Chapter 3: The Onion from Inside — Short Geological History of the Boulder Area

Geology is the study of the history of Earth. Anywhere that the rocks of Earth’s crust are exposed, there is geological information to be interpreted. How much information is available depends on the amount of the exposure and on the geological history of the area. Earth is approximately 4.6 billion years old, but few rocks can be found anywhere that are even half that age. Because of this, we have far more detailed information about more recent times than about more ancient ones. In Colorado — and Boulder County — the oldest rocks that can be dated are about 1.7 -1.8 billion years old (Ga), so we cannot find anything in the rock record here that will tell us about the preceding nearly three billion years.13

Figure 3-1 – A salad chef’s view of Boulder geology – the Denver Basin onion.14

13 Technically, there is a tiny exposure of older rocks in the northwest corner of Colorado, which is part of the Wyoming Province.

14 The onion simile is the culinary product of Kirk Johnson and Bob Raynolds. And yes, the inner layers of an onion are the youngest.
Besides the general rule that our knowledge of older periods is more fragmentary and less direct, any given location will only have a few intervals of history recorded in the surrounding rock. It is in the nature of the rock record that it is partial and usually contains many interruptions. Only by studying many rocks over large areas can we derive an overall picture of the past. The Flatirons, for example, are made up of rocks that were eroded from an ancestral mountain range that rose along a line close to the current Front Range about 300 million years ago. For the sediments to have formed the sandstone of the Flatirons, the mountains from which they originated had to have worn down. Those mountains ceased to exist long before the first dinosaur walked the earth, and the remnants we see are what was left in the basins or both sides of the ancient range. All that is left are the fragments that were compressed into the layer of rock that now makes up the Flatirons. In Chapter 6 we’ll see some of the clues those rocks contain about the ancestral mountains. The point here is that in any particular location we can only read the rocks that are actually there. The constant forces of change that work on Earth’s surface leave us only small fragments of the story in any given place. Even fewer will be exposed at the surface. There will always be gaps in our knowledge, and what we do know of Earth history is the result of the patient accumulation of fragments of information from many places by tens of thousands of geologists working over a period of many years.

When we talk about the geological history of Boulder, then, we are talking about those periods for which we have good evidence. In this book I will concentrate on an even smaller subset that is fairly easy to see and interpret. Thus, there is more emphasis in the field trips on the rocks between the beginning of the Pennsylvanian Period and the end of the Cretaceous than there is on the Precambrian rocks that make up the mountain core or the Quaternary deposits that cover the surface of much of the eastern county. The Precambrian rocks are more difficult to interpret than the sequence of upturned sediments that run roughly north and south along the mountain front. We will also consider what geologists know about periods that are missing from the local rock record, but the story of these intervals is necessarily more speculative, and the evidence comes from other localities.

**Precambrian Boulder**

The earliest rocks in Boulder County (and in nearly all of Colorado) are about 1.7-1.8 billion years old (Tweto 1980a, 5; Tweto 1980b, 37; Gable 1980a, passim). There are two major types of rock of about this age that are widely distributed. One is the Boulder Creek **Granodiorite** [a granitelike rock with specific composition], most easily seen a short distance up Boulder Canyon [FT17], just west of the rocks of the Fountain Formation. The other is a group of metamorphic rocks found through much of Boulder County
and in many other places in Colorado. Several of the field trips visit examples of these and other Precambrian rocks. The metamorphic rocks are sometimes called the Idaho Springs Group (or, in older literature, the Idaho Springs Formation) named for the town of Idaho Springs in Clear Creek Canyon along I-70.

Note that when we talk about the age of these rocks, we are referring to the time when they solidified. That is what the radiometric methods can date. In the case of the granodiorite, it is the time when the molten material crystal-lized below a critical temperature. The metamorphic rocks in Boulder County mostly began as sedimentary rocks and were then folded and partially melted by heat and pressure. The measured age is the time they recrystallized. There is no way to tell how old the original sedimentary rocks are for certain, but the overall tectonic history of this part of the continent has convinced investigators that they are not more than a few hundred million years older than their radiometric dates (Hutchinson 1976, 74; Tweto 1980b, 40). We know for certain that the metamorphic rocks are older than the Boulder Creek Granodiorite, because there are places where the pluton has intruded into the metamorphic rock.

Most of the granitic rocks in Boulder County are somewhat younger, having been formed about 1.4 billion years ago. They are often known as Silver Plume Granite, from the town of Silver Plume on I-70 west of Idaho Springs. This is the age of the most extensive group of granites in Colorado, and they extend north into southeastern Wyoming. They mark a time when a very large system of plutons welled up from far below the surface of the earth and intruded into the much of the North American continental mass, including the part that is now Colorado. These granites are generally gray to light pink in the southern parts of our area. In the northern part of Boulder County and extending north into Wyoming more of the granite is salmon colored. We will see examples of these differences in granite compositions in several field trips.

At the time the batholith that formed the Boulder Creek Granodiorite emerged, our section of North America was at the edge of the continent, and the oceanic plate that extended south was probably being subducted under another approaching plate (Figure 4-3, page 48). The 1.7-1.8 Ga metamorphic rocks are the result of a combination of rocks that were at the shoreline then and volcanic rock of an island arc that was brought in from the plate to the south. The metamorphic rocks were folded and partially melted by the pressure and heat from this interaction and from the rising plutons of igneous rock. The old sedimentary and volcanic rocks bonded together into the gneiss and schist of the metamorphic rocks that make up large parts of the core of the Rocky Mountains, including some mountain faces in Rocky Mountain National Park (FT1), some in the Indian Peaks (FT10), and the walls of the Black Canyon of the Gunnison.
The oldest of the rocks that make up the Precambrian core of our mountains are thus rocks that accreted to the edge of what is now southern Wyoming. This fits well with the fact that there are rocks in the Snowy Range in southern Wyoming that are significantly older than any found in nearly all of Colorado. They are over two billion years old. The “Wyoming province” was at the edge of the ancient North American craton at this time, and island arcs (see Chapter 4 [pages 43-53] and Appendix B [pages 405-06]) accreted against the edge of the ancestral continent. (See Figures 4-2 [page 46] and 4-3 [page 48].) The 1.7 billion-year-old metamorphics are the products of this extreme pressure cooker. The Boulder Creek Granodiorite intruded as part of this same process. A few hundred million years later, the plutons that made up the 1.4 billion-year-old granites intruded.

The Great Unconformity

All the later Precambrian time, as well as the Cambrian, Ordovician, Silurian, Devonian, and Mississippian Periods are represented in the Boulder area only by the erosion surface [FT18, WP9] that we will see on the top of the Precambrian granitic and metamorphic rocks as we go up any of the canyons towards the mountains. We will briefly investigate what we know about events during this nearly 2-billion-year interval in Chapter 5 (pages 55-61), but because we don’t have a rock record around Boulder, our information is very limited. From information we have to the north and the south, it appears that the region consisted mainly of shallow seas during most of this time, and it is quite likely that marine sedimentary rocks were deposited in Boulder during at least some intervals of this time. We can guess this because they can be found west of Colorado Springs, at Leadville, and in Glenwood Canyon along I-70. If they were deposited here, they were eroded away before the sandstone of the Fountain Formation was deposited. What we know from surrounding areas is discussed in Chapter 5 (pages 55-61).

The Pennsylvanian

The next chapter in the Boulder geology book after these missing pages is that of the Flatirons. During the Pennsylvanian Period, the Ancestral Rockies pushed up, along an axis close to that of the modern Front Range. During this period the Ancestral Rockies rose, and as soon as the highlands began to push up, the forces of erosion began to eat them away, washing sediments down into basins on both sides. In the Boulder area, a basin formed in front of the Ancestral Rockies fairly close to what is now the Denver Basin. Such a basin is formed by downfolding caused by the same pressures that cause the mountain range to rise upwards, and the weight of the accumulating sediments presses the basin down still deeper. When we examine the rocks of the Fountain Formation, we will see how geologists have learned this.
The Fountain Formation is made up mainly of classic fluvial \[\text{river-borne}\] deposits. There are many signs that rivers deposited the sands and gravels. Moreover, it is also evident that these rivers had high energy — that they had the power to move large pieces of debris out of the mountains. If you were to look at particles deposited by a river like the Mississippi through most of its length, you would find that the grains are very small and uniform in size. Even at flood stage, the Mississippi does not move large rocks, or even pebbles. It is moving down too gentle a slope.

**The Permian**

The uplift of the Ancestral Rockies continued into the early part of the Permian, beginning roughly 280 Ma, and the Fountain Formation is generally thought to continue into the Early Permian. The most characteristic Permian rocks are above the Fountain, however, in the Lyons Formation. In Boulder County, the Lyons consists of the lithified remains of windblown sand dunes, much like the Great Sand Dunes in southern Colorado. We’ll look at the Permian in more detail in Chapter 7, but the picture that emerges of the overall history is that the uplift of the Ancestral Rockies was complete, the uplands had mostly eroded away, the climate was drier, and the sand from the river channels was being blown and sorted by the wind.

The overall picture of the continents at this time is consistent with our view locally. The continents were joined together into the supercontinent called Pangaea, resulting in a dry, continental climate in the interior. Boulder was in the western interior of Pangaea.

We do not have large numbers of fossils from the Permian in Boulder County, which is not surprising based on what the Lyons tells us about the environment. There are, however, quite a few small animal trackways that have been found in the Lyons.

One geological feature that shows well in the Permian rocks around Boulder is that of facies changes \[\text{changes in the depositional environment of rock formation(s)}\]. Both the Lyons Formation and the Ingleside Formation show distinctly different modes of deposition as one moves north and south along the Front Range. We will see some examples in Chapter 7 and associated field trips.

By the end of the Permian, there was very little relief around Boulder. The Ancestral Rockies had been almost completely flattened out, and the low mudflats that remained have left their signature in the weak, valley-forming Lykins Formation, named after Lykins Gulch, north of Left Hand Canyon in Boulder County \[\text{FT 7, WP8}\]. The low mudflats of the later Permian left us with rock formations, but virtually no fossils — only a few wavy limestone deposits left by blue-green algae or cyanobacteria that matted with sand to
leave hummocks (known as stromatolites) between the mudstone layers \[FT7, WP9; FT12, WP7\].

**The Triassic**

The upper part of the Lykins Formation is of Triassic age, but there are only a few rocks around Boulder from most of the Triassic or the from the Lower Jurassic. This means that we do not have definitive evidence of what was going on during that time, but we can infer from the rocks elsewhere in Colorado that during this period Boulder was low in elevation. The beginning of the Triassic mark the greatest worldwide extinction recorded in the geologic record.

**The Jurassic**

The Western Interior seaway is most commonly associated with the Cretaceous Period, because of the massive loads of sediment it has left, including most of the 10-14,000 feet of fill in the Denver Basin. The seaway was also an important feature during the Jurassic, however. For the region as a whole, students of the period distinguish six cycles of inundation by the sea and subsequent regression during the Jurassic alone (Brenner and Peterson 1994). The Jurassic inundations were not nearly as extensive as those of the Cretaceous, and Boulder has no marine sediments from the Jurassic. The Morrison and other sediments from the period are deposits from meandering rivers and lakes.

Above the Lykins in most places in Boulder County is the Morrison, one of the most famous and widespread bodies of rock in the American West. It is named for Morrison, Colorado, a few miles south of Boulder. The Morrison has produced many of the specimens of Jurassic dinosaurs in museums throughout the world. None have been found in Boulder, however, at least partly because there are no broad exposures here. The places that we see the Morrison around Boulder occur where it has been uplifted with the rest of the sedimentary layers and where it is also capped with the more durable rocks of the Dakota Group. The Morrison consists of sandstone, siltstone, mudstone, and freshwater limestone laid down in relatively flat and marshy terrain. We will examine the Morrison Formation fairly carefully in Chapter 8 (pages 87-90) and on several field trips.

**The Cretaceous**

Where the Morrison is well exposed in the area, it is protected above by the Dakota Group, which dates from the mostly from the Early Cretaceous. We will examine the Dakota Group in more detail in Chapter 9 (pages 91-123),
but it includes some durable sandstone that forms one of the prominent hogbacks along the mountain front. The Dakota Hogback is the next ridge to the east of the Fountain-Lyons hogback (see Figures 1-1 [page 4] and FT7-WP10 [page 210]). The Dakota Group is also very widespread in the Western Interior of North America, and is an important source of fossils of Cretaceous dinosaurs. In the Boulder area it includes both sandstone and shale, representing lowland continental terrain as it was beginning to be inundated by the inland Cretaceous seaway. Most of the Dakota here was probably deposited at various parts of river deltas, where the rivers flowed into the Cretaceous interior seaway.

Above the Dakota we find a series of marine shale, sandstone, and limestone. They are mostly not very durable, so they do not form major hogbacks. However, they represent thousands of feet of deposits in the Denver Basin, the seafloor detritus of 25 million years when Boulder and all the surrounding region was under water. The thickest of these deposits is the Pierre Shale, itself thousands of feet thick where it has not been eroded away.

Keep in mind that this period of Boulder being underwater lasted for a long time — half as long as all the time from the withdrawal of the Cretaceous seaway to the present. At its greatest extent, the Cretaceous seaway extended far to the west of Boulder, covering all of Colorado and extending partway into Utah. It also stretched far to the east over the modern Great Plains.

There are some interesting clues in the Boulder area to the final stage of the Cretaceous, as the seas receded from the region. We will examine these in Chapter 9 and in associated field trips [FT14; FT23]. In the Late Cretaceous Fox Hills and Laramie Formations we will see river deltas and beaches that mark the final retreat of the seaway, just as the Dakota marks its beginning advance.

The Rise of the Modern Rocky Mountains

At about the end of the Cretaceous, as the sea was making its final withdrawal from central North America, the Rocky Mountains began to “pooch out,” in the phrase of David Love, the Grand Old Man of Wyoming geology. This event is called the Laramide orogeny. An orogeny is a mountain-building event, and this one is named after Laramie, Wyoming, to our north. Our mountains began to rise at the very end of the Cretaceous and continued through the beginning of the Cenozoic Era. This is when the sediments laid down in earlier eras were pushed up and eroded down to the edges we see lifted to the west of Boulder today.\(^{15}\)

Great quantities of sediment were washed from the mountains into the Denver Basin as the mountains rose. These sediments, which consist of

\(^{15}\) The erosion is actually a more complicated story, which is discussed in Chapter 10.
fragments from all the older rocks that were raised with the Rockies, now form the fill on which Denver and surrounding areas are built, as well as many of the features we see jutting out from the foothills. Since Boulder is situated on the lip of the Denver Basin and a little above it, sediments that eroded from the mountains above Boulder were either deposited in the Denver Basin or carried on down the river system to the Mississippi delta in the Gulf of Mexico. It is clear, however, that in the mountains the overlying sediments were stripped off rapidly, because debris derived from the underlying granite and metamorphic rocks show up in the sediments associated with the Laramide uplift.

The sediments that were washed down as the modern Rockies were uplifted are lithified to various degrees. Some are fairly solid rock where they are exposed, while others are still poorly consolidated.

**The Tertiary and Quaternary Periods**

The story of the last 65 million years of Boulder geology is very interesting for a number of reasons. It is, of course, the time that all the landscape we see around us was shaped from the materials that were deposited earlier, but it is also the subject of heated debates among geologists, because it includes some interesting geological puzzles.

One important question that has not yet been fully resolved is the detailed story of the formation of the Rocky Mountain Front Range — the peaks that we see forming the continental divide above Boulder. We know that they began pushing up about 65 million years ago, but we also know that the story is more complicated than that. 65 million years is enough time for a mountain range to rise and to be generally eroded back down to a far less jagged landscape than the one displayed by our mountains. In fact, we know that much erosion had already taken place halfway through this span of time and that much of the sculpting of the modern peaks and canyons took place a lot more recently. The dispute is over the exact sequence and the mechanisms responsible. Some of the issues will be discussed in Chapter 10 (pages 125-144). This chapter also discusses several other events associated with the uplift of the mountains. They include the emplacement of bodies of molten rock between older sediments, or sometimes cutting through them. The percolation of hot, mineral-rich water into the cracks and weaknesses of the Precambrian core left valuable minerals that later attracted the miners and camp followers to Boulder and a dozen little boomtowns above it.

A final narrative chapter covers the erosive action of ice-age glaciers and streams tumbling down from the mountains, which left a large number of interesting landforms that we will explore.
Boulder’s Position along the Front Range

Though the formations that are upended along our mountain front are the ones that fill the Denver Basin, Boulder is actually at the edge of that basin, rather than being in it. Boulder is on the northwest lip of the basin, and since further development of the basin after the Cretaceous formed in lockstep with the rise of the Rockies, the sediments that sloughed off the Front Range as it rose were mostly washed into the basin past Boulder.

Thus, the Tertiary Arapahoe Formation, Denver Formation, and Dawson Arkose, which are found at various locations to our south, are not present in Boulder. The closest occurrence of these rocks is about 15 miles southeast of Boulder (Madole 1973). Our rock record ends at the close of the Cretaceous, except for Tertiary igneous intrusions and Quaternary alluvial deposits and glacial till. During Cretaceous time, there was one huge basin extending north, south, and west, but as the Front Range pushed up, some relatively higher sections rose slightly and divided the Cretaceous area of deposition into a number of smaller basins. The relatively higher rise to the northeast of Boulder is sometimes called the Greeley Arch, and it divides the Denver Basin from the Cheyenne Basin to the north.

Another important north-south variation is very clear in Boulder County — it shows in the appearance at the north end of the county of some rock formations such as the Ingleside that extend into Wyoming, but that pinch out north of Boulder. This, together with some other variations we will see on our field trips, is because of the difference in the axes of the Ancestral Front Range and the modern Front Range (see Figure 6-4 [page 71]).

Because these two uplifts occurred in roughly the same position, people usually think of them as being along the same axis. This picture is accurate enough to explain patterns that we see over long distances. The Fountain Formation goes south to the Colorado Springs area and north into Wyoming under a different name — the Casper Formation (Maughan and Wilson 1960).

The similarities are strong enough to distract us from other important patterns, however. The formation of sediments along a mountain front show a number of predictable shifts over time (as the mountains are worn down) and over distance (as one moves farther from the mountains). Because the modern Front Range rose at an angle to the Ancestral Rockies, the sediments pushed up along the front of our mountains actually expose a sequence that is progressively farther from the original Ancestral Rockies axis the farther north you travel.

This means that even though the Fountain Formation is continuous along the mountain front, the rocks exposed by the modern uplift farther north were deposited farther from the mountains than the same formation farther
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south. In the north, some of this deposition is classified as a different formation — the Ingleside. Similar changes can be traced in the Lyons Formation. This north-south change in depositional characteristics manifests itself in a number of ways in Boulder’s rocks. We will see it in the field trips, and it is illustrated and discussed in Chapter 7 (pages 77-85).

Boulder’s Red Rocks

The red to pink to salmon color of many of Boulder’s rock formations is striking. It is responsible for much of the look of our mountain backdrop and for much of Boulder’s architecture. The color itself is from hematite, a form of iron oxide (mostly Fe₂O₃) that is generally red. The hematite in our rocks was not present when the sediments were deposited. It was formed from iron-bearing minerals — primarily biotite and hornblende — that were partly converted to hematite in the rock strata after they were buried, changes referred to as authigenic. Such transformations are dependent on the conditions over many tens of millions of years. One environment that is conducive to the formation of hematite was the arid desert that prevailed in Boulder Country during the Pennsylvanian and Permian periods (see Chapters 6 and 7 [pages 63-85]). This was the time during which our red rocks were formed. The definitive paper describing the details is Walker (1967b).
Figure 3-2 – An outcrop of the Fountain Formation showing alternating maroon coloring produced by alteration of iron minerals after formation of the rock and whitened layers that were lightened by later reduction of the iron oxides. The lighter layers are the ones that have larger grain size and are more permeable. At Contact Corner on Flagstaff Mountain {FT18,WP9}. 