurs dominate.
	Triassic	245			Dinosaurs evolve, abundant conifers, small mammals.
Paleozoic	Permian	290		Ancestral Rockies eroded away.	Mass extinction of marine animals & trilobites.
	Pennsyl-vanian	330		Ancestral Rockies uplifted, erosion, redeposistion if sediment	First reptiles, first forest.
	Missis-sippian	360			Amphibians, sharks dominate large trees and seed ferns.
	Devonian	410		Shallow seas	First insects, first sharks, fishes abundant
	Silurian	440		Mass wasting, erosion	First jawed fish & land plants.
	Ordovician	505			Invertebrates dominate, first fishes
	Cambrian	570			Trilobites dominate, abundant marine life & invertebrates
Precambrian	Proterozoic	2500		Major igneous intrusions and metamorphism, Ancient Rockies Orogeny	Continents form by plate tectonics, multicellular life forms at the end.
	Archaen	4600			Earth forms and cools

Geologic Time Period History

Name: ___Teacher Copy__

The beginning of the ____ was ____ millions of years before present, which is ____ inches from the end.

1 inch= 10 million years

Time Era	Time Period	Millions of years go	Inches from end	Rocky Mountain National Park Geologic History	World Wide Geologic History
Cenozoic	Current	0	0	Look around!	Look around!
	Quaternary	1.7	~1/8	Mass wasting, stream erosion, interglacial	Ice ages, mammoths, sea level changes
	Tertiary	65	6.5	Pinedale Glaciation, Bull Lake Glaciation, Volcanism, start of Laramide Orogeny.	First grasses, modern mammals
Mesozoic	Cretaceous	140	14	Laramide Orogeny, Western Interior Seaway advancement & retreat	First flowers, dinosaurs mass extinction
	Jurassic	210	21	Desert conditions.	First bids & mammals, dinosaurs dominate.
	Triassic	245	24.5		Dinosaurs evolve, abundant conifers, small mammals.
Paleozoic	Permian	290	29	Ancestral Rockies eroded away.	Mass extinction of marine animals and trilobites.
	Pennsyl-vanian	330	33	Ancestral Rockies uplifted, erosion, redeposistion if sediment	First reptiles, first forest.
	Missis-sippian	360	36		Amphibians, sharks dominate large trees and seed ferns.
	Devonian	410	41	Shallow seas	First insects, first sharks, fishes abundant
	Silurian	440	44	Mass wasting, erosion	First jawed fish & land plants.
	Ordovician	505	50.5		Invertebrates dominate, first fishes
	Cambrian	570	57		Trilobites dominate, abundant marine life & invertebrates
Precambrian	Proterozoic	2500	250	Major igneous intrusions and metamorphism, Ancient Rockies Orogeny	Continents form by plate tectonics, multicellular life forms at the end.
	Archaen	4600	460		Earth forms and cools

Theme

Glaciers helped to shape the landscape of Rocky Mountain National Park

Goals

The students will:

- Realize that glaciers shaped the u- shaped valley we see today.
- Understand how glaciers create landforms.
- Appreciated how glaciers grow and shrink based on climate.

Objectives

The students will be able to:

- Compare and contrast a valley that was shaped by water and a valley that was shaped by ice.
- List three pieces of evidence that show a glacier carved the landscape.
- Explain how glaciers form, grow and move.

Time

45-50 minute

Grade Level

3rd-6th

Location

Moraine Park Museum

The Mystery of the Valley Lesson

Preparation

Set out sandboxes in a location out of the way of the visitors, but overlooks Moraine Park. Moisten sandboxes and find 5 small cups. Fill a pail with water and set next to area of sandboxes.

Engage (10 min)

Explain that today they are going to be trained as Geodetectives and solve the Mystery of the Valley. Explain that Geodetectives look for clues on the landscape to solve geological mysteries.

Take the students down the path in front of Moraine Park Museum. Divide the students into 4 or 5 teams. Provide each team with a sketch of Moraine Park before ice age. Ask them to look at the sketch and compare it to what they see in front of them. What is the same? What is different? Explain that about 20,000 years ago the landscape changed the way it looked.

Explain that as Geodetectives they are going to use clues on the landscape to make a hypothesis what happened to the valley. They will then test their hypotheses by using a model.

Hand each team a set of clues (labeled photos of a moraine, a cirque, and a U-shaped Valley). Have the teams look at the valley, consult the clues and develop a hypothesis about what could have carved the valley. Provide a hint that whatever carved the valley was a force of erosion. Ask the students what things can cause erosion.

Once the teams have developed their hypotheses, have each team report their ideas. Explain that to test their hypotheses they will use models and try out each force of erosion on a mountain. They test whether the valley was created by an earthquake/rockslide, by rain, by a river, or by ice/a glacier.

Explore (15 min)

Have the teams of students gather around the sandboxes. The students will build a mountain and attempt to recreate moraine park valley using rocks, rain, a „river," and a glacier. With each test, they should observe the results and take notes or draw their observations in their journal to compare and contrast their tests.

Tell the students that they will need to make one big mountain in the middle of their sandbox. Tell the students that they will need to record their observations about the results of each test using descriptive words or sketches.

Materials

- 5 sandboxes
- 5 plastic cups (approx. 12 oz)
- One 5 gallon pail filled with water
- Moraine Park sketch (x6)
- Glacial landform pictures: u-shaped valley, lateral moraine, terminal moraine
- Spray bottles (x6)
- Set of 3 clue cards (x6)
- Ice cubes
- Rocks/pebbles

State Standards

4th Grade:
Science
Life Sciences: 3.a; 3.c

Reading, Writing, and Communicating
Research and Reasoning: 1.a
Writing and Composition: 2.b

5th Grade:
Science
Earth Systems Science: 2.a; 2.b;

Reading, Writing, and Communicating
Oral Expression and Listening: 1.a; 1.c; 1.e; 2.a;
Research and Reasoning: 1.b;

6th Grade
Science
Earth Systems Science: 1 a., 1 b.

Explain that they will use a handful of rocks to test the rockslide/ earthquake hypothesis. Before conducting the rockslide test ask the students how a rockslide could carve a valley and if they saw any evidence of a rockslide valley during their initial observation. To test the rock hypothesis, have the students place a small pile of rocks on top of their mountain and then knock it down one slope of the mountain. After conducting the rock test ask the students about how the shape of the mountain changed, what new landforms were created by the rock slide and where the rocks ended up. Have them record this in their journal.

Explain that they will use a spray bottle to test the rain hypothesis. Before conducting the rain test ask the students how a rainstorm could carve a valley and if they saw any evidence of rain impacting the valley during their initial observation. To test the rain hypothesis, have the students create a rainstorm using spray bottles at the top of their mountain for a few moments. After conducting the rain test ask the students about how the shape of the mountain changed, what new landforms were created by the rain storm and where the sediment from the mountain ended up. Have them record this in their journal.

Explain that they will use a cup of water to test the river hypothesis. Before conducting the river test ask the students how a river could carve a valley and if they saw any evidence of a river carving the valley during their initial observation. To test the river hypothesis have the students pour a cup of water off the top of their mountain. The water should flow down one side of the mountain. After conducting the river test ask the students about how the shape of the mountain changed, what new landforms were created by the river and where the sediment from the mountain ended up. Have them record this in their journal.

Explain that they will use a block of ice to test the glacier hypothesis. Before conducting the glacier test, ask the students what a glacier is. Response should include: made of snow and ice accumulated over time, is there year round, and moves under its own weight and gravity- a slow moving river of ice. To test the glacier hypothesis, have the students place their ice block at the top of their mountain and slowly push it down one side of the mountain. After conducting the glacier test ask the students about how the shape of the mountain changed, what new landforms were created by the glacier and where the sediment from the mountain ended up. Have them record this in their journal.

Explain (6 min)

Ask students what they think carved Moraine Park based on their observations from their models. Make sure they explain why they think that way.

Inform the students that even though they weren‟t here when this valley was created and the model doesn‟t quite give the whole story there is still evidence left behind on the land that tells the story of what shaped the mountains.

Explain to the students a few of the features that they might look for to determine what carved the valley. A river valley is shaped like the letter "V", while a glacial valley is shaped like the letter "U". A river valley will cut down through the material, while the glacial valley looks like it has been bulldozed. At the end and on the sides glacial valley material is deposited creating ridges on the landscape. The ridges of unconsolidated material are called moraines. The moraines on the sides of a glacial valley are called lateral-means side. The moraine at the end of the glacial valley is called a terminal or end moraine. The moraines are made up of an assortment of rock of various sizes; look for a collection of boulders that look like they were dropped randomly. A river won‟t create ridges and sorts out material as the water flows downstream (big boulders towards the start of a river, fine material towards the mouth).

Elaborate (2 min)

Walk students back down to the area that overlooks the valley. Ask the students to look around the valley (behind them, in the distance, directly in front of them, to the side) to see if they can find any signs of evidence of the glacier that carved this valley.
Students should be able to point out u-shaped valley (though a few will say v-shaped, but make sure that they are focusing on the entire valley). Ask students if they are able to see any ridges on the landscape (they may have to look behind them). The area that the students are standing on is an end moraine. Point out the South Lateral Moraine (the ridge with the densely packed trees on the left side of the valley). Mention to the students that if they were to walk on that ridge then they would be walking on a random assortment of rock sizes. When a moraine forms it pushes rocks of all shapes and sizes into a giant pile at the sides, or at its furthest end.

Ask the students what created the valley – have them vote (rockslide, rain, river, or glacier) and ask how they know. Students should be able to say a glacier created the valley because they can see certain features on the landscape.

Elaborate (10 min)

For a 55 min. to 1hr. program you can include this section.

Using the pictures and sandboxes, have the students try to determine which features in their sandboxes may look like glacial landforms. Have them use the labeled flags to mark each landform and then ask each group to present ONE feature they identified. They will probably be able to find moraines

(lateral and terminal), cirques and U-shaped valleys as well. Be sure to identify any other glacial landforms you see that they missed (ie: a tarn (if you pour water in the cirque, or an arête).

Conclusion (3 min)

Ask the students what they think would happen if a glacier never carved the landscape or the mountains were never formed. Students should respond that the area would be flat, similar to Kansas. Explain to the students that because a glacier carved the huge valley of Moraine Park, certain plants and animals moved in to the area. If there wasn‟t a glacier carving the valley, they would see different plants and animals living in the area.

Remind the students that even though they weren‟t around when much of the land was formed; there is evidence of what created the landscape all around them. Challenge the students to explore other areas of Rocky Mountain National Park and see if they can find other evidence of glaciers being in Rocky Mountain National Park.

Geodetective Log

Case #1: The Mystery of the valley

What carved the valley?

Hypothesis:

Observations:

Test # 1: Rockslide/Earthquake	**Test # 2: Rain**
Test # 3: River	**Test # 4: Glacier**

Conclusion:

RESTORATE A
STAY

Clue # 3: U-Shaped Valley

Theme

The geology of RMNP is because of different geologic events forming the park to what you see today.

Goals

Students will recognize metamorphic and igneous rocks.

Students will explain the origin of their "pet rock"

Students will know why there metamorphic rocks found at the alluvial fan

Objectives

Students will give a detailed rock description

Students will use the geologic history of RMNP to explain when metamorphic rocks are found at the alluvial fan

Time

20 min presite/ intro
60 min field work

Location

Alluvial Fan @ RMNP

Grade Level

Can be adapted for all grade levels

Materials

Field notebook & pencil
Rock cycle chart
Rock identification chart or list of rocks found in RMNP
Rock description guidelines (set by teacher)

Rocks of the Alluvial Fan Lesson

Introduction

Welcome everyone to RMNP.

Engage
Give the student a minute to look around. Ask them to think of questions they want answers to and write down 3 observations. When everyone is done taking in the beauty group back together and talk about the observations. The discussion lead into the background information the students get about RMNP.

Explain

- Review with the students the different rocks found in RMNP and how they were formed.
- Access prior knowledge of the rock cycle and explain how each rock can be related to one another.
- Teach the students about the Lawn Lake flood and glacier history of Horseshoe Park
    - Do not give too much information away here. The goal is to determine why there are metamorphic rocks in the alluvial fan that originated in silver plume granite mountains.
    - Background information on the alluvial fan can be found in the teacher guide

Explore

- Break students up for field work as desired
    - Students will find a "pet rock" and give a detailed rock description
        - To adapt to all ages of students you can set the expectation of details wanted in the rock description.
        - Younger students can draw their pet rock or write +/- 3 observations.
- Students will next count rocks in a designated area and record if the rock is metamorphic or igneous. 100 rocks is good but you can decide how many you want counted.
    - Break students up to different locations of the alluvial fan.
    - Bring students back together to share the results with everyone.
    - First have the students write down why they think there are metamorphic rocks mixed in. Then share and start a formal discussion of the different hypothesis

Explain

Lead the discussion into RMNP history. The rocks in the alluvial fan are a combination of schist, gneiss, and granite. The students should find a variety of different size rocks within the alluvial fan ranging from silt and

sand size to boulders. When the students count the different rocks they will find there are not as many metamorphic rocks as igneous. The students should know the mountains where Lawn Lake is located and that the alluvial fan cut through is made up of Silver Plume Granite 1.3 billion years old. The reason for the unsorted rocks in the alluvial fan is because not only is that characteristic of flood areas, but the alluvial fan also cut through a glacier moraine. Moraine characteristics are also unconsolidated poorly sorted material. The glacier moraine also accounts for the metamorphic rocks seen in the alluvial fan area. The glacier started high in the alpine where the mountains are made of the metamorphic rocks. The glacier carried the metamorphic rocks down and deposited them in the lateral moraine the alluvial fan cut through.

Elaborate

After you have shared the history of why there are both ignrous and metamorphic rocks at the alluvial fan have the students participate in determining what the area looked like before the flood, even thousands of years ago when the glaciers filled the valley. Have the students think about what the alluvial fan will look like in the feature and what the area might look like in the flood never happened.

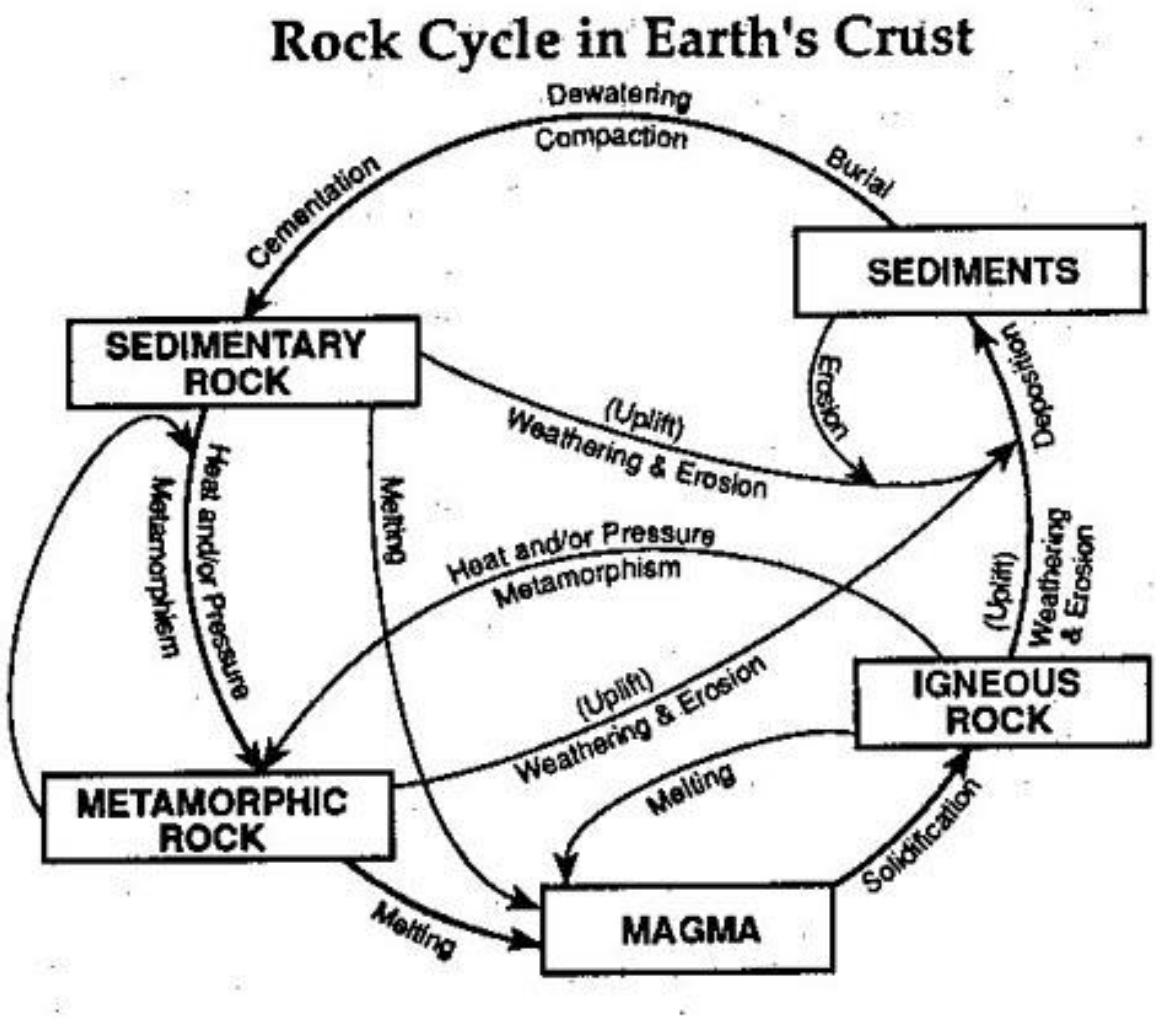
- You can have students either discuss or draw this part.

Evaluate

Students can turn in their field work results. Evaluation standards are teacher preference.

Conclusion

There are many different geologic processes that shape RMNP. The take home message is the rocks of RMNP have gone through a lot. There are a variety of reasons why RMNP looks as it does today.


Rock Cycle in Earth's Crust
Dewatering
Compaction
Cementation
Burial
SEDIMENTS
SEDIMENTARY ROCK
Erosion
Deposition
(Uplift)
Weathering & Erosion
Heat and/or Pressure
Metamorphism
Melting
Heat and/or Pressure
Metamorphism
(Uplift)
Weathering & Erosion
(Uplift)
Weathering & Erosion
IGNEOUS ROCK
METAMORPHIC ROCK
Melting
Solidification
Melting
MAGMA

Formation Properties Table

Age	Unit Name (Symbol)	Location(s)	Description	Local and Global Significance	Geologic Hazards	Suitability for Development and Recreation	Resource Potential and Protection
QUATERNARY	Alluvial fan deposit (Qf)	Mouth of the Roaring River in Horseshoe Park	Dimensions: 42.3 acres (17 ha), 364,000 yd³ (278,314 m³); maximum thickness—44 ft (13 m), average thickness—5.3' (1.6 m); largest boulder—14' × 17.5' × 21' (4m x 5m x 6 m) weighing 452 tons (410 t); sediment ranges from very large boulders to silt	Lawn Lake dam failure on July 15, 1982, deposited fan; very local deposit	Potential for rockfall and flows	Popular recreation area, safety hazard for visitors who climb on rocks	None
	Holzwarth debris flow deposit (Qd)	W side of Kawuneeche Valley (N of Baker Gulch, near Never Summer Ranch)	Lobate mass of mud, sand, and gravel 40 to 100 feet (12 to 30 m) wide; pushed trees to the edge of track and scoured soil (1 ft [0.3 m])	Deposited on June 16, 1978; similar flows occurred between 1969 and 1974 in Baker Gulch; local deposits	Potential for future flows	Surface water flow down the track has produced deep gullies	None
	Valley alluvium (Qa)	Kawuneeche Valley, Moraine Park, North St. Vrain Creek	Gravel, sand, and silt along streams and in alluvial fans along valley margins; also deposits at the margins of lateral moraines (as at Hidden Valley) where moraines dammed streams	Record of climate change (i.e., lake sediments and alluvium of Pinedale and Bull Lake age)	None	Case- by- case, site evaluation necessary for risk of flooding or mass wasting	Sand and gravel deposits may contain groundwater
	Bog deposits (Qo)	East Inlet area, Cache La Poudre headwaters	Organic- rich deposits, probably < 25 ft (8 m) thick	Used to date glacial events; probably late Pinedale or younger in age	None	Unsuitable—wetland	None
	Colluvium (Qc)	Widespread throughout park	Rock debris ranging from silt to boulders; includes talus, solifluction deposits, block fields, and nivation scree (excavation around snow banks); nearly 10 ft (3 m) thick; covers large areas, obscures bedrock	Covers most slopes above tree line	Potential for rockfall and soil movement	Case- by- case, site evaluation necessary for risk of flooding or mass wasting	None
	Landslide deposits (Ql)	Kawuneeche Valley; Jackstraw, Sundance, and Sprague Mountains	Slumps and earth flows of till; large, nearly intact masses of volcanic rocks; jumbled, hummocky masses or relatively intact blocks of Precambrian rocks; slumps of sedimentary rocks and colluvium	Movement varies from none to rapid	Potential for rejuvenated landsliding	Unsuitable—potential for mass wasting	None
	Rock- glacier deposits (Qr)	Abundant—both sides of the Continental Divide and both sides of Never Summer Mountains	Lobate and tongue- shaped masses of rock debris, ranging in size from large blocks to silt; steep fronts; hummocky, commonly furrowed, upper surfaces that slope at relatively low angles; occur at valley heads in alpine environments	Rock glaciers related to three intervals of glaciation	Potential for rockslides	Unsuitable—unstable slopes	None
	Till of neoglaciation (Qh)	Near existing snow and ice masses (e.g., Andrews Glacier)	Fresh to slightly weathered with stony, sandy deposits mainly forming small end moraines near the headwalls of cirques; angular rocks on the surfaces of the end moraines; soil development weak or absent	Deposited by small glaciers that advanced short distances between 120 and 5,000 years ago	Potential for rockslides	Unsuitable—unstable slopes	None
	Till of Pinedale age (Qp)	Moraine and Horseshoe Parks, Wild Basin, Kawuneeche Valley, North Inlet	High (65–100 ft [20–30 m]), sharp- crested moraines; unfilled and undrained kettles. Glaciation began about 30,000 years ago; glacial maximum between 23,000 and 20,000 years ago; deglaciation 15,000 to 12,000 years ago; prior to 10,000 years ago, all Pinedale glaciers disappeared.	Three ages of till—oldest to youngest: pre- Bull Lake, Bull Lake, and Pinedale (no pre- Bull Lake within the park)—distinguished and correlated on the basis of (1) areal and geomorphic position, (2) topographic expression, and (3) degree of weathering	Potential for rockfalls	Suitable for trails—steep slopes	Sand and gravel deposits may contain groundwater
	Till of Bull Lake age (Qb)	Bierstadt Lake, W of Beaver Meadows Entrance, S of Sandbeach Lake, E of Copeland Mountain	More subdued topographic expression than till of Pinedale age; unlike till of Pinedale age, does not dam lakes and rarely contains kettle ponds as a result of infilling by sediment and establishment and incision of spillways. Soil development in Bull Lake till is markedly stronger than in till of Pinedale age. Beginning of Bull Lake glaciation unknown; Bull Lake glaciers present until about 127,000 years ago.		None	Suitable—often stable for development of trails, roads, facilities	Sand and gravel deposits may contain groundwater
	Diamicton (QNd)	Near Meeker Campground	Unsorted, unstratified, unconsolidated, deposit of boulders, cobbles, and pebbles in a silty sand matrix; resembles till, but interpreted as fan deposit of Neogene or Quaternary age	Alluvial origin, not glacial—significant distinction for Cenozoic climatic history and evolution of early drainage	None	N/A—minor deposits	None
TERTIARY	Troublesome Formation (Tt)	E side of Kawuneeche Valley	Gray and orange- gray tuffaceous mudstone and sandstone, volcanic ash beds, and minor clayey limestone and conglomerate; contains several inter- layered basaltic lava flows	Deposited between 23 and 29 Ma	N/A—minor deposits	N/A—minor deposits	Potential fossil mammals
	Extrusive and intrusive igneous rocks	Never Summer Mountains	Eruption of volcanic rocks with intrusion of granite and granodiorite; lavas range from basalt to rhyolite; flows probably issued from volcanic vents in Never Summer Mountains or vicinity of Porphyry Peaks (outside the park). Include rock units: trachyandesite and basalt (Ta), volcanic breccia (Tbr), rhyolite (Tr), rhyolite welded tuff (Trw), volcanic rocks undifferentiated (Tv), rhyolite porphyry and granite of Mt Cumulus stock (Tg), granodiorite monzonite of Mt. Richthofen stock (Tgd), and andesite porphyry (Tap)	Evidence of volcanism between 23 and 29 Ma; volcanic breccia near Lulu Mountain and Seven Utes Mountain and thick welded tuff suggest local caldera source	Rockfall potential in steep terrains above tree line	N/A—remote locations	Obsidian near Specimen Mountain
CRETACEOUS DEVONIAN (?)	Pierre Shale (Kp)	Summits of Mount Cirrus and Howard Mountain	Dark- gray shale underlain by interbedded silty shale and sandstone that grade downward into dark- gray to black marine shale; metamorphosed to a dense brown- green rock characterized by hackly fracture; exposed where pushed up by intrusive igneous rocks in the Never Summer Mountains	Remnant of the Cretaceous Interior Seaway; documents > 11,000 ft (3,353 m) of uplift since about 70 Ma	N/A—minor deposits	N/A—minor deposits	Ammonite fossils well known outside Rocky Mountain National Park
	Kimberlite (Dk)	Hayden Gorge and W of Isolation Peak	Dark- gray to dark- olive- green rock, friable, easily disintegrates; occurs in small dikes; identified by distinctive mineralogy: high biotite content, pyrope garnet, chrome- rich pyroxene, and carbonate cement	Only rock from Earth's mantle in Rocky Mountain National Park; Age: Paleozoic—post- Silurian and pre- Pennsylvanian possibly Devonian	N/A—minor deposits	N/A—minor deposits	Similar intrusions W of Ft. Collins contain trace diamonds; no diamonds have been identified in park deposits

Age	Unit Name (Symbol)	Location(s)	Description	Local and Global Significance	Geologic Hazards	Suitability for Development and Recreation	Resource Potential and Protection
PRECAMBRIAN	Gabbro of the Iron Dike (Yg)	Hidden Valley, Trail Ridge Road, S face of Mount Chapin, Longs Peak Ranger Station	Distinctive rusty brown color at surface; contains, among other minerals, iron; limonite (brown staining formed by weathering of iron- bearing minerals) occurs at rock joints; probably emplaced by a single, rapid eruption originating in a deep, upward- propagating crack. Dike has been traced 85 miles (120 km) from the small mining town of Magnolia (W of Boulder), past Allenspark, into park, and N into Medicine Bow Mountains.	Iron- rich soil supports distinctive plant communities Age: 1,317 Ma	N/A—narrow dike	N/A—narrow dike	None
	Silver Plume Granite (Ysp)	Lumpy Ridge, McGregor Mountain, Longs Peak, Trail Ridge Road	Medium- to coarse- grained crystalline igneous rock; contains quartz, feldspar, mica, and minor amounts of other minerals; intruded into older biotite schist and gneiss; flowed upward and outward into the biotite schist and gneiss and rotated the older rocks into the flat- lying orientation observed today; crosscuts Ygh	Age: 1,420 Ma	Rockfalls in steep terrain, especially above tree line	Stable bedrock	Building stone
	Granite of Hagues Peak (Ygh)	Hagues Peak, Mummy Mountain, and Stormy Peaks	Tan, coarse- grained to very coarse- grained, porphyritic granite composed of quartz, microcline, oligoclase, and biotite; contains flow- aligned phenocrysts of microcline 1- to- 3- in (2.5- to- 7.6- cm) long, and scattered, small, partially assimilated inclusions of biotite schist that contain large recrystallized crystals of microcline	Notable for marking an intrusive event (1,480 Ma)	Rockfalls in steep terrain, especially above tree line	Stable bedrock	Large crystals of microcline (feldspar)
	Mafic dikes (Yd)	Near Eagle Cliff, Continental Divide (series of dikes)	Form a northwest- trending swarm of black to light- gray, fine- to medium- grained metabasalt or meta- andesite; very minor unit	Older than Ysp (> 1,430 Ma) but younger than Ygh	Rockfalls in steep terrain, especially above tree line	Part of stable bedrock	None
	Pegmatite (YXp)	Rock Cut, spires at Poudre Lake–Milner Pass	Coarse- grained igneous rocks with interlocking crystals of quartz, feldspar, and mica in dikes, lenses, or veins; both older and younger pegmatites (related to Xbc and Ysp) present in the park but not easily distinguished	Contemporaneous with Xbc or Ysp	Rockfalls in steep terrain, especially above tree line	Part of stable bedrock	Specimens of biotite, quartz, feldspar, tourmaline, garnet
	Boulder Creek Granodiorite (Xbc)	Paradise Park, Adams Lake, Lake Verna	Similar to granite but darker gray and less commonly pink; contains more biotite and commonly shows banded, streaky fabric	Intruded about same time as regional metamorphism (1,664 Ma)	Rockfalls in steep terrain, especially above tree line	Stable bedrock	Large crystals of microcline (feldspar)
	Biotite schist and biotite gneiss (Xs)	Chasm Lake–Mount Meeker, Hallett Peak, Ypsilon Mt., Eagle Cliff, Loch Vale, East Inlet	Banded metamorphic rocks marked by alternating layers containing more or less biotite	Oldest rocks in park (1,700 Ma) and some of the oldest in the National Park System; Jackstraw Mountain landslide deposit	Rockfalls in steep terrain, especially above tree line	Suitable—with caution on steep slopes	Building stone

Theme

The geologic formations of the foothills of northern Colorado offer a colorful and dynamic story of landscape formation that spans of 300 million years

Goals

1. Students will discover and explore the earth science processes behind the creation of the landscape between Loveland and the mouth of the Big Thompson Canyon.

Objectives

Participants will:

1. Discuss the general geologic history of Colorado, from 1.7 bya to the present.

2. Distinguish between the processes of weathering and erosion.

3. Learn how sedimentary deposition caused by erosion occurred over millions of years.

4. View the results of folding of sedimentary strata to form the existing hogbacks.

Time

1.5 hours

Location

Big Thompson Elementary, Loveland

Grade Level

K-5 families with kids

Foothills Geology Lesson

Introduction: Introduce self. Deliver theme and goals.

Engage: Have participants take a long view from the Big T nature area in the cardinal directions. Explain that within sight is 1.7 billion years of geologic history, from Milner Mountain to the Devils Backbone

Explain: Give a ~15 min. summary of Colorado geologic history.

- Details can vary to adapt for different grade levels.
- Use field notebook as a guide
    - Precambrian uplifting
        - Using Precambrian Map card.
    - Ancestral Rockies, periods of ocean sediment deposition
        - Using the plastic bag example or Foam model.
        - Explain different formations of the foothills and their different depositional environments.
            - Explain the principle of horizontality.
    - Present day Rockies, weathering, Laramide Orogeny.
        - Show how the Laramide Orogeny pushed the sedimentation, forming the foothills
            - Plastic bag example or foam model.
    - Present the rock cycle
    - Explain the difference between weathering and erosion
        - Erosion - as weathering occurs, erosion is the process of carrying away the smaller rock particles.
            - Agents of erosion include:
                - Streams
                - glaciers
                - waves
                - animals
                - wind
        - Weathering is the breakdown of rocks into smaller pieces by mechanical or chemical methods
            - Mechanical Weathering – rocks broken apart by physical force
            - Chemical weathering – oxidation, plant acids (lichens), acid rain
        - An example to show the students would be a ball of popcorn. Show how spraying water on the popcorn is an example of weathering and pouring water on the popcorn is erosion. (pour enough water to move the popcorn downhill)

Explore: The students should be at page 3 in their field notebook**.** After explaining the history of Colorado geology have the students tell the story

Materials

-Excursion to the Past

- Geologic Map, Masonville Quadrangle

- Geologic Information for Big T School, January 2011

- The Devil's Backbone, Product of the Rockies

- Hand-drawn diagram of strata near Big T school

- Rock samples, igneous, metamorphic, sedimentary

- Set Precambrian Rock cards, laminated

- Set Rock Cycle cards

- Foam sedimentary strata model

- Colorado Geology Time Scale bookmarks

of the area around Big T Elementary. From the Nature area the students can see a hogback in the distance. Have the students write in the field journal on page 3 the story of how the hogback was put there by geologic processes.

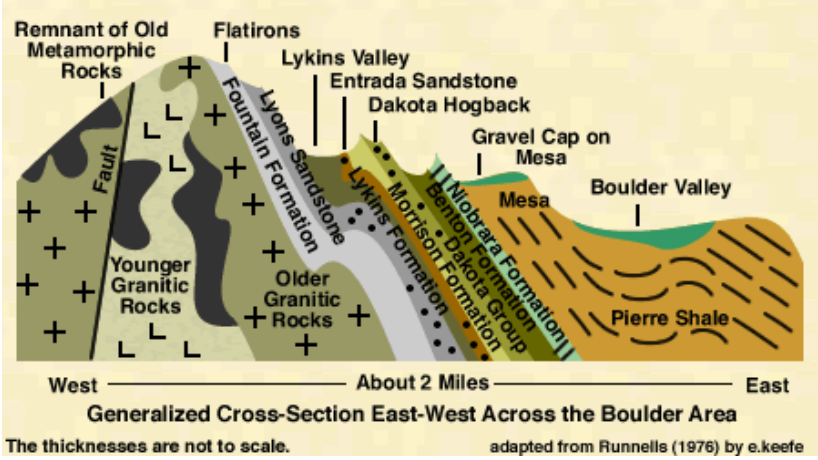
Elaborate: after the students have shared, reiterate the hogbacks formed first by the inland sea lying down hundreds of feet of sediment that turned into sedimentary rock and then tilted when the Rockies build up and uplifted to what you see today. Refer back to foam model. Backtrack referring to strata layers in the model and the Colorado Geologic Timescale bookmarks. When reviewing the formation and explaining the process transition into the geologic terms and characteristics of sedimentary rocks. Eventually lead the students into the different formations and depositional environments of the foothills. Have the students pull out their field guide and follow along with you.

Evaluate: As the students are filling out their notebooks, cold call and ask for volunteers to answer questions.

Explore: Walk the students to the outcrop of **Lykins** formation (grey carbonate, slightly reacts to acid test) to the west of the school on Highway 34. Using the clue sheet in their field guide, have the students identify what formation they are looking at. Within the field guide, have them fill out the information of the formation and sketch what they see. Point out the fractures and bedding within the formation, the vegetation, and any other features. After the students have answered the questions, and sketched, next have the students write the story of how the formation got to the location right next to the school.

After the students have completed the first road cut outcrop, have the students walk further down the road to the next large road but outcrop. This is the **Lyons** formation (red sandstone) on top of **Ingleside** formation (red sandstone). Have the students identify the formation and share observations. Guide to show how the formation is different t hen the first. Next have the students fill out their field guide and sketch the second outcrop. To elaborate on the story of how the formation was deposited next to the school, have the students make the connection that this outcrop must have been deposited before and is older than the first road cut because it dips underneath.

Field Guide to the Geologic Formations of the Colorado Foothills



Geologist Name: _____

Date:_____

Personal Goal of todays field study:

_____

_____

_____

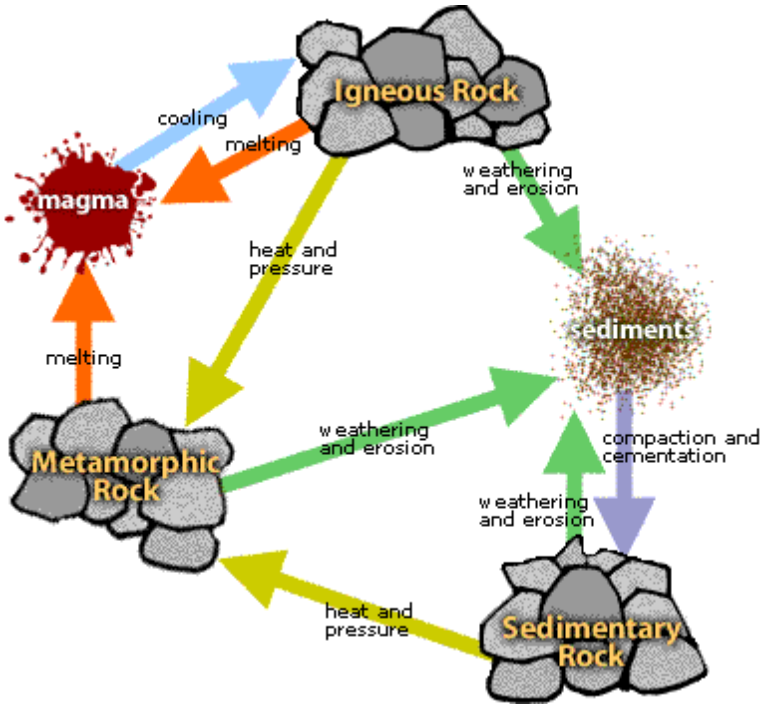
_____

Geologic History of the Foothills

_____-Colorado was covered by a sea of watch and sediments were deposited.

_____-The Laramide Orogeny uplifted the Rocky Mountains and moved all the sediment.

The Rock Cycle



The Foothills are sedimentary rocks with evidence of weathering and erosion from metamorphic and igneous rocks.

How I think the foothills formed

_____

_____

_____

_____

_____

_____

_____

_____

_____

Geologic Terms

Principle of Horizontality- _____

Principle of Superposition- _____

Erosion vs. Weathering

Weathering is the _____ of rocks; erosion is the _____ of rocks

Examples of weathering – _____

Characteristics of Sedimentary Rocks

Cross-Bedding-_____

Sediment Size

_____-_very large;

_____-Large size; easy to see different size pieces in the rock

_____-Small size; hard to see different pieces in the rock

_____-Very small size; cannot see different pieces in the rock

Pebble

Sand

Silt

Sedimentary Rocks found in the Foothills

Name of Rock	Characteristics	Depositional Environment
Conglomerate	Fragments of Rounded pebbles bonded together by **mud**.	river
Sandstone	**Sand** Sized Particles	beaches and deserts
Shale	**Clay** Particles	deep, calm fresh water
Siltstone & Mudstone	Mixture of **Clay** and **Silt**	River; shallow sea
Limestone	Mixture of Shells, Coral, and Marine Skeletons	deep ocean water

Foothill Formations

Age- million years ago	Formation	Rock Type	Description	Weathering Characteristics	Depositional Environment
Jurassic 150 mya	Morrison	Limestone, sandstone, shale & clay	Light and dark grey; dinosaur fossils;	Forms slopes; reacts to acid test	Floodplain; shallow sea
Jurassic 230 mya	Entrada	Quartz and sandstone	Orange; cross-bedding	Resistant	Coastal Dunes; beach
Triassic 250 mya	Lykins	Sandstone; siltstone; shale	Red	soft; valleys and slopes; slightly reacts to acid test	Flat shallow marine area
Permian 270 mya	Lyons	Sandstone	Orange; pinkish-gray	hard ridges	Flat shallow marine area
Permian 290 mya	Ingleside	Quartz Sandstone	Reddish-pink	Ripple marks;	near-shore beach; shallow marine
Pennsylvanian 305 mya	Fountain	Sandstone; conglomerate	Red	Local hard ridges	alluvial fans; braided steams

Study Site 1

Location: first road cut east of school

1. What size are the pieces in the formation?
2. Pebbles Sand Silt Mud/Clay
3. Does the rock react to the acid test? Yes No
4. What color is the formation? _____
5. Is there evidence of weathering? Yes No
   Why?_____
   _____
6. Is there evidence of erosion? Yes No
   Why?_____
   _____
7. What is the name of the formation? _____
8. How old is the formation? _____ mya _____ period

   Draw the formation- include cracks, plants, color and size

---

Write the story of how the rock got placed next to your school

_____
_____
_____
_____
_____
_____
_____
_____

Study Site 2

Location: second road cut east of school

1. What size are the pieces in the formation?
2. Pebbles Sand Silt Mud/Clay
3. Does the rock react to the acid test? Yes No
4. What color is the formation? _____
5. Is there evidence of weathering? Yes No
   Why?_____
   _____
6. Is there evidence of erosion? Yes No
   Why?_____
   _____
7. What is the name of the formation? _____
8. How old is the formation? _____ mya _____ period

   Draw the formation- include cracks, plants, color and size

---

How is this formation different then the first outcrop? Is it older or younger? Same depositional environment or different?

_____
_____
_____
_____
_____
_____
_____
_____

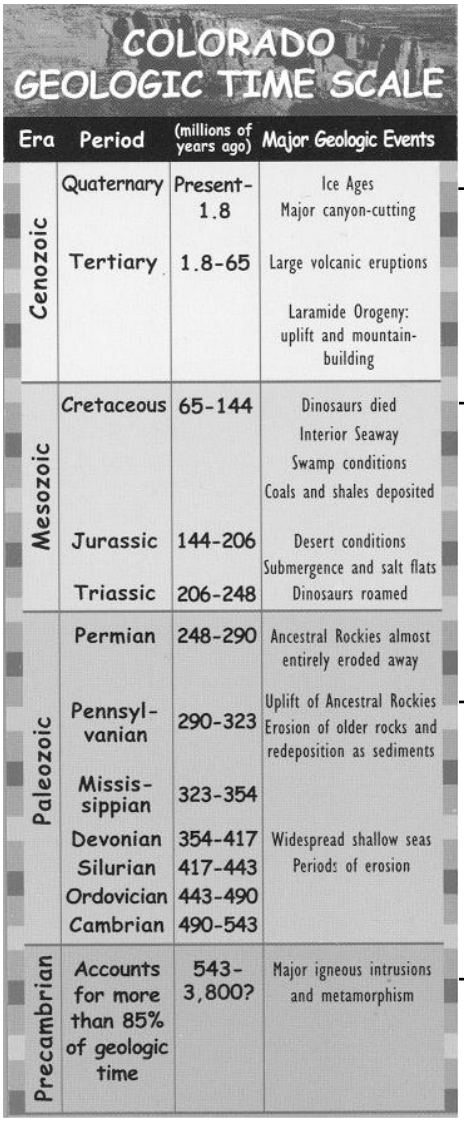
Appendix

Geologic Time Scale

Geologic time is divided into a four-level hierarchy of time intervals:

- EONS -- The first and largest division of geologic time.
- ERAS -- The second division of geologic time; each era has at least two periods.
- PERIODS-- The third division of geologic time. Periods are named for either *location* or *characteristics* of the defining rock formations.
- EPOCHS -- The fourth division of geologic time; represents the subdivisions of a period.

The time of the transition from one interval of geologic time to the subsequent one is usually marked by a relatively abrupt change in fossil types and numbers.



COLORADO GEOLOGIC TIME SCALE

Era	Period	(millions of years ago)	Major Geologic Events
Cenozoic	Quaternary	Present-1.8	Ice Ages Major canyon-cutting
	Tertiary	1.8-65	Large volcanic eruptions Laramide Orogeny: uplift and mountain-building
Mesozoic	Cretaceous	65-144	Dinosaurs died Interior Seaway Swamp conditions Coals and shales deposited
	Jurassic	144-206	Desert conditions Submergence and salt flats
	Triassic	206-248	Dinosaurs roamed
Paleozoic	Permian	248-290	Ancestral Rockies almost entirely eroded away
	Pennsylvanian	290-323	Uplift of Ancestral Rockies Erosion of older rocks and redeposition as sediments
	Mississippian	323-354	
	Devonian	354-417	Widespread shallow seas Periods of erosion
	Silurian	417-443	
	Ordovician	443-490	
	Cambrian	490-543	
Precambrian	Accounts for more than 85% of geologic time	543-3,800?	Major igneous intrusions and metamorphism

30,000-11,000 years ago - Pinedale Glaciers

300,000-127,000 years ago - Bull Lake Glaciers

70 Ma – 28 Ma Laramide Mountain Building

285 Ma – Ancestral Rockies Mountain Building

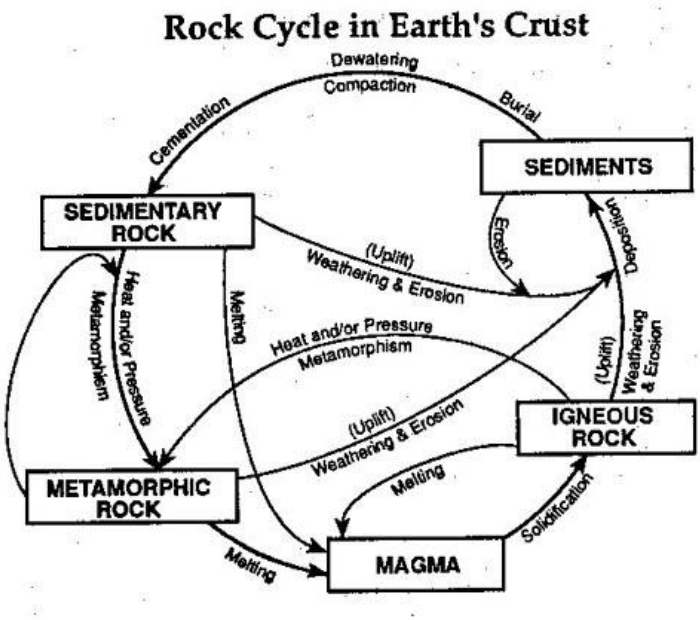
1700 Ma – Precambrian Mountain Building

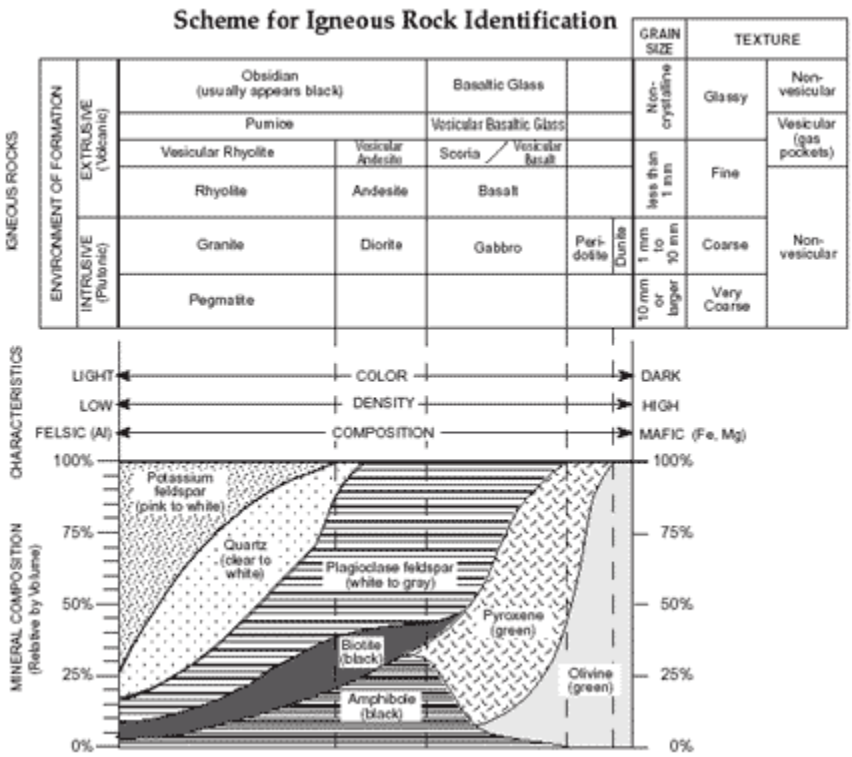
Table 1-1. Geologic events and deposits in Colorado through time.

Era	Period	Millions of Years Ago	Events and Geologic Deposits	Features
Cenozoic (Age of Mammals)	Quaternary	1.8	Development of present topography: Neoglaciation (small cirque glaciers); Altithermal phase (warming); Ice Age (large valley glaciers in mountains) Dune, wind, landslide, glacial deposits	Great Sand Dunes; widespread faulting
	Tertiary	65	Uplift (to present elevations) and mountain-building; Laramide Orogeny (major canyon cutting); San Juan and Thirty Nine Mile Volcanic Fields White River Formation (ash and many mammal fossils), Denver Formation, Arapahoe Conglomerate, Dawson Arkose (delta and river sediments)	Florissant fossil beds; San Juan Mtns. (largest volcanic area in Colorado); rich mineral deposits;
	(K-T boundary)		**Asteroid impact causes worldwide extinction of plants and animals**	**End of dinosaurs**
Mesozoic (Age of Reptiles)	Cretaceous	144	Deep and shallow marine and swamp conditions Laramie Formation (interbedded sands and coal), Pierre Shale (fine gray muds), Niobrara Limestone, Benton Shale (black muds), Dakota Formation (beach and sand bars)	Oysters; oil in eastern Colorado; coal in western Colorado
	Jurassic	206	Desert conditions; intermittent streams; Brief submergence and "salt" flats Morrison Formation (streams), Ralston Creek Formation ("salt" flats), Navajo Sandstone (dune), Carmel Formation (stream), Entrada Sandstone (dune)	Dinosaurs; vanadium, radium, and uranium concentrations in organic materials
	Triassic	248	Desert conditions; mudflats; alluvial plains, dune fields Coastal plain, dune, or delta deposits; Lykins Formation	Early dinosaurs
Paleozoic (Age of Fishes)	Permian	290	Deep basins and deserts; Ancestral Rockies almost entirely removed by erosion Maroon Formation (red bed deposits)	Tracks of early reptiles in Lyons Formation
	Pennsylvanian	323	Uplift of Ancestral Rockies; Erosion of older sediments; shallow seas and evaporite basins Fountain, Hermosa, and Minturn Formations	Flatirons and Red Rocks Park
	Mississippian	354	Widespread open ocean then withdrawal of the sea Leadville Limestone, Molas Formation (soil/pebbles/chert)	Brachiopods, corals
	Devonian	417	Embayments of western sea covering much of Colorado; Deposition of marine limestone; Intrusion of kimberlite volcanics Parting Sandstone, Dyer Dolomite	Fossil fish, algae, brachiopods, mollusks, corals
	Silurian	443	Shallow seas and marine deposition	Corals, brachiopods
	Ordovician	490	Deepening and widening of sea; Deposition of limestone and dolomite Manitou Formation, Harding Sandstone, Fremont Limestone	Earliest known vertebrate, agnathids (jawless fish)
	Cambrian	543	Invasion of the sea from the west and east Sawatch Quartzite (e.g., Glenwood Canyon)	First hard-shelled animals, e.g., trilobites
Precambrian	Accounts for more than 85% of geologic time	4,600	"Lipilian Interval" (long period of erosion) Pikes Peak Granite (pink, coarse-grained), Silver Plume Granite (light pinkish gray, fine-grained), Boulder Creek Granite (dark gray, faintly banded), Red Creek Quartzite	Front Range "core"; Early soft-bodied marine organisms

from *Ground Water Atlas of Colorado,* Colorado Geological Survey Special Publication 53

Common Rocks and the Rock Cycle





Scheme for Metamorphic Rock Identification

TEXTURE		GRAIN SIZE	COMPOSITION	TYPE OF METAMORPHISM	COMMENTS	ROCK NAME	MAP SYMBOL
FOLIATED	MINERAL ALIGNMENT	Fine	MICA, QUARTZ, FELDSPAR, AMPHIBOLE, GARNET, PYROXENE	Regional (Heat and pressure increase with depth)	Low-grade metamorphism of shale	Slate	
		Fine to medium			Foliation surfaces shiny from microscopic mica crystals	Phyllite	
					Platy mica crystals visible from metamorphism of clay or feldspars	Schist	
	BAND-ING	Medium to coarse			High-grade metamorphism; some mica changed to feldspar; segregated by mineral type into bands	Gneiss	
NONFOLIATED		Fine	Variable	Contact (Heat)	Various rocks changed by heat from nearby magma/lava	Hornfels	
		Fine to coarse	Quartz	Regional or Contact	Metamorphism of quartz sandstone	Quartzite	
			Calcite and/or dolomite		Metamorphism of limestone or dolostone	Marble	
		Coarse	Various minerals in particles and matrix		Pebbles may be distorted or stretched	Metaconglomerate	

Scheme for Sedimentary Rock Identification

INORGANIC LAND-DERIVED SEDIMENTARY ROCKS					
TEXTURE	GRAIN SIZE	COMPOSITION	COMMENTS	ROCK NAME	MAP SYMBOL
Clastic (fragmental)	Pebbles, cobbles, and/or boulders embedded in sand, silt, and/or clay	Mostly quartz, feldspar, and clay minerals; may contain fragments of other rocks and minerals	Rounded fragments	Conglomerate	
			Angular fragments	Breccia	
	Sand (0.2 to 0.006 cm)		Fine to coarse	Sandstone	
	Silt (0.006 to 0.0004 cm)		Very fine grain	Siltstone	
	Clay (less than 0.0004 cm)		Compact; may split easily	Shale	
CHEMICALLY AND/OR ORGANICALLY FORMED SEDIMENTARY ROCKS					
TEXTURE	GRAIN SIZE	COMPOSITION	COMMENTS	ROCK NAME	MAP SYMBOL
Crystalline	Varied	Halite	Crystals from chemical precipitates and evaporites	Rock Salt	
	Varied	Gypsum		Rock Gypsum	
	Varied	Dolomite		Dolostone	
Bioclastic	Microscopic to coarse	Calcite	Cemented shell fragments or precipitates of biologic origin	Limestone	
	Varied	Carbon	From plant remains	Coal	

Formation Properties Table

Age	Unit Name (Symbol)	Location(s)	Description	Local and Global Significance	Geologic Hazards	Suitability for Development and Recreation	Resource Potential and Protection
QUATERNARY	Alluvial fan deposit (Qf)	Mouth of the Roaring River in Horseshoe Park	Dimensions: 42.3 acres (17 ha), 364,000 yd³ (278,314 m³); maximum thickness—44 ft (13 m), average thickness—5.3' (1.6 m); largest boulder—14' x 17.5' x 21' (4m x 5m x 6 m) weighing 452 tons (410 t); sediment ranges from very large boulders to silt	Lawn Lake dam failure on July 15, 1982, deposited fan; very local deposit	Potential for rockfall and flows	Popular recreation area, safety hazard for visitors who climb on rocks	None
	Holzwarth debris flow deposit (Qd)	W side of Kawuneeche Valley (N of Baker Gulch, near Never Summer Ranch)	Lobate mass of mud, sand, and gravel 40 to 100 feet (12 to 30 m) wide; pushed trees to the edge of track and scoured soil (1 ft [0.3 m])	Deposited on June 16, 1978; similar flows occurred between 1969 and 1974 in Baker Gulch; local deposits	Potential for future flows	Surface water flow down the track has produced deep gullies	None
	Valley alluvium (Qa)	Kawuneeche Valley, Moraine Park, North St. Vrain Creek	Gravel, sand, and silt along streams and in alluvial fans along valley margins; also deposits at the margins of lateral moraines (as at Hidden Valley) where moraines dammed streams	Record of climate change (i.e., lake sediments and alluvium of Pinedale and Bull Lake age)	None	Case-by-case, site evaluation necessary for risk of flooding or mass wasting	Sand and gravel deposits may contain groundwater
	Bog deposits (Qo)	East Inlet area, Cache La Poudre headwaters	Organic-rich deposits, probably < 25 ft (8 m) thick	Used to date glacial events; probably late Pinedale or younger in age	None	Unsuitable—wetland	None
	Colluvium (Qc)	Widespread throughout park	Rock debris ranging from silt to boulders; includes talus, solifluction deposits, block fields, and nivation scree (excavation around snow banks); nearly 10 ft (3 m) thick; covers large areas, obscures bedrock	Covers most slopes above tree line	Potential for rockfall and soil movement	Case-by-case, site evaluation necessary for risk of flooding or mass wasting	None
	Landslide deposits (Ql)	Kawuneeche Valley; Jackstraw, Sundance, and Sprague Mountains	Slumps and earth flows of till; large, nearly intact masses of volcanic rocks; jumbled, hummocky masses or relatively intact blocks of Precambrian rocks; slumps of sedimentary rocks and colluvium	Movement varies from none to rapid	Potential for rejuvenated landsliding	Unsuitable—potential for mass wasting	None
	Rock-glacier deposits (Qr)	Abundant—both sides of the Continental Divide and both sides of Never Summer Mountains	Lobate and tongue-shaped masses of rock debris, ranging in size from large blocks to silt; steep fronts; hummocky, commonly furrowed, upper surfaces that slope at relatively low angles; occur at valley heads in alpine environments	Rock glaciers related to three intervals of glaciation	Potential for rockslides	Unsuitable—unstable slopes	None
	Till of neoglaciation (Qh)	Near existing snow and ice masses (e.g., Andrews Glacier)	Fresh to slightly weathered with stony, sandy deposits mainly forming small end moraines near the headwalls of cirques; angular rocks on the surfaces of the end moraines; soil development weak or absent	Deposited by small glaciers that advanced short distances between 120 and 5,000 years ago	Potential for rockslides	Unsuitable—unstable slopes	None
	Till of Pinedale age (Qp)	Moraine and Horseshoe Parks, Wild Basin, Kawuneeche Valley, North Inlet	High (65–100 ft [20–30 m]), sharp-crested moraines; unfilled and undrained kettles. Glaciation began about 30,000 years ago; glacial maximum between 23,000 and 20,000 years ago; deglaciation 15,000 to 12,000 years ago; prior to 10,000 years ago, all Pinedale glaciers disappeared.	Three ages of till—oldest to youngest: pre-Bull Lake, Bull Lake, and Pinedale (no pre-Bull Lake within the park)—distinguished and correlated on the basis of (1) areal and geomorphic position, (2) topographic expression, and (3) degree of weathering	Potential for rockfalls	Suitable for trails—steep slopes	Sand and gravel deposits may contain groundwater
	Till of Bull Lake age (Qb)	Bierstadt Lake, W of Beaver Meadows Entrance, S of Sandbeach Lake, E of Copeland Mountain	More subdued topographic expression than till of Pinedale age; unlike till of Pinedale age, does not dam lakes and rarely contains kettle ponds as a result of infilling by sediment and establishment and incision of spillways. Soil development in Bull Lake till is markedly stronger than in till of Pinedale age. Beginning of Bull Lake glaciation unknown; Bull Lake glaciers present until about 127,000 years ago.		None	Suitable—often stable for development of trails, roads, facilities	Sand and gravel deposits may contain groundwater
	Diamicton (QNd)	Near Meeker Campground	Unsorted, unstratified, unconsolidated, deposit of boulders, cobbles, and pebbles in a silty sand matrix; resembles till, but interpreted as fan deposit of Neogene or Quaternary age	Alluvial origin, not glacial—significant distinction for Cenozoic climatic history and evolution of early drainage	None	N/A—minor deposits	None
TERTIARY	Troublesome Formation (Tt)	E side of Kawuneeche Valley	Gray and orange-gray tuffaceous mudstone and sandstone, volcanic ash beds, and minor clayey limestone and conglomerate; contains several inter-layered basaltic lava flows	Deposited between 23 and 29 Ma	N/A—minor deposits	N/A—minor deposits	Potential fossil mammals
	Extrusive and intrusive igneous rocks	Never Summer Mountains	Eruption of volcanic rocks with intrusion of granite and granodiorite; lavas range from basalt to rhyolite; flows probably issued from volcanic vents in Never Summer Mountains or vicinity of Porphyry Peaks (outside the park). Include rock units: trachyandesite and basalt (Ta), volcanic breccia (Tbr), rhyolite (Tr), rhyolite welded tuff (Trw), volcanic rocks undifferentiated (Tv), rhyolite porphyry and granite of Mt Cumulus stock (Tg), granodiorite monzonite of Mt. Richthofen stock (Tgd), and andesite porphyry (Tap)	Evidence of volcanism between 23 and 29 Ma; volcanic breccia near Lulu Mountain and Seven Utes Mountain and thick welded tuff suggest local caldera source	Rockfall potential in steep terrains above tree line	N/A—remote locations	Obsidian near Specimen Mountain
CRETACEOUS (DEVONIAN?)	Pierre Shale (Kp)	Summits of Mount Cirrus and Howard Mountain	Dark-gray shale underlain by interbedded silty shale and sandstone that grade downward into dark-gray to black marine shale; metamorphosed to a dense brown-green rock characterized by hackly fracture; exposed where pushed up by intrusive igneous rocks in the Never Summer Mountains	Remnant of the Cretaceous Interior Seaway; documents > 11,000 ft (3,353 m) of uplift since about 70 Ma	N/A—minor deposits	N/A—minor deposits	Ammonite fossils well known outside Rocky Mountain National Park
	Kimberlite (Dk)	Hayden Gorge and W of Isolation Peak	Dark-gray to dark-olive-green rock, friable, easily disintegrates; occurs in small dikes; identified by distinctive mineralogy: high biotite content, pyrope garnet, chrome-rich pyroxene, and carbonate cement	Only rock from Earth's mantle in Rocky Mountain National Park; Age: Paleozoic—post-Silurian and pre-Pennsylvanian possibly Devonian	N/A—minor deposits	N/A—minor deposits	Similar intrusions W of Ft. Collins contain trace diamonds; no diamonds have been identified in park deposits

Age	Unit Name (Symbol)	Location(s)	Description	Local and Global Significance	Geologic Hazards	Suitability for Development and Recreation	Resource Potential and Protection
PRECAMBRIAN	Gabbro of the Iron Dike (Yg)	Hidden Valley, Trail Ridge Road, S face of Mount Chapin, Longs Peak Ranger Station	Distinctive rusty brown color at surface; contains, among other minerals, iron; limonite (brown staining formed by weathering of iron-bearing minerals) occurs at rock joints; probably emplaced by a single, rapid eruption originating in a deep, upward-propagating crack. Dike has been traced 85 miles (120 km) from the small mining town of Magnolia (W of Boulder), past Allenspark, into park, and N into Medicine Bow Mountains.	Iron-rich soil supports distinctive plant communities Age: 1,317 Ma	N/A—narrow dike	N/A—narrow dike	None
	Silver Plume Granite (Ysp)	Lumpy Ridge, McGregor Mountain, Longs Peak, Trail Ridge Road	Medium- to coarse-grained crystalline igneous rock; contains quartz, feldspar, mica, and minor amounts of other minerals; intruded into older biotite schist and gneiss; flowed upward and outward into the biotite schist and gneiss and rotated the older rocks into the flat-lying orientation observed today; crosscuts Ygh	Age: 1,420 Ma	Rockfalls in steep terrain, especially above tree line	Stable bedrock	Building stone
	Granite of Hagues Peak (Ygh)	Hagues Peak, Mummy Mountain, and Stormy Peaks	Tan, coarse-grained to very coarse-grained, porphyritic granite composed of quartz, microcline, oligoclase, and biotite; contains flow-aligned phenocrysts of microcline 1- to- 3- in (2.5- to- 7.6- cm) long, and scattered, small, partially assimilated inclusions of biotite schist that contain large recrystallized crystals of microcline	Notable for marking an intrusive event (1,480 Ma)	Rockfalls in steep terrain, especially above tree line	Stable bedrock	Large crystals of microcline (feldspar)
	Mafic dikes (Yd)	Near Eagle Cliff, Continental Divide (series of dikes)	Form a northwest-trending swarm of black to light-gray, fine- to medium-grained metabasalt or meta-andesite; very minor unit	Older than Ysp (> 1,430 Ma) but younger than Ygh	Rockfalls in steep terrain, especially above tree line	Part of stable bedrock	None
	Pegmatite (YXp)	Rock Cut, spires at Poudre Lake–Milner Pass	Coarse-grained igneous rocks with interlocking crystals of quartz, feldspar, and mica in dikes, lenses, or veins; both older and younger pegmatites (related to Xbc and Ysp) present in the park but not easily distinguished	Contemporaneous with Xbc or Ysp	Rockfalls in steep terrain, especially above tree line	Part of stable bedrock	Specimens of biotite, quartz, feldspar, tourmaline, garnet
	Boulder Creek Granodiorite (Xbc)	Paradise Park, Adams Lake, Lake Verna	Similar to granite but darker gray and less commonly pink; contains more biotite and commonly shows banded, streaky fabric	Intruded about same time as regional metamorphism (1,664 Ma)	Rockfalls in steep terrain, especially above tree line	Stable bedrock	Large crystals of microcline (feldspar)
	Biotite schist and biotite gneiss (Xs)	Chasm Lake–Mount Meeker, Hallett Peak, Ypsilon Mt., Eagle Cliff, Loch Vale, East Inlet	Banded metamorphic rocks marked by alternating layers containing more or less biotite	Oldest rocks in park (1,700 Ma) and some of the oldest in the National Park System; Jackstraw Mountain landslide deposit	Rockfalls in steep terrain, especially above tree line	Suitable—with caution on steep slopes	Building stone

Foothills Formations

INTERVALS OF TIME		MILLIONS OF YEARS AGO	FORMATION	THICKNESS (FEET)	DESCRIPTION	WEATHERING CHARACTERISTICS
ERA	PERIOD					
CENO-ZOIC	QUATERNARY	2	NOT NAMED	0-25	GRAVEL, SAND, SILT	LOOSE
	TERTIARY	70				
MESOZOIC	CRETACEOUS		LARAMIE, FOX HILLS, PIERRE, NIOBRARA, BENTON, DAKOTA	10,400	GRAY TO TAN SHALES, SANDSTONES, LIMESTONES, FOSSILS	SANDSTONES STAND ON RIDGES, SHALE FORMS SLOPES
		135	MORRISON	300	SHALE TO SANDSTONE	FORMS SLOPES
	JURASSIC	180	ENTRADA	30	CROSS-BEDDED SANDSTONE	RESISTANT
	TRIASSIC	225	LYKINS	675	RED SHALE, SILTSTONE, SANDSTONE	SOFT. VALLEYS AND SLOPES
PALEOZOIC	PERMIAN		LYONS	220	PINK SANDSTONE	HARD RIDGES
	PENNSYLVANIAN	270	FOUNTAIN	800	RED SANDSTONES AND CONGLOMERATE	LOCALLY HARD RIDGES
	MISSISSIPPIAN	305				
	DEVONIAN	350				
	SILURIAN	400				
	ORDOVICIAN	420				
	CAMBRIAN	500				
		600				
PRECAMBRIAN		1700	IDAHO SPRINGS FM, BOULDER CREEK GR.	UNKNOWN	METAMORPHIC & IGNEOUS ROCKS	CRYSTALLINE, HARD

APPROXIMATE AGE OF THE EARTH = 4.6 BILLION YEARS

Geologic and Stratigraphic Column for the Boulder Area (Based on Runnells, 1976)

Vocabulary

Ablation As applied to glacier ice, the process by which ice below the snow line is wasted by evaporation and melting.

Alluvial fan An assemblage of sediments marking place where a stream moves from a steep gradient to a flatter gradient and suddenly loses transporting power. Typical of arid and semiarid climates but not confined to them.

Andesite A fine-grained volcanic rock of intermediate composition, consisting largely of plagioclase and one or more mafic minerals.

Anticline A fold that is convex upward, or that had such an attitude at some stage of its development.

Aphanitic A textural term meaning "fine-grained" that applies to igneous rocks.

Archean An eon of geologic time extending from about 3.9 billion years to 2.5 billion years ago.

Arête A narrow, saw-toothed mountain ridge developed by glacier erosion in adjacent cirques.

Arkose A sedimentary rock formed by the cementation of sand-sized grains of feldspar and quartz.

Asthenosphere The weak or "soft" zone in the upper mantle just below the lithosphere, involved in plate movement and isostatic adjustments. It lies 70 to 100 km below the surface and may extend to a depth of 400 km.

Aureole A zone surrounding an igneous intrusion, in which contact metamorphism has taken place.

Basalt A dark colored extrusive igneous rock composed chiefly of calcium plagioclase and pyroxene. Extrusive equivalent of gabbro underlies the ocean basins and comprises oceanic crust.

Basin A synclinal structure, roughly circular in its outcrop pattern, in which beds dip gently toward the center from all directions.

Batholith A large, discordant, intrusive body of igneous rock.

Bed load Material in motion along a stream bed.

Bedding A collective term used to signify presence of beds, or layers, in sedimentary rocks and deposits.

Bedding plane Surface separating layers of sedimentary rocks and deposits. Each bedding plane marks termination of one deposit and beginning of another of different character, such as a surface separating a sandstone bed from an overlying mudstone bed. Rock tends to breaks or separate, readily along bedding planes.

Bedrock Any solid rock exposed at the Earth's surface or overlain by unconsolidated material.

Block fault Mountain- A linear mountain that is bounded on both sides by normal faults

Bottom Set Bed Layer of fine sediment deposited in a body of standing water beyond the edge of a

growing delta and which is eventually built over by the advancing delta. Similarly bottom set beds may accumulate in the wind shadow of a sand dune and be preserved beneath it as the dune advances.

Boundary The tectonic region in which two plates meet.

Breccia A clastic rock in which the gravel-sized particles are angular in shape and make up an appreciable volume of the rock.

Brittle Structural behavior in which a material deforms permanently by fracturing.

Burial metamorphism Takes place in an environment where pressure and temperature are barely more intense than during diagenesis, typically in a deepening sequence of sediments.

Carbonate rock A rock consisting primarily of a carbonate mineral such as calcite or dolomite, the chief minerals in limestone and dolostone, respectively.

Cenozoic The current geologic era, this began 66.4 million years ago and continues to the present.

C**hemical sediment** Sediment formed by chemical precipitation from water.

Cirque A steep-walled hollow in a mountain side, shaped like an amphitheater, or bowl, with one side partially cut away. Place of origin of a mountain glacier.

Clastic Refers to rock or sediments made up primarily of broken fragments of pre-existing rocks or minerals.

Clay The name for a family of finely-crystalline sheet silicate minerals

Cleavage of a mineral: The tendency of a mineral to split along planes determined by the crystal structure

Col Mountain pass formed by enlargement of two opposing cirques until their head walls meet and are broken down.

Columnar jointing The type of jointing that breaks rock, typically basalt, into columnar prisms. Usually the joints form a more or less distinct hexagonal pattern.

Compaction Reduction of pore space between individual particles as the result of overlying sediments or of tectonic movements.

Compression Squeezing a material from opposite directions.

Conglomerate A clastic sedimentary rock composed of lithified beds of rounded gravel mixed with sand.

Contact metamorphism Metamorphism genetically related to the intrusion (or extrusion) of magmas and taking place in rocks at or near their contact with a body of igneous rock.

Continental arc A belt of volcanic mountains on the continental mainland that lie above a subduction zone.

Continental crust The part of the crust that directly underlies the continents and continental shelves. Averages about 35 km in thickness, but may be over 70 km thick under largest mountain ranges.

Continental Divide the watershed of North America comprising the line of highest points of land separating the waters flowing W from those flowing N or E, coinciding with various ranges of the Rockies, & extending SSE from NW Canada to NW S. America

Continental ice glacier An ice sheet that obscures all but the highest peaks of a large part of a continent.

Convergent boundary A boundary between two plates of the Earth's crust that are pushing together.

Core Innermost zone of Earth. Consists of two parts, an outer liquid section and an inner solid section, both chiefly of iron and nickel with about 10 percent lighter elements. It is surrounded by the mantle.

Craton The stable portions of the continents that have escaped orogenic activity for the last 2 billion years. Made predominantly of granite and metamorphic rocks.

Crevasse Deep crevice or open fracture in glacier ice.

Cross-bedding Bedding laid down at an angle to the horizontal, as in many sand dunes.

Cross-cutting relationships Geologic discontinuities that suggest relative ages: A geologic feature is younger than the feature it cuts. Thus, a fault cutting across a rock is younger than the rock.

Crust The upper part of the lithosphere , divided into oceanic crust and continental crust .

Crystal The multi-sided form of a mineral, bounded by planar growth surfaces, that is the outward expression of the ordered arrangement of atoms within it.

Crystalline Having a crystal structure.

Cumulate An igneous rock that forms by crystal settling.

Current ripple mark An asymmetric ripple mark formed by wind or water moving generally in one direction. Steep face of ripple faces in direction of current. compare oscillation ripple mark .

Debris flow Fast-moving, turbulent mass movement with a high content of both water and rock debris. The more rapid debris flows rival the speed of rock slides.

Decomposition (chemical weathering) Weathering processes that are the result of chemical reactions

Deflation A process of erosion in which wind carries off particles of dust and sand.

Dehydration Any process by which water bound within a solid material is released.

Depositional environment The nature of the environment in which sediments are laid down. They are immensely varied and may range from the deep ocean to the coral reef and the glacial lake of the high mountains. The nature of the depositional environment may be deduced from the nature of the sediments and rock deposited there.

Diagenesis All the physical, chemical, and biologic changes undergone by sediments from the time of their initial deposition, through their conversion to solid rock, and subsequently to the brink of metamorphism.

Differential weathering Weathering that occurs at different rates, as the result of variations in composition and mechanical resistance of rocks, or differences in the intensity of weathering processes.

Dike A tabular igneous intrusion that cuts across the surrounding rock.

Dip The angle that a structural surface such as a bedding plane or fault surface makes with the horizontal, measured perpendicular to the strike and in the vertical plane.

Dip slip fault A fault on which the movement is parallel to the dip of the fault plane.

Discharge In a stream, the volume of water passing through a channel in a given time.

Disconformity An unconformity in which the beds above the unconformity are parallel to the beds below the unconformity.

Discordant Cutting across surrounding strata.

Disintegration (mechanical weathering) The processes of weathering by which physical actions such as frost wedging break down a rock into fragments, involving no chemical change.

Dissolution A chemical reaction in which a solid material is dispersed as ions in a liquid.

D**ivergent boundary** Boundary between two crustal plates that are pulling apart.

Dome An uplift or anticlinal structure, roughly circular in its outcrop exposure, in which beds dip gently away from the center in all directions.

Drag fold A minor fold produced within a weak bed or adjacent to a fault by the movement of surrounding rocks in opposite directions.

Drainage basin The area from which a stream and its tributaries receives its water.

Drainage divide The line that separates one drainage basin from another.

Drift Glacial deposits laid down directly by glaciers or laid down in lakes, ocean, or streams as result of glacial activity.

Drumlin Streamlined hill, largely of till, with blunt end pointing into direction from which ice moved. Occur in clusters called drumlin fields.

Ductile Structural behavior in which a material deforms permanently without fracturing.

Earthflow A form of slow, but perceptible, mass movement, with high content of water and rock debris. Lateral boundaries are well-defined and the terminus is lobed. With increasing moisture content grades into a mudflow.

Elastic Non-permanent structural deformation during which the amount of deformation (strain) is proportional to the stress.

Elastic rebound The statement that movement along a fault is the result of an abrupt release of a progressively increasing elastic strain between the rocks on either side of the fault.

Elasticity The tendency for a body to return to its original shape and size when a stress is removed.

Eon The primary division of geologic time which are, from oldest to youngest, the Hadean, Archean, Proterozoic, and Phanerozoic eons.

Epoch A division of geologic time next shorter than a period. Example: the Pleistocene epoch is in the Quaternary period.

Equilibrium line On a glacier the line separating the zone of accumulation from the zone of ablation .

Era A division of geologic time next smaller than the eon and larger than a period. Example: The Paleozoic era is in the Phanerozoic eon and includes, among others, the Devonian period.

Erratic A stone or boulder, glacially transported from place of origin and left in an area of different bedrock composition.

Esker A winding ridge of stratified drift . Forms in a glacial tunnel and, when ice melts, stands as ridge up to 15 m high and kilometers in length.

Evaporite A mineral or rock deposited directly from a solution (commonly seawater) during evaporation. For example, gypsum and halite are evaporite minerals.

Exfoliation The process by which concentric scales, plates, or shells of rock are stripped or spall from the bare surface of a large rock mass.

Exfoliation dome A large dome-shaped form that develops in homogeneous crystalline rocks as the result of exfoliation.

Extrusive Pertaining to igneous rocks or features formed from lava released on the Earth's surface.

Fault The surface of rock rupture along which there has been differential movement of the rock on either side.

Foliation A planar structure that develops in metamorphic rocks as a result of directed pressure.

Fold and thrust mountains Mountains, characterized by extensive folding and thrust faulting, that form at convergent plate boundaries on continents.

Foot wall block The body of rock that lies below an inclined fault plane. compare hanging wall block

Fossil Evidence in rock of the presence of past life, such as a dinosaur bone, an ancient clam shell, or the footprint of a long-extinct animal.

Fractional crystallization A sequence of crystallization from magma in which the early-formed crystals are prevented from reacting with the remaining magma, resulting in a magma with an evolving chemical composition.

Frost wedging A type of disintegration in which jointed rock is forced apart by the expansion of water as it freezes in fractures.

Geologic column The arrangement of rock units in the proper chronological order from youngest to oldest.

Geologic time scale The chronological sequence of units of Earth time.

Glaciation The formation, advance and retreat of glaciers and the results of these activities.

Glacier A mass of ice, formed by the recrystallization of snow, that flows forward, or has flowed at some time in the past.

Glacier ice Ice with interlocking crystals that makes up the bulk of a glacier.

Gneiss A coarse, foliated metamorphic rock in which bands of granular minerals (commonly quartz and feldspars) alternate with bands of flaky or elongate minerals (e.g., micas, pyroxenes). Generally less than 50% of the minerals are aligned in a parallel orientation.

Gondwana The southern portion of the late Paleozoic supercontinent known as Pangea. It means, literally "Land of the Gonds" (a people of the Indian subcontinent). The variant Gondwanaland found in some books, therefore, is a tautology.

Graded bedding Type of bedding sedimentary deposits in which individual beds become finer from bottom to top.

Gradient Slope of a stream bed or hillside. The vertical distance of descent over horizontal distance of slope.

Granite Light colored, coarse grained, intrusive igneous rock characterized by the minerals orthoclase and quartz with lesser amounts of plagioclase feldspar and iron-magnesium minerals. Underlies large sections of the continents.

Granitic belt A region of granitic rock, one of two characteristic regions within cratons .

Ground moraine Till deposited from main body of glacier during ablation.

Hanging valley A valley whose mouth is high above the floor of the main valley to which it is tributary. Usually, but not always, the result of mountain glaciation.

Hanging wall block The body of rock that lies above an inclined fault plane. compare foot wall block

Hardness Resistance of a mineral to scratching, determined on a comparative basis by the Mohs scale .

Hinge fault A fault along which there is increasing offset or separation along the strike of the fault plane, from an initial point of no separation.

Horn The sharp spire of rock formed as glaciers in several cirques erode into a central mountain peak.

Ice sheet A broad, mound-like mass of glacier ice that usually spreads radially outward from a central zone.

Ice shelf A floating ice sheet extending across water from a land-based glacier.

Icecap A small ice sheet.

Igneous rock A rock that has crystallized from a molten state.

Inclined fold A fold whose axial plane is inclined from the vertical, but in which the steeper of the two limbs is not overturned. compare overturned fold.

Inclusion (xenolith) A fragment of older rock caught up in an igneous rock.

Index fossil A fossil that identifies and dates the strata in which it is typically found. To be most useful, an index fossil must have broad, even worldwide distribution and must be restricted to a narrow stratigraphic range.

Index mineral A mineral formed under a particular set of temperature and pressure conditions, thus characterizing a particular degree of metamorphism.

Inner core The solid innermost part of the core with a diameter of a little over 1,200 km.

Interlobate moraine Ridge formed along junction of adjacent glacier lobes.

Intrusive Pertaining to igneous rocks formed by the emplacement of magma in pre-existing rock.

Island arc A curved belt of volcanic islands lying above a subduction zone. compare continental arc.

Isoclinal fold A fold in which the limbs are parallel.

Isostasy The condition of equilibrium, comparable to floating, of units of the lithosphere above the asthenosphere.

Joint A surface of fracture in a rock, without displacement parallel to the fracture.

Kettle Depression in ground surface formed by the melting of a block of glacier ice buried or partially buried by drift.

Lahar A mudflow composed chiefly of pyroclastic material on the flanks of a volcano.

Laminar flow Fluid flow in which flow lines are distinct, and parallel and do not mix. compare turbulent flow .

Lateral moraine Moraine formed by valley glaciers along valley sides.

Laurasia The northern portion of the late Paleozoic supercontinent called Pangea.

Lava dome A steep-sided rounded extrusion of highly viscous lava squeezed out from a volcano and forming a dome-shaped or bulbous mass above and around the volcanic vent. The structure generally develops inside a volcanic crater.

Limestone A sedimentary rock composed mostly of the mineral calcite, $CaCO_3$.

Lineation A general term applying to any linear feature in a metamorphic rock.

Liquefaction The transformation of a soil from a solid to a liquid state as the result of increased pore pressure.

Lithification The process by which an unconsolidated deposit of sediments is converted in to solid rock. Compaction, cementation and recrystallization are involved.

Lithosphere The rigid outer shell of the Earth. It includes the crust and uppermost mantle and is on the order of 100 km in thickness.

Load Of a stream, the amount that it carries at any one time.

Luster The manner in which light reflects from the surface of a mineral, described by its quality and intensity.

Mafic Referring to a generally dark-colored igneous rock with significant amounts of one or more ferromagnesian minerals, or to a magma with significant amounts of iron and magnesium.

Magma Molten rock, containing dissolved gases and suspended solid particles. At the Earth's surface, magma is known as lava.

Mantle That portion of the Earth below the crust and reaching to about 2,780 km, where a transition zone of about 100 km thickness separates it from the core.

Mantle plume A hypothetical column of hot, partially molten material that rises from an indeterminate depth in the mantle and is thought by some geologists to provide a driving force for plate movement. compare hot spot .

Marble A metamorphic rock composed largely of calcite. The metamorphic equivalent of limestone.

Margin The tectonic region that lies at the edge of a continent, whether it coincides with a plate boundary or not.

Medial moraine Formed by the merging of lateral moraines as two valley glaciers join.

Mesosphere A zone in the Earth between 400 and 670 km below the surface separating the upper mantle from the lower mantle.

Mesozoic An era of time during the Phanerozoic eon lasting from 245 million years ago to 66.4 million ago.

Metamorphic rock A rock changed from its original form and/or composition by heat, pressure, or chemically active fluids, or some combination of them.

Metamorphic zone A mappable region in which rocks have been metamorphosed to the same degree, as evidenced by the similarity of mineral assemblages in them.

Metamorphism The processes of recrystallization, textural and mineralogical change that take place in the solid state under conditions beyond those normally encountered during diagenesis.

Monocline A simple fold, described as a local steepening in strata with an otherwise uniform dip.

Moraine Landform made largely of glacier till.

Mountain glacier see valley glacier.

Mudflow Form of mass movement similar to a debris flow but containing less rock material.

Nonclastic A term applied to sedimentary rocks that are not composed of fragments of pre-existing rocks or minerals. The term "crystalline" is more commonly used.

Nonconformity An unconformity that separates profoundly different rock types, such as sedimentary rocks from metamorphic rocks.

Normal fault A dip-slip fault on which the hanging wall block is offset downward relative to the foot wall block. compare reverse fault.

Oceanic crust That part of the crust underlying the ocean basins. Composed of basalt and having a thickness of about 5 km.

Original horizontality Refers to the condition of beds or strata as being horizontal or nearly horizontal when first formed.

Orogeny The process of mountain building.

Oscillation ripple mark A symmetric ripple mark formed by waves, which move water back and forth. compare current ripple mark.

Outer core The outermost part of the core. It is liquid, about 1,700 km thick, and separated from the inner, solid core by a transition zone about 565 km thick.

Outwash Beds of sand and gravel laid down by glacial melt water

Overturned fold An inclined fold in which one limb has been tilted beyond the vertical, so that the stratigraphic sequence within it is reversed. compare inclined fold.

Paleozoic An era of geologic time lasting from 570 to 245 million years ago.

Pangea A supercontinent that existed from about 300 to 200 million years ago, and included most of the continental crust of the Earth.

Pegmatite An extremely coarse-grained igneous rock with interlocking crystals, usually with a bulk chemical composition similar to granite but commonly containing rare minerals enriched in lithium, boron, fluorine, niobium, and other scarce metals. Pegmatites are also the source for many gem-quality precious and semiprecious stones.

Period In the geologic time scale a unit of time less than an era and greater than an epoch. Example: The Tertiary period was the earliest period in the Cenozoic era and included, among others, the Eocene epoch.

Phaneritic A textural term meaning "coarse-grained" that applies to igneous rocks.

Phanerozoic the most recent eon of geologic time beginning 570 million years ago and continuing to the present.

Phenocryst Any relatively large, conspicuous crystal in a porphyritic igneous rock

Piedmont glacier A glacier that spreads out at the foot of mountains, formed by the coalescence of two or more valley glaciers.

Plate A rigid segment of the Earth's lithosphere that moves horizontally and adjoins other plates along zones of seismic activity. Plates may include portions of both continents and ocean basins.

Plate boundaries The zones of seismic activity long which plates are in contact. These may coincide with continental margins, but usually do not. Movement between plates is predominately horizontal, and may be divergent, or convergent, or side-by-side.

Plate tectonics A theory of global tectonics according to which the lithosphere is divided into mobile plates. The entire lithosphere is in motion, not simply those segments composed of continental material. compare continental drift

Plucking (quarrying) A process of erosion in which the glacier pulls loose pieces of bed rock.

Plume The movement of water along flow lines from a point source of ground water pollution toward its eventual emergence at the surface.

Plunging fold A fold in which the axis is inclined at an angle from the horizontal.

Pluton An igneous intrusion.

Porphyritic A texture of an igneous rock in which large crystals (phenocrysts) are set in a matrix of relatively finer-grained crystals or of glass.

Precambrian An informal term to include all geologic time from the beginning of the Earth to the beginning of the Cambrian period 570 million years ago.

Principle of faunal and floral succession Groups of animals and plants have succeeded one another in a definite and discernible order.

Proterozoic The geologic eon lying between the Archean and Phanerozoic eons, beginning about 2.5 billion years ago and ending about 0.57 billion years ago.

Pyroclastic Pertaining to clastic material formed by volcanic explosion or aerial expulsion from a volcanic vent.

Rain shadow formed by blocking moisture-bearing winds with mountain barriers.

Recessional moraine Ridges of glacial till marking halt and slight readvance of glacier during its general retreat.

Regional metamorphism Metamorphism affecting an extensive region, associated with orogeny .

Relative time Dating of rocks and geologic events by their positions in chronological order without reference to number of years before the present.

Reverse fault A dip-slip fault on which the hanging wall block is offset upward relative to the foot wall block. compare normal fault.

Rhyolite A fine-grained silica-rich igneous rock, the extrusive equivalent of granite.

Rift (graben) A valley caused by extension of the Earth's crust. Its floor forms as a portion of the crust moves downward along normal faults.

Ripple marks of oscillation Symmetrical ripple marks formed by oscillating movement of water such as may be found along the coast just outside the surf zone.

Rio Grande Rift The Rio Grande Rift is a rift valley extending north from Mexico, near El Paso, Texas through New Mexico into central Colorado, and is part of the Basin and Range Province.

Rock cycle The concept of a sequence of events involving the formation, alteration, destruction and reformation of rocks as a result of geologic processes and which is recurrent, returning to a starting point. It represents a closed system. compare rock system.

Rock flour Finely divided rock material ground by glacial action and fed by streams fed by melting glaciers.

Rock glacier A mass of ice-cemented rock rubble found on slopes of some high mountains. Movement is slow, averaging 30 to 40 cm/yr.

Sandstone A clastic sedimentary rock in which the particles are dominantly of sand size, from 0.062 mm to 2 mm in diameter.

Schist A strongly foliated, coarsely crystalline metamorphic rock, produced during regional metamorphism, that can readily be split into slabs or flakes because more than 50% of its mineral grains are parallel to each other.

Schistosity The foliation in a schist, due largely to the parallel orientation of micas.

Seafloor spreading Process by which ocean floors spread laterally from crests of main ocean ridges. As material moves laterally from the ridge, new material replaces it along the ridge crest by welling upward from the mantle. compare continental drift, plate tectonics

Seamount (guyot) A volcanic mountain on the seafloor. If flat-topped, it is a guyot.

Sedimentary rock Rock formed from the accumulation of sediment, which may consist of fragments and mineral grains of varying sizes from pre-existing rocks, remains or products of animals and plants, the products of chemical action, or mixtures of these.

Shale A mudstone that splits or fractures readily.

Shatter cone A distinctively striated conical structure in rock, ranging from a few centimeters to a few meters in length, believed to have been formed by the passage of a shock wave following meteorite impact.

Shear Rock deformation involving movement past each other of adjacent parts of the rock and parallel to the plane separating them.

Shear strength The resistance of a body to shear stress.

Shear stress The stress on an object operating parallel to the slope on which it lies.

Sheeting A type of jointing produced by pressure release (unloading) or exfoliation.

Silica Silicon dioxide (SiO2) as a pure crystalline substance makes up quartz.

Sill A tabular igneous intrusion that parallels the planar structure of the surrounding rock.

Slaty cleavage A style of foliation common in metamorphosed mudstones, characterized by nearly flat, sheet-like planes of breakage, similar in appearance to a deck of playing cards. compare cleavage

Slickenside A polished and smoothly striated surface that results from friction along a fault plane.

Sorting The range of particle sizes in a sedimentary deposit. A deposit with a narrow range of particle sizes is termed "well-sorted."

Stratification The accumulation of material in layers or beds.

Stratified drift Debris washed from a glacier and laid down in well-defined layers.

Stratigraphy The succession and age relation of layered rocks.

Striations Scratches, or small channels, gouged by glacier action. Occur on boulders, pebbles, and bedrock. Striations along bedrock indicate direction of ice movement.

Strike The compass direction of the intersection between a structural surface (e.g., a bedding plane or a fault surface) and the horizontal.

Strike-slip fault (transcurrent fault) A fault on which the movement is parallel to the fault's strike.

Subduction zone A narrow, elongate region in which one lithospheric plate descends relative to another.

Surging glacier A glacier that moves rapidly (tens of meters per day) as it breaks away from the ground surface on which it rests.

Syncline A fold that is convex downward, or that had such an attitude at some stage in its development.

Talus A slope built up by the accumulation of rock waste at the foot of a cliff or ridge.

Tarn A lake in the bedrock basin of a cirque.

Temperate glacier A glacier whose temperature throughout is at, or close to, the pressure point of ice, except in winter when it is frozen for a few meters below the surface.

Tensile fracture A fracture caused by tensional stress in a rock.

Tension A stress that tends to pull a body apart.

Tephra A general term for all pyroclastic material.

Terminal moraine (end moraine) Ridge of till marking farthest extent of glacier.

Thrust fault A reverse fault on which the dip angle of the fault plane is 15 degrees or less.

Till (unstratified drift) Glacial drift composed of rock fragments that range from clay to boulder size and randomly
arranged without bedding.

Transform boundary A plate boundary in which plates on opposite sides of the boundary move past each other in opposite directions.

Transform fault A plate boundary that ideally shows pure strike-slip movement. Associated with the offset segments of midocean ridges.

U-shaped valley A valley carved by glacier erosion and whose cross-valley profile has steep sides and a nearly flat floor, suggestive of a large letter "U".

Unconformity A buried erosion surface separating two rock masses.

Uniformitarianism principle acknowledges that past processes, even if the same as today, may have operated at different rates and with different intensities than those of the present.

Valley glacier (alpine glacier, mountain glacier) Streams of ice that flow down valleys in mountainous areas.

Viscosity The internal resistance to flow in a liquid.

Volcanic ash The dust-sized, sharp-edged, glassy particles resulting from an explosive volcanic eruption.

Weathering The process by which Earth materials change when exposed to conditions at or near the Earth's surface and different from the ones under which they formed. compare decomposition , disintegration .

Welded tuff A pyroclastic rock in which glassy clasts have been fused by the combination of the heat retained by the clasts, the weight of overlying material, and hot gases.

Zone of accumulation The area in which ice accumulates in a glacier.

Zone of fracture The near surface zone in a glacier that behaves like a brittle substance.