Living Map – Geology and Landforms of Boulder County

Note: This outline contains much more content than you will need or should try to include in your program. Please use this as background information and use selectively to meet the needs of your audience.

Presentation Theme: From the Great Plains to the Continental Divide, Boulder County's fascinating geologic story is told in our dramatic landscape.

Background -- Geology and Landforms of Boulder County
Boulder County straddles the transition zone between two great geographic regions in North America: the **Front Range** of the Southern Rocky Mountains and the **Great Plains**. The abrupt and dramatic rise from the mile-high prairie to over 14,000 feet at Longs Peak creates the rich diversity of landscapes, life zones, and ecosystems found in Boulder County. Our geologic history also shaped the landforms that we see today.

Ancient Landscapes
Three hundred million years ago, the Ancestral Front Range uplifted about 30 miles west of where the current Front Range is today. Millions of years of weathering and erosion wore those ancient peaks away and buried them in sediment and debris thousands of feet thick. Shallow seas periodically advanced and retreated from Colorado, leaving behind even more sedimentary material. Dinosaurs evolved, flourished, and went extinct in this area.

Renewed Uplift
Renewed uplift began about 65 million years ago, fracturing and tilting sedimentary rock layers and giving birth to the "modern" Front Range of Colorado. The Colorado Mineral Belt was created during this mountain-building period, as mineral-rich solutions were injected into fractures of older rock. These solutions hardened to form veins of precious metals, which have been mined extensively in Boulder County and throughout the mountains of Colorado. The Colorado Mineral Belt extends in a SW/NE belt from the San Juan Mountains to Boulder County. Gold, silver, lead, zinc, and tungsten have all been part of Boulder County's colorful mining history.

Today's Rockies
About nine million years ago, the most recent episode of mountain-building began forming the present-day Rocky Mountains. The western U.S. from the Sierra Nevada Range in California to the Colorado Front Range was uplifted by 5,000 feet or more. The Great Plains and the Colorado Plateau were also uplifted to modern-day elevations during this period, and Colorado's 14,000 foot peaks were also born. Deep valleys and canyons were cut as erosion was accelerated by the regional uplift.

Finishing Touches
As wind, water, ice, and gravity continued to erode and transport sediment downstream, nearly two-billion-year-old igneous and metamorphic rocks were exposed along the Continental Divide to the west. Within the last two million years, valley glaciers above 8,000 feet put the finishing touches on the Front Range, carving out the high country scenery that we enjoy today and sending sands, gravels, and rocks to the plains below. Today's landscape is only the most recent chapter in the dynamic and ongoing geologic story of Boulder County.

- Please see the ***Summary of Boulder County Geologic History*** below for more details

Activity Set-up

- Unfold Living Map and place on floor, north edge to blackboard
- Mount *Life Zones of Boulder County* banner on blackboard (optional)
- Place town labels on map that are most relevant to the program location: e.g, Nederland, Boulder, Louisville, Lafayette, Lyons, Longmont, etc.
- Place the "We Are Here" label on the map at the program location
- Place landmark labels on map that are most relevant to the program location: e.g. the Flatirons, Longs Peak, Continental Divide, Arapaho Glacier, Haystack Mountain, etc.
- Place drainage labels on map that are most relevant to the program location: e.g. Boulder Creek, Lefthand Creek, St. Vrain Creek, Rock Creek, etc.

Activity

- Presenters stand at north side of map at front of room
- Arrange students around the remaining three sides of the map, standing for the intro and orientation to the map so they can see everything, and sitting for the wildlife exercise
- **Question:** What is this a map of? (Boulder County – area: 742 square miles)
- **Question:** What is a "county"? (a geographic area and unit of local government)
    - Colorado is divided into 64 counties
    - Boulder County is one of the original 17 counties created in 1861 as part of the Colorado Territory (Colorado became a state in 1876)
    - Largest county in Colorado: Las Animas County in SE Colorado (4,771 square miles)
    - Boulder County area is 742 square miles (51 of 64 counties in land area)
- **Question:** Where is north on this map? (Place north arrow on map and have students identify where south, east, and west are)
- **Question:** Where are we today? (school location; orient kids to the map: towns, drainages, landmarks, etc.)
- **Question:** Where are the **mountains** in Boulder County? (West side of map)
- **Question:** What do we call these mountains? (The Front Range of the Southern Rocky Mountains. The **Rocky Mountains** continue north of Colorado all the way to northern Canada, and south to New Mexico)
- **Question:** Where are the **plains**? (East side of map)
- **Question:** What's in between the mountains and the plains? (The **foothills**)
- **Question:** Where do you think the lowest and highest elevations in BoCo are? (East edge of map where St. Vrain Creek leaves BoCo [just under 5,000 feet], and northwest corner of map at Longs Peak [over 14,000 feet])
- **Question:** How much does the elevation change between the lowest point in Boulder County and the highest point? (about 9,000 feet of elevation change)
- **Question:** What is the **Continental Divide** and where is it? (The high peaks on the western boundary of Boulder County that determine whether water flows west to the Pacific Ocean or east to the Atlantic Ocean)
- **Question:** Scientists tell us that the Earth is about 4.6 billion years old. How old are the oldest rocks in BoCo? (Almost 2 billion years old) [Walk around the map and allow students to touch a piece of **Boulder Creek Granodiorite]**. Boulder Creek Granodiorite, one of the oldest **igneous** rocks (e.g. granite, basalt, obsidian) in the Boulder area, formed 10-15 miles below the earth's surface, as molten rock (**magma**) slowly cooled and turned into rock. **Metamorphic** rocks (e.g. quartzite, gneiss, schist), created by extreme heat and pressure deep within the earth also make up the oldest "basement rocks" in BoCo.

- **Question:** Where will you find these "basement rocks" of BoCo? (Generally, beneath younger rocks although, as we will see later, we also find igneous and metamorphic rocks in BoCo – from the plains (Valmont Butte) to the Continental Divide -- where they have been exposed at the surface due to weathering and erosion of the younger rocks.) *** See the *Forming the Flatirons* demonstration below***
- **Question:** Has BoCo always looked like this map? (No -- but encourage and reinforce answers about how BoCo may have looked over time)
- **Statement:** Let's see how BoCo's landscape has changed over millions of years of geologic time.
- **Statement:** This is how BoCo looked about 300 million years ago when the **Ancestral Rockies** uplifted about where today's Rockies are (Show ***Ancient Denvers Ancestral Rockies – Fountain Formation*** poster). Over millions of years, the Ancestral Rockies almost disappeared.
- **Question:** How did that happen? (**Weathering and Erosion**)
- **Question:** What is weathering? (Temperature, water, ice, and chemicals split, dissolve, and crumble big rocks into smaller rocks)
- **Question:** What is erosion? (the transport of weathered material from one place to another due to gravity, water, wind, and ice)
- **Question:** What happened to all the rocks, pebbles, and sand that weathered and eroded from the Ancestral Rockies? (As the Ancestral Rockies eroded, sediments were deposited in alluvial fans at the foot of the mountains, and the sediments were compacted and cemented together to form the **sedimentary** rock known as the **Fountain Formation**) [Walk around the map and allow students to touch a piece of Fountain Formation}
- **Question:** Where can you find this rock today? (Boulder **Flatirons**)
- **Statement:** Some of the sand that was eroded from the Ancestral Rockies was picked up by winds and deposited in huge **sand dunes** at the foot of the mountains. About 280 MYA, part of BoCo looked like this: (Show ***Ancient Denvers Sand Planet – Lyons Sandstone*** poster) Over time, these sand dunes were buried and cemented to form the **sedimentary** rock known as **Lyons Sandstone**. [Walk around the map and allow students to touch a piece of Lyons Sandstone]
- **Question:** Where can you find Lyons Sandstone in BoCo today? (Along foothill trails in BoCo, in quarries near the town of Lyons, and in many buildings at CU-Boulder, where it was used as building stone)
- **Statement:** Erosion from the Ancestral Rockies continued to bury the mountains in Colorado in their own debris, and the landscape in BoCo was nearly flat. Sea levels began to rise, and mighty rivers that flowed from ancient mountains in Utah brought and deposited sand and gravel throughout Colorado, all the way east to BoCo and beyond. (Show ***Ancient Denvers Colorado's East Coast – Dakota Sandstone*** poster) Over millions of years, these sands and gravels became the **sedimentary** rock known as the **Dakota Formation (**about 100 mya).
- **Question:** Where can you find the Dakota Formation in BoCo today? (The erosion-resistant Dakota sandstones and conglomerates form the **Dakota "Hogback,"** that marks the transition from the plains to the foothills in BoCo.
- **Statement:** Sea level continued to rise, and eventually covered Colorado. (Show ***Ancient Denvers Submarine Colorado – Pierre Shale*** poster) The **Western Interior Cretaceous Seaway** stretched from the Arctic Ocean to the Gulf of Mexico, and from Utah to Iowa. As **plate tectonic forces** began to cause uplift in Colorado about 70 mya, the sea finally retreated, leaving behind muddy deposits over a mile thick beneath BoCo. Over time, this mud was buried and compacted and formed the **sedimentary** rock **Pierre Shale**. [Walk around the map and allow students to touch a piece of Pierre Shale]
- **Question:** Where can you find Pierre Shale in BoCo today? (Most of the Pierre Shale in BoCo is beneath our feet. It is not often found at the surface because it erodes away so easily. You can see the shale in a few road cuts north of Boulder along Highway 36.)
- **Statement:** As the shallow seas retreated about 70 mya, the mountain-building continued, uplifting the **Laramide Rockies** in about the same position as today's Rockies. This uplift also tilted many of the sedimentary rock layers up to the angle that we see them today (e.g. Flatirons).

- **Statement:** Let's see if we can find out how the Flatirons were created. (Conduct the ***Forming the Flatirons*** **demonstration**)
- **Question:** What eventually happened to the Laramide Rockies? (Over millions of years they eroded away to rolling hills and plains)
- **Statement:** About 9 mya, our most recent period of mountain-building formed the **present-day Rockies**. Deep valleys and canyons were cut as erosion was accelerated by this regional uplift.
- **Question:** Can you find on the map some of these **valleys** and **canyons** that were created by stream and river erosion? (Have students identify streams that begin in the mountains and create canyons down to the plains)
- **Question:** What other force of nature helped create our mountain landscapes? (**Valley glaciers**)
- **Statement:** Valley glaciers formed above 8,000 feet in elevation (e.g. approximate elevation of the Peak to Peak Highway between Nederland and Allenspark) several times over the last 2 million years, carving out **glacial cirques**, jagged **ridges and peaks**, and **U-shaped valleys** in the mountains of BoCo.As the glaciers melted and receded, streams carried large amounts of sand and gravel to the plains below.
- **Statement:** The City of Boulder gets some water from what's left of **Arapaho Glacier.**
- **Question:** Does anybody know where Arapaho Glacier is on the map? (Boulder Creek watershed along the Continental Divide)
- **Statement:** By the end of the last Ice Age, about 16,000 years ago, most of the glaciers and melted and receded back into the highest mountains of BoCo, and our landscape looked like this: (Show ***Ancient Denvers Ice Age Summer – Quaternary Sediments*** poster)
- **Question:** What animals do you see in this picture that once lived here, but are now extinct? (camels and mammoths)
- **Statement:** What animal moved into Colorado about 13,000 years ago and began hunting camels, mammoths, and other wild game? (Humans)
- **Conclusion:** Geology is a dynamic and ongoing process that continues today, and our current landscape is only the most recent chapter in the geologic story of Boulder County.

***NOTE: This outline is only a suggested program template. Please modify or tailor your program to be appropriate for your group**

(December 2011, Colbenson)

SUMMARY OF BOULDER COUNTY GEOLOGIC HISTORY

4.6 BYA (billion years ago): Earth formed

1.7 BYA: The **Colorado Basement Province** adhered itself to the much older core of North America during **Precambrian** times, in repeated collisions of **continental accretion**, about where Wyoming is today. Major mountain building associated with the continental collisions buried and deformed existing rock into metamorphic basement rocks (gneiss and schist). As accretion continued, igneous plutons (intrusive bodies of magma that cool and form rock deep underground) intruded the basement rocks several times during the Precambrian. **Boulder Creek Granodiorite** (1.7 BYA), the **Silver Plume Granite** of Long's Peak (1.4 BYA), and **Pike's Peak Granite** (1 BYA) were intruded during this period. Today, more than 85% of Colorado's basement rocks are buried beneath younger rocks. They are exposed only where erosion has uncovered them, such as along the crest of mountain ranges (Long's Peak) and in some deep canyons (Boulder Creek).

Boulder Creek Granodiorite, one of the oldest rocks in the Boulder area, formed 10-15 miles below the earth's surface. Named for its exposures along Boulder Creek, Boulder Creek Granodiorite is also exposed on Flagstaff Mountain, and on the Walker Ranch and Bald Mountain Boulder County Parks and Open Space properties.

1.4 Billion Year Unconformity (missing geologic time) between **Boulder Creek Granodiorite** (1.7 BYA) and **Fountain Formation** (300 MYA).

- Unconformity due to non-deposition and/or erosion between Precambrian and Pennsylvanian time.
- From sandstones, shales, and limestones preserved in other areas of Colorado (e.g. near Colorado Springs), we know that periods of uplift and erosion occurred and that shallow seas and low-lying landscapes covered much of Colorado during the time interval that is missing in the Boulder area.
- "Contact Corner", a switchback turn on the Flagstaff Mountain road, is a good place to observe the unconformity and see the Fountain Formation overlying the Boulder Creek Granodiorite.

300 MYA: The shallow seas ebbed in Colorado, as the **North American Plate** collided and bonded with other crustal plates to begin the formation of one giant continent called **Pangea**. These collisions impacted the Colorado area by causing the **Ancestral Rockies** to uplift **(Colorado Orogeny)**. Although the Ancestral Rockies had nothing to do with the modern Rocky Mountains, the **Ancestral Front Range** was almost parallel to, and only about 20-30 miles further west of today's Front Range. As the Ancestral Rockies eroded, sediments were deposited in alluvial fans; the sediments were compacted and cemented together to form the **Fountain Formation**. The Fountain Formation was named for exposures along Fountain Creek near Manitou Springs, and is also exposed in the **Flatirons** in Boulder, the Red Rocks Amphitheater west of Denver, and the Garden of the Gods near Colorado Springs. Tracks of small amphibians and early reptiles are fossilized in the rocks of the Fountain Formation.

300 MYA - 225 MYA: Erosion of the Ancestral Rockies continued, as a shallow sea advanced westward toward the mountains. Fields of coastal sand dunes developed along the eastern flank of the Ancestral Front Range. Some of these dune areas are preserved in the **Lyons Sandstone**, which is named for exposures near the town of Lyons. This buff to salmon-colored sandstone has been extensively quarried for building stone (e.g. CU-Boulder Campus).

Between the Ancestral Rockies (300 MYA) and the Laramide Orogeny (65 MYA):

- The Ancestral Rockies were eroded down nearly to sea level.

190-135 MYA: During the **Jurassic Period,** the shallow sea retreated to the east. The lowland climate became more humid, lush vegetation developed, and dinosaurs flourished. Sediments deposited in swamps, lakes, and floodplains formed the colorful sandstones, siltstones, and shales of the **Morrison Formation**. Named for exposures near Morrison, Colorado, the Morrison Formation is known for dinosaur fossils at many sites around Colorado, including Dinosaur Ridge near the town of Morrison.

135-65 MYA: The **Cretaceous Period** was dominated by the **Western Interior Cretaceous Seaway**, a widespread but relatively shallow sea that covered the interior of the western U.S. and Canada, including the Boulder area, as well as northeastern Mexico. At its maximum extent, it connected cold ocean waters from northern arctic areas with warm ocean waters from today's Gulf of Mexico. The seaway was as much as 1,000 miles across (west-central Utah to eastern Iowa), and deposited nearly 9,000 feet of sediment that hardened into shale, sandstone and limestone. In Boulder, the oldest Cretaceous rocks are part of the **Dakota Formation**. The erosion-resistant Dakota Formation sandstones form the **Dakota Hogback** that frames the skyline in north Boulder. The entire Boulder Valley is underlain by sedimentary rock known as **Pierre Shale,** a soft, easily eroded rock that typically forms valleys. Fossils of animals that lived in the ancient sea can still be found today.

- Dinosaurs became extinct by the end of the Cretaceous Period, about 65 MYA. The Morrison Formation contains dinosaur fossils at many sites around Colorado, including Dinosaur Ridge near the town of Morrison.

65 MYA: When the shallow seas made their final retreat about 70 million years ago, sediments as thick as 2 miles covered the eroded basement stumps of the Ancestral Rocky Mountain uplifts. The **Laramide Orogeny**, which uplifted the **Laramide Rockies** in about the same position as today's Rockies, was **probably** triggered by **continental accretion** and **subduction** on the west coast of North America, although this is not known for certain. The uplift of the Rockies so far inland from the **North American-Pacific plate boundary** is a geologic anomaly. The Laramide uplifting tilted and fractured the sedimentary **Fountain Formation,** and subsequent erosion exposed the **Flatirons** that we see today. As the sedimentary rocks were uplifted and eroded away, the resistant basement rocks (e.g. Boulder Creek Granodiorite) emerged at the summits. The corresponding western-tilting portion of the Fountain Formation is exposed near Aspen and is known as the **Maroon Formation**.

The **Colorado Mineral Belt** was also created during the Laramide mountain-building period as mineral-rich solutions were injected into fractures of older rock, including the Boulder Creek Granodiorite. These solutions hardened to form veins of precious metals, which have been mined extensively in Boulder County and throughout the mountains of Colorado. Gold, silver, lead, zinc, and tungsten have all been part of Colorado's colorful mining history. The Colorado Mineral Belt extends in a SW/NE belt from the San Juan Mountains to Boulder County.

40 MYA: The **Laramide Rockies** eroded away to low rolling hills and plains, the basins filled with eroded debris.

9 MYA: The most recent episode of mountain-building formed the **present-day Rocky Mountains**, when the western U.S. from the Sierra Nevada's in California to the Colorado Front Range was uplifted by 6,000 feet or more. The **Great Plains** and the **Colorado Plateau** were also uplifted to modern-day elevations during this period. It was during this time that Colorado's fourteeners were born. Deep valleys and canyons were cut as erosion was accelerated by the regional uplift (e.g. Black Canyon of the Gunnison River).

1.5 MYA: In the Pleistocene, as the climate cooled and precipitation increased, **valley glaciers** formed in the mountains west of Boulder above 8,000 feet. (North American ice sheets did not extend into Colorado) The glaciers moved downslope, carving out glacial cirques, jagged peaks, and U-shaped valleys. The last major glaciation in Colorado began to recede about **10,000 years ago**. As the valley glaciers began to melt, the swollen streams transported large amounts of sand and gravel to the plains. The streams cut wide swaths in the soft sediment and surfaces were planed creating the flattened mesa tops that flank the foothills. Table Mountain and Haystack Mountain, north of Boulder, are examples of isolated mesa remnants that have resisted erosion.

Erosion continues to be the dominant geologic force altering the Boulder-area landscape today. Present-day sedimentary deposits could potentially be buried under future deposits and become lithified to form new rock units.

To the west of the Boulder area, **isolated lava flows** continued until quite recently. The latest lava flow, near Dotsero, Colorado, occurred about **4,000 years ago,** and is visible from Interstate Highway 70.

Updated June, 2011 (LJC)

Forming the Flatirons Demonstration

Objectives:

Students will:
1) Understand how uplift and erosion created Boulder County's landscape
2) Observe a demonstration of how the Flatirons were formed.

Background:

Most of us have noticed the unique form of the Flatirons formation in Boulder. They are the flat, reddish-brown rocks that tilt up at an angle from the hillside in Chautauqua Park. They are a part of the Fountain Formation, which formed about 300 million years ago.
The Fountain Formation was formed by stream-deposited sand, pebbles, and cobbles eroded and carried down from the Ancestral Rockies. The deposits washed out of canyons and streams as alluvial fans, and eventually hardened into rock. When mountain **uplift** resumed about 65 million years ago, the cemented sediment was tilted upward at an angle over 50 degrees. Softer sediments washed away (**eroded)**, leaving behind the Flatirons we see today.

Materials:

2 towels each in red, green, blue and beige.

Procedure:

Ask students who has seen the Flatirons before. Hold up a picture for those who have not.
Ask them for some ideas about how those rocks got pointed up at such a steep angle from the ground!? Take a few guesses. Discuss briefly the process of **uplift –** when the movement of plates causes land to crunch/smoosh together, bend, crack, etc.
Fold towels in half twice and make two identical stacks end-to-end. Explain, as you lay each towel layer down, that each layer represents different rock formations from oldest rock at the bottom to newest formations at the top of the stack as shown:

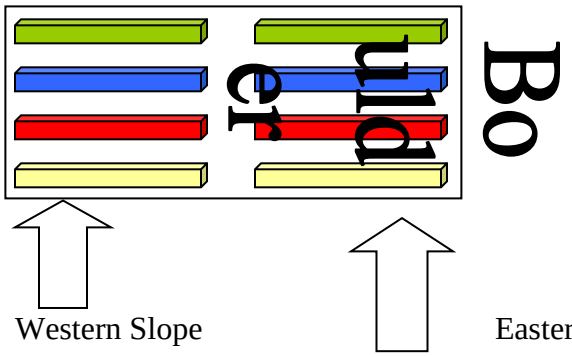
Post- Cretaceous Seaway rocks 

Cretaceous Seaways rocks

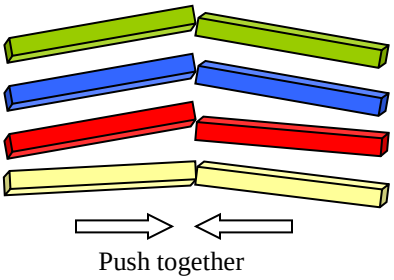
Fountain Formation - Flatirons 

Precambrian rock 

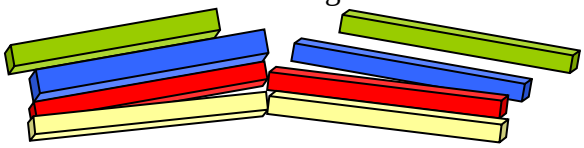
The red towel (Flatirons) will be the third towel down in the stack, near the bottom. Look at the diagram for an example.
Explain that the rectangle created by the two stacks represents Colorado, with eastern plains and western mountains separated by the gap. Boulder can be located at the gap, conveniently where the 'Flatirons" will emerge.



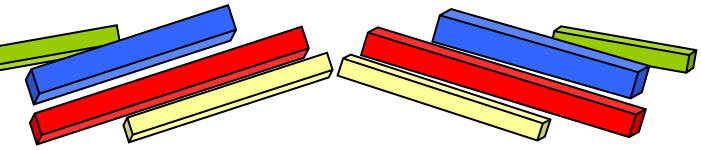
Explain to students that they will watch a demonstration of what happens when uplift occurs. *Remind them that, in contrast to the demo, uplift takes place on a scale of millions of years, it's not something that one could observe.
Slowly push the two stacks together, and watch the mountains rise:



Peel away the top towel, explaining that over time, rocks are eroding and being washed far away from where the red towel will emerge.



Peel back (erode) the Cretaceous Seaway towel, *keeping in mind that this is the Dakota Ridge, and should stay close to our mountains. Leave it slanted up against the 'mountains'.
Can you see the Flatirons forming yet? If not, erode some more! Keep in mind that the uppermost part of the Flatirons was also eroded away, which results in their 'stand-up' appearance.



Folding back the red towels a little bit causes them to stand more on end, leaning on the 'mountains' created by the other towels.