CENOZOIC VOLCANIC, TECTONIC, AND GEOMORPHIC FEATURES
OF CENTRAL COLORADO

R. C. Epis
Colorado School of Mines
Golden, Colorado 80401

G. R. Scott
R. B. Taylor
U.S. Geological Survey
Denver, Colorado 80225

C. E. Chapin
New Mexico Bureau of Mines
Socorro, New Mexico 87801

Abstract
Withdrawal of the late Cretaceous sea from Colorado marked the end of a long history of marine events and the start of a shorter but eventful Cenozoic continental history. Laramide uplift started about 70 m.y. ago; streams generally eroded the sedimentary cover, and deeply beveled Precambrian rocks. Erosion kept pace with uplift so that few mountains stood very high above adjacent aggrading basins. A widespread, late Eocene surface of general low relief developed on Precambrian rocks during about 10 million years of tectonic and magmatic quiescence. Eocene basin-fill deposits accumulated in small grabens that formed during the bevelling.

In Oligocene time, the late Eocene surface was covered by volcanic and lesser alluvial deposits. Locally, channels were cut into the surface, and these also were filled and covered by alluvial and volcanic material. Drainages that developed as early as Laramide time and were firmly established in Eocene time were extensively disrupted by Oligocene volcanism. The Florissant Lake Beds and the Antero Formation accumulated behind volcanic dams.

In early Miocene time, uplift and faulting caused further disruption of the drainage system and fragmentation of the late Eocene surface. Regional block faulting of basin-and-range style in Miocene and Pliocene time resulted in offsets of the surface of 1,500 to possibly 12,000 m., and resulting grabens were deeply filled with tectonic sediments. Volcanism continued until at least 19 m.y. ago, but most of the alluvial and volcanic channels had been severed in early Miocene time. These channels can be reconstructed only by piecing together segments that lie on exhumed portions of the late Eocene surface or have been preserved in down-faulted blocks.

Late Pliocene canyon cutting exceeded that during any other part of the Cenozoic; accelerated uplift caused erosion of canyons 180 - 300 m. deep at mountain flanks. Resulting sediments are not abundant, but they can be found in upper parts of graben fills.

Major present-day geomorphic elements are post-Laramide and are related to middle and late Cenozoic volcanism, uplift, basin-and-range style block faulting, and attendant erosion.

Introduction
The information for this summary of volcanic, tectonic, and geomorphic features of central Colorado is taken in part from three recent articles by the authors (Epis and Chapin 1975; Scott 1975; and Taylor 1975) in GSA Memoir 144, "Cenozoic history of the Southern Rocky Mountains." edited by B. F. Curtis. Earlier major articles on Cenozoic structural geology, volcanic fields, and erosion surfaces were written by Hills (1888, 1900); Cross (1894); Lee (1917); Van Tuyl and Lovering (1935); Rich (1935); Wahlstrom (1947); Knight (1953); Chapin and Epis (1964); Epis and Chapin (1968); Steven and Epis (1968); and Scott and Taylor (1975).

In constructing this Cenozoic story, we have drawn on recent geologic mapping of the Pueblo 2° quadrangle (Scott and others, in press) where volcanic rocks, faults, and geomorphic surfaces are well preserved. In addition, we were able to obtain radiometric or fossil ages for many of the important deposits.
We thank C. Hedge, J. Obradovich, and C. Naeser of the U.S. Geological Survey for isotopic and fission-track ages and E. Lewis for identifications of vertebrate fossils. In addition to helpful discussion with B. Bryant, G. A. Izett, P. W. Lipman, T. A. Steven, O. Tweto, R. E. Van Alstine and C. T. Wrucke, we thank them for supplying us with unpublished information.

The area considered here contains many of the major geomorphic elements of the southern Rocky Mountains (fig. 1). These include the southern Front Range; Rampart Range; South Park; southern Mosquito Range; upper Arkansas River Valley; southern Sawatch Range; northern San Luis Valley; northern Sangre de Cristo Range; Wet Mountain Valley; Wet Mountains; and Great Plains to the east.

Figure 2 contains a generalized, composite stratigraphic table and a summary of related tectonic and geomorphic events for the area under discussion.

Laramide Orogeny and Late Eocene Erosion Surface

Laramide events, pertinent to the Cenozoic history of central Colorado, include intrusion of plutonic rocks, volcanism, uplift, erosion, and deposition and deformation of orogenic sediments. Laramide igneous activity began about 72 m.y. ago, but most of the intrusives are 70 to 50 m.y. in age (Tweto 1975). The only large Laramide intrusive in this area is the stock of Whitehorn Granodiorite, northeast of Salida, which has an age of about 70 m.y. (Wrucke 1974). Several small, intermediate-to-acid intrusives are known in South Park. Laramide volcanism closely followed the onset of intrusion, and volcaniclastic rocks are preserved in the orogenic basin-fills of South Park, the Denver basin and the Canon City-Florence basin. Uplift began far to the west about 70 m.y. ago and contributed a significant influx of sand deposited in the *Baculites eliasi* zone of the Pierre Shale (upper transition member) in the Canon City-Florence basin. However, retreat of the sea from this basin was delayed, and continued deposition of marine beds formed the Trinidad Sandstone and the lower half of the Vermejo Formation (Cretaceous). When uplift began in central Colorado, channels were established (fig. 3) through which orogenic arkosic and volcaniclastic materials were delivered to basins of deposition. One Cretaceous horizon and one Paleocene horizon in the Dawson Formation near Colorado Springs contain andesitic detritus that is petrographically similar to andesite in the South Park Formation, indicating areas west of South Park were sources for volcaniclastic detritus and that channels crossed the site of the Front Range uplift to basinal areas on the Great Plains. A volcaniclastic unit in the Poison Canyon Formation near Canon City also contains andesite clasts similar to those in the South Park Formation and suggests a channel source either in South Park or near the Whitehorn Granodiorite stock. Erosion stripped the sedimentary cover from Precambrian rocks along these major channels and then worked laterally. Locally, parts of pre-Paleozoic and pre-Mesozoic surfaces were exhumed and still are preserved with small outcrops of sedimentary rocks on them, but generally erosion cut below these old surfaces.

Continued erosion in Eocene time, accompanied by a generally stable base level, culminated in a single well-formed, widespread montane surface - the late Eocene surface. Most of the surface is a broad plain, but, locally, it has relief of a few hundred meters along major channels bounded by ridges and where monadnocks escaped planation. Cutting of the late Eocene surface occurred during a period of post-Laramide tectonic and magmatic quiescence ending before deposition of the Wall Mountain Tuff in early Oligocene time (35 m.y.). During formation of the surface, erosion apparently kept pace with uplift so that mountains never stood very high above adjacent aggrading basins. Paleontologic
Figure 1. Composite of Army Map Service plastic relief maps (20 quadrangles) showing major geomorphic elements of central Colorado. Dashed line is approximate location of schematic structure section shown in Figure 12 (after Epis and Chapin 1975).
<table>
<thead>
<tr>
<th>AGE</th>
<th>Epoch</th>
<th>PRESERVED DEPOSITS</th>
<th>PLAINS</th>
<th>IGNEOUS ACTIVITY</th>
<th>TECTONIC</th>
<th>GEOMORPHOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>115</td>
<td>Pliocene</td>
<td>Igneous Activity</td>
<td>Terrane Formation</td>
<td>Slight differential uplift</td>
<td>Terrace formation</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Miocene</td>
<td>Igneous Activity</td>
<td>Major uplift</td>
<td>Beginning of strong uplift, block-faulting &amp; formation of local basins</td>
<td>Partial deposition of drainage into local grabens; part of late Eocene surface used for transportation and deposition of detritus</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Oligocene</td>
<td>Igneous Activity</td>
<td>Northward and northeastward restriction of sea flows, Construction of Coffeys volcano; lavas filled with tuffaceous beds, Drainage eastward to Great Plains, Dissipating and damming of drainages</td>
<td>Volcanic eruption of andesite,</td>
<td>Stability of mountain blocks and faults</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>Eocene</td>
<td>Igneous Activity</td>
<td>Alluvial filling of palaeovalleys and local grabens, Major erosion of lamalite uplands and aggregation of adjacent basins, covering of widespread surface of trenched and buried streams,</td>
<td>Erosion of sediments - northward overlying Precambrian basement, New surface cut into Pre-Mississippian rocks, locally terrane bordered by sedimentary range front</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Late Cretaceous</td>
<td>Igneous Activity</td>
<td>Uplift of Laramie ranges &amp; formation of basins</td>
<td>Uplift for west</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Late Cretaceous and Cenozoic volcanic and sedimentary deposits and related tectonic and geomorphic events of central Colorado.
Figure 3. Inferred paleovalleys from Paleocene volcanic source areas in South Park to near Canon City and to a Paleocene channel northeast of Colorado Springs. Andesitic volcanism near South Park is confirmed by volcaniclastic rocks in the South Park Formation.
and geomorphic evidence indicates that the surface formed at elevations less than 900 m. (2,920 ft.) in a warm, subhumid climate, conditions which are dramatically different from those of today. Using the surface as a structural datum, it is clear that major, present-day geomorphic elements of the region post-date the Laramide orogeny and must be related to younger tectonic activity.

Locally derived arkosic alluvial material of early and middle Eocene age - Huerfano Formation and Echo Park Alluvium - overlies the surface and fills grabens that developed as the surface was cut (fig 4).

Three grabens are known:
1) at Huerfano Park and its northward extension in the Wet Mountain Valley;
2) at Echo Park and its northward extension in the valley of Currant Creek; and
3) at Oil Creek and its northward extension along Fourmile Creek.

The Echo Park Alluvium lacks volcanic clasts except in a few places where it contains clasts of Laramide volcanic rocks. These clasts consist of fewer rock types and a higher proportion of hypabyssal and plutonic rocks than those typical of the younger Tallahassee Creek Conglomerate of early Oligocene age.

Oligocene Volcanism

In early Oligocene time, ash flows of the Wall Mountain Tuff were extruded from a caldera probably near Mount Aetna (fig. 5) in the present Sawatch Range. The ash flows generally followed valleys, but the present outcrop pattern of tuff indicates that they also overflowed interfluvies and spread widely over the late Eocene surface, covering much of the area from South Park southward to the Wet Mountain Valley and eastward across the present Rampart Range onto the Great Plains near Castle Rock. Andesitic and rhyodacitic volcanism from various centers followed, with deposition of laharc breccias, lavas and ash-flow tuffs through at least 28 m.y. ago.

Streams eroded and channeled the Wall Mountain Tuff immediately following its extrusion. They deposited gravel of the Tallahassee Creek and Castle Rock Conglomerates across the tuff and many parts of the late Eocene surface (fig 6). These conglomerates contain volcanic rocks from early activity in the Thirtynine Mile volcanic field. Later, minor channels were cut, and they also were filled by Tallahassee Creek Conglomerate (fig 6).

Beginning about 34 m.y. ago, the Thirtynine Mile Andesite was erupted from numerous local vents and spread across much of the area north of the Arkansas River. Lake basins formed along the north side of the volcanic pile where drainages were diverted and blocked. The Florissant Lake Beds and the Antero Formation accumulated in these basins to the level of spillover (fig 7). The Badger Creek Tuff (which may also have been erupted from the Mt. Aetna cauldron) makes up a large part of the ashy material in the Antero Formation. Some pre-volcanic channels remained open and active through all of Tertiary time, but most were occupied for only part of that time.

The Gribbles Park, Thorn Ranch, and East Gulch Tuffs were erupted about 29 m.y. ago and transported along paleovalleys as shown in Figure 8. Growth of the large, composite Guffey volcano (comprised mainly of the upper member of the Thirtynine Mile Andesite) in the central portion of the volcanic field further contributed to disruption of drainages. The volcano must have formed a barrier to northward and northeastern spreading of these ash-flow tuffs, and confined them to areas west, southwest, south, and southeast of the site of the volcano. The source of these younger ash flows is unknown, but it must have been west or southwest of the main portion of the present volcanic field.

After deposition of these ash-flow tuffs, the paleovalleys remained open into early Miocene time, and streams deposited volcanioclastic debris from fairly distant
Figure 4. Inferred late Eocene paleovalleys through which detritus of the Echo Park Alluvium and the Huerfano Formation was carried. The Echo Park and Wet Mountain Valley grabens subsided at about the same rate as they were filled. The grabens probably began to form late in Eocene time. Undoubtedly, many more streams engaged in lateral planation than are shown here.
Figure 5. Paleovalleys existing at the time of emplacement of ash flows of the Wall Mountain Tuff. Drainage pattern is based on scattered outcrops of the tuff and on the evolution of drainages during Echo Park and Tallahassee Creek times. Ash flows filled valleys, overrode many interfluves, and crossed the ancestral Rampart Range. The dashed line shows the inferred extent of the Wall Mountain Tuff based on outcrops; the maximum extent may have been much greater. The extent west of the inferred source at Mt. Aetna and east of Figure 5 near Castle Rock is not shown.
Figure 6. Inferred paleovalleys used during deposition of the Tallahassee Creek Conglomerate. Locally the alluvium was spread across the late Eocene surface, as in High Park, but elsewhere it was confined to channels cut during Tallahassee Creek time. The northwest-trending paleovalley through Rosita is lined by an ash-flow sheet that was deposited both north and south from the Rosita volcanic center.
Figure 7. Present extent of the Thirtynine Mile Andesite showing how the Florissant Lake Beds (horizontal lines) and the Antero Formation (stippled) were deposited in water impounded by andesitic laharic breccias. The Florissant Lake Beds were deposited behind a dam formed by the lower member of the Thirtynine Mile Andesite and, later, the lake beds were covered by the upper member of the Thirtynine Mile Andesite. Arrows show trends of paleovalleys.
Figure 8. Late Oligocene paleovalleys existing at time of deposition of the East Gulch, Thorn Ranch, and Gribbles Park Tuffs (29 m.y.). These tuffs were nearly the last deposits to occupy these channels before the beginning of block-fault movement in early Miocene time. We believe that many of the paleovalleys of early Oligocene time, especially across the Wet Mountains, also remained open until early Miocene time.
sources. The Goat Creek-Hillside channel (fig. 8) in early Miocene time, carried well-rounded clasts of syenite, Dakota Sandstone; jasper from an equivalent of the Ralston Creek Formation; and Leadville Limestone, all from sources apparently existing at that time along the trend of the present Sangre de Cristo Range. East of McClure Mountain (fig. 8) this channel carried clasts of Cambrian syenite from the McClure Mountain Complex. The Oak Creek and Howard paleovalleys, and a paleovalley southwest of Wellsville, carried rounded andesite clasts; andesite and other volcanic rocks, probably derived from the Bonanza volcanic field and from the Rito Alto center, apparently veneered the ancestral Sangre de Cristo Range. The Trout Creek paleovalley carried clasts of rhyolite from the Nathrop Volcanics (28-29 m.y., Van Alstine 1969). The Divide paleovalley (fig. 9) carried clasts of Wall Mountain Tuff, Thirty-nine Mile Andesite and phonolite (28 m.y.) from Cripple Creek.

Neogene Uplift and Block Faulting

Late in early Miocene time, major differential block faulting began (fig. 9) and orogenic deposits started to fill grabens between upthrown blocks. At this time, the drainage in the upper Arkansas valley, near Buena Vista, went southward through Poncha Pass into the San Luis Valley, which is the northern extension of the Rio Grande rift zone. In Pliocene time, a northwest-trending fault scarp south of Poncha Springs (fig. 9) blocked the valley. Drainage was diverted southeastward from Salida essentially along the present Arkansas River valley. The Divide paleovalley also was blocked by faulting, probably in Pliocene time, and the modern northeastward course of the South Platte River was established.

All of the fault-block basin fills were deposited between early Miocene and late Pliocene time. These include such deposits as the Santa Fe (?) Formation, Dry Union Formation, and Wagontongue Formation of Johnson (1937). By this time, nearly all paleovalleys in the mountains had been disrupted and the upper parts of the basin fills were being deposited by small streams flowing directly to the basins from nearby highlands (fig. 10).

In late Pliocene time, accelerated uplift and increased runoff from high areas cut deep canyons in the flanks of the mountains. Apparently, the greatest rise of mountains, at least locally, took place at this time. The most convincing documentation of this rise is along the northwest-trending fault south of Poncha Springs (fig. 9). There, early late Pliocene vertebrate fossils of Ash Hollow (~5 m.y. old) faunal zones were found in volcaniclastic beds derived from the rising Sangre de Cristo Range before it was completely unroofed of its volcanic cover. Above the volcaniclastic rocks is a sequence of gravel beds, composed almost exclusively of Precambrian rocks, that dips southward into the northwest-trending normal fault; this upper sequence (and still younger Pliocene deposits) was derived after the Precambrian core of the Sangre de Cristo Range was exposed. The crest of the range now rises 4,000 ft. (1,200 m.) above the gravel and indicates that there was at least this magnitude of uplift since late Pliocene time. We infer that uplift of this magnitude has also taken place elsewhere along the Rio Grande rift zone in late Miocene to late Pliocene time (Chapin and Seager 1975).

Summary

The Cenozoic tectonic and geomorphic development of central Colorado presented here is based chiefly on erosion surfaces and thickness, distribution and stratigraphic relations of volcanic and associated volcaniclastic deposits. Locations of paleovalleys are somewhat speculative in places because of volcanic cover or later erosion of deposits in them, but we believe that the interpretations presented are largely correct. Perhaps the most important conclusion to be drawn from our studies is that impressive, present-day geomorphic elements of the Southern Rocky Mountains (figs. 2, 10, and 12) are not the result of the Laramide
Figure 9. Principal Neogene faults that blocked paleovalleys and disrupted the late Eocene surface. Blockages are shown by bars upstream from faults. Nearly all paleovalleys were blocked when these faults became active in early Miocene time. Most of the faults had earlier histories of movement, many as early as Precambrian. Faults compiled from Scott and others (in press), Bryant and Wobus (1975), and Tweto (1974a and 1974b).
Figure 10. Miocene-Pliocene basin fills and alluvial deposits (stippled). After fault blockage, the drainage went directly from highlands to adjoining basins and broad valleys. Major drainages were not reestablished, except in the grabens, until accelerated uplift provided new high areas and greatly increased runoff in late Pliocene time. The late Pliocene drainage system that resulted from canyon cutting is essentially the modern system.
orogeny. The late Eocene, pre-volcanic surface deeply beveled Laramide uplifts and reduced them to the level of adjacent aggrading basins. The geomorphic elements we see today are the result of middle to late Cenozoic volcanism, uplift, basin-range style block faulting and attendant erosion.

References


Tweto, O., 1974a, Geologic map and sections