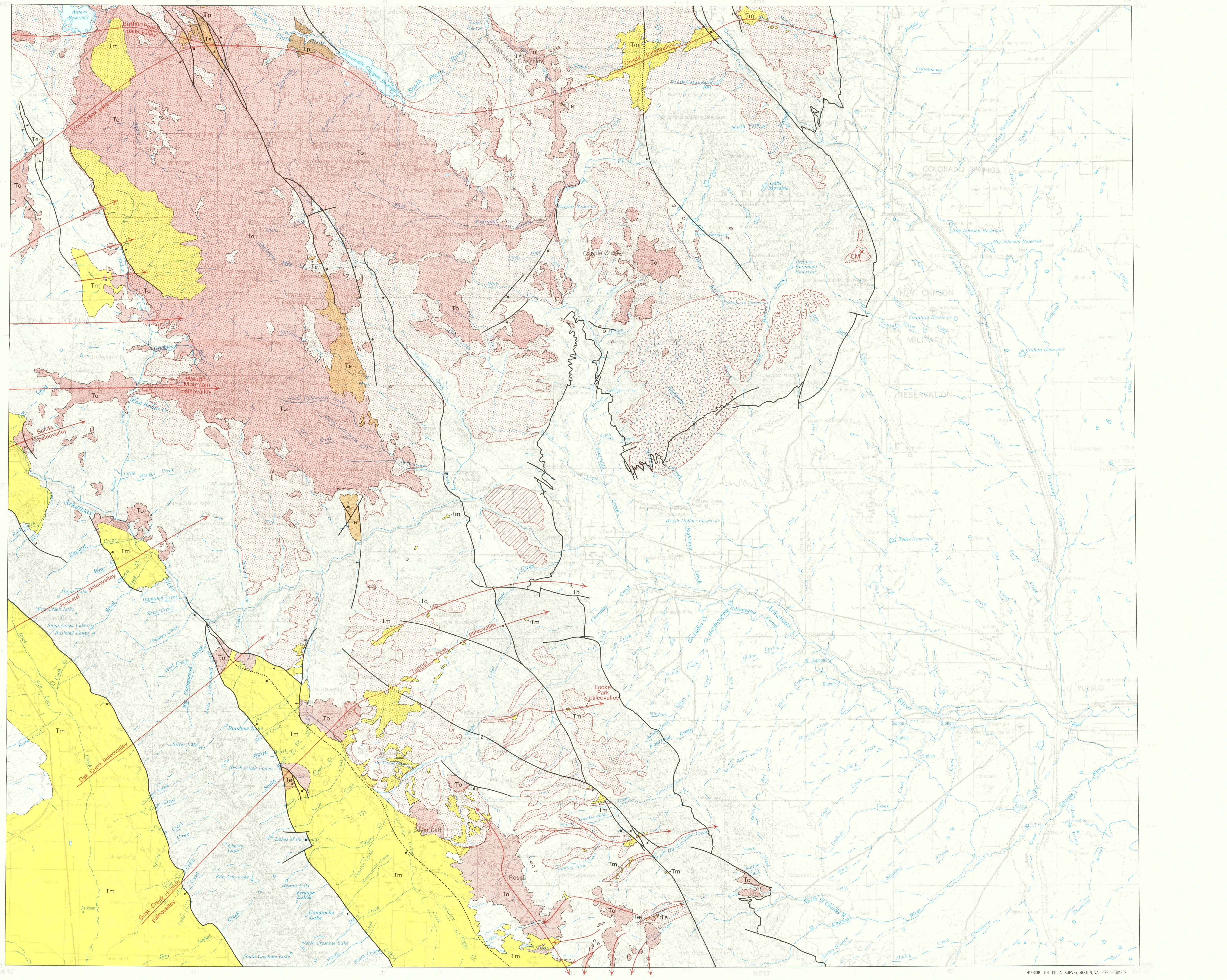
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS INVESTIGATIONS SERIES
MAP I–1626

Base from U.S. Geological Survey, Greeley, 1976, and Denver, 1978

Geology of Greeley quadrangle generalized from Tweto (1979) and Braddock and Cole (1978); geology of Denver quadrangle generalized from Bryant and others (1981)



Base from U.S. Geological Survey, Pueblo, 1962

SCALE 1:250 000

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1986—G84262

Geology of Pueblo quadrangle generalized from Scott and others (1978)

LIST OF MAP UNITS

- Tmo — MIOCENE AND OLIGOCENE ROCKS
- Tm — MIOCENE ALLUVIUM IN PALEOVALLEYS AND BASINS
- To — OLIGOCENE VOLCANIC ROCKS, ALLUVIUM, AND LAKE SEDIMENTS
- Tep — EOCENE AND PALEOCENE ROCKS
- Te — EOCENE ALLUVIUM
- Tp — PALEOCENE ALLUVIUM IN BASINS
- TKp — PALEOCENE AND CRETACEOUS ROCKS
- LATE EOCENE EROSION SURFACE
- MESOZOIC EROSION SURFACE
- PALEOZOIC EROSION SURFACE

CONTACT

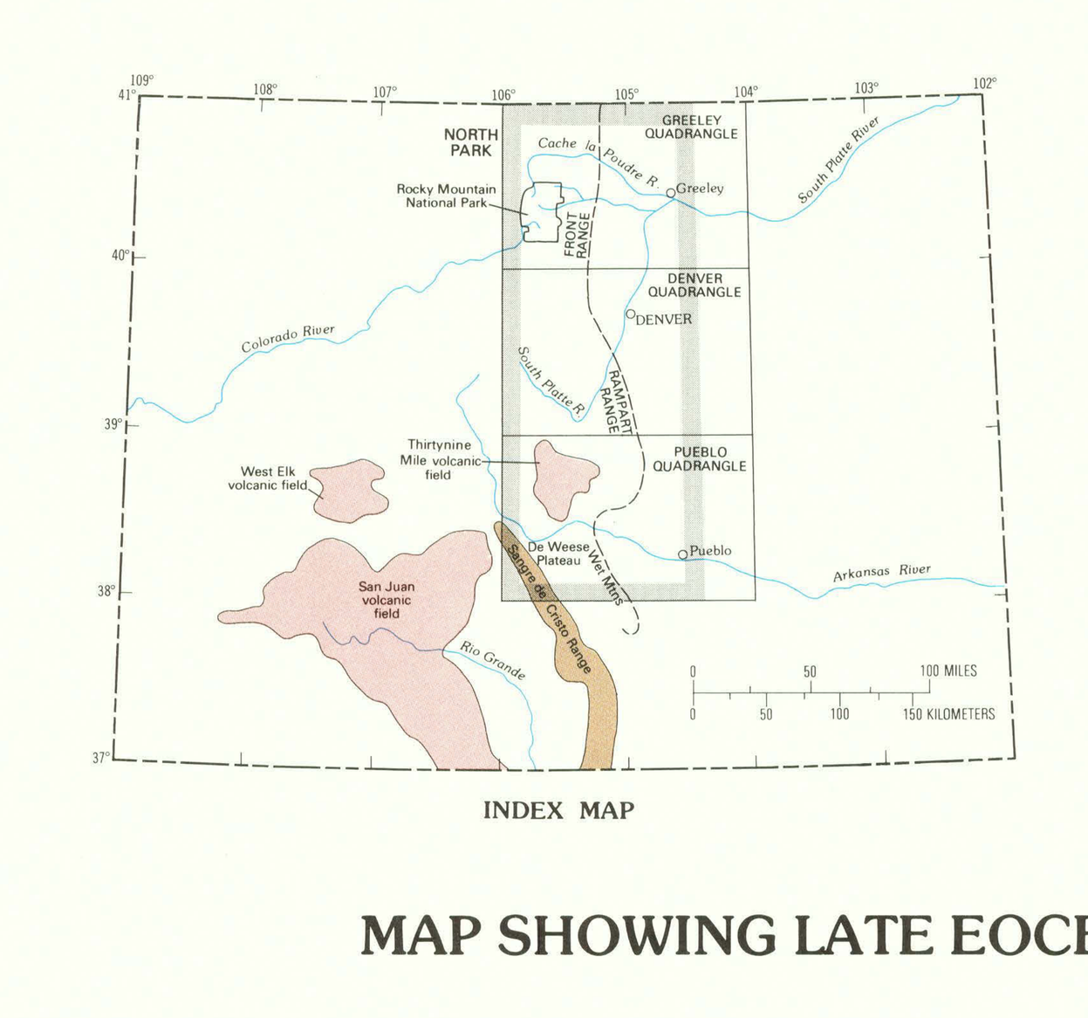
Howard paleovalley — AXIS OF PALEOVALLEY OF MIOCENE AND PROBABLE EARLIER AGES

FAULT—Dashed where approximately located or inferred; dotted where concealed; queried where doubtful. Bar and ball on downthrown side where direction of movement is known

LOW-ANGLE THRUST FAULT—Sawteeth on upper plate

× TYPE LOCALITIES OF EROSION SURFACES NAMED BY VAN TUYL AND LOVERING (1935) AND OUR EVALUATION OF THE SURFACES

- OB — Orodell Berm, T. 1 N., R. 71 W., Greeley quadrangle. Bench of unknown origin about 1,500 ft (460 m) below late Eocene erosion surface
- MM — Mount Morrison, T. 4 S., R. 70 W., Denver quadrangle. The top of a landslide about 1.5 m.y. old, not a geomorphic surface
- FH — Flagstaff Hill, T. 1 N., R. 71 W., Greeley quadrangle. About 700 ft (210 m) below late Eocene erosion surface. Significance unknown
- BP — Bergen Park, T. 4 S., R. 71 W., Denver quadrangle. Part of late Eocene erosion surface
- OM — Overland Mountain, T. 2 N., R. 72 W., Greeley quadrangle. Part of late Eocene erosion surface
- CM — Cheyenne Mountain, T. 15 S., R. 67 W., Pueblo quadrangle. Part of late Eocene erosion surface
- GR — Green Ridge, T. 11 and 12 N., R. 74 W., Greeley quadrangle. Part of late Eocene erosion surface
- FT — Flattop Mountain, T. 4 N., R. 74 W., Greeley quadrangle. Possibly part of late Eocene erosion surface, based on altitude and perfection of development. Called part of a major erosion surface by Van Tuyl and Lovering (1935) and by Wahlstrom (1947), but evidence or origin, such as overlying sedimentary or volcanic deposits, has not been found



INDEX MAP

INTRODUCTION

This map portrays all available information on remnants of the widespread late Eocene erosion surface in the Front and Rampart Ranges, the Wet Mountains, the De Weese Plateau, the Thirtynine Mile volcanic field, and the Elkhorn Upland. To support the identification of remnants of this surface, we have shown the general distribution of Eocene, Oligocene, and Miocene sedimentary rocks and of Oligocene volcanic rocks. In addition, the inferred axes of paleovalleys of Miocene and earlier Tertiary age have been drawn. Many of the faults that disrupted the streams in Neogene and later times have also been shown to demonstrate the former continuity of paleovalleys and surfaces. Surfaces of Paleozoic and Mesozoic age also are shown because the rocks overlying them were removed by streams in early Tertiary time and in some areas the exhumed surfaces are essentially coincidental with the late Eocene erosion surface.

Geomorphic erosion features like those shown here have been previously identified in other places, and are part of a widespread late Eocene erosion surface that covered parts of southern Wyoming, additional areas in Colorado, and parts of northern New Mexico; similar surfaces probably will eventually be found and identified as late Eocene in other areas of the Rocky Mountains.

PREVIOUS WORK

Previous reports concerning Tertiary and Quaternary geomorphic erosion surfaces in the Front Range concentrated on their age, number, and sequence. The number of surfaces inferred by different authors varied from one (Wahlstrom, 1947), to two (Lee, 1917, p. 28), to four (Little, 1925), to eleven (Van Tuyl and Lovering, 1935), and the ages assigned to these surfaces ranged from Eocene to Quaternary. The variation in the number of surfaces postulated resulted from meager knowledge about the tectonic history within the mountains. Because we now have many radiometric ages of volcanic rocks overlying the erosion surfaces, as well as detailed maps, we have a far better knowledge of Neogene faulting within the mountain blocks, and we can better understand the evolutionary sequence of tectonism and erosion. Most early workers concentrated their studies on the Front Range. Because of the scarcity of datable rocks lying on the surface in the Front Range (except for volcanic rocks in the Specimen Mountain area of Rocky Mountain National Park), the sequence of Tertiary geomorphic development was difficult to determine and age assignments were based on little solid evidence. The geomorphic history was first deciphered by Charles E. Chapin and Rudy C. Epis (1964) in the Thirtynine Mile volcanic field of the Pueblo 1° x 2° quadrangle where they later (Epis and Chapin, 1968) mapped a widespread ash-flow tuff sheet that covered a remarkably planar prevolcanic erosion surface. The ash-flow tuff, later named Wall Mountain Tuff, lies at the base of the Thirtynine Mile volcanic pile. Six K-Ar age determinations of the tuff from widely separated outcrops indicate an age of 35–36 m.y., that is, earliest Oligocene. Geologic mapping by Stark and others (1949) and by Sawatzky (1964) showed that this erosion surface truncates folded and faulted strata of the South Park Formation of late Paleocene age. A K-Ar age determination of a crystal-rich tuff in the upper part of the South Park Formation is 59.7±2.0 m.y. (Bryant and others, 1975). Therefore, the surface was cut sometime between about 59 and 36 m.y. ago, or during late Paleocene and Eocene time.

The details were refined and amplified in the following reports: Chapin and Epis (1964), Epis and Chapin (1968), Taylor (1974), Epis and Chapin (1975), Taylor (1975), Scott (1975), Scott and Taylor (1975), and Epis and others (1976, 1980). Cenozoic rocks of the three quadrangles discussed here are shown on four maps: Greeley quadrangle (Tweto, 1979, and Braddock and Cole, 1978), Denver quadrangle (Bryant and others, 1981), and Pueblo quadrangle (Scott and others, 1978). The areas that yielded geomorphic information most helpful to studies of the Eocene erosion surface include the Rampart Range, Wet Mountains, Wet Mountain Valley, De Weese Plateau, Upper Arkansas Valley, Thirtynine Mile volcanic field, South Park, Badger Flats, Florissant basin, and the Cripple Creek-Pikes Peak area.

ACKNOWLEDGMENTS

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GEOMORPHIC DEVELOPMENT

Because the several reports listed above have described in detail the development of geomorphic features of this area, this discussion will be brief and will pertain principally to the Pueblo, Denver, and Greeley 1° x 2° quadrangles. Development of the modern southern Rocky Mountains began in Late Cretaceous time about 67 m.y. ago. Gradual uplift resulted in erosion of the sedimentary rocks that covered the Precambrian basement, and the eroded materials were deposited in adjoining basins during latest Cretaceous and Paleocene time. Part of the basin fill was volcaniclastic detritus eroded from concurrently erupted volcanic rocks. Although we believe that these sediments were transported through discrete channels, only a generalized drainage pattern can be inferred (Scott, 1975, fig. 2). Continuing early Tertiary erosion gradually uncovered large parts of the much older surfaces on which the Paleozoic and Mesozoic rocks had been deposited; some parts of these surfaces are still preserved with small remnants of younger sedimentary cover. However Tertiary erosion generally destroyed the erosion surface and cut into the Precambrian rocks below. Some of these exhumed surfaces, such as in the Cripple Creek area, became part of the late Eocene erosion surface, and Oligocene deposits locally covered the surface.

Continued Eocene erosion, during a time of tectonic stability and relatively constant base level, produced a well-formed, widespread montane pediment, the only widespread Cenozoic surface of low relief in the mountains. Echo Park Alluvium (Eocene) was carried across this surface, but now is preserved only where covered by younger volcanic rocks or where deposited in basins, grabens, or paleovalleys. Where the truncated rocks were easily eroded, the surface became broad and flat, such as that represented by the even crestline of the Rampart Range; there, thick grus, a weathering product of Pikes Peak Granite, was easily carved by the ancient streams. On layered rocks of variable resistance to weathering, such as the metamorphic rocks of the Front Range, early Tertiary erosion carved broad channels bordered by resistant ridges or monadnocks as high as several hundred meters. The Eocene erosion surface from the South Platte River northward into Wyoming is characterized by these broad channels.

The Eocene erosion surface is still preserved beneath Oligocene and Miocene volcanic and sedimentary rocks in the Thirtynine Mile, San Juan, and West Elk volcanic fields. In this map area, the oldest rock overlying the Eocene erosion surface is the Wall Mountain Tuff of early Oligocene age (35 m.y.). This tuff covered large areas of the mountains and went nearly 40 km (25 mi) across the Great Plains. Less than 10 percent of the inferred original extent of the Eocene buried erosion surface is preserved in the Pueblo, Denver, and Greeley quadrangles. Close to 90 percent of the surface has been modified or destroyed. It is least modified where it has been protected from erosion on the upstream side of mountain blocks that were faulted up in Oligocene and Neogene time. The erosion surface on the De Weese Plateau, for example, was protected by the rise of the Wet Mountains.

Although the surface has been long exposed to erosion, the depth of stream cutting has been slight. Large areas of the De Weese Plateau have retained accordance of ridge crests, and flat bottomed valleys have changed little from their shapes in Tertiary time. Large areas of deeply weathered rock are evidence of a long exposure time, and across this plateau, ridge and valley alike, the rocks are too weathered to be useful for rubidium-strontium dating. We infer that most of the modern surface is only a few meters to a few tens of meters below the late Eocene surface. This inference is supported by the positions of remnants of Wall Mountain Tuff and of volcanic flows from the Rosita and Silver Cliff volcanic centers that lie at elevations near those of the major modern flat areas. Deep valleys have been cut into this surface only where streams have later breached the adjacent uplifted Wet Mountain block.

The original altitude and climate during cutting of the late Eocene erosion surface at Florissant, Colo.—and possibly over much of the original extent of the surface—were deduced by MacGinitie (1953, p. 66). He concluded that the flora in the Florissant Lake Beds of Oligocene age indicates "* * * a very moderate elevation for the Florissant region in the Oligocene. It appears unlikely that its altitude could have been greater than 3,000 feet at the most." MacGinitie (p. 67) considered the Florissant flora to be comparable to the Green River flora of middle Eocene age in Wyoming: "The Green River and Florissant floras both show a peculiar endemism and very much the same general facies. The Florissant flora is a logical derivative of the Green River [flora], a fact which indicates a gradual evolution under similar physical conditions in the same general area, under the influence of a slow climatic change trending toward drier and cooler conditions." MacGinitie (p. 77) then concluded that "The climate was subhumid and warm temperate, not unlike the present climate of Monterrey, in the state of Nuevo Leon, Mexico. Warm winters and hot summers prevailed, and abundant sunshine is indicated." Thus, the surface was formed at altitudes lower than about 900 m (2950 ft), but it is now at altitudes between 2,300 and 3,800 m (7,500 and 12,500 ft) (Epis and Chapin, 1975). Most of this uplift probably took place in Miocene time and later. Unfortunately, the Miocene and younger deposits on the erosion surface do not provide clues concerning the rate of uplift comparable to those provided by the Florissant Lake Beds.

Oligocene sedimentary and volcanic deposits form the principal cover on the Eocene erosion surface in the Pueblo quadrangle. Many streams were dammed or diverted by volcanic flows and forced into new courses. The Florissant Lake Beds and lake beds of the Antero Formation were deposited behind such volcanic dams. Sediments of the Castle Rock Conglomerate (equivalent in age to the Chadron Formation) were carried east to northeast across the Rampart Range near Divide, and sediments of the White River Group (Chadron and Brule Formations) were transported across the northern end of the Front Range near Virginia Dale. Similar deposits probably also covered parts of the surface in intervening areas of the Denver and Greeley quadrangles and spread eastward onto the plains, but if so, these deposits have been eroded away.

Starting about 28 m.y. ago the late Eocene erosion surface and overlying Oligocene deposits were severely disturbed by block faulting, and some major paleovalleys were segmented. Up-faulted mountain blocks and intervening grabens have as much as 6,000 m (19,700 ft) of relative offset. From late Oligocene time on, drainage emptying into these grabens deposited the thick basin fills that characterize the Oligocene and Miocene deposits of the San Luis Valley, Upper Arkansas Valley, Wet Mountain Valley, South Park, Middle Park, and North Park.

We have designated the alluvial deposits in most paleovalleys as Miocene despite a lack of definitive evidence. These sediments are the youngest materials transported in the paleovalleys and should equate with the Ogallala Formation of Miocene age, which is the youngest part of the basin fill on the plains. The gravel in the paleovalley at Divide is no older than 28 m.y. because it contains clasts of the phonolite of Cripple Creek, which has an age of about 28 m.y. (J. D. Obradovich, written commun., 1973). Similarly the deposits in the Tanner Peak paleovalley are no older than 29 m.y. because they contain clasts of the Gribbles Park Tuff, which has an age of about 29 m.y. (Taylor, 1975). The Miocene channel deposits are as much as 200 m (650 ft) thick, and the clastic materials range in size from large boulders to silt; the largest boulders are 4.5 m (15 ft) across, but 2 m (6.6 ft) boulders are common. The clasts in most of the channel deposits are mainly Precambrian metamorphic and igneous rocks. However, many channel deposits in the Pueblo quadrangle and in the Specimen Mountain area (Greeley quadrangle) also contain Tertiary volcanic rocks.

The Miocene paleovalleys range in depth below the Eocene surface from about 60 m (200 ft) in the Divide paleovalley to 240 m (790 ft) in the Clear Creek paleovalley; other paleovalleys probably were cut to similar depths. The widths of alluvial deposits indicate that few of the Miocene paleovalleys were more than 1.6 km (1 mi) wide. The few channel deposits that remain generally were preserved where streams changed to a different valley alinement and were unable to erode their previously deposited alluvium. Isolation of a stream from a former channel was caused by capture, by downcutting to a lower base level, or by faulting.

Uplift apparently accelerated in Pliocene time, and the resulting erosion deepened the canyons to 135 to 170 m (445 to 560 ft) below the bottoms of their Miocene channels; the larger streams cut deeper and longer canyons. Some canyons were cut downward from the late Eocene surface, whereas others were deepened from Miocene channels. The positions of many canyons were inherited from courses established as early as Paleocene or Eocene time, but others were newly created during the Pliocene. Faults control some reaches, but most canyon locations seem to have been established by superposition.

Part of the detritus from Pliocene canyon cutting was carried onto the plains, much of it out of Colorado, but part of it remains in the Nussbaum Formation of Pliocene age (about 3.0 m.y. old according to vertebrate identifications by Cary Madden, *in* Scott, 1982, p. 7). Some detritus also forms the uppermost fill in some grabens. The greatest known amount of Pliocene uplift—about 1,200 m (3,940 ft)—in the area is shown by the upper part of the Dry Union Formation at the northern end of the Sangre de Cristo Range. Elsewhere Pliocene uplift probably was much less.

Study of the evolution of the Tertiary landscape helps to provide an explanation of the history of the present topography of the Rocky Mountains, particularly of those parts least affected by glaciers. The geomorphic history furnishes insight into intrusive and volcanic environments and clues to depths of emplacement of plutons and possible associated hydrothermal ore deposits. The locations of Oligocene-Miocene paleovalleys and their deposits assist in prospecting for uranium deposits, such as those in the Tallahassee Creek area. This study also provides a basis for recognizing Neogene tectonics and evidence for the trends and magnitude of Neogene faulting.

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MAP SHOWING LATE EOCENE EROSION SURFACE, OLIGOCENE-MIOCENE PALEOVALLEYS, AND TERTIARY DEPOSITS IN THE PUEBLO, DENVER, AND GREELEY 1° x 2° QUADRANGLES, COLORADO

By
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1986

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