

# **FIELD GUIDE TO THE GEOLOGY ALONG THE OLD KILN TRAIL**

## **Boulder, Colorado**

### **City of Boulder Open Space and Mountain Parks**

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On the Old Kiln Trail you will be walking through geologic time across older and older rocks. You will see various kinds of sedimentary rocks, see how these rocks control landforms, see fossils associated with these rocks, and observe dramatically changing environments. You can find a detailed geologic/stratigraphic sequence at [http://ci.boulder.co.us/files/openspace/pdf\\_education/Boulder\\_Sediments.pdf](http://ci.boulder.co.us/files/openspace/pdf_education/Boulder_Sediments.pdf). Print this guide to locate where you are in time and to identify past environments as you walk along the trail.

#### **Brief Summary of the Geologic History of the Front Range.**

About 300 million years ago (mya) an earlier mountain range, called the Ancestral Rocky Mountains, was uplifted. Sediments eroded from the Ancestral Rockies were deposited by rivers flowing from the mountains into the sea (Fountain, Lyons). The Flatirons are formed from these ancient deposits. Over a period of nearly 200 million years, the Ancestral Rocky Mountains were worn down, eroded away, and eventually buried under sediments deposited along the shoreline of the ocean, and in rivers and lakes (Lykins, Canyon Spring, Morrison, Lytle Formations). At this time, Boulder (now over 5000 feet elevation) was near sea level. Between about 100 – 64 mya, ocean water from the Gulf of Mexico and Canada flooded this area, eventually covered Colorado, and deposited thousands of feet of sand and mud (Dakota, Benton, Niobrara, Pierre). Then, beginning around 70 mya, the present (Laramide) Rocky Mountains were uplifted and the sea retreated. As the mountains rose, all the previously deposited sedimentary rocks were tilted up against the rising mountains (creating the Flatirons and the tilted rocks we see along the Old Kiln Trail – view geologic cross-section at <http://bcn.boulder.co.us/basin/watershed/geology/crosssec.html>).

#### ***DIRECTIONS TO STOPS AND LOCATIONS OF INTEREST ARE GIVEN IN ITALICS.***

*Trail begins from the Four Mile Creek Trailhead off Lee Hill Road, west of Broadway in North Boulder. The hike is about a mile round trip with 400 ft elevation gain. It goes up the Dakota Ridge with a short, moderate climb at the beginning and then follows an old road uphill.*

#### **TRAILHEAD**

**Note:** GPS tour datum is all WGS84

N 40° 03' 750"

W 105° 17' 340"



Figure 1. View to the south from the trailhead.

From the trailhead, you can see the contact between two dramatically different landscapes -- the Great Plains to the east and the Rocky Mountains to the west. This is a good location to view the Flatirons, the peaks west of Boulder, and Dakota Ridge on your right. Remember, the mountains you see today were not here during the formation of the rocks we see along the trail.

*Follow the hiking/biking Foothills Trail south to the Four Mile Creek crossing.*

N 40° 03' 699"

W 105° 17' 365"

**Stop 1.** Stream Crossing: note the small size of the stream as you cross the bridge and the broad, gently sloping area to the south and west. Keep this in mind at Stop 3.



Figure 2. One of many landslides coming down the east slope of the Dakota Ridge.

*Follow the hiking/biking Foothills Trail south across the creek to the first trail junction with the Old Kiln Trail. Take the trail that goes north (right), back toward Lee Hill Road.*

N 40° 03' 614"

W 105° 17' 485"

**Stop 2.** View south at trail junction: There are many kinds and generations of landslides on the east slope of Dakota Ridge (Figure 2). As you follow the Old Kiln Trail uphill, you will get a close look at the surface of one of these landslides. The highest part of Dakota Ridge to the west is composed of steeply tilted sandstones and some shales. The grass covered slopes on the east side of Dakota Ridge are underlain by the Benton Formation, which is almost entirely composed of mudstones and shale. The Benton forms a slippery base for landslides to move down slope.

*Continue on the trail north (to the right) to the first exposure of light-colored shaley rock on your left and the large boulders near Four Mile Creek on your right.*

N 40° 03' 779"

W 105° 17' 525"

**Stop 3.** Boulders along Four Mile Creek and the Smoky Hill Shale: On your right along Four Mile Creek, look at the different kinds of boulders here and scattered across the surface (fluvial terrace) between the trail and the houses to the east. There are examples of different kinds of sedimentary rocks (conglomerate and sandstone) and a few boulders of granite (1.7 billion years old). The granite is exposed at least a mile to the west up Four Mile Canyon. These boulders are rounded, indicating that they have been carried here by a large flood. The flow of the present creek is not capable of carrying such large boulders. However, there have been major climate changes, including glacial episodes in the higher mountains and periods of higher rainfall, in the last hundred thousand years,



Figure 3. Granite boulder along Four Mile Creek.

The surface that you walked across to get here is the fluvial (river) terrace of Four Mile Creek. It is underlain by gravel deposits formed during floods and higher river flows in the past.

The rocks exposed on the left side of the trail, to the east, and up the hill on the Old Kiln Trail were deposited before the uplift of the present (Laramide) Rocky Mountains. During the Cretaceous, about 100 to 70 million years ago, Colorado was covered by a

shallow sea that spread from the Arctic Ocean to the Gulf of Mexico, Through time, the sea rose and fell depositing different kinds of sediments depending on location of the nearest high land, where the shoreline was located, water depth, and temperature. We will see evidence of these changes as we continue along the trail.



Figure 4. Colorado was covered by a shallow sea during the Cretaceous.

The first rock unit we will see along the rail is the Upper Cretaceous Niobrara Formation (formed about 86-82 million years ago). The Niobrara is divided into two members: Smoky Hill and Fort Hays. This outcrop is the Smoky Hill Member, the upper part of the Niobrara Formation. Here the Smoky Hill is a limey shale (Figure 5). An occasional fish scale (bluish-gray color) can be found here (if you find one, please return it for the next visitor to find). Shells of clams and oysters are common at other locations along the Front Range. The Fort Hays (next stop), the lower member of the Niobrara, will be seen around the corner.





Figure 5. Exposure of Smoky Hill Member of the Niobrara Formation.

N 40° 03' 812"

W 105° 17' 630"

**Stop 4.** Fort Hays Limestone and the old limestone kiln: The Fort Hays Limestone is tan to light-gray, and can be viewed to the right of the kiln. Small amounts of shale separate the limestone beds. The limestone is more resistant to weathering and erosion and stands out more than the thin, darker and recessed shale. Limestone is not very common along the mountain front. Most sediment deposited in the inland sea was mud (clay) and sand. In fact, the Fort Hays is the most carbonate-rich, mud-poor unit in the entire Western Interior Seaway<sup>2</sup>. An explanation for this unusual limestone occurrence is that this was a time when the shoreline and the source of the mud and sand was far away. Thus, mud and sand did not reach this area. Also, warm tropical water moved up from the south, creating an environment suitable for limestone formation<sup>3</sup>. The repetition of beds of limestone alternating with thin layers of shale have been interpreted to represent climate change resulting from differences in the orbit of the earth and sun<sup>2</sup>.

Limestone (calcium carbonate,  $\text{CaCO}_3$ ) is used to produce "lime" for plaster, mortar, and cement. To produce the lime from limestone, the rock is heated in the lime kiln to 500-600 degrees C. This heating drives off the carbon dioxide leaving lime as a residue. Historically, there were four kilns at Two Mile Creek and this one (now deteriorated) along Four Mile Creek. This kiln was probably constructed in the 1880's. According to Gleichman and Mutaw, (1998)<sup>1</sup>, the Four Mile Creek kiln is noted for its crudity of construction, which led to much wastage due to over or under burned lime. Lime produced here may have been used in construction of some of the University of Colorado's earliest buildings.



Figure 6. Lime kiln and Fort Hays Limestone (upper right).

*Walk past the kiln and uphill to the trail junction and overlook*

N 40° 03' 705"

W 105° 17' 679"

**Stop 5.** Old Kiln Trail junction and overlook: This trail junction is the approximate location of the contact between Niobrara Formation and older Benton Group (stratigraphically below, but uphill). The Benton (about 97-89 mya) underlies the vegetation-covered slope uphill extending to the first sandstone outcrop (Stop 6). The Benton is composed of mudstones and shales that are not well exposed along the Front Range. In addition, the Benton is frequently covered by landslides. The road uphill is along the side of one of these landslides. Notice boulders of Dakota sandstone scattered across the surface.

*Follow the Old Kiln Trail uphill. The next stops are along a section of sandstone and shale beds of the Dakota Group. The first exposure of sandstone is at:*

N 40° 03' 752"

W 105° 17' 796"

Note: The Lower Cretaceous Dakota Group (about 135-97 mya) is a widespread unit found across the West and Midwest. Along the Front Range it is subdivided into the South Platte (younger) and Lytle Formations (older). The South Platte is further divided into the Muddy/J Sandstone, Skull Creek Shale, and Plainview Sandstone. However, these subdivisions are not clearly discernible along the Old Kiln Trail. For simplicity, they will be described here primarily by rock type and topographic expression.

The South Platte Formation of the Dakota Group represents the first Cretaceous marine flooding of Colorado along the Western Interior Seaway (Figure 4). At times, this part Colorado was at and below sea level. During deposition of the South Platte Formation, fluxuations in sea level (or changes in the level of the sea floor) caused deepening and

shallowing of the water (technically, transgressions and regressions). These environmental changes are represented in the types of rock formed. Generally, sandstones are more resistant to erosion than shale/mudstone (that contains large quantity of clay). Sandstones form topographic ridges, whereas shales/mudstones form valleys or vegetation covered slopes. Look north across Lee Hill Road. The two high ridges are mostly sandstone and the vegetation-covered slope in between is mainly shale.

The Lytle Formation is the oldest unit of the Dakota Group is not marine and it formed before the development of the seaway and flooding of this part of Colorado. The Lytle will be discussed at Stop 9.

*Walk uphill and around the corner to the alternating sandstone and shale beds pictured below.*



Figure 7. Cross-bedded sandstones and shale beds of the upper part of the Dakota Group (J or Muddy Sandstone).

N 40° 03' 753"

W 105° 17' 807"

**Stop 6.** Upper Dakota Group sandstones and shales:

The sandstones (and shale) at this stop are called the J or Muddy Sandstone of the South Platte Formation. They are interpreted to represent a deltaic environment near the inland sea. Deltas are complex environments (think of the Mississippi Delta today). Sluggish, meandering rivers with many migrating channels, sand bars, floodplains and swamps, tidal channels and nearshore deposits characterize this environment. At this time, North America lay closer to the equator so the climate was more tropical. Go to <http://www.dmns.org/main/minisites/ancientDenvers/dakota.html> for a picture of the landscape at this time.



The rocks along the trail are composed of fine-grained well-sorted sandstone and mudstone. Look closely at the sandstone and details of the bedding (orientation of the layers). There are excellent examples of cross-beds that form where flowing currents of water have deposited sand at different angles. To see a close-up example of cross-bedding go to: [http://walrus.wr.usgs.gov/seds/bedforms/photo\\_pages/pic28.html](http://walrus.wr.usgs.gov/seds/bedforms/photo_pages/pic28.html). The cross-beds in the sandstone along the trail indicate currents flowing in different directions, interpreted to have formed in a meandering river or tidal channel.

*Walk farther up the trail. Look at the thickening and thinning of the beds.*



Figure 8. Beds in the right half of the picture thicken and thin representing migrating channels along a river.

These are examples of channels in a meandering river system that were abandoned and then filled with fine sand. The sand-filled channels were then covered with silt, making them clearly visible. Remember, all these rocks were deposited horizontally, and they have been tilted with the rise of the present Rockies.

*Continue farther along the trail to the organic rich mudstones (Figure 9).*

N 40° 03' 747"

W 105° 17' 825"

**Stop 7.** Swamp deposits and fossil plant roots: These organic-rich (black) mudstones (Figure 9) are interpreted to represent a swamp on the floodplain between the meandering channels. Roots of the swamp plants are preserved in the sandstone below the mudstone (Figure 10).





Figure 9. Organic-rich mudstones, representing a swamp, alternating with sand-filled channels. See detail of roots of swamp plants preserved in the sandstone below the mudstone (Figure 10).



Figure 10. Close-up of sandstone (Figure 9) showing fossil plant roots (black line at end of pencil) that grew into the sandstone below the mudstone. Reddish stains are found along fractures to left and right of roots.

The Upper Dakota Group rocks you have just seen at Stop 6 and 7 continue north across Lee Hill Road and form the high east ridge of Dakota Ridge.

*Continue along the trail. The next stop is an exposure of sandstone (not prominent).*

N 40° 03' 743"  
W 105° 17' 864"

**Stop 8.** Middle Dakota Group and trace fossils in marine sandstone: As you look across Lee Hill Road to the north, you can see the middle Dakota unit below (west) the Muddy/J Sandstone that is covered with vegetation and forms a valley between the two prominent sandstone ridges. The middle part of the Dakota Group is termed the Skull Creek Shale, part of the South Platte Formation. It is not well exposed along this trail, but can be seen in the road cut along Lee Hill Road. The middle Dakota is mostly mudstone and shale that was deposited below sea level and in deeper water. Look for a resistant sandstone exposed along the trail. Close observation of the sandstone will reveal a block that contains single and branching tubes (Figure 11). These are trace fossils. These fossils are not the actual remains (hard parts) of the organisms. Rather, they are evidence of the activity of some marine organisms as they moved through the sediment in burrows and feeding tubes.



Figure 11. Trace fossils: burrows of marine organisms. Pencil for scale.

*Continue up the trail to the next prominent ridge of sandstone. Remember, as you hike uphill, you are crossing older and older units.*

N 40° 03' 757"

W 105° 17' 885"

**Stop 9.** Lower Dakota Group sandstone, cross-beds and pebbles: Along the trail at the bend is a sandstone unit corresponding to the western high ridge (north) across Lee Hill Road. This sandstone is interpreted to represent the Lytle Formation, the lowest unit of the Dakota Group. The Plainview, lowest unit of the South Platte Formation is not exposed.





Figure 12. Lower part of the Dakota Group corresponding to the western prominent ridge across Lee Hill Road.

If you look carefully, you can see where small faults have cut and polished the sandstone (slickensides). Also, look for many excellent examples of cross-bedding in the layers.

As you walk uphill toward the west end of the outcrop, notice the scattered pebbles in the layers of sandstone. The presence of these pebbles is used to identify the Lytle Formation. In other sections along Dakota Ridge, the Lytle is characterized by large concentrations of rounded pebbles and cobbles. Lytle sediments were deposited by rivers flowing from highlands as far away as Utah.

An excellent example of cross-bedding can be found in an isolated block along the trail.

*Continue uphill to the next sandstone outcrop.*

N 40° 03' 751"

W 105° 17' 985"

**Stop 10.** Lakes and rivers: The Upper Jurassic Morrison Formation (about 155-145 mya) underlies the Dakota Group. Numerous terrestrial (on land in contrast to marine) environments are represented in the Morrison including rivers, floodplains, lakes and marshes. Much of the Morrison consists of multi-colored clays and soils, often shades of purple, red, and green. The Morrison Formation is famous for dinosaur fossils and uranium deposits farther west. Along the Front Range, the Morrison is not well-exposed and forms vegetation-covered slopes on the west side of Dakota Ridge. At this stop along the Old Kiln Trail, the gray sandstone is more resistant to erosion (than adjacent shale) so it forms a prominent ridge. This sandstone was deposited in migrating river channels. Observe the beautiful examples of cross-bedding here.





Figure 13. Cross-bedded sandstone in the Morrison Formation.

*Continue up the trail to the limestone illustrated in Figure 14.*

N 40° 03' 744"

W 105° 18' 103"

**Stop 11.** Morrison Formation limestone. The hard, blue-gray layers exposed here are limestones ( $\text{CaCO}_3$ ) in the Morrison Formation, interpreted to have formed in a freshwater lake or marsh.



Figure 14. Limestone in the Morrison Formation.

*Continue up the trail. Look for the white sandstone in the recessed area in figure 15. If you reach the red shale, you have gone too far.*

N 40° 03' 745"

W 105° 18' 019"

**Stop 12.** White cross-bedded sandstone: The sandstone at this stop is the Middle Jurassic Canyon Springs Member of the Sundance Formation (about 165-161 mya), a cross-bedded sand dune deposit. It does not stand out as a prominent ridge since the sand

is not well-cemented and thus is more easily eroded. A better exposure is in the road cut on the north side of Lee Hill Road (Figure 16). It is easy to pick out between the red Lykins Formation below (west) and the vegetation-covered Morrison Formation above (east).



Figure 15. Canyon Springs Sandstone Member of the Sundance Formation is the white sandstone along the Old Kiln Trail.



Figure 16. View of Lykins (red mudstones on left) stratigraphically below the Canyon Springs Member of the Sundance Formation (white) looking north across Lee Hill Road. The Morrison Formation is the gray strata on the far right. View is oldest strata on the left to youngest strata on right side of the picture.

*Continue up to the bend in the trail. Look closely at the strata to find the ripples.*

N 40° 03' 747"

W 105° 18' 038"

**Stop 13.** Lykins ripples and mudcracks: Along the Old Kiln Trail and along Ridge Drive (paved road at end of trail) is the upper part of the Lykins Formation. It is composed of bright red, fine-grained sandstone and siltstone. The Lykins Formation ranges from Permian into the Triassic, at a time when the Ancestral Rocky Mountains were deeply eroded and a shallow continental sea occupied this region (during much of



geologic time shallow seas flooded the continent). Look closely at the layering of the strata at the bend in the trail for the succession of ripple marks (Figure 17). These ripples record sediment moved back and forth by tidal action.



Figure 17. Lykins mudstones showing ripple marks (below pencil).

At times, the mud flats were exposed to the atmosphere where they dried and cracked as shown by the mud cracks in the isolated block on the north side of the trail (Figure 18).



Figure 18. Lykins showing mudcracks (on right side of trail going uphill). Pencil for scale.

Look to the north. Notice that Lee Hill Road and Old Stage Road run up a valley. This valley occurs in the Lykins Formation along the mountain front between Dakota Ridge, and the Lyons Sandstone, that forms the next ridge to the west. Since the Lykins Formation is mostly mudstone, it is easily eroded forming a valley.

*Continue up the trail onto Ridge Drive (dirt road). Walk past the building on the left. Look for additional ripples in the sandstone and shale, especially on the underside of the sandstone beds.*

N 40° 03' 695"  
W 105° 18' 077"



**Stop 14.** Sole marks: As you walk south along Ridge Drive, look at the underside of the sandstone layers that are exposed by erosion. At the bottom of the fine-grained sandstone are features called sole marks. You will be looking at the bottom of a layer in the same way you look at the sole on your shoe if you turn it over. Look for features like the photograph below. Unfortunately, these don't show up well in some light. Sole marks are formed where flowing currents of water sculpt depressions in the underlying mud. These depressions (often airfoil-shaped) are then filled with the sand in the layer above. There are several places along the road where interesting sole marks are formed above mudstones. Look for good examples of ripple marks also.



Figure 19. Sole marks indicating scours in underlying mudstone by current carrying and depositing sand.

*As you walk along Ridge Drive, notice the direction and orientation (strike and dip) of the Lykins strata. It is going to change abruptly. See if you can find this location.*

N 40° 03' 659"

W 105° 18' 109"

**Stop 15.** Fault zone: This is where orientation of the strata (dip and strike) change direction due to faulting. A fault is break in the rock where the two sides moved relative to one another.

*Continue a short way farther south along Ridge Drive to the location illustrated below (Figure 20).*

N 40° 03' 645"

W 105° 18' 121"

**Stop 16.** Fault clearly exposed: Note the numerous small offsets in the strata by the change in composition, color, and thickness of the layers. There are also small folds and kinks at the south end of the exposure.



Figure 20. Fault zone with numerous offsets between sandstone and shale.

This fault extends across the Lykins Valley through the quarry to the northwest. You can see a change in direction of the strata in the light-colored Lyons Sandstone marking the fault.

*This is the conclusion of the field guide. Return down the Old Kiln Trail to the trailhead. You will be walking forward in time as you go downhill. When you reach the trail junction, you can take the trail to the right (not as steep) or to the left (the way you came) to return to the parking area.*

#### References Cited:

1. Gleichman, Peter J. and Robert Mutaw, 1998, Cultural Resources of City of Boulder Open Space: Mt. Sanitas and Related Parcels, Native Cultural Services.
2. Locklair, Robert and Sageman, Bradley, 2006, Evaluation of tectonic and oceanographic forcing factors on the formation of exceptionally carbonate-rich hemipelagic facies, Cretaceous Western Interior Basin, GSA Abstracts and Programs, Vol. 38, No.7, p. 388.
3. Longman, Mark W., Barbara A. Luneau, and Susan M. Landon, 1998, Nature and distribution of Niobrara Lithologies in the Cretaceous Western Interior Seaway of the Rocky Mountain Region, The Mountain Geologist, Vol. 35, No. 4, p 137-170.

#### Additional Resources:

Bridge, Raymond, 2004, The Geology of Boulder County, Lone Eagle Publications, Boulder, CO., 468 p.

Matthews, Vincent, Katie KellerLynn, and Betty fox, 2003, Messages in Stone, Colorado Geological Survey, 157 p.