Late Cenozoic History of the Northern Colorado Front Range

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ABSTRACT

Restoration of the Late Eocene erosion surface indicates that the Mummy Range and Medicine Bow Mountains rose about 3,000 ft above a Late Eocene pediment which had developed by stream erosion on Precambrian crystalline rocks. The mountains were much more rounded in the Late Eocene and the pediment was at grade with streams that flowed eastward onto the Great Plains. Volcanic rocks were extruded on this surface during Oligocene and Miocene time, but processes which resulted in topographic smoothing continued long after. Renewal of uplift began in the Miocene and continued until recent time. About 2,500 ft of eastward tilting can be demonstrated. Major post-Miocene normal faulting occurred along the Upper Colorado and Laramie Rivers Lineament on the west flank of the Front Range. Elsewhere, normal faulting accompanied uplift but most of the displacements were about 300 ft or less. Evidence for Pleistocene faulting is present locally in the Poudre Canyon.

Mio-Pliocene uplift was accompanied by canyon-cutting. Stream piracy caused a major change in the course of the Cache la Poudre River. Development of the Poudre Canyon, which is 2,200 ft deep near Kinikinik, occurred in 3 major stages. The earliest was a wide valley that probably matured in Miocene time. Uplift and tilting initiated an intermediate stage characterized by a narrower, but nevertheless mature U-shape valley. The third stage is a narrow, youthful, V-shape valley. Multi-storied valley profiles are common except in the uppermost reach of the Cache la Poudre River, where the intermediate and latest stages of canyon development have not yet occurred. The combination of continued uplift and a change to colder, wetter climate caused alpine glaciers to develop in Pleistocene time.

INTRODUCTION

The investigated area (Fig. 1) includes the northernmost part of Rocky Mountain National Park and extends northward to the Colorado-Wyoming boundary. Most of this area is drained by the Cache la Poudre and Laramie rivers. Its post-Eocene history is similar to Front Range areas farther south.

The Late Eocene erosion surface (Fig. 5) includes remnants of a once extensive pediment (Scott and Taylor, 1986), which extended into Wyoming. Fenneman (1931) referred to this surface as the Rocky Mountain peneplain. Because it originally was nearly flat and at grade with streams that flowed eastward onto the Great Plains, it is an important datum for understanding later tectonic events.

STRATIGRAPHIC FRAMEWORK

Precambrian (Proterozoic) crystalline rocks (Tweto, 1979) are extensively exposed in the mountains. The oldest rocks are Precambrian X metamorphics, principally gneiss and schist, which formed 1.7 billion or more years ago. They are intruded by Precambrian X and Y batholiths, stocks and dikes of granitic rocks.

Paleozoic and Mesozoic sedimentary rocks (Fig. 2) are absent in most of the mountainous area. Exposures are limited to the eastern and western mountain fronts, a faulted reentrant near Livermore, the northern part of the Laramie River valley, and overthrust terrain near Cameron Pass on the west side of the Front Range. Mississippian and older Paleozoic sedimentary rocks were stripped from this part of the
Front Range by pre-Pennsylvanian erosion. The Permo-Pennsylvanian Fountain Formation rests unconformably on the Precambrian rocks along the eastern front of the mountains. These beds are in turn overlain by the Ingleside, Owl Canyon, and Lyons Sandstone formations of Permian age, and the Lykins Formation of Upper Permian and Lower Triassic age. Near Cameron Pass, on the west side of the range, most of the Permo-Pennsylvanian strata are absent due to non-deposition associated with uplift of the "Ancestral Rocky Mountains." There the oldest sedimentary rocks, which are equivalent to the Lykins, have been mapped as the Chugwater Formation (Upper Permian and Lower Triassic) by Braddock and Cole (1990). Jurassic formations are present on both sides of the range. Cretaceous strata are demarcated at the base by the Dakota Sandstone, a prominent hogback-forming unit. The Upper Cretaceous is predominantly marine shale, but contains limestone units (Greenhorn and Niobrara). The total thickness of Mesozoic and Paleozoic strata is about 10,000 ft east of the Front Range, 8,100 ft in the Laramie River valley (Beckwith, 1942), and 8,300 ft in North Park (Hail, 1965).


In North Park, the Coalmont Formation (Hail, 1965), of Paleocene and Eocene age, includes up to 7,000 ft of conglomerate, arkosic sandstone, carbonaceous shale and claystone, and some coal. East of the mountains, equivalent beds are present near Denver but absent at the latitude of Fort Collins due to non-deposition and/or pre-Oligocene erosion.

Oligocene and Miocene volcanic rocks overlie the Precambrian in the southwest part of the investigated area. Almost all sedimentary rocks of Oligocene age in northeast Colorado are placed in the White River Formation. This unit consists of pink to white tuffaceous claystone and siltstone with interbeds of sandstone and conglomerate. Volcanic glass and ash-flow tuff are common. On the Great Plains, the thickness of the White River ranges up to 665 ft (Moore, 1963). White River outcrops are common in North Park, but are rare in the study area. Miocene strata, on the other hand, range up to 1,800 ft thick in North Park (Montagne and Barnes, 1957, p. 56). These beds, called the North Park Formation, contain calcareous ashy sandstone, conglomerates, limestone, shale, bentonite, volcanic ash and tuff (Hail, 1965). In the Front Range, small patches of Miocene gravel (Tweto, 1979; Scott and Taylor, 1986) locally overlie the Precambrian. Equivalent beds on the High Plains are assigned to the Ogallala Formation, which consists of conglomerate, sandstone, siltstone and limestone deposited as a nearly flat-lying alluvial sheet about 300 ft thick (Moore, 1963). Near the Front Range, the conglomerates contain boulders, up to 3 ft and more in diameter, which consist of virtually all rock types found in the mountains. Moore (1963) considered these unfossiliferous continental deposits to be Pliocene, but Love and Christiansen (1985) referred them to the Miocene and Tweto (1979) mapped them as Miocene and Pliocene(?). West of Cheyenne, Wyoming, the Union Pacific Railroad ascends from the High Plains to the Late Eocene erosion surface via an east-sloping topographic feature, called the Gangplank, which is composed of Ogallala beds.

Pleistocene glacial deposits and Quaternary alluvium are present in the valleys and tend to conceal suspected or inferred faults.

Restoration of the Late Eocene Erosion Surface

A restoration of the Late Eocene erosion surface, which slopes generally eastward, is shown in Figure 3. Contours depict the elevation of this surface as it would appear today if the post-Eocene canyons, cirques and other erosional features had not formed. In the volcanic terrain, the contours are drawn on elevations at the base of the volcanics. In the pediment terrain, they are based on the actual elevations of the smooth surface. Parts of the pediment were remarkably flat, but restoration of the surface indicates numerous hills (monadnocks) were present, some rising several hundred feet above the general level. Many geologists who have studied the pediment believe that only a few
Late Cenozoic History of the Northern Colorado Front Range

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FIGURE 2. Generalized stratigraphic relationships in and adjacent to the investigated area. Closely spaced vertical lines indicate major gaps in the sedimentary record. Disconformities and minor gaps are not shown. Permian to Cretaceous strata, shown as absent in the Front Range, are locally present in the Laramie River Valley. No vertical or horizontal scales.

tens of feet of material have been removed from the flat areas since Eocene time. Exceptions to this would include the Miocene paleovalleys which are discussed later. Figure 6 shows that these valleys were incised below the Late Eocene surface, and it would not be correct to utilize the base of the channel-fill as control for contouring the older surface.

The Mummy Range and Medicine Bow Mountains, which rise about 3,000 ft above the pediment, are contoured by smoothing the topography, eliminating glacial cirques and other obvious post-Eocene erosional features. Many authors have ignored these mountains, focusing instead on the pediment, because of the obvious difficulty of discriminating between Eocene and post-Eocene erosional features and determining the age of topographic smoothing in mountainous terrain. They correctly point out that the smooth upland surface north of Trail Ridge Road in Rocky Mountain National Park is developed partly on Oligocene volcanics (Raup, 1996, p. 43-46). Notwithstanding the violence of volcanic eruptions, processes resulting in topographic smoothing continued into Miocene time; and, since the mountains obviously were present, an attempt to portray them is useful even if the restoration can not be accurate.

OLIGOCENE-MIOCENE PALEOVALLEYS

Raup (1996, p. 43-46) and others have described a radiometrically dated Oligocene ash-flow tuff in cliffs surrounding Iceberg Lake north of Trail Ridge Road in Rocky Mountain National Park. The volcanic material, which was derived from the Never Summer Range to the west, occupies a valley cut into the underlying Late Eocene erosion surface. In the area of this
investigation, Figure 4 shows modern topography in the headwaters of the Cache la Poudre River which is interpreted to mimic the Miocene erosion surface. The Late Eocene surface is the base of the Oligocene volcanics, which have been tilted. The hill at the southeast end of the profile may mimic both the Late Eocene and Miocene surfaces. Although Pleistocene glaciation affected the valley, its depth and shape are largely inherited from the Miocene.

Scott and Taylor (1986) showed several paleovalleys represented by patches of coarse gravel that typically rest unconformably on Precambrian crystalline rocks or, locally, on Oligocene beds. They commonly occur on hilltops and ridges several hundred feet above the nearest permanent streams. Their elevation decreases eastward toward the mountain front. The gravels contain stream-rounded boulders up to 3 ft or more in diameter. Typically, the boulders are composed predominantly of Precambrian crystalline rocks. Beckwith (1942) described boulders of volcanic rock in the Laramie River Valley and stated that their size and abundance decreases northward away from the source.

The paleovalleys may have originated in Late Eocene or Oligocene time. The gravels, however, were the last materials transported in them. Lithologically,
they more nearly resemble the Miocene Ogallala and North Park Formations than the Oligocene White River Formation.

Most of the paleovalleys mapped by Scott and Taylor (1986) trend in easterly directions. It is easy to imagine that they were connected in Miocene time, forming a dendritic drainage pattern. The most obvious difference between the Miocene and present drainage patterns is that the ancient Cache la Poudre River exited the mountains near Livermore, almost 10 miles north of its present location. As discussed later, the section of the South Fork of the river downstream from Kellcy Flats Campground (Sec. 5, T8N, R72W) developed later, capturing the upper part of the river and causing abandonment of the Livermore segment.

**Mio-Pliocene Uplift and Canyon-Cutting**

The Miocene paleovalleys mark the first of several pulses of uplift which affected the Front Range in Late Cenozoic time. The large size of the stream-rounded boulders indicates that the Miocene uplift was strong. As uplift continued, the canyon of the South Fork of the Cache la Poudre River (hereinafter called Poudre Canyon), which is more than 2,200 ft deep near Kinikinin, developed mainly during Pliocene and Pleistocene time.

As previously discussed, the uppermost part of the Cache la Poudre valley has a simple U-shaped profile (Fig. 4). Farther downstream, however, profiles across the Poudre Canyon are multi-storied and indicate three major stages of development (Fig. 5). In Figure 6, the restored upper story, which is very wide and mature, represents an older Miocene stage of the valley. An intermediate, narrower but nevertheless mature, U-shaped valley was cut into the floor of the older valley (Stage 2). The third, or present stage is a narrow, V-shaped, youthful valley which has been incised into the floor of the intermediate valley. At the Big Narrows and many other places, the river is cutting down into bedrock and the present stage is a gorge with steep to vertical sides. The most common geomorphic vestiges of the first and second stages are curved, concave upward segments of ridges which are shaped like a reclining crescent or comma, that include portions of an old valley wall and the adjacent valley floor (Fig. 5). Uplift appears to have occurred in pulses which increased as a crescendo from Miocene to recent time. Pauses, which allowed the first and second stage valley floors to develop, were not of sufficient duration to permit the development of a pediment. The second and third stages are believed to be mainly Pliocene, but age differentiations are not practical and canyon-cutting has continued to the present.
FIGURE 5. The upper Cache la Poudre Canyon on Highway C-14 near the Big South Campground. The valley is multi-storied, with stages 1 and 2 of the canyon-cutting cycle well displayed below the Late Eocene erosion surface, which forms the nearly flat upland to right of the river. Each concave-upward segment of the valley profile, which is shaped like a reclining crescent or comma, includes the wall and part of the floor of an ancient valley. Such relics of older valleys are common from here to the mouth of the canyon.

Tilting

Unlike the earlier Laramide Orogeny, post-Eocene movement was dominated by vertical uplift and tilting. There is no evidence of regional compression. Along a northeast-trending line extending from Hagues Peak in the Mummy Range to Sec. 5, T8N, R70W, the erosion surface slopes an average of 265 ft per mi. The portion of this line that is represented by the pediment surface slopes about 135 ft per mi. Farther north, from a high point in Sec. 5, T9N, R74W eastward to the base of a Miocene outlier located 1/2 mile north of Livermore (Braddock et al., 1988b), the average gradient is 197 ft per mi and the portion that is represented by the pediment is 151 ft per mi. For comparison, the Cache la Poudre River has an average gradient of about 100 ft per mi in the mountains, 70 ft per mi where it is incised below the pediment, and 20 ft per mi on the Great Plains. In Late Eocene time, the slope of the pediment surface was probably less than 20 ft per mi. Subtracting 500 ft for an initial slope, the pediment appears to have been tilted approximately 2,500 ft eastward as the area was differentially uplifted.

Uplift and eastward tilting probably involved the Great Plains as well as the Front Range. Leonard and Langford (1994) presented a case against significant post-Laramide faulting at the eastern front of the southern Front Range, and this also appears to be the case for the northern part of the range. The Late Eocene surface intersected the modern erosion surface at an undetermined distance east of the Front Range.

Faults

Normal faulting accompanied uplift and tilting. In the pediment area of the Late Eocene erosion surface, there are numerous places where excessive crowding of contours, which is incompatible with a topographic surface of low relief, indicate reactivation of Precambrian faults (Fig. 3). Typically, the vertical slip on individual faults ranges up to about 300 ft. Greater movement occurred in the southwest part of the area where volcanic activity had been intense. As discussed later, greater movement also was associated with the Upper Colorado and Laramie Rivers Lineament.
No evidence is known that would clearly indicate reactivation of movements along the Laramide faults that are associated with the en echelon mountain front anticlines which plunge southeastward into the Great Plains. This is consistent with the interpretation that Late Cenozoic movement was predominantly vertical and not a response to compression.

The Upper Colorado and Laramie Rivers Lineament

An obvious north-south lineament approximately 40 miles long is formed by the upper reaches of the Colorado and Laramie Rivers. Several fault zones were mapped by Braddock and Cole (1990) along the upper 6 miles of the Colorado River valley. Farther south, faults probably are present beneath the glacial till and alluvium (Raup, 1996, p. 8). Till and volcanics cover most of the fault zone from the headwaters of the Colorado River north to Chambers Lake, which is a source of the Laramie River. Here, a north-trending fault separates sheared Precambrian granitic rocks on the west from gneiss to the east (Tweto, 1979). It can be traced northward about 4 miles before disappearing beneath the Laramie River alluvium. Further north, Laramide folds and thrust faults were described by Beckwith (1942).

Unlike the Cache la Poudre River, which has adjusted to uplift by cutting a canyon, the upper Laramie River flows in a valley that was created primarily by Laramide and later tectonic events. Chapin’s Figure 1 (1983) postulated a Laramide wrench fault along the valley. Wrench faulting is a plausible explanation for many of the compressional structures mapped by Beckwith (1942).

In T9-10N, R75-76W, a post-Miocene normal fault, upthrown on the east, is required along or adjacent to the Laramie River Valley to account for nearly 2,000 ft of difference in the elevation of Miocene deposits. At Chambers Lake, this fault approximately coincides with the lineament described above. Farther north, it appears to be largely concealed. About 8,000 ft of Paleozoic and Mesozoic strata in Beckwith’s syncline (1942, Plate 1, Cross Section H-H’) are absent on the hanging wall of the western overthrust, where the Precambrian is unconformably overlain by Miocene beds. This may be explained by a high structural position following Laramide compression, pre-Miocene erosion of the elevated older strata, and, finally, post-Miocene normal faulting along a pre-existing zone of weakness to form the Laramie River Valley.

Reorganization of the Poudre River Drainage

The ancient (Miocene) Cache la Poudre River flowed northeastward from the Mummy Range and exited the mountains near Livermore, almost 10 miles north of its present location. Small patches of Miocene gravel are now found nearly 400 ft above the Little South Fork of the Poudre River (Abbott, 1976). This would have been the most direct route of transport from the Mummy Range to the thick, coarse gravels in Sec. 3, T9N, R71W west of Livermore (Braddock and Connor, 1988).

Capture of the old stream by the present South (main) Fork of the river, which is believed to have occurred east of Kelley Flats Campground (Sec. 5, T8N, R72W), probably was caused by a combination of weaker bedrock and steeper gradient. The Poudre Canyon is cut primarily in metamorphic rocks (mainly gneiss and schist), which are more easily eroded than the granites that are extensive to the north and south; locally, faults and shear zones control the overall course of the canyon (Shaver et al., 1988; Abbott, 1976; Braddock et al., 1988). The present canyon mouth is
about 800 ft lower than Livermore. The distance from the canyon mouth to the point of capture is also less. Clearly, the gradient from the present mouth of the canyon to the point of capture was much greater.

Figure 6 indicates that the capture occurred during Stage 2 of the Poudre Canyon's development. Abandonment of the ancient river segment between Kelley Flats and Livermore probably occurred during early Pliocene time. This is based on the Miocene age assigned to the abandoned gravels by Scott and Taylor (1986), the position of the gravels within the uppermost story of the composite valley profile, and entrenched meanders downstream from the point of capture. The meanders cut across faults and shear zones, indicating that they are independent of local structure. They were established during Stage 2, when the valley was mature, and entrenched during late Pliocene and Pleistocene uplift.

**PLEISTOCENE GLACIATION**

As uplift of the Front Range continued into the Pleistocene, the combination of high altitude and colder, wetter climate favored the development of alpine glaciers. Biscuit-board topography refers to a glacial landscape characterized by smooth or rolling uplands on the sides of which are cirques resembling the bites made by a biscuit-cutter in the edge of a slab of dough. Such topography is common along high parts of the Front Range in Rocky Mountain National Park, the Mummy Range, Medicine Bow Mountains, and elsewhere. The rolling uplands may have been covered by snow and ice, but the ice was not thick enough to erode the landscape; thus these uplands represent the pre-glacial surface. The cirques, on the other hand, were sites of thick ice and intense erosion.

Three glacial advances are known to have occurred in and adjacent to Rocky Mountain National Park (Braddock and Cole, 1990). Pre-Bull Lake till was deposited 400,000 to 500,000 years ago, but most of it was obliterated or buried by subsequent glacial advances. The Bull Lake glaciation occurred 130,000 to 150,000 years ago (Madole and Shroba, 1979) and left extensive deposits. The Pinedale stage glaciers advanced about 35,000 years ago, began to recede about 13,000 years ago, and essentially disappeared about 10,000 years ago (Madole and Shroba, 1979). The Bull Lake and Pinedale moraines extend to nearly the same downvalley positions. The lowest, which is in the North St. Vrain valley between Meeker Park and Allens Park, is at an elevation of 8,000 ft.

Eschman (1957) observed three terminal moraines, with different degrees of weathering and erosion, on the Michigan River in North Park near Gould. This is in apparent agreement with the information from Rocky Mountain National Park. These moraines are 800 to more than 1,000 ft higher due to their location on the windward side of the mountain range.

Pinedale tills are extensive in the vicinity of Cameron Pass, the Big and Little South Forks of the Cache la Poudre River and the upper Laramie River valleys. Bull Lake glaciation undoubtedly affected this area also, but the tills have not been differentiated. Raup (1996, p. 57) describes evidence which indicates ice accumulated to such great thickness in the upper
Colorado River Valley that some flowed northeastward over the Continental Divide at Milner Pass and then down the Cache la Poudre River Valley. The extensiveness of till on Joe Wright Creek and the distribution of glacial lakes indicates that an ice field existed in the vicinity of Chambers Lake and the south part of Green Ridge. This is consistent with a 400 ft per mi gradient estimated for the top of the ice in Poudre Canyon by the difference in elevation of a lateral moraine near Kinikinik and the terminal moraine. The lateral moraine reaches an elevation of 8,850 ft (1,130 ft above the Poudre River) east of the Roaring Creek tributary. Three miles down the valley, the terminal moraine (Home Moraine) has an elevation of only 7,628 ft.

**HAS UPLIFT CEASED?**

Uplift may have continued into recent time and there is no indication that it will stop soon. The most obvious evidence is along the Cache la Poudre River. Below Poudre Falls, which can be seen from Colorado Highway 14, the river has cut down to a level which is about 50 ft below the glacially polished bedrock surface, providing a measure of post-glacial erosion (Fig. 7). Hair-splitters might argue that the uplift which initiated this erosion could have occurred in Pleistocene time, and it is difficult to either support or deny this possibility. Another effect of recent uplift can be seen about one mile below the Big Narrows. Here, glacial outwash once filled the valley to a level about 75 ft above the present river. Erosion of this material is occurring at the present time. Since stream volumes probably have decreased with the disappearance of glaciers, it would be difficult to attribute this erosion to climatic change alone.

At least 6 knickpoints occur along the Cache la Poudre River, suggesting the possibility of Quaternary faulting. Knickpoints are places where vigorous headward erosion in a youthful valley is attacking a more mature valley farther upstream. Below a knickpoint, the river's gradient is typically very steep, the valley has steep sides and may be a gorge, the stream itself is a waterfall or treacherous rapid, and gravel bars are absent. Above a knickpoint, the gradient is gentler, the valley is wider and more flaring, the stream is more placid and gravel bars may be present. The Big Narrows and Poudre Falls are classic examples of knickpoints. Multiple knickpoints alone do not prove Quaternary faulting. Indeed, three knickpoints, correlative with the three recognizable stages of canyon development, are expected. It is the other three knickpoints that suggest the possibility of Quaternary faulting.

Movement may have occurred along the Poudre River Shear Zone in Pleistocene time. The shear zone is concealed by Quaternary alluvium along a flat section of valley floor which extends both downstream and upstream from Rustic for a total distance exceeding 5 mi (Shaver et al., 1988). The valley floor ranges up to 1,800 ft in width and contrasts markedly with the V-shaped valley farther downstream. At the downstream end of Indian Meadows, a local baselevel approximately coincides with the emergence of the shear zone from beneath the alluvium and a knickpoint. The Quaternary alluvium is glacial outwash with boulders up to 4 ft in diameter. In some localities the gravel occurs as much as 50 ft above the present river, and water well data show that it extends as much as 65 ft below the level of the river, indicating an original thickness of at least 100 ft. The coincidence of the local baselevel, narrowing of the valley floor, and emergence of the shear zone from beneath the outwash probably is not fortuitous. It is difficult to escape the conclusion that aggradation was caused by Pleistocene fault movement along the Poudre River Shear Zone, which created a depression and a local baselevel. Headward erosion and downcutting at the knickpoint has resulted in the removal of about 50% of the original fill in Recent geologic time.

**Note:** References for this and all other papers are included in a comprehensive reference list at the end of this volume.
North view of Dakota hogback at Turkey Creek along U.S. Highway 285. The Dakota hogback consists, in ascending order, of Lytle Sandstone, Plainview Sandstone, Skull Creek Shale, and "J" Sandstone. The upper sandstone ("J") is partly saturated with oil in the outcrop. Underlying the Dakota is the Jurassic Morrison Formation. Dinosaur bones were quarried from this formation at several places along the east flank of the Front Range. Green Mountain is visible in the distance on the righthand side of the photo. Photo by Jack Rathbone.