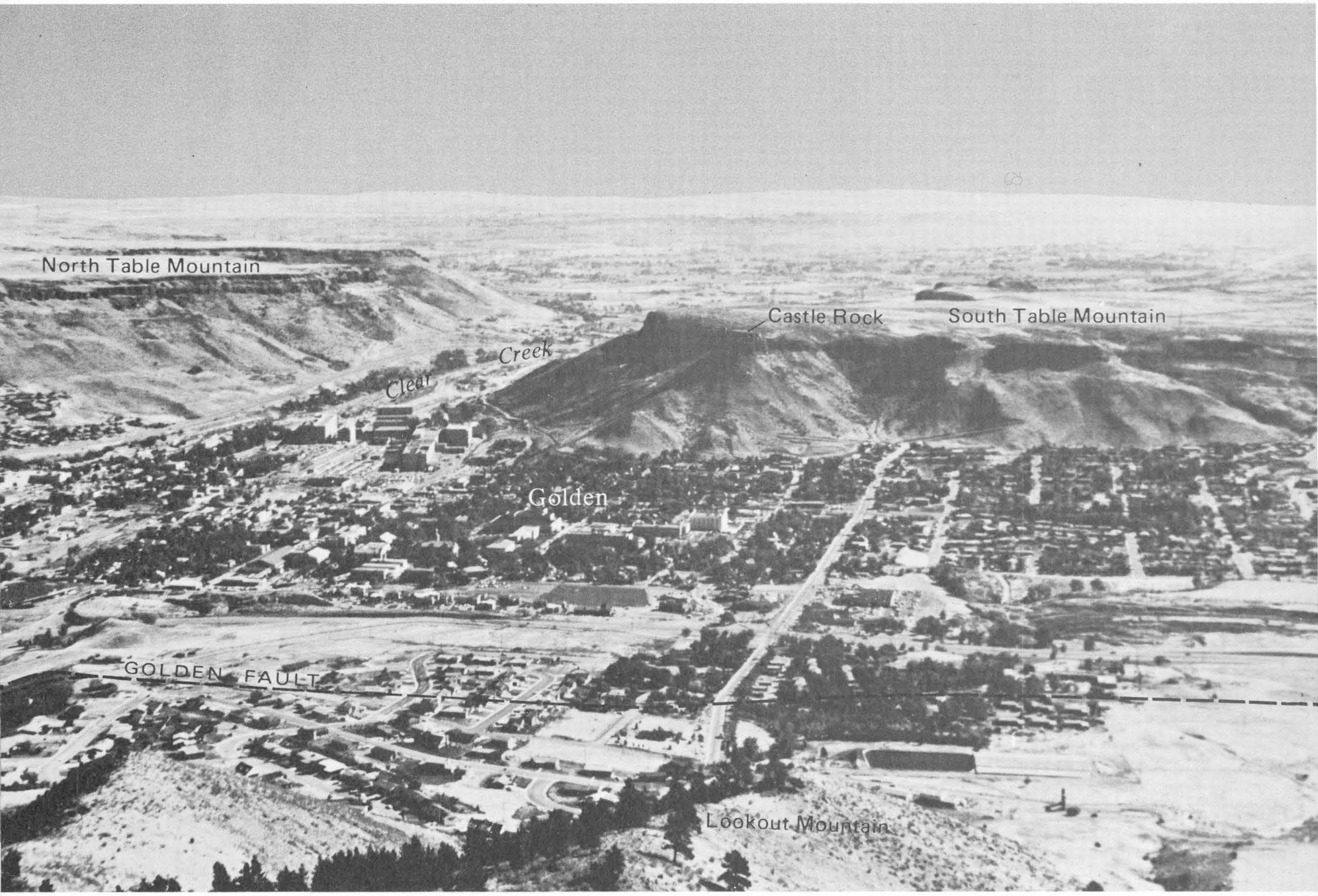
Geology of the Golden Quadrangle, Colorado

GEOLOGICAL SURVEY PROFESSIONAL PAPER 872

GEOLOGY OF THE GOLDEN QUADRANGLE, COLORADO

FRONTISPIECE.—Physiographic setting of the Golden quadrangle as viewed northward from Lookout Mountain. The hummocky surface of Table Mountains. The escarpment between the Southern Rocky Mountains and the Great Plains physiographic provinces forms the Group. The Rocky Flats Alluvium (Qrf) forms the gently eastward sloping surface beyond the Tertiary intrusives. Arrows indicate the



an old landslide (ls) lies between Golden and North Table Mountain. Other landslides are present on the steep flanks of North and South east (right) face of Mount Zion. The sinuous ridge in the left middle ground is a hogback formed by resistant sandstone in the Dakota approximate directions of the west and south edges of the quadrangle.

Geology of the Golden Quadrangle, Colorado

By RICHARD VAN HORN

GEOLOGICAL SURVEY PROFESSIONAL PAPER 872

Geology of part of the Denver urban area, Colorado, with emphasis on deposits of Pleistocene age and their economic potential, engineering characteristics, and environmental implications

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1976

UNITED STATES DEPARTMENT OF THE INTERIOR

THOMAS S. KLEPPE, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress Cataloging in Publication Data
Van Horn, Richard, 1920–
Geology of the Golden quadrangle, Colorado.
(Geological Survey Professional Paper 872)
Bibliography: p.
Includes index.
Supt. of Docs. no.: I 19.16:872
1. Geology–Colorado–Jefferson Co.
I. Title. II. Title: Golden quadrangle, Colorado. III. Series: United States Geological Survey Professional Paper 872.
QE92.J4V36 557.88'84 75-619065

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock Number 024-001-02794-1

CONTENTS

TABLES

MEASURED SECTIONS OF BEDROCK AND SURFICIAL DEPOSITS

ILLUSTRATIONS

GEOLOGY OF THE GOLDEN QUADRANGLE, COLORADO

By RICHARD VAN HORN

ABSTRACT

The Golden quadrangle, Jefferson County, Colo., lies at the western edge of the rapidly developing Denver metropolitan area. As in many other rapidly developing urban areas, the rock types and geologic setting are not everywhere entirely suitable for certain types of construction. Recognition of geologic factors is essential to sound planning for efficient land use in this area of variable foundation conditions and dwindling availability of construction materials.

The quadrangle lies athwart the boundary between the Front Range of the southern Rocky Mountains and the Colorado Piedmont of the Great Plains. No geologic map accompanies this report; it has, instead, been published as U.S. Geological Survey Miscellaneous Geologic Investigations Map I-761-A (Van Horn, 1972). Precambrian metamorphosed sedimentary and volcanic rocks form the mountains of the Front Range. They include a mica schist unit; hornblende gneiss unit and four subunits; a microcline-quartz-plagioclase-biotite gneiss unit; and interlayered gneiss unit. These rocks have been folded, faulted, and intruded by pegmatite and hornblende-biotite lamprophyre dikes. The Precambrian rocks are overlain unconformably by Paleozoic sedimentary rocks of the Fountain Formation. Paleozoic, Mesozoic, and Cenozoic sedimentary rocks overlying the Fountain are, from oldest to youngest, the Lyons Sandstone, Lykins Formation, Ralston Creek Formation, Morrison Formation, Dakota Group, Benton Shale, Niobrara Formation, Pierre Shale, Fox Hills Sandstone, Laramie Formation, Arapahoe Formation, and Denver Formation. These rocks have been folded, faulted, and intruded by monzonite dikes. Lava flows of latite occur within the Denver Formation.

Unconformably overlying the bedrock are superficial deposits of Pleistocene and Holocene age which include: pre-Rocky Flats alluvium, Rocky Flats Alluvium, Verdos Alluvium and a contained rhyolitic volcanic ash possibly equivalent to the Pearlette Ash Member of the Sappa Formation, Slocum Alluvium, Louviers Alluvium, Broadway Alluvium, Piney Creek Alluvium, post-Piney Creek alluvium, alluvial fan deposits, transported mantle deposits, colluvium, loess, landslide deposits, and artificial fill.

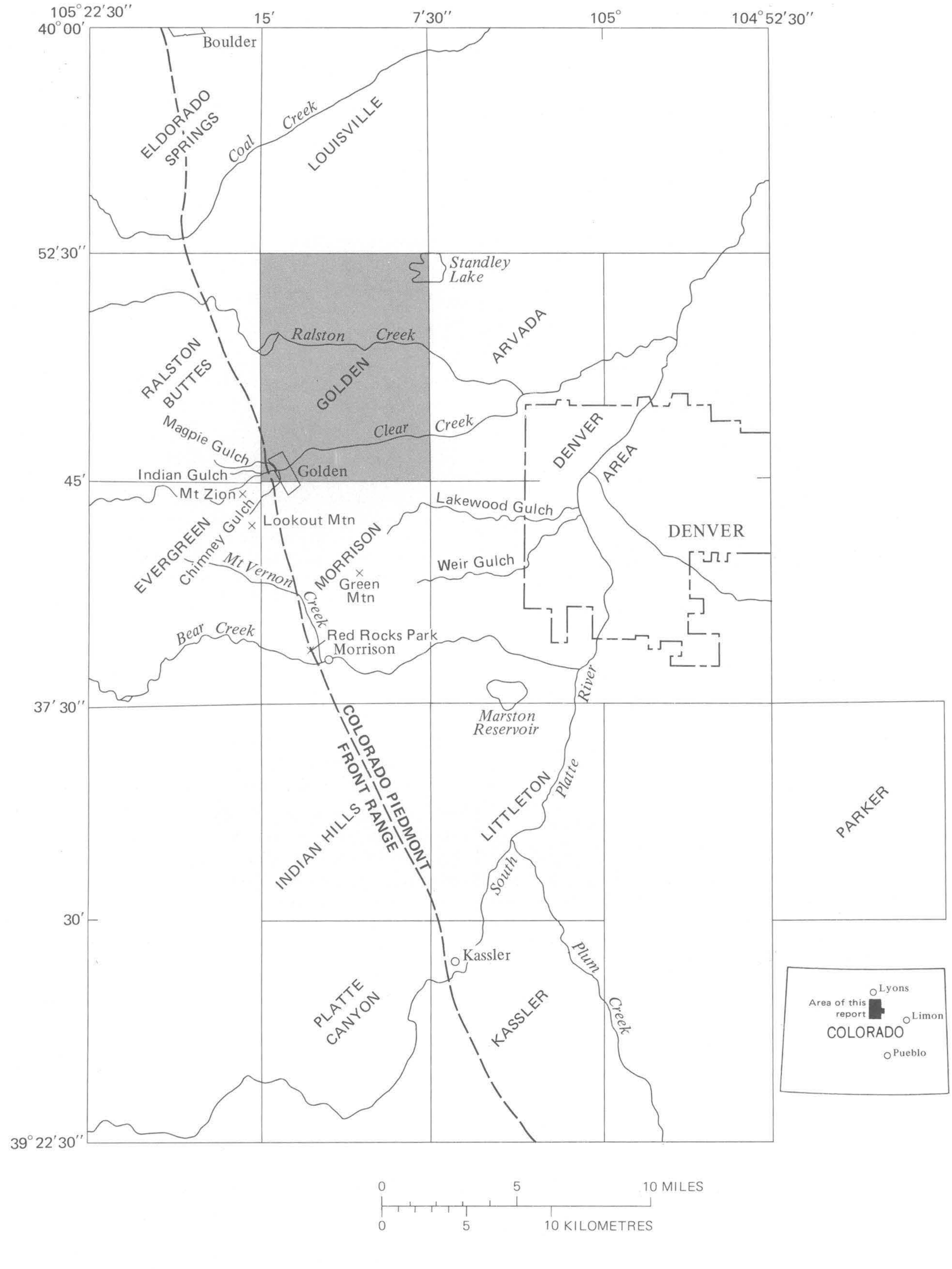
Near, and west of, the foothills of the Front Range of the Rocky Mountains are steeply dipping metamorphic, sedimentary, and igneous rocks. East of the foothills the sedimentary rocks dip gently eastward into the Denver basin. The Precambrian rocks record probable volcanic and marine sedimentary events and were deformed at least three times. The Paleozoic and Mesozoic rocks record two invasions of shallow seas into the area. The youngest Mesozoic and Tertiary rocks indicate volcanic activity in the foothills and in the Front Range. The landscape of today is the result of recurrent episodes of erosion and alluviation during Quaternary time. At least eight periods of alluviation resulted in some changes of major valleys and several instances of stream piracy. The alluvial deposits had soils formed on them and were eroded during intervals between alluviations. Strongly developed soils formed prior to deposition of the Louviers Alluvium, and less strongly developed soils formed after deposition of the Louviers. Deposits of alluvial fans, transported mantle, colluvium, and landslide debris have been forming continuously throughout Quaternary time. In 1968 there were five active landslides on North and South Table Mountains.

Sources for large amounts of sand and gravel, rock for crushing, coal, common clay, and shale suitable for expanded aggregate are present in the area. Foundation problems may result from potentially expansive parts of the colluvium, transported mantle, and the Ralston Creek, Morrison, Benton, Pierre, Fox Hills, Laramie, Arapahoe, and Denver Formations. Differential settlement is a potential cause of foundation failure in deposits of loess, artificial fill, and landslide debris. The surficial materials, and most of the shale, the mudstone, and the Denver Formation (except the latite), probably can be excavated with power equipment. The remainder of the rock units locally will require blasting to excavate. The alluvial deposits provide the best drainage for disposal of effluent from small septic systems, but care should be taken to see that the systems are not discharging noxious wastes into the ground water. The cut-slope stability of the geologic units is affected by attitude of the bedding and joints, rock type, and physiographic setting. Some of the geologically significant events that occurred during 26 of the years between 1878 and 1914 are tabulated.

INTRODUCTION

Knowledge of the composition, physical properties, and geometry of the materials that underlie the land surface is a necessary adjunct to proper land-use planning in urban areas. This report delineates the rock and surficial deposits, describes their structural and topographic settings, and provides information pertaining to their suitability for various construction and other economic uses. Recognition of these geologic factors is essential to sound planning for efficient land use in this area of variable foundation conditions and dwindling availability of construction materials.

The Golden quadrangle, Jefferson County, Colo., is one of several quadrangles in the rapidly developing Denver metropolitan area that have been, or are being, studied by the U.S. Geological Survey (fig. 1). Fieldwork started in the Golden quadrangle during the summer of 1952 and was carried on intermittently until the winter of 1962. The geology was mapped on aerial photographs at a scale of 1:17,500 and transferred to a topographic base map by means of an ER-55 projector. The geologic map has been published separately as Miscellaneous Geologic Investigations Map I-761-A (Van Horn, 1972), which should be consulted for better understanding of this report. Features pertaining to bedrock are shown in red on the geologic


105°22'30"
40°00'
15'
7'30"
105°
104°52'30"
52'30"
45'
37'30"
30'
39°22'30"
Boulder
ELDORADO SPRINGS
Coal Creek
LOUISVILLE
Standley Lake
Ralston Creek
ARVADA
RALSTON BUTTES
GOLDEN
Magpie Gulch
Clear Creek
Indian Gulch
Golden
DENVER AREA
Mt Zion
Lakewood Gulch
Lookout Mtn
DENVER
EVERGREEN
Chimney Gulch
MORRISON
Mt Vernon Creek
Green Mtn
Weir Gulch
Bear Creek
Red Rocks Park
Morrison
Marston Reservoir
South Platte River
COLORADO PIEDMONT
FRONT RANGE
LITTLETON
PARKER
INDIAN HILLS
Kassler
Plum Creek
PLATTE CANYON
KASSLER
Lyons
Area of this report
Limon
COLORADO
Pueblo
0 5 10 MILES
0 5 10 KILOMETRES

map (Van Horn, 1972), whereas those pertaining to the surficial deposits are shown in black. The red locality numbers shown on the geologic map are keyed to Pierre Shale fossil localities in table 3. Localities from which samples were obtained for lithologic and materials tests are shown in figure 3. Color designations in this report follow the Munsell color identification system (Goddard and others, 1948; Munsell Color Co., Inc., 1954). The rocks older than the Pierre Shale are given cursory treatment in this report as they were described in considerable detail in a publication on the adjoining Ralston Buttes quadrangle (Sheridan and others, 1967).

Data gathered since a bedrock geology map was issued (Van Horn, 1957b) have required changes in the mapping of faults in the northwestern part of the quadrangle and revision of the contact between the Laramie and Arapahoe Formations in the northern part. The delineation and terminology of the Precambrian map units also have been changed to accord with the subdivisions mapped in the Ralston Buttes quadrangle (Sheridan and others, 1967).

ACKNOWLEDGMENTS

Cretaceous fossils were identified by W. A. Cobban, unless otherwise noted. These determinations were essential in delineating the complicated structural patterns in the Pierre Shale in the northern part of the quadrangle. The Los Angeles abrasion test and some of the other materials tests mentioned in the report were made by personnel of the Colorado Department of Highways. Clay and other minerals in the Pierre, Fox Hills, and Laramie Formations were identified principally by A. J. Gude III using X-ray diffraction techniques on the fraction smaller than 74 microns. One suite of 10 samples from the Denver and Rio Grande Western Railroad (previously known as the Denver and Salt Lake Railway) cut at Plastic siding was identified by F. A. Hildebrand using information obtained from X-ray diffraction on particles of less than one-half micron, microscopic examination of thin sections, the electron microscope, and differential thermal analysis of the fraction smaller than 2 microns. By the use of X-ray diffraction techniques Paul Blackmon identified the clay and other minerals found in soils developed on Quaternary deposits. G. A. Macdonald, H. A. Powers, and R. E. Wilcox were most helpful in the interpretation of some of the volcanic features found at Ralston dike and at North Table Mountain. The cooperation of Mrs. Pansy Parshall Hook, of the Golden Historical Museum, and Miss Patricia Van Horn enabled me to compile the data contained in the summary of historical geologic events (p. 108). All the landowners were gracious in allowing me access to their property.

◀ FIGURE 1.—Location of the Golden quadrangle and other quadrangles in the Denver area for which geologic maps have recently been published by the U.S. Geological Survey. Eldorado Springs (Wells, 1967); Louisville (Spencer, 1961; Malde, 1955); Ralston Buttes (Sheridan and others, 1967); Golden (this report; Van Horn, 1957b, 1972); Denver area (Hunt, 1954); Morrison (Smith, 1964; Gable, 1968; Scott, 1972); Indian Hills (Scott, 1961; Bryant and others, 1973); Littleton (Scott, 1962); Platte Canyon (Peterson, 1964); Kassler (Scott, 1963a, b); Evergreen (Sheridan and others, 1972); Parker (Maberry and Lindvall, 1972); Arvada (Lindvall, 1972).

PREVIOUS WORK

Although the Golden area had been settled by 1850 and coal mines were operating in 1861 or 1862, the first general geologic study of the area was that by Hayden (1869). More detailed work by members of Hayden's survey was reported in 1874 and the first colored geologic map of the area was published in 1877 (Hayden, 1874, 1877).

The next, and perhaps the most important, geologic study of this area was published in 1896 (Emmons and others, 1896). Subsequent publications deal mainly with particular stratigraphic or structural problems in the area east of the Front Range. Important contributions to the present understanding of structure and stratigraphy in the area have been made by Leo Lesquereux, Arthur Lakes, H. B. Patton, G. L. Cannon, N. M. Fenneman, G. B. Richardson, W. T. Lee, Victor Ziegler, J. Harlan Johnson, F. H. Knowlton, R. L. Heaton, F. M. Van Tuyl, T. S. Lovering, W. A. Waldschmidt, R. W. Brown, and L. W. LeRoy.

Many of the publications are concerned with the controversial sequence of beds above the Fox Hills Sandstone—the "Laramie problem"—and with the details of the Golden fault and associated faults. These problems are briefly discussed in this report at the beginning of the sections on Cretaceous and Tertiary stratigraphy and on structure.

PHYSIOGRAPHY

The Golden quadrangle is principally in the Colorado Piedmont section of the Great Plains physiographic province but includes a small part of the Front Range of the Southern Rocky Mountains province (frontispiece and fig. 2). The dividing line between these two provinces is the steep escarpment that marks the east edge of the hard Precambrian rocks of the mountains. East of the escarpment, hogbacks and valleys formed on the upturned sedimentary rocks of Paleozoic and Mesozoic age make up the foothills. East of the foothills most of the area is terraced and slopes eastward. This general eastward slope is broken only by the lava-capped mesas of North and South Table Mountains, which rise steeply 800–1,000 feet above Clear Creek, and by Ralston dike, which forms a steep-sided

FIGURE 2.—The principal landforms of the Golden quadrangle are strikingly displayed by this shaded-relief map. Alluvial terraces in the eastern part of the quadrangle rise westward and abut sharp-crested, northwest-trending hogbacks and the foot of the Rocky Mountain Front Range. This pattern is interrupted near Golden by two lava-capped mesas. From U.S. Geological Survey Golden 7½-minute quadrangle (shaded relief), scale 1:24,000, 1965.

ridge southeast of Ralston Reservoir. Most of the bedrock is covered by terrace alluvium, and on the steeper slopes, by colluvium. Landslides form small but distinctive patches of hummocky terrain on many of these steep slopes.

STRATIGRAPHY

The stratigraphic nomenclature used in this report has evolved over a period of almost 100 years. During this time some stratigraphic terms have been used in many different ways, formations have been redefined and renamed, and the age designation of some rock units has been changed. Table 1 shows the geologic units in the Golden quadrangle and indicates which of them were not mapped separately.

The measured section G25 (fig. 3) of bedrock included in this report is part of an almost continuous exposure along Ralston Reservoir and Ralston Creek. The section was measured when the water in the reservoir was at a low stage, and a tape-and-compass survey was made between control stations located by planetable. The individual sections for the Fountain through Benton were included in another report (Van Horn, in Sheridan and others, 1967) and are not repeated here. The numbering system of beds used in that report is continued here.

PRECAMBRIAN ROCKS

The nomenclature of the Precambrian rock units used in the earlier map of the Golden quadrangle (Van Horn, 1957b) has been discarded in favor of the nomenclature of the more precisely named rock units in the adjoining Ralston Buttes quadrangle (Sheridan and others, 1967). These new units were traced eastward into the Golden quadrangle from the edge of the Ralston Buttes quadrangle by photogeologic methods and comparison with the earlier mapping. As the rocks have been described in detail by Sheridan, Maxwell, and Albee (1967), they are discussed only briefly here. The Precambrian rocks are described in order of their appearance from north to south because their relative ages are unknown.

METAMORPHOSED SEDIMENTARY AND VOLCANIC(?) ROCKS

Metamorphic rocks, mostly covered by colluvium, occupy an area of about 1.5 square miles in the southwestern part of the quadrangle. These resistant rocks form the easternmost slopes of the Front Range and, although outcrops are common, individual units are generally difficult to follow for any distance. These rocks were originally deposited as sediments (Lovering and Goddard, 1950, p. 20) and perhaps in part as volcanics (Sheridan and others, 1967, p. 5), and were later metamorphosed. The strong easterly foliation, which dips from 58° N. to 56° S., is a reflection of original sedimentary bedding. The rocks have been folded and faulted and have been intruded by pegmatite and hornblende-biotite lamprophyre dikes. The Precambrian rocks are overlain with angular unconformity by sedimentary rocks of the Fountain Formation.

MICA SCHIST UNIT

A narrow band of mica schist, north of Cressmans Gulch, is principally muscovite, biotite, and quartz. Alternating layers of different amounts of these materials give the rock a light- to dark-gray banding. It commonly weathers brown and at places the mica gives it a silvery sheen.

HORNEBLENDE GNEISS UNIT

The horneblende gneiss unit consists of four subunits: (1) interlayered hornblende gneiss, amphibolite, and biotite-quartz-plagioclase gneiss; (2) garnetiferous schist; (3) mica schist; and (4) layered calc-silicate gneiss and associated rock.

INTERLAYERED HORNBLENDE GNEISS, AMPHIBOLITE, AND BIOTITE-QUARTZ-PLAGIOCLASE GNEISS

The interlayered hornblende gneiss, amphibolite, and biotite-quartz-plagioclase gneiss extends from Golden Gate Canyon northward to a point about halfway to Cressmans Gulch. The unit is predominantly a gray biotite gneiss composed of biotite, plagioclase, and quartz. This gneiss is interlayered with dark-gray to black amphibolite, hornblende gneiss, and biotite gneiss. The amphibolite is principally hornblende and plagioclase. The hornblende and biotite gneisses are principally plagioclase, quartz, and hornblende or biotite. Several of these dark-colored layers, 3–10 feet thick, crop out on the north side of Golden Gate Canyon. Near the north border of this unit a 10-foot-thick layer of light-gray quartzite forms a bold west-trending outcrop, interrupted by a pegmatite dike. The quartzite is composed of subround quartz grains and small amounts of biotite.

GARNETIFEROUS SCHIST

A layer of garnetiferous schist, 50–80 feet thick, is present in Golden Gate Canyon. It is principally quartz and feldspar, but contains garnet and biotite as accessory minerals. The rock is light to medium gray with black flecks of biotite and flattened purple garnet crystals as much as one-half inch in diameter. The garnetiferous schist is lenticular and is enclosed in the layered calc-silicate gneiss and associated rock. This layer was previously mapped as garnet gneiss (Van Horn, 1957b).

MICA SCHIST

The mica schist south of Cressmans Gulch is poorly exposed in the Golden quadrangle. It is light to medium gray and in the Golden quadrangle is principally quartz, muscovite, and biotite. The mica schist forms a thick layer overlain and underlain by the layered calc-silicate gneiss and associated rock.

LAYERED CALC-SILICATE GNEISS AND ASSOCIATED ROCK

The layered calc-silicate gneiss and associated rock occurs on both sides of Cressmans Gulch. It is various

TABLE 1.—*Formations of the Golden quadrangle, Colorado*

Era	System	Series	Age	Rock unit		
Cenozoic	Quaternary	Holocene		Artificial fill		
				Post-Piney Creek alluvium		
				Piney Creek Alluvium		
		Holocene and Pleistocene	Order does not show age relations	Landslides		
				Colluvium		
				Transported mantle		
				Alluvial fan	Young	
					Old	
		Pleistocene		Loess		
			Pinedale	Broadway Alluvium		
			Bull Lake	Louviers Alluvium		
			Sangamon or Illinoian	Slocum Alluvium		
			Yarmouth or Kansan	Verdos Alluvium	Pearlette Ash Member equivalent[1]	
			Aftonian or Nebraskan	Rocky Flats Alluvium		
		Pleistocene(?)		Pre-Rocky Flats alluvium		
	Tertiary	Paleocene		Denver Formation and associated Tertiary latite and monzonite		
Mesozoic	Cretaceous	Upper		Arapahoe Formation		
				Laramie Formation		
				Fox Hills Sandstone		
				Pierre Shale		
				Niobrara Formation	Smoky Hill Shale Member	
					Fort Hays Limestone Member	
				Benton Shale	Carlile Shale equivalent[1]	
					Greenhorn Limestone equivalent[1]	Bridge Creek Shale Member equivalent[1]
						Hartland Shale Member equivalent[1]
						Lincoln Limestone Member equivalent[1]
					Graneros Shale equivalent[1]	
		Lower		Dakota Group	South Platte Formation[1]	
					Lytle Formation[1]	
	Jurassic	Upper		Morrison Formation		
				Ralston Creek Formation		
	Triassic(?)			Lykins Formation	Strain Shale Member[1,2]	
Paleozoic	Permian				Glennon Limestone Member[1,2]	
					Bergen Shale Member[1,2]	
					Falcon Limestone Member[1,2]	
					Harriman Shale Member[1,2]	
				Lyons Sandstone		
	Pennsylvanian			Fountain Formation		
Precambrian			Order may not reflect age	Hornblende biotite lamprophyre		
				Pegmatite		
				Interlayered gneisses	Garnetiferous quartz-biotite schist	
				Microcline-quartz-plagioclase-biotite gneiss unit		
				Hornblende gneiss unit	Layered calc-silicate gneiss and associated rock	
					Mica schist	
					Garnetiferous schist	
					Interlayered hornblende gneiss, amphibolite and biotite-quartz-plagioclase gneiss	
				Mica schist unit		

[1] Not mapped separately.
[2] Of LeRoy (1946).

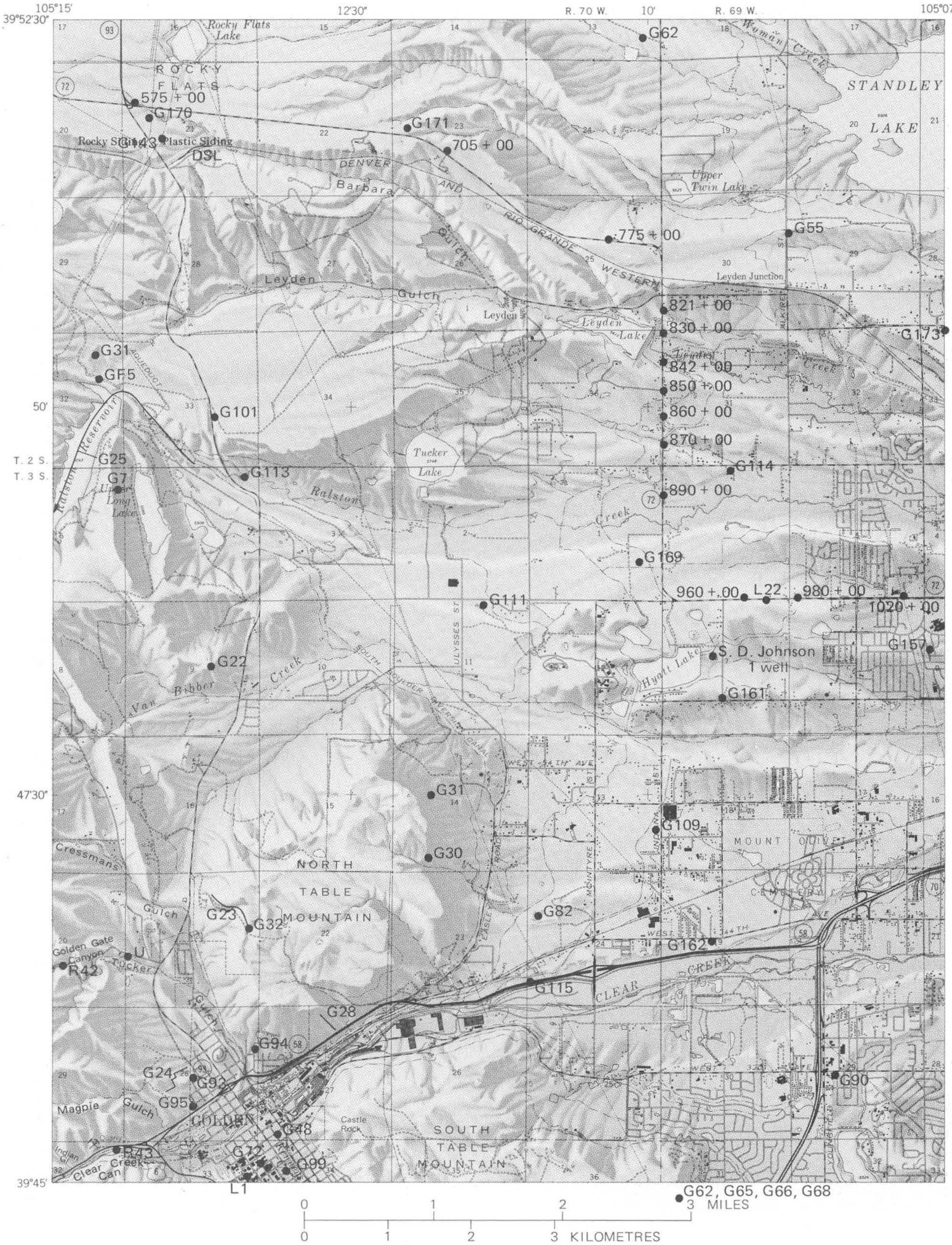


FIGURE 3.—Localities of measured sections and samples obtained for lithologic and materials-tests data of the Golden quadrangle mentioned in this report. Base from U.S. Geological Survey Golden 7½-minute quadrangle (shaded relief), scale 1:24,000, 1965.

shades of gray, apparently well laminated, and is composed principally of epidote, quartz, hornblende, and plagioclase.

MICROCLINE-QUARTZ-PLAGIOCLASE-BIOTITE GNEISS UNIT

Microcline-quartz-plagioclase-biotite gneiss, or briefly, microcline gneiss, occupies most of the area between Golden Gate and Clear Creek Canyons. Midway between the two canyons are thin layers of amphibolite and dikes of hornblende-biotite lamprophyre. Pegmatite dikes have intruded the rock near the east end of the outcrop.

The main body of the rock is a pink to gray, fine- to medium-grained foliated gneiss. Small amounts of biotite give a crudely layered and black speckled appearance. The rock is composed principally of quartz, microcline, and plagioclase with smaller amounts of biotite. However, in the first canyon north of Clear Creek (Magpie Gulch), the rock is interlayered with dark-gray amphibolite that contains plagioclase, quartz, and hornblende in about equal amounts, and a small amount of biotite.

INTERLAYERED GNEISS

The interlayered gneiss extends from the southern quadrangle boundary part way up the north valley wall of Clear Creek to about the working face of the large abandoned quarry. The north margin is marked by a bed of garnetiferous quartz-biotite schist, a subunit of the interlayered gneiss.

The interlayered gneiss is dominantly a gray fine-grained plagioclase-quartz-biotite gneiss; at places the rock is pink because of potassic feldspar. Interlayered with the gneiss are thin beds of dark-gray amphibolite. The rock is hard and breaks into sharp angular fragments when fresh. Fresh rock from the abandoned quarry in sec. 32 shows minor alteration along fractures and of the feldspar; a sample examined by J. Berman (Hickey, 1950, p. 10) was predominantly quartz, potassic feldspar, and oligoclase, with smaller amounts of micas, hornblende, magnetite, apatite, zircon, and sphene.

GARNETIFEROUS QUARTZ-BIOTITE SCHIST

A layer of garnetiferous quartz-biotite schist, 15–25 feet thick, marks the north contact of the interlayered gneiss in Clear Creek Canyon. The garnetiferous quartz-biotite schist is predominantly quartz, biotite, and garnet. The rock is mottled medium gray, pale pink, and dark brown, and the garnet crystals give the weathered surface a rough, bumpy appearance. The garnet crystals, which range from 0.1 to 1 inch in diameter, are larger and more abundant in the western part of the outcrop area than in the eastern part. They are fractured, have inclusions of quartz and mica, and generally are altered. Small blebs of fresh-looking garnet are deep ruby red. This layer was previously mapped as garnet gneiss (Van Horn, 1957b).

IGNEOUS ROCKS

Igneous rocks consisting of pegmatite and hornblende-biotite lamprophyre intrude the Precambrian rock units at several places, but do not intrude the younger sedimentary rocks. They are probably of Precambrian age.

PEGMATITE

Three small pegmatite dikes are shown on the accompanying geologic map. They are coarsely crystalline and consist principally of quartz, potassic feldspar, and small amounts of mica. The dikes cut across the foliation of the enclosing metamorphic rocks. The largest dike is 1,300 feet long and 100 feet wide.

HORNBLENDE-BIOTITE LAMPROPHYRE

Two east-trending hornblende-biotite lamprophyre dikes, previously mapped as biotite syenite (Van Horn, 1957b), are located between Clear Creek and Golden Gate Canyon. They are dark gray flecked with pink, and are composed mainly of biotite, hornblende, and potassic feldspar. The biotite forms irregularly shaped black phenocrysts as much as 5 mm across, and the pink to white feldspar and dark-green hornblende phenocrysts are generally smaller. Although these dikes are plainly visible on aerial photographs, in the field they are poorly exposed but are marked by a weathered zone that is less resistant than the enclosing rock. At the only exposure found, the dike is 2 feet thick. Both dikes terminate abruptly at the contact of the Precambrian rocks and the Fountain Formation.

PALEOZOIC ROCKS

Rocks of Paleozoic age include the Fountain Formation, Lyons Sandstone, and the lower part of the Lykins Formation. These rocks are sparsely fossiliferous and originally all were included in a red-bed sequence assigned to the Trias (Hayden, 1869). Later, Emmons, Cross, and Eldridge (1896) assigned them to the Wyoming Formation. The Wyoming Formation has been abandoned. The rocks formerly assigned to it in the Denver area were subdivided into the Fountain, Lyons, and Lykins by Fenneman (1905). (See fig. 4.)

PENNSYLVANIAN AND PERMIAN

FOUNTAIN FORMATION

In the Golden quadrangle the Fountain Formation consists of about 800 feet of conglomerate, sandstone, and mudstone. North of Tucker Gulch it occupies a valley between the mountains to the west and a low hogback of Lyons Sandstone to the east; south of Tucker Gulch the upper half is cut out by the Golden fault and the lower half is overlain by thick deposits of surficial material. The Fountain Formation rests on an eroded surface cut on folded and faulted Precambrian rocks, thus marking a pronounced angular unconformity. Sparse pebbles of lime-

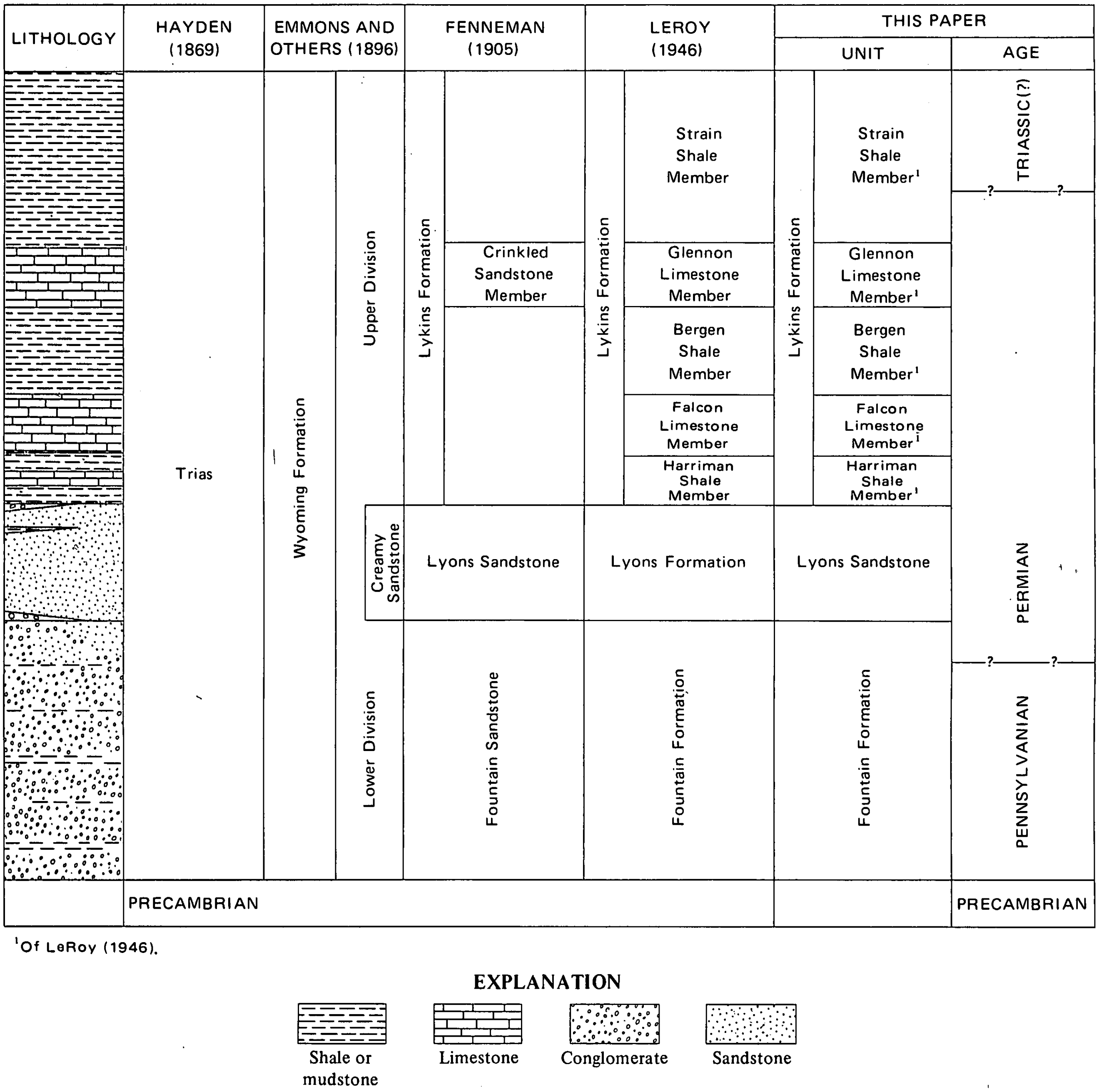


FIGURE 4.—Correlation of formations mostly of Paleozoic age as used in the vicinity of Golden by various authors.

stone in the Fountain suggest that Mississipian and older Paleozoic rocks were once present nearby. These older rocks evidently were completely eroded from the Golden area before deposition of the Fountain began in the Middle Pennsylvanian.

The Fountain is composed of pink to reddish-orange, coarse- to fine-grained, crossbedded, arkosic conglomeratic sandstone and conglomerate interbedded with lenticular, dark-reddish-brown, micaceous, silty, indurated mudstone and pinkish-gray, fine-grained, crossbedded, quartzose sandstone. The base of the formation is commonly marked by a sedimentary breccia containing many angular cobbles and small boulders. Within a few feet this breccia gives way to the normal conglomeratic sandstone. Conglomeratic sandstone is generally predominant in the formation, except for the lower 150 feet where mudstone is dominant. Well-developed mudcracks were seen in the mudstone in one place west of the quadrangle. In the upper 30 feet there are several lenticular quartzose sandstone beds similar to sandstone in the overlying Lyons Sandstone. The Fountain generally weathers to smoothly rounded outcrops. The coarse fraction of the formation, which includes cobbles as much as 7 inches in diameter, is composed of quartz and pink feldspar and minor amounts of schist, gneiss, quartzite, granite, and limestone. The finer fraction is principally quartz and feldspar, much of which appears to be pink microcline. The grains are subangular to subround and moderately to strongly cemented in a clayey matrix that has much red iron oxide, probably hematite, and silica.

Thin light-gray streaks, spots, and zones are common; south of Clear Creek the light-gray color is as prevalent as the pink. The color change, which most commonly is roughly parallel to the bedding and is very abrupt, in most places occurs in the sandstone and conglomerate beds, generally where they are in contact with the mudstone. There is no apparent change in texture or degree of cementation of the sandstone across the color boundary. At most places the light gray is adjacent to a dark-red mudstone, but at some places the mudstone also contains light-gray horizons. X-ray fluorescence analyses of four samples indicate there is less elemental iron in the light-gray beds than in adjacent red beds (Hubert, 1960, p. 59).

The Fountain overlies the Precambrian rocks with pronounced angular unconformity; the base of the Fountain cuts sharply across the structural and lithologic trends in the Precambrian. Although the contact is poorly exposed at most places, the float indicates that the eroded surface of the Precambrian, on which the Fountain was deposited, is relatively planar. At a few places outside the Golden quadrangle the rocks underlying the Fountain are deeply weathered (Wahlstrom, 1948; Hubert, 1960, p. 46).

AGE AND CORRELATION

No fossils have been found in the Fountain in or near this area, hence the Pennsylvanian and Permian age designation depends on correlation of units outside the area believed to be equivalent to the Fountain. The first fossils noted in this formation, dated as Early Pennsylvanian by David White, were found in the Glen Eyrie Shale Member of the Fountain Formation (Finlay, 1907, p. 588–589) about 80 miles south of Golden. The Ingleside Formation, defined from outcrops about 80 miles north of Golden (Butters, 1913, p. 68), is now regarded as equivalent to the upper part of the Fountain Formation, and contains fusulinids of Permian age (Heaton, 1933, p. 119; Maughan and Wilson, 1960, p. 42). Thus, the Fountain appears to be Pennsylvanian in the lower part and Permian in the upper part. This concept had been intimated earlier by Maher (1946, p. 1760) on the basis of correlation of widely spaced well logs.

ORIGIN

The Fountain is of terrestrial origin. The conglomeratic beds at many places occupy channels that cut into underlying mudstone or conglomeratic beds. Crossbedding is well developed in the conglomeratic beds. The mudstone beds are massive, generally less than 20 feet thick, and appear to be lenticular. The mudstones represent flood-plain or lake deposits cut by streams that deposited the coarse material in the eroded channels. The terrestrial sediments of the Fountain interfinger eastward with marine Pennsylvania and Permian deposits (Maher and Collins, 1952).

The source of the arkosic material in the Fountain was a Precambrian highland of Pennsylvanian-Permian time—the ancestral Rocky Mountains—west of Golden. The highland had been mostly stripped of any earlier Paleozoic rocks and had been deeply weathered before the Fountain was deposited on a gently eastward-sloping surface of low relief.

PERMIAN

LYONS SANDSTONE

The Lyons Sandstone, about 150 feet thick, is light-gray to grayish-orange, fine- to medium-grained, crossbedded, quartzose sandstone but includes some conglomerate, siltstone and mudstone. The light-gray color is predominant in this area and for many years the Lyons was called the "creamy sandstone" and was thought to be a separate unit from the grayish-orange Lyons found farther north. The Lyons Sandstone forms a low hogback north of Tucker Gulch, about midway between the Front Range and the high hogback formed by the Dakota Group. South of Tucker Gulch it has been cut out by the Golden fault. The sandstone, which makes up the greatest part of the Lyons, is composed principally of fine- to medium-grained quartz particles, strongly cemented by silica. Most of the grains are subround and many have a slightly to moderately frosted surface. A small amount of light-gray argillaceous material generally is present. The crossbedding, though present at most outcrops, is not well displayed in this area. Thompson (1949) described the crossbedding as well as many other unusual features of the Lyons.

A bed of light-gray conglomerate as much as 100 feet thick marks the top of the formation north of Cressmans Gulch. The pebbles and cobbles (as much as 4 inches in diameter) are predominantly quartz and chert but include some sandstone. Between Cressmans Gulch and Tucker Gulch this conglomerate is missing, and mudstone of the Lykins Formation rests directly on sandstone of the Lyons; but south of Golden, conglomerate is again present at the top of the Lyons (LeRoy, 1946, p. 28). A similar conglomerate is interbedded with sandstone in the lower 40 feet of the Lyons in Cressmans Gulch. This lower unit contains sandstone concretions as much as 2 feet in diameter, and it fills channels cut into the underlying Fountain Formation.

Thin beds of siltstone are present at a few places throughout the Lyons. Some of them fill channels cut into underlying sandstone beds. A thin reddish-brown mudstone bed that occurs in the Ralston Buttes quadrangle (Van Horn, in Sheridan and others, 1967, p. 41) was not found in the Golden quadrangle, but could be present in the poorly exposed upper 40 feet of the formation.

Although the contact with the underlying Fountain Formation is lithologically abrupt and unconformable, the unconformity is possibly no more significant than the numerous unconformities represented by stream-channel deposits cutting into mudstone beds within the Fountain. The presence of several lenticular Lyons-like quartzose sandstone beds in the upper 30 feet of the Fountain probably indicates that the sea was encroaching on the area, and these sandstone beds may represent an interfingering of the Lyons and Fountain. Although part of the upper Fountain has undoubtedly been removed by the transgressing sea, this boundary is, perhaps, best described as being transitional.

AGE AND CORRELATION

No fossils, other than a few reptile tracks, have been found in the Lyons. The Permian age was assigned by Gilmore (in Lee, 1927, p. 12) on the basis of these tracks. This age is corroborated by the stratigraphic position of the Lyons between two formations of established Permian age—the Ingleside and the Lykins.

ORIGIN

The origin of the Lyons has been the subject of much conjecture. Thompson (1949, p. 67–71) proposed a beach-deposit origin because of features similar to those he observed on a modern beach near Balboa, Calif. Certain aspects of the crossbedded sandstones have been construed to indicate eolian deposition (Tieje, 1923, p. 202), and the conglomerates are probably fluvial. The Lyons was probably deposited at or near the strandline of a transgressing sea, and many of the complex terrestrial and marine features of a seacoast are present in it.

PALEOZOIC AND MESOZOIC(?) ROCKS

PERMIAN AND TRIASSIC(?)

LYKINS FORMATION

The Lykins Formation, as used in this report, follows the original definition of Fenneman (1905, p. 24) as partly amended by LeRoy (1946, p. 31). It consists principally of mudstone and smaller amounts of limestone and is about 450 feet thick. The Lykins crops out north of Tucker Gulch in the western half of the valley between the low hogback formed by the Lyons and the high hogback formed by the Dakota. South of Tucker Gulch the Lykins Formation is cut out by the Golden fault, except at the small knoll along the west side of sec. 21, T. 3 S., R. 70 W., where a thin slice of it is exposed between faults in the Golden fault zone. Limestone float occurs at places between this knoll and Clear Creek. This float seems to be derived from some of the limestone beds in the Lykins, and probably marks the trace of the Golden fault.

The Lykins Formation is principally a grayish-red mudstone but includes some limestone and a few thin beds of very fine grained sandstone. LeRoy (1946, p. 30–47) has named and described five members of this formation. In ascending order they are the Harriman Shale Member, 55 feet thick; Falcon Limestone Member, 3 feet thick; Bergen Shale Member, 30 feet thick; Glennon Limestone Member, 14 feet thick; and Strain Shale Member, 350 feet thick. The two limestone members are in the lower fourth of the formation and a third limestone (unnamed), about a foot thick, is 13 feet above the base.

LIMESTONE BEDS

The unnamed limestone bed 13 feet above the base of the Lykins is very light to medium gray. It contains many small vugs and weathers to a sugary texture. The Falcon Member and the lower 4 feet of the Glennon Member are very light gray, hard, finely crystalline to dense, dolomitic limestone; the upper 10 feet of the Glennon Member is a reddish-brown, tough, silty limestone. Vugs in the limestones contain calcite crystals. Although both limestones have the characteristic irregular wavy bedding of the "crinkled" limestone or sandstone of Fenneman (1905, p. 25), the bedding is mostly obscured because the alternate bands are nearly the same color. A small outcrop of the Falcon Limestone Member along the extension of Alameda Parkway in Red Rocks Park, 6 miles south of Golden, appears to have poorly developed ripple marks (fig. 5). They are similar to current ripple marks modified by wave action (Schrock, 1948, p. 95). The wavy bedding is emphasized by alternating reddish-brown and pale-red beds. The bulk of the rock is pale red, but the bedding is marked by a thin reddish-brown layer. Individual waves have a length of about 1 inch and an amplitude of 0.2 inch. Many of the individual laminae are subparallel to adjacent laminae but at places several laminae may converge to form a thin band in which individual laminae cannot be distinguished. At other places adjacent subparallel laminae may diverge and then converge, to form small lentils. There are as many as 100 of these laminae per inch. Where weathered, the upper surfaces of the laminae have a distinctive dimpled appearance. Individual dimples are roughly circular, about an inch in diameter, and 0.2 inch deep. Adjacent areas contain small domes of the same size. The domes are generally connected to other domes by low saddles. The overall appearance of these features is similar to interference ripple marks. At some places there are domelike structures as much as 3 feet in diameter with amplitudes of about 0.5 foot. Individual laminae in the domes have the characteristic wavy bedding, although the amplitude of each wave is very small and the laminae usually are parallel.

FIGURE 5.—Ripple marks in the Lykins Formation exposed along the extension of Alameda Parkway in Red Rocks Park.

Several disassociated segments of the dayscladacean alga *Mizzia minuta* Johnson and Dorr (USGS accession No. EG-55-12D [No. 55-RR-5 of Van Horn, in Sheridan and others, 1967, p. 42]) were found and identified by Richard Rezak (written commun., Jan. 27, 1956). The collections came from the upper part of the Glennon exposed along Ralston Creek just west of the Golden quadrangle. According to Rezak the genus *Mizzia* has been found only in Permian rocks of the world, and in North America it has been recognized only in rocks of Guadalupian age. Rezak also stated that the large domelike structures in the Glennon appear to be due to blue-green algae.

MUDSTONE BEDS

Mudstone of the Harriman, Bergen, and Strain Members is grayish red, tough, and moderately calcareous. The basal 2 feet of the Harriman is very sandy and moderately calcareous but within a few feet grades upward into the normal very fine grained mudstone. The mudstone is composed of subangular to subround silt-sized grains in a matrix of clay-sized material. The reddish-brown clay matrix, which presents a very uniform appearance to the unaided eye, contains many thin anastomosing channels of denser color when viewed in thin section. These zones are probably the result of a secondary concentration of iron oxide. At places there are mottles as much as an inch in diameter of light-bluish-gray mudstone, and at one place the small channelways of iron oxide terminate abruptly against these mottled spots. The mottled spots probably are also secondary and were formed after the channelways. The Strain Member is slightly coarser grained than the other members and contains some 0.1- to 1-inch-thick beds of light-gray, very fine grained, silty sandstone interbedded with the mudstone.

The poorly displayed bedding in the mudstone generally consists of uniformly sized and roughly parallel layers of thick to thin beds. At several places, however, the bedding is very lenticular; each lentil is about an inch long and 0.3 inch thick, and overlaps adjacent lentils. The lenticular structures, which are figured by Van Horn (in Sheridan and others, 1967, p. 43), do not form a well-defined zone. They are similar to the structures described by Moore and Scruton (1957, p. 2733–2735) which were found in the part of the "regular layers" that occurred in water 6–360 feet deep near the Mississippi Delta.

The contact of the Lykins with the underlying Lyons Sandstone is lithologically abrupt. The discontinuous conglomerate at the top of the Lyons could be construed to result from an erosional period intervening between the two formations. The merging of the Lyons and Lykins in northern Colorado described by Butters (1913, p. 70) indicates that any unconformity found at the contact has only local significance and that no long period of time intervened between the deposition of these formations. This merging relationship in northern Colorado has been reaffirmed in terms of currently accepted nomenclature by Maughan and Wilson (1960, p. 39–40). They showed the Lyons interfingering with the lower part of the Satanka Shale and stated that the upper part of the Satanka is equivalent to the lower part of the Lykins.

AGE AND CORRELATION

The Permian age of the lower part of the Lykins (below the Strain Shale Member) is established by the occurrence of the algae *Mizzia* in the Glennon Member. The Permian age has been postulated for many years, most recently by Broin (1958) and by Oriel and Craig (1960, p. 45), who have correlated the "crinkled" sandstone or limestone of Fenneman (Glennon Limestone Member of LeRoy) with the Forelle Limestone of Permian age. Broin also correlated two carbonate-evaporite members of the Lykins that overlie the Forelle in northern Colorado with the Ervay Tongue of the Phosphoria Formation (Permian) and the Little Medicine Tongue of the Dinwoody Formation (Triassic). A dolomitic limestone bed that is about 90 feet above the Glennon Limestone has been correlated with the Ervay Tongue of the Park City Formation by M. R. Mudge (in McKee and others, 1959). Mudge placed the contact between rocks of Permian and Triassic age at the top of the dolomitic limestone. Even though no limestone or dolomite beds were recognized above the Glennon in the vicinity of Golden, probably the upper part of the Strain is Triassic.

ORIGIN

The algae and the ripple marks(?) indicate a shallow water origin of the limestone beds in the Lykins. According to Richard Rezak (written commun., Jan. 27, 1956), "the association of fragments of *Mizzia* with stromatolitic sediments [the large domelike structures] indicates a shallow-water, nearshore, marine environment, possibly intertidal. The crinkly limestone of the Lykins (Glennon Limestone Member), especially the upper 8 inches of the topmost unit at Ralston Reservoir, very closely resembles the intertidal algal deposits of south Florida and the Bahamas."

The crinkled structure of limestones in the Lykins has been ascribed to tectonic stress (Fenneman, 1905, p. 26) and to deformation of the limestone before it had consolidated into a rock (LeRoy, 1946, p. 37). It seems to me, however, that most of these features are a fortuitous preservation of ripple marks and algal growths.

MESOZOIC ROCKS

Rocks of the Mesozoic age include the upper part of the Lykins Formation (described in the previous section), Ralston Creek Formation, Morrison Formation, Dakota Group, Benton Shale, Niobrara Formation, Pierre Shale, Fox Hills Sandstone, Laramie Formation, Arapahoe Formation, and lower part of the Denver Formation. The upper part of the Lykins Formation is probably Triassic in age, the Ralston Creek and Morrison are of Jurassic age, and the rest are of Cretaceous age. (See fig. 6.) The Benton, Niobrara, and Pierre are of marine origin; the Fox Hills is transitional between marine and terrestrial; the rest are terrestrial.

JURASSIC

RALSTON CREEK FORMATION

The Ralston Creek Formation was recognized and described as the Ralston Formation by LeRoy (1946, p. 47–57) and renamed by Van Horn (1957a, p. 756). The Ralston Creek is exposed at a few places near the western base of the high hogback formed by the Dakota Group. It is about 100 feet thick.

The Ralston Creek is composed of varicolored claystone, limestone, calcareous siltstone, and chalcedony. Light-gray to grayish-red siltstone beds are predominant in the lower third of the formation; these massive beds, 1–15 feet thick, are generally calcareous but a few appear to be siliceous. The rest of the formation is principally claystone but includes several thin limestone and siltstone beds. The claystone is grayish red, grayish orange, dusky red, pale green, or light gray; it is tough, silty, and generally calcareous, and occurs in beds 1–14 feet thick. The limestone is generally light gray, but at places is grayish red or grayish orange. When weathered it has the rough grainy appearance of an indurated siltstone.

At places disseminated nodules or thin layers of chalcedony form a small but important part of the formation. It is moderate red, white, and light and dark gray, and occurs as discrete layers as much as 0.4 foot thick or as small disseminated nodules in siltstone or limestone, in the middle and upper part of the Ralston Creek.

The relation of the Ralston Creek to the underlying Lykins Formation is not clear. At most places in the Golden and adjoining Ralston Buttes quadrangles, the two formations appear to be conformable and there is no evidence of any extended interval of erosion or nondeposition between the two. Just west of the Golden quadrangle at Ralston Creek, however, a 5-foot-thick bed of sandstone at the base of the Ralston Creek Formation may be an erosional remnant of the Entrada Sandstone (Van Horn, in Sheridan and others, 1967, p. 44). This sandstone was not found elsewhere in the Ralston Buttes or the Golden quadrangles. It is not possible, at present, to definitely correlate this bed with the Entrada or to determine how much Entrada may have originally been present. Possibly the sandstone bed is merely a stream-channel deposit and has no regional significance.

AGE AND CORRELATION

The Jurassic age of the Ralston Creek is shown by fossils collected near the Golden quadrangle. Fossil collections from the Ralston Creek Formation of the Kassler quadrangle, 20 miles south of Golden, include "fresh-water gastropods identified by J. B. Reeside as *Gyraulus veternus* Meek and Hayden and *Lymnaea morrisonensis* Yen, and algae identified by R. E. Peck as *Echinochara spinosa* Peck of Kimmeridgian age" (Scott, 1963b, p. 92). *Unio*-like pelecypods identified by T. C. Yen (Imlay, 1952, p. 961) which were collected from just west of the Golden quadrangle may compare with *Vetulonaia faberi* Holt, a species found in the Morrison Formation. From this same locality LeRoy (1946, p. 51, 55) had previously collected and identified the algae *Aclistochara*, which he believed indicated a freshwater or possibly brackish-water environment. The zone containing chalcedony has been widely used in subsurface correlations in the Denver basin, and Ogden (1954) has pointed out the occurrence of chalcedony at about this same horizon at several places in the Rocky Mountain area. The chalcedony beds have also been used as a paleotectonic marker to separate the Kimmeridgian from the Oxfordian by McKee and others (1956), who placed the base of the overlying Morrison Formation at the top of chalcedony beds. The base of the Morrison in the present report, however, is placed at the base of a sandstone about 25 feet above the chalcedony beds.

ORIGIN

Coarsening of the upper part of the Lykins Formation probably indicates a withdrawal of the sea. Fossils in the succeeding Ralston Creek show that some of it was depos-

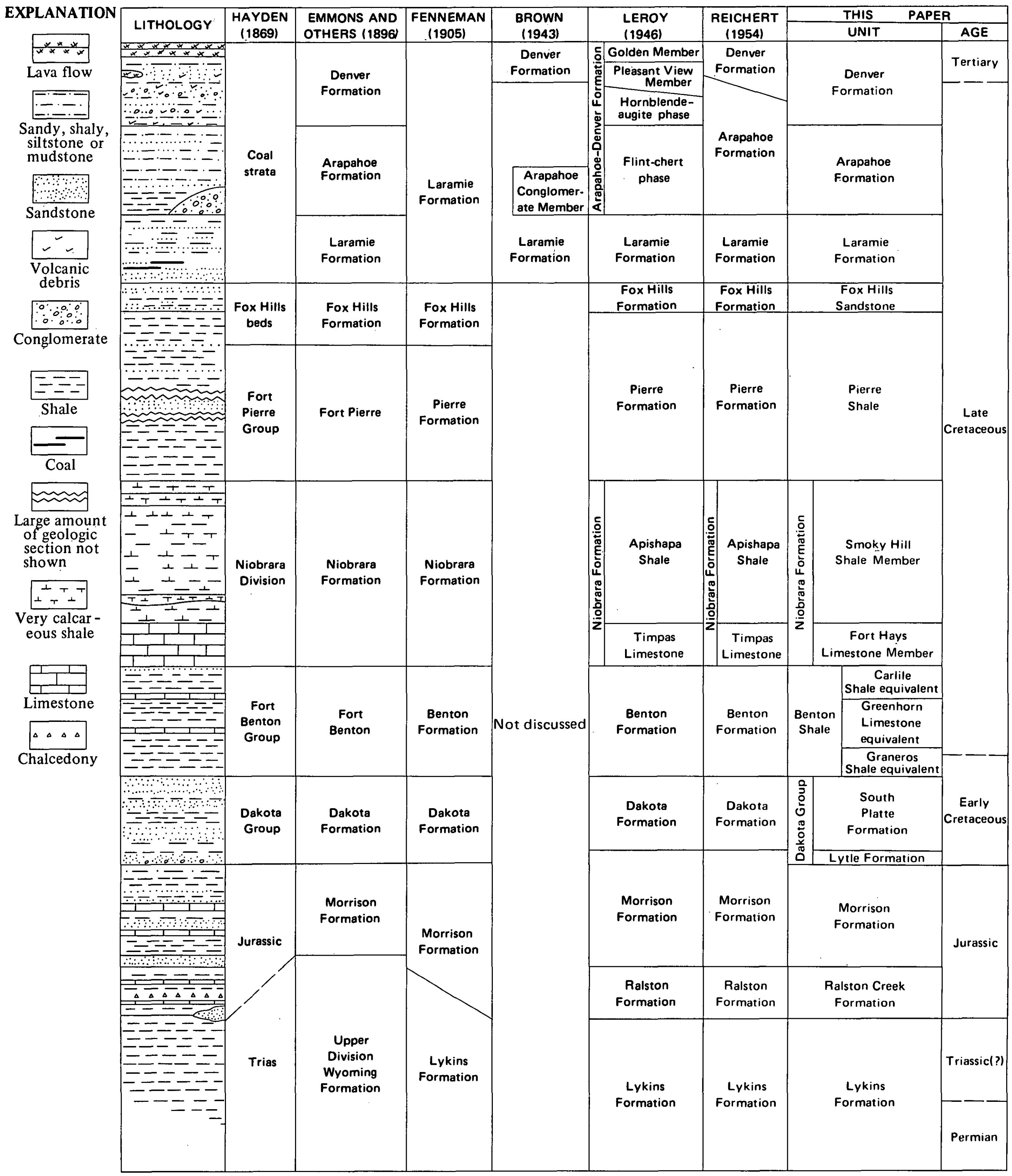


FIGURE 6.—Correlation of formations mostly of Mesozoic and Tertiary age as used in the Golden area by various authors.

ited in fresh or brackish water, and gypsum beds found only 10 miles south of Golden (LeRoy, 1946, p. 53) indicate it was deposited near sea level. It is possible that the marine conditions passed gradually into the terrestrial and that the Lykins and the Ralston Creek were not separated by a long period of deposition and erosion.

MORRISON FORMATION

The Morrison Formation, about 250 feet thick, consists of varicolored mudstone, limestone, siltstone, and sandstone. North of Tucker Gulch the Morrison crops out on the west slope of the high hogback formed by the Dakota Group; south of Tucker Gulch it crops out only in the small knoll along the west side of sec. 21, T. 3 S., R. 70 W., as part of a thin slice in the Golden fault zone. South of this place is has been cut out by the Golden fault. The Morrison Formation is principally greenish-gray, dusky-red, and dark-gray claystone and mudstone. Montmorillonite, illite, and kaolinite are present throughout the formation (Keller, 1953). A basal sandstone, 10–40 feet thick, is very light gray and contains limonite dots and concretions as large as one-half inch in diameter. It may be thin bedded, crossbedded, or massive. The sandstone cuts out beds in the underlying Ralston Creek Formation at places. Above the basal sandstone the lower part of the Morrison is principally dusky-red mudstone and thin beds of very light gray, fine-grained, calcareous sandstone. The middle part of the Morrison is poorly exposed but appears to consist mostly of greenish-gray to dusky-red claystone and of some beds of medium-gray dense, brittle limestone. In the upper part of the Morrison, thin beds of light- to dark-gray sandstone are interbedded with thick beds of claystone. A few thin beds of fine-grained sandstone near the top contain tiny white blebs of interstitial clay and a small amount of limonite nodules and black mineral grains. The quartz grains are mostly subround and have a frosted to matte surface. These sandstones break down when soaked in water and a moderate quantity of clay is visible.

The basal sandstone of the Morrison Formation partly lies in channels cut into the Ralston Creek Formation. This disconformable relation, which is well exposed on the south side of Ralston Reservoir, is probably of minor extent inasmuch as the chalcedony beds of the Ralston Creek Formation are not known to be cut out by erosion nor is the top of the Ralston Creek known to be significantly higher than the chalcedony beds in this area.

AGE AND ORIGIN

No fossils were identified from the Morrison Formation in the Golden quadrangle. Algae, freshwater mollusks, dinosaurs, and plant remains have been reported from nearby areas, and most geologists now agree that the Morrison is of Late Jurassic age and of terrestrial origin as established earlier by Baker, Dane, and Reeside (1936, p. 55, 58, 63) and Yen (1952, p. 34, 35). It was probably deposited on a surface of low relief that contained sluggish streams and many lakes and swamps.

CRETACEOUS

Rocks of Cretaceous age, which make up the bulk of the sedimentary rocks in the Golden quadrangle, consist of the Dakota Group, Benton Shale, Niobrara Formation, Pierre Shale, Fox Hills Sandstone, Laramie Formation, Arapahoe Formation, and the lower part of the Denver Formation. The total thickness of the Cretaceous rocks is about 10,000 feet, and much of this is contained in one formation—the Pierre Shale.

DAKOTA GROUP UNDIFFERENTIATED

The Dakota Group along the eastern front of the Rocky Mountains in Colorado has been studied intensively by K. M. Waagé. The results of his investigations have been published in several papers, three of which contain stratigraphic information from the vicinity of Golden (Waagé, 1955, 1959, 1961). The Dakota Group of the present report is virtually the same as that of Waagé. The two formations of the Dakota (South Platte above and Lytle below) and their several members were not mapped separately by me in the Golden quadrangle, although they are shown on my measured section along Ralston Creek in the adjacent Ralston Buttes quadrangle (Van Horn, in Sheridan and others, 1967, p. 46–47) and in figure 7 of the present report.

The Dakota Group consists predominantly of sandstone, siltstone, and claystone, but near the base it contains some conglomerate and conglomeratic sandstone. The thickness of the Dakota is generally about 300 feet in this area, but it varies considerably along the strike. South of Tucker Gulch the Dakota has been cut out by the Golden fault; north of Tucker Gulch it forms a high, steeply sloping hogback (fig. 8). Between Tucker Gulch and the hogback is a thin slice of the upper part of the Dakota with faults on both sides. From Tucker Gulch to Van Bibber Creek the east side of the hogback is marked by a long sinuous scar caused by the surface caving into an abandoned clay mine.

Rocks of the Dakota Group in most places are noncalcareous, hard, and resistant to erosion, and in many places they contain fragments of fossil plants. The rocks are mostly light-gray, fine- to medium-grained sandstone that is commonly crossbedded and ripple marked at places, light- to medium-gray siltstone, and dark-gray claystone.

The sandstone beds at the base of the South Platte and Lytle Formations are locally conglomeratic; the pebbles are predominantly light-gray chert. These beds generally

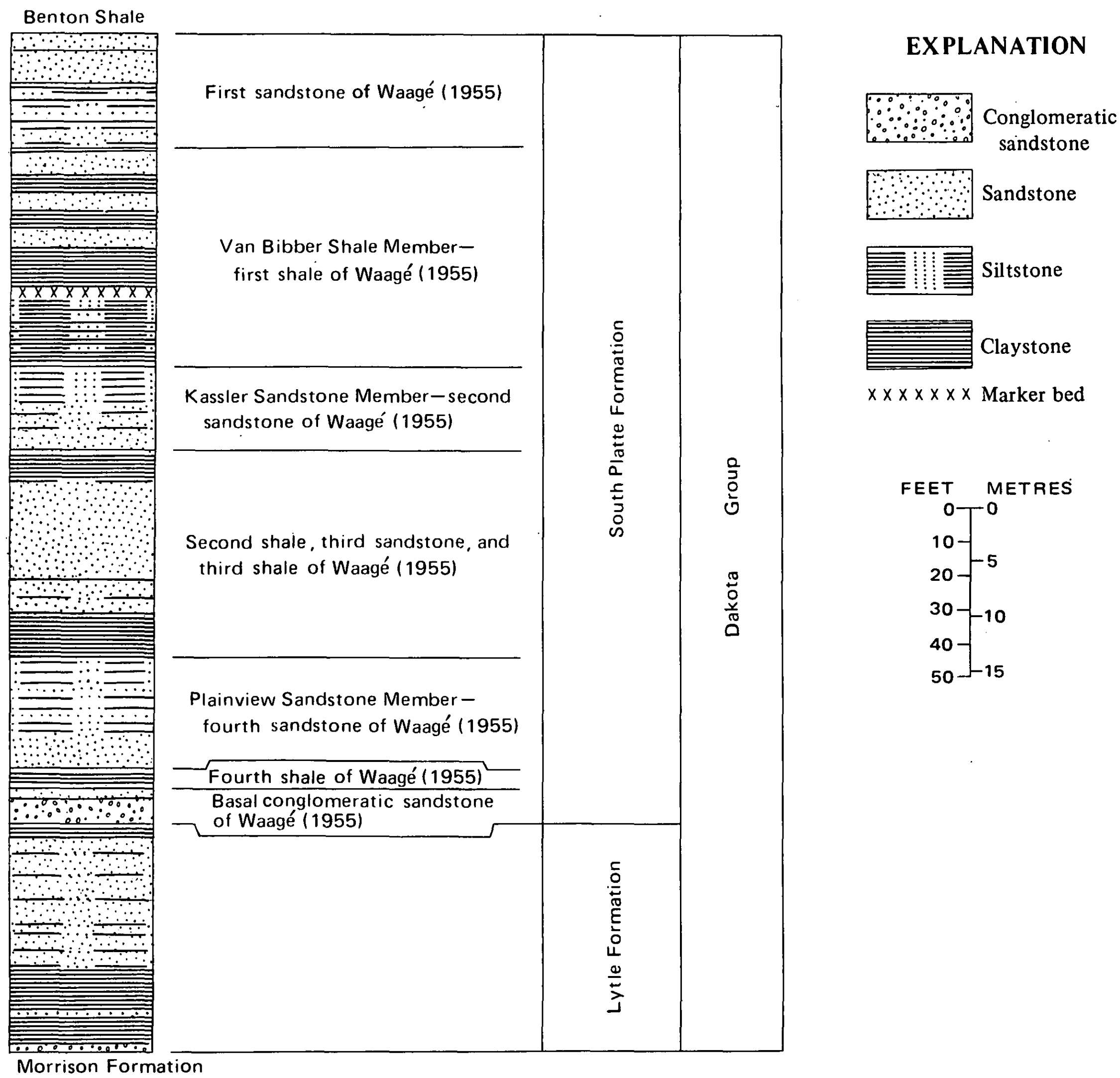


FIGURE 7.—The Dakota Group showing the lithology and the nomenclature used in the text.

appear massive although they are locally crossbedded. At many places they have yellowish-brown ferruginous spots as large as one-quarter inch in diameter. Sandstone and siltstone beds in the upper part of the Dakota are crossbedded and ripple marked at many places. Ripple marks are particularly well exposed along the sinuous scar on the bed forming the footwall of the clay mine between Tucker Gulch and Van Bibber Creek. The top of the Dakota is composed of a thick, light-gray, medium- to fine-grained, quartzose sandstone.

Prominent jointing is also well exposed in the clay mine. The joints are spaced from 6 inches to 12 feet apart, are nearly vertical and perpendicular to bedding, and form planes of weakness along which blocks of sandstone tend to break. Where exposed in clay mines a few hundred feet below the ground surface, the joints appear to be tight even though some are slightly offset. The joints are most closely spaced where the Dakota is near the Golden fault just north of Tucker Gulch; they are more widely spaced to the north where the fault is farther east. Several small faults, virtually parallel to the joints, are also exposed in the old clay workings.

Claystone beds, though generally covered, form a large part of the Dakota. Those in the South Platte Formation are generally dark gray and weather into small, roughly cubical blocks. The claystone in the Lytle Formation is commonly greenish gray but is otherwise similar in appearance to the claystone above. Clay-mineral determinations reported by Keller (1953, p. 93) and Waagé (1961, p. 12 and 23) indicate that kaolinite is probably the predominant clay mineral in the Dakota of the Golden area, although montmorillonite and illite are also present.

FIGURE 8.—Southwestward view of the hogback of the Dakota Group north of Tucker Gulch. The nearly accordant ridges of the Precambrian metamorphic rocks of the Front Range, in the background, result from late Tertiary erosion. The white scars on the hogback of the Dakota Group, in the middle distance, are the result of mining of refractory clayrock in the Dakota. A similar scar can be seen on the small knoll of Laramie Formation, just to right of the most distant ranchhouse, which resulted from open-pit mining of refractory clayrock. The high grass-covered hill shown near the center of the right side of the picture is a monzonite intrusive of Paleocene age. The dark-gray gullied scar on its left side is the result of mining Pierre Shale for use as expanded aggregate. The mottled dark- and light-gray artificial fill shown at the center of the left side of the picture is barnyard manure. Photograph by H. E. Malde, U.S. Geological Survey, taken June, 1, 1971.

The second shale, which is near the middle of the South Platte Formation, is a mixture of kaolinite and illite (Waagé, 1961, p. 33).

The relation of the Dakota Group to the underlying Morrison is not clear in this area: both formations consist of lithologically similar sandstone and mudstone near the contact, the principal difference being the interstitial blebs of white clay in the sandstone of the Morrison. Beds of sandstone in the Dakota are more abundant and slightly thicker than in the Morrison, and they do not contain interstitial clay. No unconformity was seen between the formations, although Waagé (1955, p. 23) indicated that the contact is marked by an unconformity both north and south of the Golden quadrangle.

AGE

No fossils have been reported from the Lytle Formation, but Waagé (1961, p. 10) indicated that it is probably equivalent to the part of the Cloverly Formation of Wyoming that contains Early Cretaceous nonmarine fossils. Very few fossils have been reported from the South Platte Formation in this area. Tracks of *Ignotornis mcconnelli* Mehl (a bird), *Walteria jeffersonensis* Mehl (a web-footed quadruped), and (?)*Anomoepus* sp. (probably a bipedal dinosaur) from the Dakota between Tucker Gulch and Van Bibber Creek have been reported by Mehl (1931, p. 441–452). Fossils found in the Denver area are principally land plants but also include dinosaur tracks, fish scales, and some poorly preserved casts of bivalves from the uppermost sandstone (Johnson, 1931, p. 358–360). Marine fossils, chiefly *Inoceramus comancheanus* Cragin (Early Cretaceous), have been reported in the Golden area by Waagé (1961, p. 78) from his second shale near the middle of the South Platte Formation.

ORIGIN

The Lytle is similar to the Morrison Formation and is undoubtedly of terrestrial origin. Most of the fossils in the South Platte Formation indicate a terrestrial origin except for the marine pelecypod *Inoceramus comancheanus* (Waage, 1961, p. 41). Utilizing these meager paleontologic and lithologic data, Waage (1961, p. 93–96) proposed a deltaic origin for the South Platte Formation in the vicinity of Golden. The marine fossils in the second shale of Waage (1955) indicate a transgression of the sea across the delta, but deltaic conditions resumed with the advent of the overlying Kassler Sandstone Member and continued for the remainder of the Dakota deposition.

BENTON SHALE

The Benton Shale, about 500 feet thick, is principally shale, but contains thin beds of bentonite, siltstone, and limestone. North of Tucker Gulch it is exposed in a few places east of the hogback formed by the Dakota Group, but south of the gulch it is cut out by the Golden fault. One outcrop in the north bank of Tucker Gulch (see fig. 51) shows Benton sandwiched between the Dakota (not visible in fig. 51) to the east and Fountain to the west.

The outcrop is narrower, perhaps as a result of faulting, south of Van Bibber Creek than it is north of the creek. The mapped distribution of the shale south of Van Bibber Creek is based on a single, small, poorly exposed outcrop of limestone that crops out about 1 mile north of Tucker Gulch. The limestone is believed to be part of the Fort Hays Limestone Member of the Niobrara Formation. Possibly the southeast-trending fault that crosses the Dakota at Van Bibber Creek trends more southerly and is a strike fault cutting out part of the Benton. If so, this indicates that the fault is vertical or dips eastward and that the rocks east of the fault have been moved upward relative to those west of the fault.

An excellent exposure along the bank of Ralston Reservoir, in the adjoining Ralston Buttes quadrangle, the paleontologic and lithologic equivalents of the widely used subdivisions of the Benton Group—in ascending order, the Graneros Shale, Greenhorn Limestone, and Carlile Shale—were recognized. Within the limits of the Greenhorn Limestone the equivalents of the Lincoln Limestone Member, Hartland Shale Member, and Bridge Creek Limestone Member were also recognized. The Benton Shale is poorly exposed in the Golden quadrangle, so these equivalents are only discussed in generalized form in this report. A more detailed discussion and a measured section at Ralston Reservoir are given in an earlier report (Van Horn, in Sheridan and others, 1967, p. 48–49).

GRANEROS SHALE EQUIVALENT

The lower 180 feet of the Benton—the Graneros Shale equivalent—is principally dark-gray, noncalcareous, clayey shale which weathers into a multitude of flat flakes. The shale beds are generally about 3 feet thick but are as much as 40 feet thick at places. The shale is interbedded with 0.1- to 1-foot-thick beds of blocky-weathering siltstone. The siltstone is calcareous at places; it is dark yellowish brown in the upper part and dark to medium gray in the lower part. X-ray examination of a shale sample from the Graneros (unit 119 of measured section of Van Horn, in Sheridan and others, 1967, p. 49) of the Ralston Buttes quadrangle showed major amounts of quartz, minor amounts of kaolinite, mica, and chlorite, and traces of feldspar (table 4).

GREENHORN LIMESTONE EQUIVALENT

The middle part of the Benton—the Greenhorn Limestone equivalent—is about 260 feet thick. Like the lower part, the middle is principally noncalcareous, fissile, clayey shale, but unlike the lower part it is black to light gray. The beds are generally about 3 feet thick but are much thicker at places. Very distinctive beds of very light bentonite, generally less than 1 foot thick, are interbedded with the shale in the lower 140 feet. At most places the bentonite beds have been stained pale yellowish orange. No clay mineral tests were made of the bentonite, but according to J. L. Stout (LeRoy and Schieltz, 1958, p. 2459) it is probably montmorillonite. A few thin medium- to yellowish-gray limestone beds are present in this part of the section. The upper 120 feet of the Greenhorn equivalent is principally black to light-gray, fissile shale. Throughout the upper 120 feet some very thin hard calcareous bands or lenses are present, and near the base are two limestone beds.

CARLILE SHALE EQUIVALENT

The upper 70 feet of the Benton Shale—the Carlile Shale equivalent—is principally medium-dark-gray noncalcareous siltstone, but includes a few thin beds of fine-grained sandstone.

Mineral determinations were made of two samples that were not precisely located within the Benton. X-ray analysis of a sample from the fault zone in Tucker Gulch showed major amounts of kaolinite, minor amounts of mica and chlorite, and traces of quartz, feldspar, and dolomite(?). The coarse fraction of this sample, examined with a binocular microscope, was almost entirely sand- and silt-sized aggregates of clay particles. It also contained less than 1 percent mica flakes, discus-shaped gypsum particles that were finely striated, and rounded to subangular, clear to frosted quartz grains. A sample of Benton from the vicinity of Golden is reported to contain 40 percent illite and 10 percent kaolinite (Mielenz and others, 1951, footnote 13, p. 323). It is interesting to note that none of the three samples of shale from the Benton shown in table 4 contains montmorillonite.

At Ralston Creek the ripple-marked upper surface of the top part of the Dakota Group is overlain by minutely crossbedded siltstone, about 12 feet thick, of the Benton

Shale. These transitional siltstone beds pass laterally into the typical black shale of the Benton which overlies the Dakota in most of the Golden quadrangle.

AGE AND ORIGIN

No fossils were found in the Benton of the Golden quadrangle. Marine fossils were reported by Van Horn (in Sheridan and others, 1967, p. 42) from the Greenhorn Limestone equivalent. According to W. A. Cobban (written commun., Oct. 27, 1954) the fossils indicate a Late Cretaceous age (Cenomanian and Turonian) for this part of the Benton. The entire formation is undoubtedly of marine origin.

NIOBRARA FORMATION

The Niobrara Formation, about 350 feet thick, is composed of the Fort Hays Limestone Member and the overlying Smoky Hill Shale Member. Both members contain abundant Foraminifera which were noted but not identified. The measured section of locality G25A–D included in this report is a continuation of the previously published measured sections of Paleozoic and Mesozoic rocks in the adjoining Ralston Buttes quadrangle (Van Horn, in Sheriden and others, 1967). Bed 180 (G25–A) of the present report immediately overlies bed 179 of the earlier report along the northwest shore of Ralston Reservoir.

The earliest study of the Niobrara in the Golden area used a threefold division of the formation (Emmons and others, 1896, p. 66–69). The lower division is equivalent to the Fort Hays Limestone Member, and the middle and upper divisions are equivalent to the Smoky Hill Shale Member. Later workers, using terminology applied to the Niobrara in southeastern Colorado, called the lower limestone division the Timpas Limestone and the upper two divisions the Apishapa Shale. The Timpas, at its type locality, includes more than the lower division limestone, so the term was misapplied in the Denver area. The Timpas and Apishapa have been abandoned everywhere in favor of Fort Hays and Smoky Hill, respectively (Scott and Cobban, 1964).

FORT HAYS LIMESTONE MEMBER

The Fort Hays Limestone Member, about 28 feet thick, is 78 percent limestone and 22 percent shale. It occurs north of Tucker Gulch and east of the hogback of the Dakota Group, where it generally forms a small bench between the Benton Shale and the Smoky Hill Shale Member. South of Van Bibber Creek only one outcrop of limestone was seen and that was a poorly exposed outcrop located about 1 mile north of Tucker Gulch. North of Van Bibber Creek there are several good exposures in abandoned limestone quarries.

The Fort Hays is principally medium- to yellowish-gray, hard, dense limestone. Individual limestone beds are as much as 2 feet thick but are generally about 1 foot thick. They are interbedded with medium-dark-gray, calcareous shale beds that are about 0.3 foot thick. Fragments of *Pseudoperna* and *Inoceramus* are abundant at some places in the member, and are particularly noticeable on weathered surfaces. Large fish teeth are also present and are most abundant in the shaly limestone bed at the base.

No evidence of an unconformity between the Niobrara Formation and the underlying Benton Shale was noted in the Golden quadrangle, although there is certainly an abrupt lithologic boundary between the siltstone of the Benton and the overlying limestone of the Niobrara. An unconformity, or at least a diastem, between these units in eastern Colorado was reported by Johnson (1930a).

AGE AND ORIGIN

The fossil *Inoceramus deformis* Meek (fossil loc. 1; USGS Mesozoic loc. D17) was collected from near the middle of the member a short distance north of measured section G25–A. This fossil, according to W. A. Cobban (written commun., Oct. 27, 1954), marks the lower part of the Niobrara Formation and equivalent rocks over the entire western interior region, and is of Late Cretaceous age. The Fort Hays is of marine origin.

SECTION G25–A.—*Fort Hays Limestone Member of the Niobrara Formation*

[Measured on the northwest side of Ralston Reservoir, Golden quadrangle; location shown in fig. 3. Tr., Trace]

	Thickness (ft)
Niobrara Formation:	
Smoky Hill Shale Member, unit 231.	
Fort Hays Limestone Member:	
230. Limestone, medium- to yellowish-gray, dense; abundant fragments of *Inoceramus* and *Pseudoperna* are exposed on weathered surface	0.5
229. Shale, medium-dark-gray, calcareous	2.0
228. Limestone, medium- to yellowish-gray, dense	.4
227. Shale, medium-dark-gray, calcareous	.4
226. Limestone, medium- to yellowish-gray, dense	.3
225. Shale, medium-dark-gray, calcareous	.5
224. Limestone, medium- to yellowish-gray, dense	.3
223. Shale, medium-dark-gray, calcareous	.2
222. Limestone, medium- to yellowish-gray, dense; attitude N. 1° W., 57° E	1.0
221. Shale, medium-dark-gray, calcareous	.2
220. Limestone, medium- to yellowish-gray, dense	1.6
219. Shale, medium-dark-gray, calcareous	.1
218. Limestone, medium- to yellowish-gray, dense	.3
217. Shale, medium-dark-gray, calcareous	.4
216. Limestone, medium- to yellowish-gray, dense. Los Angeles Abrasion loss is 24.4 percent	2.1
215. Shale, medium-dark-gray, calcareous	.1
214. Limestone, medium- to yellowish-gray, dense	.9
213. Shale, medium-dark-gray, calcareous	Tr.
212. Limestone, medium- to yellowish-gray, dense	.7
211. Shale, medium-dark-gray, calcareous	.1
210. Limestone, medium- to yellowish-gray, dense	.4
209. Shale, medium-dark-gray, calcareous	.1
208. Limestone, medium- to yellowish-gray, dense	.1
207. Shale, medium-dark-gray, calcareous	.1
206. Limestone, medium- to yellowish-gray, dense	1.5
205. Shale, medium-dark-gray, calcareous	.1

	Thickness (ft)
Niobrara Formation—Continued	
Fort Hays Limestone Member—Continued	
204. Limestone, medium- to yellowish-gray, dense	1.0
203. Shale, medium-dark-gray, calcareous	.2
202. Limestone, medium- to yellowish-gray, dense	.7
201. Shale, medium-dark-gray, calcareous	.3
200. Limestone, medium- to yellowish-gray, dense	.3
199. Shale, medium-dark-gray, calcareous	Tr.
198. Limestone, medium- to yellowish-gray, dense; some stylolitic structure	1.0
197. Shale, medium-dark-gray, calcareous	.2
196. Limestone, medium- to yellowish-gray, dense	1.1
195. Shale, medium-dark-gray, calcareous	.1
194. Limestone, medium- to yellowish-gray, dense; some ferruginous concretions, as much as ½ by 1½ in	1.3
193. Shale, medium-dark-gray, calcareous	.1
192. Limestone, medium- to yellowish-gray, dense	2.2
191. Shale, medium-dark-gray, calcareous	Tr.
190. Limestone, medium- to yellowish-gray, dense	.8
189. Shale, medium-dark-gray, calcareous; contains thin limestone lentils as much as 4 ft long	.2
188. Limestone, medium- to yellowish-gray, dense; contains some stylolitic structures	1.3
187. Shale, medium-dark-gray, calcareous	.1
186. Limestone, medium- to yellowish-gray, dense; contains ferruginous concretions as much as ½ by 2 in	.9
185. Shale, medium-dark-gray, calcareous	.1
184. Limestone, medium- to dark-gray, dense	.2
183. Shale, medium-dark-gray, calcareous	.5
182. Limestone, yellowish-gray, shaly	.4
181. Shale, medium-dark-gray, calcareous	.2
180. Limestone, yellowish-gray, shaly; numerous fish teeth	.5
Note: The Fort Hays is very fossiliferous and contains numerous microfossils as well as macrofossils. *Inoceramus deformis* is diagnostic of the Fort Hays and is abundant throughout this outcrop.	
Total Fort Hays Limestone Member	28.1
Total Niobrara Formation	347.1
Benton Shale, unit 179 of Van Horn (in Sheridan and others, 1967, p. 48).	

SMOKY HILL SHALE MEMBER

The Smoky Hill Shale Member of the Niobrara Formation, about 320 feet thick, is composed of shale, chalk, and bentonite. It is present east of the bench formed by the Fort Hays north of Tucker Gulch but is poorly exposed at most places.

The Smoky Hill is principally composed of light- to yellowish-gray calcareous fissile shale. Illite and montmorillonite are the predominant clay materials in the shale beds of the upper part of the member (LeRoy and Schieltz, 1958). Two persistent thin-bedded chalk beds are present in the Smoky Hill—a 25-foot-thick light-gray chalk bed 150 feet above the base, and a 5-foot-thick medium-bluish-gray to yellowish-gray chalk bed 260 feet above the base. Thin layers of bentonite and selenite are present at some places. The clay minerals of three bentonite beds in the upper part of the Smoky Hill were determined by Schieltz (LeRoy and Schieltz, 1958); the upper two contain over 70 percent montmorillonite, whereas the lower bed (average of the three samples shown by Schieltz on p. 2456 and 2458) contains about 50 percent kaolinite and 20 percent montmorillonite. The top of the Smoky Hill is placed at the top of the thick sequence of yellowish-gray-weathering highly calcareous shales. Beds overlying the Smoky Hill are very weakly calcareous or noncalcareous shales that weather to a medium gray or light brown. The contact between the Smoky Hill and the underlying Fort Hays is conformable.

Age and Origin

The Late Cretaceous age of the Smoky Hill is determined by its stratigraphic position between the Fort Hays and the Pierre Shale, both of Late Cretaceous age. Marine fossils were found at two places in the upper chalk. Fossil locality 2 of the geologic map (Van Horn, 1972) (unit 235 of measured section G25-B) contained large, smooth *Baculites* sp. (USGS Mesozoic loc. D18) that is encrusted with 10 individuals of the very rare barnacle *Stramentum haworthi* (Williston). J. B. Reeside, Jr. (written commun., Sept. 14, 1954), who identified the barnacle, stated that all the specimens previsously recorded came from the Smoky Hill Chalk Member of Kansas. Fossil locality 3 (USGS Mesozoic loc. D641) contained both of these species as well as *Pseudoperna congesta* (Conrad). The fossils all indicate a marine origin.

Section G25-B.—*Smoky Hill Shale Member of the Niobrara Formation*
[Measured on the northwest side of Ralston Reservoir, Golden quadrangle; location shown in fig. 3]

	Thickness (ft)
Pierre Shale, unit 237.	
Niobrara Formation:	
Smoky Hill Shale Member:	
236. Shale, dusky-yellow, calcareous	55
235. Chalk, medium-bluish-gray to grayish-yellow; 1- to 6-in. beds, forms persistent outcrop in vicinity of Ralston Reservoir. Fossil collection D-18 (map locality 2) contained a portion of a large straight cephalopod. Attitude N. 5° W., 75° W	5
234. Shale, light-gray, grayish-yellow, light-greenish-gray, and light- and moderate-brown, calcareous. Contains thin bentonite and selenite layers	12
233. Shale, grayish-yellow, calcareous	70
232. Chalk, light-gray; 1- to 4-in. beds	25
231. Shale, grayish-yellow, calcareous	152
Total Smoky Hill Shale Member	319
Fort Hays Limestone Member, unit 230.	

PIERRE SHALE

The Pierre Shale is predominantly shale but includes some relatively thick siltstone and silty sandstone beds. The Pierre crops out in the western part of the quadrangle from the southern to the northern boundaries. It has been folded, faulted, and intruded by mafic monzonite. As a result of these structural complications the outcrop width ranges from a few hundred feet in the southern part of the quadrangle to several thousand feet in the central and northern parts.

The contact between the yellowish-gray Smoky Hill Shale Member and the overlying olive-gray Pierre Shale is well exposed along the northwest shore of Ralston Reservoir. Here the Smoky Hill is strongly calcareous whereas the Pierre is weakly calcareous or noncalcareous. Except for the marked lithologic change, the contact appears conformable. A hiatus between the two formations, however, has been indicated by Reeside (1957, table 1 and fig. 16) and by LeRoy and Schieltz (1958, p. 2463). This hiatus is indicated by the sharp change in color and lithology between the two formations in the Golden quadrangle.

FOSSIL ZONES

Most of the structures shown in the Pierre are based on the mapping of fossil zones—stratigraphic zones ranging in thickness from a few feet to several hundred feet, throughout which a particular fossil or commonly associated fossils are found. These zones do not represent exact stratigraphic horizons as single beds of volcanic ash do; instead, the particular fossil, or commonly associated fossils, are found throughout a stratigraphic zone ranging in thickness from a few feet to several hundred feet. They are, however, mutually exclusive in that any one diagnostic fauna does not occur in underlying or overlying zones, with the exception of the zone of *Inoceramus typicus*, which has been found to extend into the underlying zones of *Baculites eliasi* at places outside the Golden quadrangle. For reasons explained in the description of the *Inoceramus typicus* zone, the zone of *I. typicus*, rather than the more conventionally used zone of *Baculites baculus*, is shown on the geologic map (Van Horn, 1972). On that map the zone lines are drawn on the stratigraphically highest occurrence of the diagnostic fauna; thus they approximate an exact stratigraphic position and can be used for structural and stratigraphic control. Table 2 shows the names, thicknesses, and cumulative height of zones above the base of the Pierre.

The thickness of beds between the fossil zones and distances above the base of the Pierre Shale given in the following paragraphs are not exact dimensions, but are reasonable approximations based on measured sections and on computed sections. The computed sections were determined by plotting attitudes of beds and locations of fossil zones on the geologic map (Van Horn, 1972). These data were used to compute true thicknesses of beds between fossil zones using the distances measured from the map. There is no place in the quadrangle where a single section undisturbed by faulting, or containing clearly delineated fossil zones, can be used to determine the thickness of all the zones. Therefore, the composite thickness of each zone (see table 2) was determined by comparison with thickness

TABLE 2.—*Thickness (in feet) of beds between fossils zones of the Pierre Shale*
[Leaders (...) indicate no data]

Locality	Denver and Rio Grande Western Railroad[1]		North parts secs. 28 and 29, T. 2 S., R. 70 W.[1]		Ralston Creek and reservoir at locality G25-C		North parts secs. 8, 9, and 10, T. 3 S., R. 70 W.		Composite	
Thickness to	Underlying zone	Base of Pierre	Underlying zone	Base of Pierre	Underlying zone	Base of Pierre	Underlying zone	Base of Pierre	Underlying zone	Base of Pierre
Top of Pierre Shale	1,010	7,580	860	6,750	[2]625	[2]4,645	1,025	5,010	1,000	7,250
Baculites clinolobatus	320	6,570	470	5,890	[2]610	[2]4,020	...	...	350	6,250
grandis	360	6,250	[2]510	[2]5,420	...	...	[3]480	3,985	360	5,900
Inoceramus typicus	1,450	5,890	700	4,910	...	...	320	3,505	1,450	5,540
Baculites eliasi	470	4,440	600	4,210	350	3,410	[2]700	[2]3,185	550	4,090
reesidei	40	3,970	380	3,610	[2]500	[2]3,060	...	...	40	3,540
compressus	300	3,930	...	...	...	...	...	...	340	3,500
Didymoceras cheyennense	260	3,630	1,050	3,230	...	...	900	2,485	260	3,160
Exiteloceras jenneyi	1,100	3,370	...	...	...	...	...	...	[3]200	2,900
Didymoceras stevensoni	...	...	...	...	400	2,560	...	...	400	2,700
nebrascense	...	...	...	...	400	2,160	...	...	400	2,300
Baculites scotti	100	2,270	430	2,180	200	1,760	475	1,585	200	1,900
n. sp.	220	2,170	...	...	250	1,560	...	...	250	1,700
gregoryensis	[2]1,250	[2]1,950	[2,3]800	[2]1,750	200	1,310	200	1,110	200	1,450
gilberti	...	...	[3]500	950	580	1,110	310	910	[3]600	1,250
asperiformis	...	...	...	...	...	...	100	600	100	650
maclearni	700	700	450	450	130	530	150	500	175	550
obtusus	...	...	...	...	400	400	350	350	375	375
Base of Pierre Shale	0	0	0	0	0	0	0	0	0	0

[1]Lower part from Van Horn (in Sheridan and others, 1967).
[2]A fault is present between this and the next underlying zone; therefore, the thickness may be abnormal.
[3]Poor control.

of other zones or, where one or more zonal boundaries could not be effectively located, with thickness of several zones. As an example, the thickness between the *Baculites maclearni* zone and the *B. obtusus* zone was determined in the following way. At one place the thickness is 130 feet and at another it is 150 feet (table 2). At these places the *B. obtusus* zone is 400 and 350 feet, respectively, stratigraphically above the base of the Pierre (an average of 375 ft). At two other places the thickness between the same two baculite zones could not be determined directly, but the thickness from the *B. maclearni* zone to the base of the Pierre was 700 and 450 feet. At these two places the average thickness between *B. obtusus* and the base of the Pierre (375 ft) subtracted from 700 and 450 gives an approximate thickness of 325 and 75 feet of beds between *B. maclearni* and *B. obtusus* zones. When these are added to the two direct measurements of 130 and 150 feet and the sum is divided by four the average thickness between the two fossil zones is 170 feet, which is rounded to 175 feet in table 2. In this fashion the thickness of beds between each fossil zone was determined; in some places the possible effect of structure was considered and in other places thickness determined from isolated exposures not shown in table 2 also tempered my judgment. Thus, the thicknesses shown in the composite columns of table 2 are interpretations based on measurements given in the other columns of the table and on the geologic map (Van Horn, 1972). This blend of information gives an approximate thickness of 7,250 feet of Pierre Shale. This thickness is in close agreement with that reported in the well log of the S. D. Johnson 1 Farmers Highline Canal and Reservoir Co. well (American Stratigraphic Co., 1956), which, after correction for a 2° dip, gives a thickness of 7,240 feet for the Pierre.

The fossil localities and zone lines are shown on the geologic map (Van Horn, 1972), but the fossils are listed in table 3 of the present report.

Four poorly defined major lithologic units can be recognized in the Pierre. In ascending order these are the lower shale unit (about 1,200 ft thick), lower sandstone unit (700 ft), upper shale unit (4,300 ft), and upper transition unit (1,000 ft). These are comparable to the lithologic units described by Scott and Cobban (1965), except that in the Golden quadrangle the boundary between the two middle units is placed 1,500 feet nearer the base of the section, at the top of the Hygiene Sandstone Member. The relation of various lithologic subdivisions of the Pierre Shale is shown in figure 9.

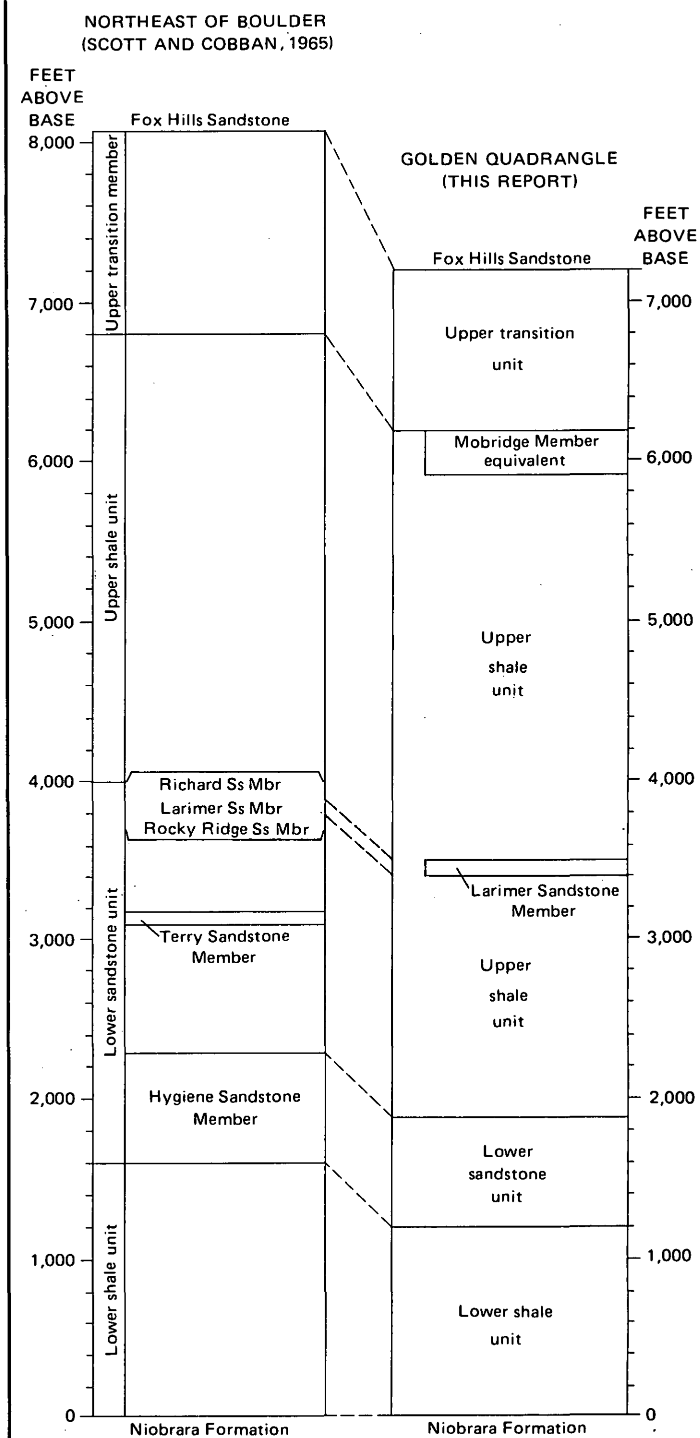


FIGURE 9.—Lithologic subdivisions of the Pierre Shale near Golden.

LOWER SHALE UNIT

The lower 1,200 feet of the Pierre is olive-gray, clayey, noncalcareous to slightly calcareous fissile shale. A few thin beds of bentonite are interbedded with the shale, and a few small selenite crystals are present in the lower 100 feet. Illite is the dominant clay mineral in the shale of this part of the Pierre (LeRoy and Schieltz, 1958, p. 2457). Montmorillonite, which is dominant in the thin bentonite beds, is also present in small amounts in the shale.

Baculites obtusus Meek was found at one locality (see table 3, D832) about 400 feet above the base of the Pierre. At this place the fossil is in light-olive-gray to dark-reddish-brown, finely crystalline, silty, calcareous concretions. *Baculites maclearni* Landes is present at two localities (see table 3) 500–600 feet above the base of the Pierre; at a locality in the Ralston Buttes quadrangle, it is present about 700 feet above the base. The fossil occurs in hard calcareous concretions and is associated with cone-in-cone structure. A single, isolated fossil locality (table 3) yielded *Baculites asperiformis* Meek at a stratigraphic horizon about 600 feet above the base of the Pierre. The fossil is younger than *B. maclearni* according to W. A. Cobban (oral commun.). *Baculites gilberti* Cobban is found near the top of the lower part of the Pierre, about 900–1,200 feet above the base. Some of these fossils weather out of shale and appear phosphatic, whereas others are associated with hard calcareous concretions. Two thin monzonite dikes intrude the shale on the west side of the Ralston Reservoir in the *Baculites gilberti* zone. These dikes could be traced for only a short distance, and the outcrop is entirely below the high-water level of the reservoir.

LOWER SANDSTONE UNIT

The lower sandstone unit, about 700 feet thick, is principally siltstone, silty shale, and sandstone. The upper and lower boundaries are poorly defined. The unit overlies the lower shale unit and is much more arenaceous than the rest of the Pierre. It is partially exposed on the northwest side of Ralston dike, along the north edge of Ralston Reservoir, and west of Rocky siding on the Denver and Rio Grande Western Railroad. At these places the unit is interbedded silty shale and sandy siltstone, and near the top it contains a 50-foot-thick silty sandstone.

The lower sandstone unit is equivalent to the Hygiene Sandstone Member of Fenneman (1905, p. 31) which, according to Scott and Cobban (1959, p. 126), contains *Baculites gregoryensis* Cobban and *Baculites scotti* Cobban. The lowest fossils indicative of the zone of *Baculites gregoryensis* Cobban are about 1,300 feet above the base of the Pierre. These commonly occur in medium-gray, finely crystalline calcareous concretions, which weather light gray to moderate yellowish brown and contain sparse grains of green glauconite.

The next highest fossil zone, the *Baculites* n.sp. zone, is in a light-olive-gray silty to sandy shale containing some moderate-yellowish-brown-weathering thin sandstone beds and ironstone concretions. This is overlain by the *Baculites scotti* zone, the top of which is about 1,900 feet above the base of the Pierre. This zone is principally siltstone and sandstone, and the fossils weather from sandy beds or are in concretions. The sandy beds are light-gray fine-grained sandstone or sandy siltstone that weather moderate reddish brown and contain small amounts of green glauconite and unidentified rounded black blebs. The concretions are finely crystalline, calcareous, and generally sandy; they are dark gray but weather moderate yellowish orange. The upper 50 feet is marked by massive to indistinctly and minutely crossbedded light-gray sandstone that locally is mottled dark gray and contains small particles of carbonaceous material at places.

UPPER SHALE UNIT

The upper shale unit of the Pierre Shale includes the fossil zones from *Didymoceras nebrascense* to *Baculites clinolobatus*. This unit, about 4,300 feet thick, is principally dark- to olive-gray clayey to sandy shale but contains some thin siltstone and sandstone beds. In the Golden quadrangle the lower 1,500 feet of the upper shale unit includes the upper part of the lower sandstone unit of Scott and Cobban (1965). (See fig. 9.) This part of the Pierre, which is very sandy north of Boulder, is principally shale in the Golden quadrangle. This change in lithology probably represents a shaling up of the sandy interval and possibly is related to the distance from the shoreline. Some of the sandstone beds, such as the Larimer Sandstone Member in the zone of *Baculites reesidei*, may extend relatively unchanged between Golden and Boulder. The fossil zones cut across this change in lithology, so that zones that are in the lower sandstone unit north of Boulder are in the upper shale unit near Golden.

In the lower part of this unit the zones of *Didymoceras nebrascense* (Meek and Hayden), *D. stevensoni* (Whitfield), *Exiteloceras jennyi* (Whitfield), and *D. cheyennese* (Meek and Hayden) are respectively about 2,300, 2,700, 2,900, and 3,160 feet above the base of the Pierre. The fossils are generally in medium- to dark-gray, hard, finely crystalline, calcareous concretions. The concretions weather to light gray and in places have a grainy appearance. The lower three fossil zones consist principally of noncalcareous shale but they also contain a few thin siltstone beds. The predominant clay mineral in the lower part of this unit is montmorillonite.

The zone of *Didymoceras cheyennense* is principally shale or sandy shale, some of which is calcareous. The fossils commonly are in hard, finely crystalline to dense, calcareous concretions. The concretions in the lower part are medium gray to dark reddish brown and contain minor amounts of unidentified small black blebs. Concretions in the upper part are light brown to olive gray and weather to a yellowish or moderate yellowish brown. They contain small amounts of sand-sized grains of quartz, greenish-gray glauconite, and unidentified black blebs. The blebs are larger and more abundant than in other zones.

The *Baculites compressus* zone, 3,500 feet above the base of the Pierre, and the *Baculites cuneatus* zone are poorly marked zones in which the fossils mainly weather out of shale, but also are present in concretions. The *Baculites cuneatus* zone is overlain by the *Baculites reesidei* zone, about 3,540 feet above the base of the Pierre. The *B. reesidei* zone is principally noncalcareous shale but, adjacent to Ralston Creek, it contains at least one 24-foot-thick bed of very fine grained silty sandstone (unit 246 of the measured section G25–C at Ralston Creek and fossil locality 44, D26). The sandstone was seen only for a few hundred feet north and east of Ralston dike; it is cut out to the north by a fault and to the south by Ralston dike. The sandstone is light gray (weathering dark yellowish orange), hard, and greatly fractured. It is composed principally of quartz grains but contains moderate amounts of an unidentified dark mineral and mica. It is possibly equivalent to the sandstone at 4,780 feet below the surface (3,710 ft above the base of the Pierre) in the S. D. Johnson 1 Farmers Highline Canal and Reservoir Co. well (American Stratigraphic Co., 1956). The fossils are in sandstone and siltstone and in concretions weathering out of shale. The siltstone is light gray to dark yellowish orange and generally sandy. The concretions are light to dark gray, silty and calcareous. According to Scott and Cobban (1959, p. 128), *Baculites reesidei* occurs in the Larimer Sandstone Member of the Pierre.

The succeeding 2,700 feet is principally clayey to silty, fissile shale but contains some thin beds of siltstone and sandstone. At places the shale is calcareous and contains hard calcareous concretions. The zone of *Baculites eliasi* Cobban, about 4,090 feet above the base of the Pierre, is marked by moderate-yellowish-brown to dark-gray calcareous concretions. They are dense to finely crystalline and have a sugary texture on weathered surfaces. The *Baculites baculus* zone is not shown as such on the geologic map (Van Horn, 1972), although it is shown in table 3, because no positively identified *Baculites baculus* was found in the Golden quadrangle. Instead a zone of *Inoceramus typicus* is shown, the top of which is approximately equivalent to the *Baculites baculus* zone of others (Scott, 1962, 1963b; Smith, 1964). Fossils in this zone generally are in yellowish-brown-weathering thin shaly limestone. Several outcrops of the limestone are present near the zone line of *Inoceramus typicus* in the salient of Pierre Shale southeast of Ralston dike. The upper part of the upper shale unit of the Pierre Shale contains the large *Baculites grandis* Hall and Meek. This fossil is present about 5,900 feet above the base of the Pierre. It was found weathering out of shale and also in hard, dense, calcareous concretions.

The zone of *Baculites clinolobatus*, as shown on the geologic map (Van Horn, 1972), forms the least satisfactory zone as a stratigraphic horizon marker. This zone could not be drawn so as to remain a relatively constant distance from the underlying *Baculites grandis* zone and the overlying Fox Hills Sandstone. This lack of uniformity is probably due to a combination of a thick, sparsely fossiliferous zone and faulting. Fossils indicative of the *Baculites clinolobatus* zone are present in the narrow band of Pierre shown in the southern part of the quadrangle. A silty sandstone at fossil locality D28[1] (south of Clear Creek) contains both *Baculites clinolobatus* Elias and *Tenuipteria fibrosa* (Meek and Hayden). The *T. fibrosa*, which is found only in this zone, was also found near the east end of the salient of Pierre southeast of Ralston dike. *Baculites clinolobatus* Elias is the guide fossil to the Mobridge Member of South Dakota of the Pierre which is equivalent to the *Baculites clinolobatus* zone of this report.

UPPER TRANSITION UNIT

The upper 1,000 feet of the Pierre is principally silty shale but contains many siltstone and silty sandstone beds. These coarser grained beds generally form thin interbeds between thicker shale beds but at places are as much as 10 feet thick. Mineral analyses by A. J. Gude III (see table 4) of eight samples from shale and siltstone beds in the upper part of the Pierre showed that both rock types contained, among other minerals, montmorillonite, kaolinite, and small amounts of illite and dolomite. An analysis by F. A. Hildebrand of a ninth sample (siltstone) showed montmorillonite, kaolinite, and small amounts of a mica-type mineral. Montmorillonite is the predominant clay mineral.

At Ralston Creek *Sphenodiscus* sp. (fossil locality D27[1], unit 248 of the measured section G25–C at Ralston Creek) was found in a silty shale in the upper 50 feet of the Pierre. According to W. A. Cobban (written commun., Oct. 27, 1954), this form is not known to exist in rocks older than the Mobridge Member of the Pierre Shale of South Dakota, although it is found in the Fox Hills Sandstone. Species of *Sphenodicus* are also present in the Fox Hills Sandstone of other areas.

AGE

The fossils collected from the Pierre Shale were identified by W. A. Cobban (written commun.), who stated that they are of Late Cretaceous age (Campanian and Maestrichtian).

ORIGIN

The fossils found in the Pierre Shale of the Golden quadrangle (table 3) all indicate a marine origin for this unit. The many siltstone and sandstone beds, some of which contain small amounts of finely divided plant remains, probably indicate a relatively shallow sea with land areas not too far distant.

[1]The fossil-collection localities table in Van Horn (1972) should be corrected to show that Map. No. 79 is USGS Mesozoic Locality D-28, 80 is D-27, and 81 is D-835.

SECTION G25-C.—*Pierre Shale*

[Measured on both sides of Ralston Reservoir and Ralston Creek, Golden quadrangle. Line of section shown in fig. 3]

	Thickness (ft)
Fox Hills Sandstone, unit 249.	
Pierre Shale:	
248. Shale, medium-gray, silty; fossil locality D27, map locality 80, *Sphenodiscus* sp. 30 ft below top, light-brown stains common. Contains numerous 0.1- to 0.2-ft-thick soft siltstone beds	40
247. Covered; sporadic outcrops of shale	1,525
246. Sandstone, yellowish-gray, very fine grained, silty, hard, greatly fractured. Outcrops on east side of Ralston dike. Contains fossil collection D26, map locality 44 *Inoceramus* cf. *I. vanuxemi* Meek and Hayden which appears to be indicative of the *Baculites reesidei* zone	25
245. Covered, occasional outcrops of medium-gray shale. Contains some hard lenticular concretions. Fossil collections D25 and D734 (map localities 25 and 24) in zone of *Didymoceras stevensoni* 110 ft below the top. Base of this unit is marked by greatly fractured and faulted zone on strike with Ralston dike	630
244. Covered, probably shale. Shale adjacent to monzonite of Ralston dike is baked. The monzonite has a 3-in.-wide chilled border	430
243. Sandstone, light-gray mottled dark-gray, massive, silty, hard, and fine-grained. Contains carbonaceous material, probably plant fragments. Attitude N. 5° W., 59° E. Outcrops on west side of Ralston dike. Contains fossil collection D3450 (map locality 21) in zone of *Baculites scotti*	50
242. Shale, medium-gray to light-olive-gray, clayey, Contains hard lenticular yellow-weathering, sandy concretions on south side of reservoir. Attitude N. 5° W., 39° E., near base. On north side of Ralston Reservoir this unit has attitude of N. 4° W., 64° E	75
241. Siltstone, yellowish-gray, sandy. Weathers into rounded to hackly (angular, very irregular shape) ⅛- to 2-in. blocks. Contains a few calcareous concretions and fossil collection D776 (map locality 17) in the zone of *Baculites* n. sp. aff. *gregoryensis* Cobban	25
240. Siltstone, poorly exposed, light-olive-gray to yellowish-gray, sandy, soft. At places weathers to hackly shaped ⅛- to 2-in. blocks	270
239. Shale, olive-gray, clayey, very fissile. Contains phosphatic baculite casts and hard lenticular concretions in upper 100 ft. Contains two intersecting monzonite dikes in upper part. The shale contains some thin bentonitelike layers in the lower 500 ft. Fish jaw and oysters 10 ft above base. Fossil collections D20, D22, and D841 (map localities 8, 10, and 9) from the zone of *Baculites gilberti* in the upper 200 ft	740
238. Shale with cone-in-cone structure. Attitude of bedding is N. 2° E., 72° E. Fossil collection D842 (map locality 5) from the zone of *Baculites maclearni*	1
237. Shale, olive-gray, clayey, very fissile; selenite in lower 100 ft	485
Total Pierre Shale	4,296
Niobrara Formation, unit 236.	

SECTION G24-A.—*Pierre Shale*

[Measured in a prospect trench at locality G24 (fig. 3) in the SW¼ sec. 28, T. 3 S., R. 70 W. It is continuous with a section of the Fox Hills Sandstone measured at the same locality]

	Thickness (ft)
Fox Hills Sandstone, unit 24.	
Pierre Shale:	
23. Shale, light-olive-gray (5*Y* 5/2), clayey	0.5
22. Sandstone, grayish-orange (10*YR* 7/4), fine-grained	.5
21. Shale, light-olive-gray (5*Y* 5/2), clayey	.7
20. Sandstone, grayish-orange (10*YR* 7/4), fine-grained	.7
19. Shale, light-olive-gray (5*Y* 5/2), clayey	1.2
18. Sandstone, grayish-orange (10*YR* 7/4), fine-grained	.4
17. Shale, light-olive-gray (5*Y* 5/2), clayey	2.3
16. Sandstone, grayish-orange (10*YR* 7/4), fine-grained	1.4
15. Shale, light-olive-gray (5*Y* 5/2), clayey	1.0
14. Sandstone, grayish-orange (10*YR* 7/4), fine-grained	1.0
13. Shale, light-olive-gray (5*Y* 5/2), clayey	.7
12. Covered	9.7
11. Shale, light-olive-gray (5*Y* 5/2), clayey	5.0
10. Sandstone, grayish-orange (10*YR* 7/4), fine-grained	3.9
9. Shale, light-olive-gray (5*Y* 5/2), clayey	2.2
8. Sandstone, grayish-orange (10*YR* 7/4), fine-grained	2.1
7. Shale, light-olive-gray (5*Y* 5/2), clayey	1.3
6. Sandstone, grayish-orange (10*YR* 7/4), fine-grained	1.9
5. Shale, light-olive-gray (5*Y* 5/2), clayey	1.2
4. Sandstone, grayish-orange (10*YR* 7/4), fine-grained	.7
3. Shale, light-olive-gray (5*Y* 5/2), clayey	69.0
2. Siltstone, light-gray (*N*7) to light-brownish-gray (5*YR* 6/1), thin-bedded. Attitude N. 26° W., 65° W	25.4
1. Shale, light-olive-gray (5*Y* 5/2), clayey; base covered	7.1
Total Pierre Shale measured	139.9

FOX HILLS SANDSTONE

The Fox Hills Sandstone is present on the west side of the low discontinuous hogback of the Laramie Formation. It forms a narrow, north-trending band that extends across the Golden quadrangle. In the northern part of the area it is principally sandstone, about 60 feet thick, and becomes more shaly southward. In the vicinity of Golden, the Fox Hills is about 100 feet thick and contains more shale than sandstone. The beds dip steeply eastward in the northern part of the area; south of Ralston Creek, however, they generally are overturned and dip steeply westward. Foraminifera, present in a few shale beds, were the only fossils found in the Fox Hills.

The delineation of the contact between the Fox Hills and adjacent formations is rather arbitrary in the southern part of the Golden quadrangle. The shale in the Fox Hills is indistinguishable from shale in the Pierre. Shale in both formations, however, is fissile and generally grayish olive, whereas the clay or claystone in the overlying Laramie Formation is blocky and of a different color. Sandstone in the Fox Hills is generally grayish orange, silty, and fine grained. It is moderately to poorly cemented except at a few places where well-cemented zones form hard rounded concretions as much as a foot across. A more rounded outcrop, finer grain size, browner color, and a somewhat dirty look distinguish sandstone of the Fox

TABLE 4.—*Semiquantitative X-ray mineralogic determinations of samples from Upper Cretaceous formations in northeastern Colorado*

[Identified by A. J. Gude III except for loc. MS. The amounts indicated are relative only to other minerals in the same sample and should not be compared to other samples. For those determinations in which the minerals are reported in order of relative abundance, the most abundant are shown on the table by the number 1 and the less abundant minerals are shown by successively larger numbers. the letter designations, from most to least abundant, are: VA, very abundant; A, abundant; Mj, major amount; P, present; Mn, minor amount; Tr., trace; ?, questionably present Lithology: co., conglomerate; ss, sandstone; st, siltstone; ct, claystone; sh, shale]

Formation		Locality No.	Unit of measured sec.	Serial No.	Montmorillonite	Kaolinite	Mica-type mineral	Illite	Other minerals	Mica	Dolomite	Quartz	Calcite	Feldspar	Lithology	Remarks
Denver Formation		G23	70	....	VA	.....	.....	.....	Tr.	Tr.	.....	.....	.....	VA[1]	cl	
		G23	18	....	VA	.....	.....	.....	Tr.	Tr.	.....	.....	.....	VA[2]	ss	
		G23	2	....	A	.....	.....	.....	.....	Tr.	.....	VA	.....	Mn[2]	st	Duplicate samples.
		G23	2	....	Mj	.....	.....	.....	Tr.	Tr.	.....	VA	.....	P[1]	st	
Arapahoe Formation		G23	1	....	A	.....	.....	.....	Tr.	.....	.....	VA	Tr.	Mn[2]	st	
		L22	.....	....	VA	Tr.	.....	.....	Tr.	Tr.	.....	A	Tr.	Mn[1]	ss	
		L1	.....	....	.....	Tr.	.....	.....	.....	Tr.	.....	A	VA	.....	ss	
Dawson Formation		18	33	204,714	1	3	.....	2	.....	.....	.....	VA	.....	A	co	
		ECJ	3	207,203	Mn	Mn	.....	.....	.....	.....	Tr.	Mj	Tr.	Mj[2]	ss	
		ECI	7	207,204	Mj	Mj	.....	.....	.....	.....	Mn	Mj	.....	Mn[1]	ss	
		ECI	8	207,205	Mj	.....	.....	.....	.....	.....	.....	Mj	.....	.....	ct	
		ECH	10	207,206	Mj	Mn	.....	.....	.....	.....	.....	Mj	.....	Mj[2]	ct	
		ECG	12	207,207	.....	.....	.....	.....	Mn[3]	.....	.....	Mj	Mj	.....	ss	
Laramie Formation	Undifferentiated from younger to older	ECG	14	207,208	Mj	.....	.....	.....	Mn[3]	.....	Mj	Mj	.....	.....	ct	
		ECF	16	207,209	Mj	Mn	.....	.....	.....	.....	.....	Mj	.....	.....	ct	
		ECE	19	207,210	Mj	Mn	.....	.....	.....	.....	.....	Mj	.....	.....	ct	
		ECD	21	207,211	Mj	Tr.	.....	.....	Mn[4]	.....	Mn	Mj	.....	.....	ct	
		ECD	24	207,212	Mj	Mn	Mn	.....	.....	.....	.....	Mj	.....	Mn	ct	
		ECC	26a	207,213	VA	Tr.	.....	.....	.....	.....	.....	Mj	.....	.....	ct	
		ECC	26b	207,214	Mj	Tr.	Tr.	.....	.....	.....	.....	Mj	.....	Mn	ct	
		18	30	204,715	1	.....	.....	2	.....	.....	.....	VA	.....	.....	ct	
		18	29	204,716	1	.....	.....	2	.....	.....	.....	VA	.....	Mn	co	
		18	28	204,717	1	2	.....	3	.....	.....	.....	VA	.....	.....	sh	
		18	26	204,718	1	2	.....	.....	.....	.....	.....	VA	.....	.....	sh	
		18	25	204,719	3	1	.....	2	.....	.....	.....	VA	.....	A	ss	
		18	22	204,720	2	1	.....	3	.....	.....	.....	VA	.....	Mn	ss	
		18	20	204,721	2	1	.....	3	.....	.....	.....	VA	.....	A	sh	
		18	18	204,722	1	2	.....	3	.....	.....	.....	VA	.....	.....	sh	
		18	15	204,723	.....	1	.....	2	.....	.....	.....	VA	.....	A	ss	
		18	13	204,724	.....	1	.....	2	.....	.....	.....	VA	.....	P	ss	
		18	10	204,725	2	1	.....	3	.....	.....	.....	VA	.....	Mn	ss	
	Lower part	DSL	11	254,377	.....	Mn	.....	.....	Mj[5]	Tr.	.....	Mn	.....	.....	ct	Same steeply dipping bed from higher, more weathered part, to lower, less weathered part.
		DSL	12	254,378	Mn	Mj	.....	.....	.....	.....	.....	.....	.....	.....	ct	
		DSL	13	254,379	.....	Mj	.....	.....	Mn[5]	Tr.	.....	Mn	.....	.....	ct	
		DSL	14	254,380	.....	Mj	.....	.....	.....	Tr.	.....	Mn	.....	.....	ct	
		DSL[6]	35	IWX387J	.....	1	.....	.....	.....	.....	.....	2	.....	.....	ss	
		DSL[6]	39	IWX387I	.....	1	2	.....	.....	.....	.....	3	.....	.....	ct	
		DSL[6]	42	IWX387H	2	1	3	.....	.....	.....	.....	4	.....	.....	ss	
		DSL[6]	43	IWX387G	1	2	3	.....	.....	.....	.....	4	.....	.....	ct	Duplicate samples.
		DSL	43	207,350	Mj	Mj	.....	.....	.....	.....	.....	Mj	.....	Mj	ct	
		DSL[6]	44	IWX387F	2	1	3	.....	.....	.....	.....	4	.....	.....	ss	
		DSL[6]	44	IWX387E	2	1	3	.....	.....	.....	.....	4	.....	.....	ss	Do.
		DSL	44	207,349	.....	Mj	.....	.....	.....	.....	.....	Mj	.....	Mj	ss	
		G25	279	219,979	Mn	Mn	.....	Tr.	.....	.....	Tr.	A	Tr.	Tr.[1]	ct	
Fox Hills Sandstone	Upper part	G25	278	219,980	P	Mn	.....	Tr.	.....	.....	.....	A	.....	A[2]	ss	
		G25	277	219,981	P	Mn	.....	Tr.	.....	.....	.....	A	.....	P[2]	ss	
		DSL[6]	1	IWX387D	1	2	3	.....	.....	.....	.....	4	.....	.....	ss	Do.
		DSL	1	207,348	.....	Mn	.....	.....	.....	.....	Mn	Mn	Mn	Mn	ss	
		ECB	29	207,215	Mn	Mn	.....	.....	.....	.....	.....	Mj	.....	Mj[2]	ss	
		ECA	31	207,216	.....	Mn	.....	.....	.....	.....	.....	Mj	.....	Mj[2]	ss	
		18	8	204,726	1	3	.....	2	.....	.....	.....	.....	.....	Mn	sh	
	Lower part	DSL[6]	C	IWX387C	1	3	2	.....	.....	.....	.....	4	.....	.....	ct	Do.
		DSL	C	207,347	Mj	Mn	.....	.....	.....	.....	Mn	Mn	Mn	Mn	ct	
		DSL[6]	2	IWX387B	2	3	4	.....	.....	.....	.....	5	1	.....	ss	Do.
		DSL	2	207,346	Mn	Mj	.....	.....	.....	.....	P	Mj	Mj	Mj	ss	
		ECA	33	207,217	Mn	Mn	.....	.....	.....	.....	.....	Mj	.....	Mj[2]	ss	
		ECA	34	207,218	Mj	Tr.	.....	.....	.....	.....	Mn	Mj	Mn	.....	sh	
		ECA	35	207,219	.....	.....	.....	.....	Mn[7]	.....	Mn	Mj	Mj	Mn[2]	ss	

See footnote at end of table, p. 27.

TABLE 4.—*Semiquantitative X-ray mineralogic determinations of samples from Upper Cretaceous formations in northeastern Colorado*—Continued

Formation		Locality No.	Unit of measured sec.	Serial No.	Montmorillonite	Kaolinite	Mica-type mineral	Illite	Other minerals	Mica	Dolomite	Quartz	Calcite	Feldspar	Lithology	Remarks
Pierre Shale	Upper transition unit	DSL[6]	A	IWX387A	1	2	4	.....	.....	.....	.....	5	3	.....	ss	Do.
		DSL	A	207,345	Mj	Mj	.....	.....	.....	.....	P	Mj	Mj	.....	ss	
		ECA	36a	207,220	.....	Mj	.....	.....	.....	.....	Mn	Mj	.....	Mn[2]	ct	
		ECA	36b	207,221	.....	.....	.....	.....	.....	Mj	Mn	Mj	.....	Mn[1]	ct	
		18	6a	204,727	1	2	.....	3	.....	.....	Tr.	.....	.....	P	sh	
		18	6b	204,728	1	3	.....	2	Mn[7]	.....	Tr.	.....	.....	Mn	sh	
		18	3	204,729	1	3	.....	2	Mn[7]	.....	Tr.	.....	.....	Mn	sh	
		18	2	204,730	1	.....	.....	2	.....	.....	.....	.....	.....	Mn	sh	
		18	1	204,731	1	.....	.....	2	.....	.....	Tr.	.....	.....	P	sh	
		NVH	1	254,367	Mj	Tr.	.....	.....	.....	Mn	.....	Mn	.....	Tr.	ct	Same steeply dipping bed from higher, more weathered part, to lower, less weathered part.
		NVH	2	254,368	Mj	Tr.	.....	.....	.....	Tr.	.....	Mn	.....	Tr.	ct	
		NVH	3	254,369	Mj	Tr.	.....	.....	.....	Mn	.....	Mn	Tr.	Tr.	ct	
		NVH	4	254,370	Mj	Tr.	.....	.....	.....	Mn	Tr.	Mn	Tr.	Tr.	ct	
		NVH	5	254,371	Mj	Tr.	.....	.....	.....	Mn	?	Mn	.....	Tr.	ct	
		NVH	6	254,372	Mj	Tr.	.....	.....	.....	Mn	?	Mn	?	Tr.	ct	
	Didymoceras nebrascense zone	MVH	7	254,373	Mj	Mn	.....	.....	.....	Tr.	.....	Mn	.....	.....	sh	Do.
		MVH	8	254,374	Mj	Tr.	.....	.....	.....	.....	.....	.....	.....	.....	sh	
		MVH	9	254,375	Mj	Tr.	.....	.....	.....	?	.....	?	.....	.....	sh	
		MVH	10	254,376	Mj	Tr.	.....	.....	.....	Tr.	.....	Tr.	.....	?	sh	
Benton Shale		G25	119	263,782	.....	Mn	.....	.....	Mn[7]	Mn	.....	Mj	.....	Tr.	sh	
		U	.....	263,781	.....	Mj	.....	.....	Mn[7]	Mn	?	Tr.	.....	Tr.	sh	
		MS	.....	289,481	.....	Mn	.....	Mj	.....	.....	.....	.....	.....	.....	sh	

[1]Potash feldspar.
[2]Plagioclase.
[3]Interlayered montmorillonite-kaolinite.
[4]Metahalloysite.
[5]Interlayered montmorillonite-illite.
[6]Identified by F. A. Hildebrand and others using thin section, differential thermal, electron microscopy, and X-ray diffraction techniques.
[7]Chlorite.

SAMPLE LOCALITIES AND REMARKS

G23.	NW¼NE¼ sec. 21, T. 3 S., R. 70 W., Golden quadrangle.	
L22.	NE¼NE¼ sec. 7, T. 3 S., R. 69 W., Golden quadrangle.	
L1.	SE¼NE¼ sec. 33, T. 3 S., R. 70 W., Golden quadrangle.	
18.	NW¼SW¼ sec. 20, T. 7 S., R. 68 W., Kassler quadrangle	Based on section in Scott (1963b, p. 105).
ECJ.	NE¼NE¼ sec. 22, T. 10 S., R. 60 W., Elbert County	Based on Dane and Pierce (1936).
ECI.	SE¼SW¼ sec. 19, T. 7 S., R. 60 W., Elbert County	Do.
ECH.	SE¼SW¼ sec. 2, T. 7 S., R. 60 W., Elbert County	Do.
ECG.	NW¼NW¼ sec. 19, T. 9 S., R. 58 W., Elbert County	Do.
ECF.	Center NW¼ sec. 2, T. 8 S., R. 60 W., Elbert County	Do.
ECE.	SW¼SW¼ sec. 7, T. 9 S., R. 58 W., Elbert County	Do.
ECD.	SE¼SE¼ sec. 6, T. 9 S., R. 58 W., Elbert County	Do.
ECC.	SW¼NW¼ sec. 5, T. 8 S., R. 57 W., Elbert County	Do.
DSL.	Center S½ sec. 21, T. 2 S., R. 70 W., Golden quadrangle	Denver and Rio Grande Western Railroad cut. The Pierre sample is from 5 ft below the base of the Fox Hills. Based on section by LeRoy (1946, p. 89, 93).
G25.	Center sec. 5, T. 3 S., R. 70 W., Ralston Buttes quadrangle	To sec. 33, T. 2 S., R. 70 W., Golden quadrangle.
ECB.	NE¼NW¼ sec. 18, T. 8 S., R. 57 W., Elbert County	Based on Dane and Pierce (1936).
ECA.	NW¼NE¼ sec. 1, T. 7 S., R. 58 W., Elbert County	Do.
NVH.	NW¼NW¼ sec. 4, T. 2 S., R. 70 W., Louisville quadrangle	Collected by H. E. Malde and R. Van Horn.
MVH.	SW¼NW¼ sec. 29, T. 1 S., R. 70 W., Eldorado Springs quadrangle	Do.
U.	NW¼SW¼ sec. 21, T. 3 S., R. 70 W., Golden quadrangle.	
MS.		Near Golden. From Mielenz, Greene, and Schieltz (1951), collector unknown.

Hills from sandstone in the Laramie Formation. The sandstone beds in the underlying Pierre are similar to sandstone in the Fox Hills, but most are thinner and are interbedded with thicker shale beds. As now defined (Lovering and others, 1932) the Fox Hills is a transition phase between predominantly marine shale below and predominantly fresh- or brackish-water deposits above. In view of this environment indefinite boundaries are, perhaps, expectable.

The clay mineralogy of the Fox Hills just south of the Golden quadrangle was examined by Gude (1950). He determined that eight out of nine samples contained more montmorillonite than kaolinite. Montmorillonite also exceeds kaolinite in three samples of the Fox Hills from the Denver and Rio Grande Western Railroad cut at Plastic siding in the north part of the Golden quadrangle (see table 4); all three samples also contained dolomite. X-ray analysis by Gude of five samples from the Fox Hills collected by Van Horn in the Kassler quadrangle 24 miles south of Golden also showed montmorillonite is more abundant than kaolinite, and four of these also contained trace amounts of dolomite. The relative amounts of montmorillonite and kaolinite were not distinctive in five samples from the east side of the Denver basin in the vicinity of Limon, Colo., about 90 miles southeast of Golden. There the amounts of montmorillonite and kaolinite are the same in three samples, montmorillonite exceeds kaolinite in one sample, and kaolinite exceeds montmorillonite in one sample. (See table 4, localities ECA and ECB.) However, two of the samples did contain dolomite.

LOCAL CORRELATION

Shale and sandstone are complexly intertongued in the Fox Hills as indicated by mineralogic, sedimentologic, and paleontologic evidence. In the north part of the Golden quadrangle the Fox Hills comprises two sandstone units separated by a thin clay. The upper part of the lower sandstone unit intertongues with shale beds to the south, and in the southern part of the Golden quadrangle and in the Morrison quadrangle a thick shale unit is present between the two sandstone units. (See fig. 10.)

In the northern part of the area the Fox Hills is composed of two sandstone beds, separated by a thin seam of clay. (See fig. 11.) The lower sandstone, which is grayish orange, is about 30 feet thick. It is very fine grained and very silty. Many poorly defined bedding planes indicate it is thin bedded. The upper sandstone, a massive bed about 35 feet thick, is very pale orange. It is fine grained and silty. Many very fine grained, rounded, dark-gray mineral grains give the sandstone a speckled appearance. No Foraminifera or other fossils were found in the clay seam or either sandstone. Mineral analysis by F. A. Hildebrand shows that both sandstones contain, in probable order of abundance, montmorillonite, kaolinite, and small amounts of a mica-type mineral; the clay seam contains montmorillonite, small amounts of a mica type mineral, and kaolinite. Analyses by A. J. Gude III of samples from the same localities gave similar results except that they showed no mica-type minerals. Both analysts reported the presence of calcite in the lower sandstone. The Fox Hills does not appear to change significantly from the railroad cut south to Leyden Creek although it is poorly exposed. The Fox Hills does not crop out between Leyden and Ralston Creeks.

At Ralston Creek the Fox Hills has changed in lithology. There it is about 70 feet thick but a few thin shale beds occur in the lower part of the formation. The lower 13 feet is mainly sandstone but the succeeding 17 feet is sandstone in beds 1–3 feet thick separated by shale beds generally less than 1 foot thick. The sandstone is grayish orange, silty, and very fine grained. The shale is medium gray and generally is fissile. The upper 40 feet of the Fox Hills at Ralston Creek is sandstone in two beds (units 277 and 278 of measured section G25-D at Ralston Creek). The lower sandstone bed is grayish orange, silty, and fine grained. It is composed principally of angular, clear to milky, quartz grains but includes as much as 15 percent black minerals and mica. A single small shell fragment and a probable fish scale were found in a washed sample. The coarse fraction of washed samples consists mainly of aggregates of silt and very fine grained sand. The upper sandstone bed is similar to the lower except it is light gray and is not as silty. X-ray analyses indicate that both sandstone beds contain more montmorillonite than kaolinite. No dolomite, however, was present.

The lower 30 feet of the Fox Hills at Ralston Creek is correlated with the lower sandstone at the Denver and Rio Grande Western Railroad cut. The upper 40 feet of the Fox Hills at Ralston Creek is correlated with the upper sandstone of the Fox Hills at the railroad cut. The log of the S. D. Johnson 1 well (fig. 3), located east of Hyatt Lake and 4 miles southeast of the Fox Hills exposure at Ralston Creek, shows 165 feet of Fox Hills which consists, in ascending order, of 90 feet of fine-grained gray sandstone with some interbedded shale in the lower part, 10 feet of gray shale, and 65 feet of medium-grained white sandstone (American Stratigraphic Co., 1956). Only the lower 90 feet of the Fox Hills shown in this log is equivalent to the Fox Hills as mapped in the Golden quadrangle.

The Fox Hills is exposed in a prospect trench near the northwest corner of Golden. (See measured section G24-B.) Here it consists of 10 feet of sandstone (units 24–26) overlain by 62.7 feet of shale (unit 27), and capped by 25 feet of alternating sandstone and shale (units 28–33). The sandstone beds are mainly grayish orange and fine grained. Samples of some beds examined with a microscope contain many silt-sized grains. They are composed principally of quartz grains but contain small amounts of mica and unidentified dark minerals. The shale beds are light olive gray, fissile, and clayey. Foraminifera resembling *Haplophragmoides* and *Robulus* are present in the middle and lower parts of the 62.7-foot shale bed.

The stratigraphic correlations are less clear near Golden than at Ralston Creek. The lower contact of the Fox Hills is placed at the base of a relatively thick sandstone. This sandstone is underlain by 40 feet of interbedded shale and sandstone in ½- to 5-foot-thick beds. Because the shale pre-

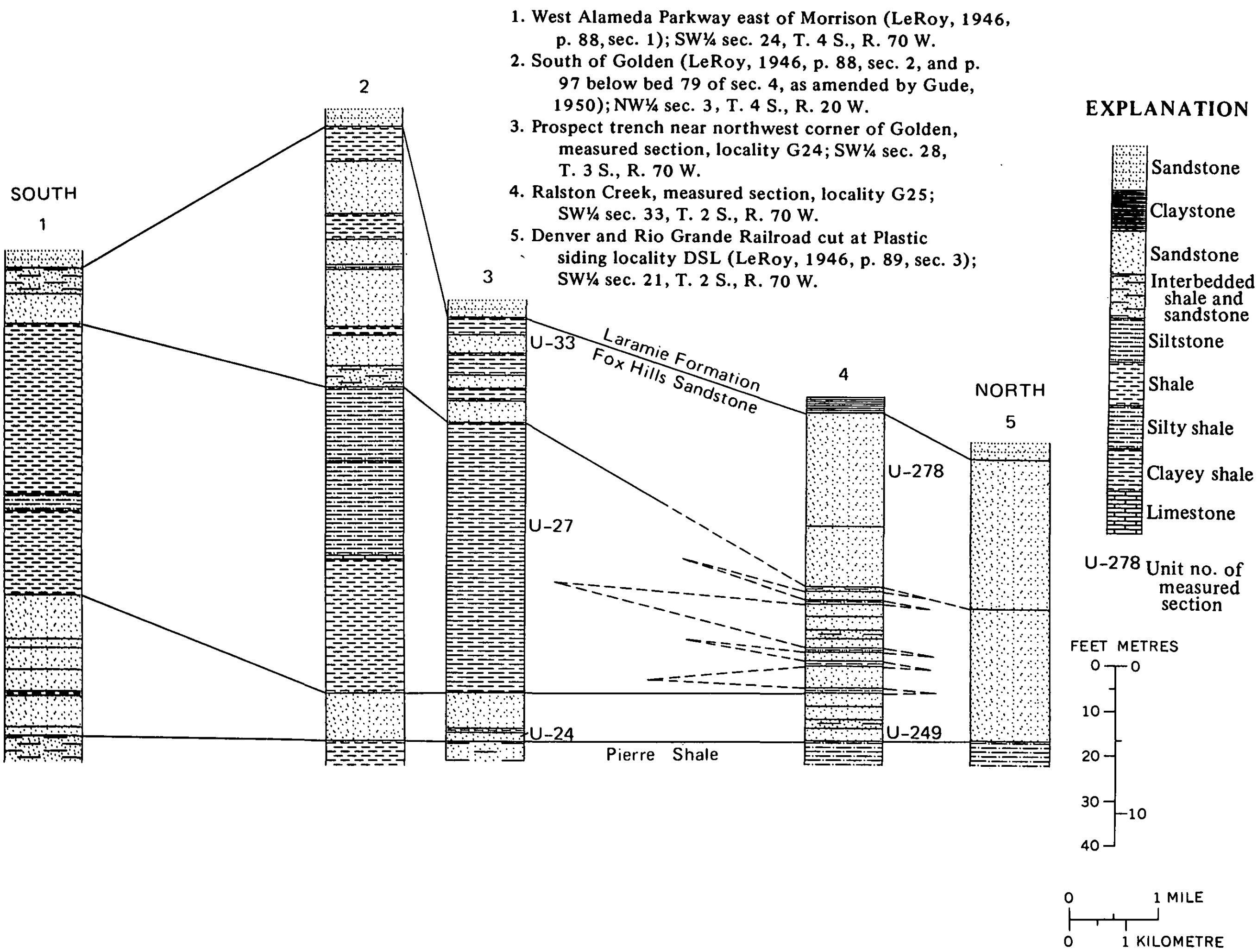


FIGURE 10.—Lithologic sections of the Fox Hills Sandstone near Golden.

dominates and most of the sandstone beds are less than 2 feet thick, these beds are assigned to the Pierre Shale. The lower sandstone beds assigned to the Fox Hills and the overlying 62.7-foot-thick shale are probably equivalent to the lower 30 feet of the Fox Hills at Ralston Creek. The alternating sandstone and shale sequence in the upper part of the prospect trench is tentatively correlated with the upper 40 feet of sandstone at Ralston Creek. (See fig. 10.)

The upper contact of the Fox Hills at the prospect trench is placed at the base of a medium-grained light-gray sandstone. This sandstone looks cleaner than underlying sandstone because of its lighter color and coarser texture; it is similar in appearance to the sandstone beds higher in the section. In addition, the beds principally composed of clay-sized material that underlie this sandstone are fissile, whereas those that overlie the sandstone are blocky.

South of Golden, LeRoy (1946, p. 86, 88) indicated that the upper part of the Fox Hills is mainly shale and the lower part is a sandstone 10–30 feet thick. Thin sandstone beds are present at a few places in the upper part of the shale. (See section 1, fig. 10.) Several sandstone beds are present in the upper part of the formation just south of Golden (Gude, 1950, p. 1702–1705). These beds are included in the Laramie Formation by LeRoy (1946, p. 97, units 80–88), although, east of Morrison, he included sandstone and an underlying thick shale in the Fox Hills.

The sandstone in the lower part of the Fox Hills south of Golden, indicated by LeRoy, is probably equivalent to the sandstone in the lower part of the Fox Hills in the prospect trench. The upper shale bed of LeRoy probably correlates with the 62.7-foot-thick shale bed in the middle part of the formation in the prospect trench. The sandstone in

FIGURE 11.—Southward view of the Fox Hills Sandstone exposed in the Denver and Rio Grande Western Railroad cut at Plastic siding, near the north end of the Golden quadrangle. The lower sandstone is to the right of sample C, which is the clay seam separating the two sandstone beds of the Fox Hills. The letters show the units sampled at locality DSL reported in table 4. The serial numbers of the samples are: A (207,345 and IWX387A); B (207,346 and IWX387B); C (207,347 and IWX387C); D (207,348 and IWX387D); E (207,349 and IWX387E); F (IWX387F); G (207,350 and IWX387G); H (IWX387H).

the upper part of the formation at the prospect trench is probably equivalent to the additional sandstone and shale beds that Gude (1950) included in the Fox Hills just south of Golden. These relations lead me to believe that there is an intertonguing of shale and sandstone beds in the Fox Hills of the southern part of the Golden quadrangle; the shale in the middle pinches out or grades into sandstone to the north, and the upper sandstone grades into shale and sandstone to the south.

AGE

The Late Cretaceous age of the Fox Hills is established by its stratigraphic position. The Fox Hills overlies Pierre Shale and underlies Laramie Formation, which are both of Late Cretaceous age.

ORIGIN

The Foraminifera in shale of the Fox Hills near Golden indicate a marine origin. LeRoy (1946, p. 90) reported several types of Foraminifera from the shale, and Moody (1947, p. 1461) reported several macrofossils of marine origin also from the shale. In addition, Moody (p. 1461) reported that sandstone of the Fox Hills underlying the shale contains *Baculites* sp. aff. *asper* Morton and *Pteria nebrascana* Evans and Shumard. This meager marine fauna, plus the lithology of these beds, probably indicates that the sandstone is of marine origin. The presence of finely broken plant remains in the sandstone beds (see measured section at Ralston Creek, and Moody, 1947, p. 1461) indicates a nearshore environment.

SECTION G25-D.—*Fox Hills Sandstone*

[Measured on the south side of Ralston Creek, Golden quadrangle. Line of section shown in fig. 3]

		Thickness (ft)
Laramie Formation, unit 279.		
Fox Hills Sandstone:		
278.	Sandstone, very light gray, fine-grained, soft; predominantly quartz with some dark minerals; occasional layers with many plant fragments. Differs from underlying sandstone in color and appears slightly more massive. X-ray laboratory sample No. 219,980, table 4, taken 2 ft above base	25.4
277.	Sandstone, grayish-orange, massive fine-grained; predominantly quartz, with some dark minerals. X-ray laboratory sample No. 219,981 table 4, taken 2 ft below top	14.2
276.	Shale, medium-gray, clayey	.1
275.	Sandstone, grayish-orange, massive, very fine grained. Predominantly quartz with some dark minerals	.2
274.	Shale, medium-gray, clayey	.1
273.	Sandstone, grayish-orange, massive, very fine grained; contains rare plant fragments; predominantly quartz with some dark minerals	1.6
272.	Shale, medium-gray, silty	.6
271.	Sandstone, grayish-orange, massive, very fine grained; predominantly quartz with some dark minerals	2.5
270.	Shale, medium-gray, clayey	.1
269.	Sandstone, grayish-orange, massive, very fine grained; predominantly quartz with some dark minerals	2.6
268.	Shale, medium-gray, clayey	.2
267.	Sandstone, grayish-orange, thin-bedded, very fine grained, silty; predominantly quartz with some dark minerals	.3
266.	Shale, medium-gray, clayey	.2
265.	Sandstone, grayish-orange, thin-bedded, very fine grained, silty; predominantly quartz with some dark minerals	.7
264.	Shale, medium-gray, clayey	.1
263.	Sandstone, grayish-orange, massive, very fine grained; predominantly quartz with some dark minerals	1.0
262.	Siltstone, moderate-brown, sandy; thin layers of plant fragments	.3
261.	Sandstone, grayish-orange, massive, very fine grained; predominantly quartz with some dark minerals	1.6
260.	Shale, medium-gray, clayey	.3
259.	Sandstone, grayish-orange, massive, very fine grained; predominantly quartz with some dark minerals. Attitude N. 6° W., 80° W.	5.0
258.	Siltstone, moderate-brown, sandy; thin layers of plant fragments	.5
257.	Sandstone, grayish-orange, thin-bedded, very fine grained, silty; some layers of plant fragments	2.7
256.	Siltstone, moderate-brown, sandy; thin layers of plant fragments	.2
255.	Sandstone, grayish-orange, thin-bedded, very fine grained, silty	2.5
254.	Shale, medium-gray, clayey	.1
253.	Sandstone, grayish-orange, thin-bedded, very fine grained, silty	.6
252.	Shale, medium-gray, clayey	.3
251.	Sandstone, grayish-orange, thin-bedded, very fine grained, silty	.5
250.	Shale, medium-gray, clayey	.3
Fox Hills Sandstone—Continued		
249.	Sandstone, grayish-orange to moderate-yellowish-brown, silty; with some 0.1-in.-diameter ferruginous concretions. Lower 1 ft contains thin beds of medium-gray shale and grayish-orange sandstone	3.0
	Total Fox Hills Sandstone	67.8
Pierre Shale, unit 248.		

SECTION G24-B.—*Fox Hills Sandstone*

[Measured in one of a series of prospect trenches at locality G24 (fig. 3) in the SW¼ sec. 28, T. 3 S., R. 70 W. It is continuous with a section of the Pierre Shale and the Laramie Formation measured at this same locality]

		Thickness (ft)
Laramie Formation, unit 34.		
Fox Hills Sandstone:		
33.	Shale, light-olive-gray (5*Y* 5/2), clayey; and four thin interbedded clayey siltstone beds near the middle	4.4
32.	Sandstone, grayish-orange (10*YR* 7/4), fine-grained; and a few thin interbedded light-olive-gray shale beds	3.5
31.	Shale, light-olive-gray (5*Y* 5/2), clayey; and a few thin interbedded grayish-orange siltstone beds	4.8
30.	Sandstone, grayish-orange (10*YR* 7/4), fine-grained; and two thin shale beds near the base	2.5
29.	Shale, light-olive-gray (5*Y* 5/2), clayey, and a few thin siltstone beds near the top	2.8
28.	Sandstone, light-gray (*N*7), medium-grained; moderately stained grayish orange by limonite	5.4
27.	Shale, light-olive-gray (5*Y* 5/2), clayey. Contains a few small clusters of gypsum. Several species of fossil Foraminifera are present in the lower half	62.7
26.	Sandstone, grayish-orange (10*YR* 7/4), fine-grained	7.8
25.	Shale, light-olive-gray (5*Y* 5/2), clayey	.8
24.	Sandstone, grayish-orange (10*YR* 7/4), fine-grained	1.7
	Total Fox Hills Sandstone	96.4

LARAMIE FORMATION

The Laramie Formation, as used in this report, follows the definition by Emmons, Cross, and Eldridge (1896, p. 72–77). The lower contact is at the top of grayish-orange, fine-grained sandstone or fissile shale of the Fox Hills Sandstone, and the upper contact is at the base of the conglomerate of the Arapahoe Formation. Where the conglomerate is absent or obscured, as it is in most of the northern part of the area, the upper contact is very indefinite. The formation in general appears to thicken eastward, from about 600 feet at Golden to nearly 1,000 feet east of Hyatt Lake.

Between Golden and Ralston Creek the Laramie forms several isolated knolls, and just north of Leyden Creek it forms a sharp hogback nearly a mile long and about 100 feet high; at other places it has been smoothly truncated and does not form distinctive ridges. Between Upper Long Lake and Van Bibber Creek the outcrop area of the formation is displaced almost a mile eastward by the fault southeast of Ralston dike.

Beds in the Laramie are lenticular and, although generalized zones have been traced for many miles, individual beds within these zones probably pinch out within a few miles. The lower part contains about equal amounts of sandstone and claystone whereas claystone is predominant in the upper part. In the Golden quadrangle, coal beds are present in the lower part.

The sandstone is light gray and medium grained. It is principally quartz but contains small amounts of dark minerals. Large concretionlike masses of sandstone occur at a few places. Normally the beds are moderately well cemented, although at places they may be either hard and quartzitic or only moderately cemented. The sandstone beds are massive to thin bedded, and at a few places they are crossbedded. They are generally noncalcareous. The sand grains are generally subround and relatively uniform in grain size within a single sample. The matrix usually appears crystalline and does not constitute a large proportion of the rock. At places very little cement is present and as a result the rock has a porous appearance. At other places some white clay is present with the cement. A few thin fine-grained sandstone and siltstone beds are in the lower part, but both are more common in the upper part.

Claystone in the Laramie is generally medium to dark gray although at places it has a brownish or reddish tinge. Claystone is predominant in the upper part of the Laramie; well logs in the eastern part of the quadrangle show only minor amounts of sandstone in the upper part. Within the Golden quadrangle the ratio of claystone to sandstone increases to the east—where the Laramie is much thicker—and appears to increase slightly to the north. The claystone in the upper part also appears to be more arenaceous than the claystone to the west.

Investigation of the clay minerals of the Laramie by Gude (1950) suggested that the Laramie could be subdivided into upper and lower parts in which kaolinite is predominant, and a middle part that is predominantly montmorillonite. Additional clay mineral investigation of claystone and sandstone beds in the Laramie (see table 4) only partly confirms such a subdivision. In the Golden quadrangle the lower 100 feet of the Laramie exposed along the Denver and Rio Grande Western Railroad cut was sampled for clay minerals. In 10 of 12 samples analyzed from six beds, kaolinite is predominant. In one sample montmorillonite is predominant, and in another kaolinite and montmorillonite are approximately equal in quantity. A mica-type mineral is also present in five of the samples. In a presumed basal Laramie sample from Ralston Creek, kaolinite and montmorillonite are present in about equal quantities, although montmorillonite is predominant in the underlying Fox Hills. Dolomite is present in only one sample of the Laramie in the Golden area but is present in several samples of the Fox Hills and Pierre.

Samples from 24 miles south of Golden, in the Kassler quadrangle, show a twofold division of the Laramie in which the upper part is predominantly montmorillonite and the lower part is predominantly kaolinite. Farther east on the east side of the Denver basin, near Limon, Colo., the clay minerals throughout the Laramie appear to be predominantly montmorillonite.

Coal beds, as much as 14 feet thick, are present in the lower 200 feet of the Laramie. No fresh coal was seen during fieldwork for this report, but Eldridge reported (Emmons and others, 1896, p. 317–387) that it is black, lustrous, and hard. It contains small amounts of pyrite.

The many abandoned coal mines give an insight into the geologic structure of the area and are therefore discussed in some detail. The lower 200 feet of the Laramie contains from one to six known coal beds, ranging in thickness from 1 to 14 feet. Individual coal beds have not been correlated from mine to mine, but within each mine individual beds have been traced sufficiently to indicate that the western edge of the Laramie mostly dips nearly vertically for as much as 700 feet below the ground surface and then bends sharply eastward to become nearly horizontal. North of the Denver and Rio Grande Western Railroad the dip at the western edge of the outcrop becomes less steep. Information on the coal mines is from various sources including the field notebooks of Whitman Cross and George H. Eldridge, the report by Emmons, Cross, and Eldridge (1896, p. 333–338), and maps on file with the Colorado State Bureau of Mines. The location of the mines and the approximate position of the mined-out coal beds are shown in figure 12. Most of the mines were developed from vertical shafts sunk into the Fox Hills. Drifts were then driven eastward at various levels to intersect the coal in the Laramie. The portal of the southernmost mine in the quadrangle, the White Ash mine, was on the south side of Clear Creek, just northwest of the Laramie outcrops shown on the geologic map. Here, the coal beds dip steeply west (overturned) from the surface downward for about 650 feet. From this point to the lowest workings, another 80 feet down, the coal is essentially vertical. In the Loveland and New Loveland mines, about 2,000 feet north on the same bed, the coal is essentially vertical between 300 and 500 feet below the surface. At the New (Little) White Ash mine, one-half mile north of Clear Creek, the coal dips 75°–80° W. (overturned) to a depth of 317 feet. The coal in the next three mines to the north dips steeply west. In the Ralston Springs mine, about one-quarter mile south of Van Bibber Creek, the coal dips west for 175 feet below the surface. South of Ralston Creek in the Tindall mine (sometimes called Tindale mine) the coal dips west for 500 feet below the surface, although at the 500-foot level the beds are nearly vertical. The nearly horizontal beds in the workings of the new Leyden mine are 1,500 feet east and 2,000 feet north of and 650 feet lower than the coal at the

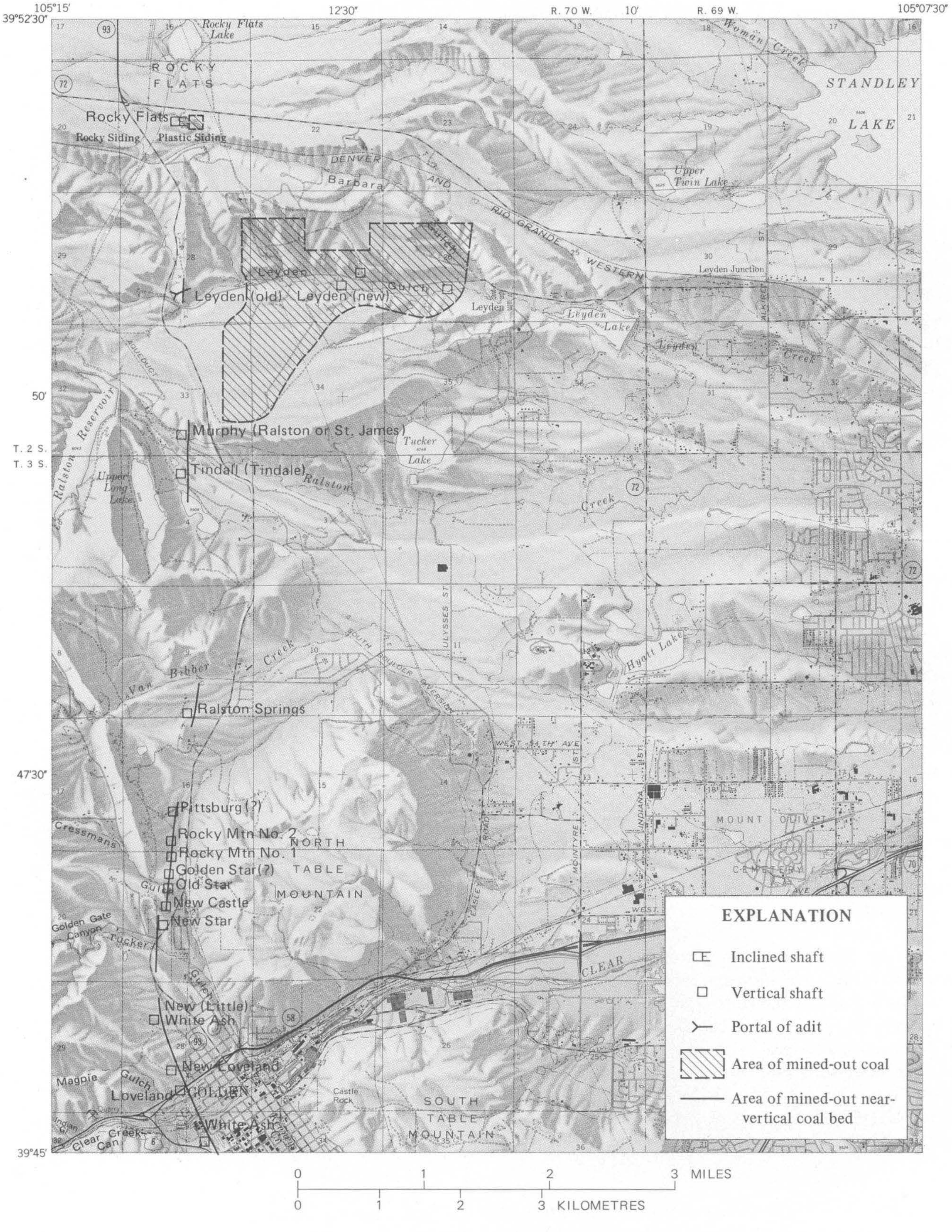


FIGURE 12.—Abandoned coal mines and the approximate area of mined-out coal in the Golden quadrangle. Base from U.S. Geological Survey Golden 7½-minute quadrangle (shaded relief), scale 1:24,000, 1965.

bottom of the Tindall shaft. Assuming the two coal beds are close to the same stratigraphic position, the radius of bending to change from vertical to horizontal is probably relatively short. A similar situation is indicated at Leyden Creek where drill-hole data (Gude and McKeown, 1952) indicated that the coal at the outcrop is dipping steeply eastward at about 5,600 feet altitude, whereas nearly horizontal beds in the new Leyden mine were worked 1,500 feet east of the outcrop at an altitude of 4,962 feet. The coal at the Rocky Flats mine in Barbara Gulch dips about 75° E. at the surface. The coal in the Capitol (Cap Rock) mine, 1,000 feet north of Rocky Flats Lake, (not in fig. 12), dips 45° E. at the surface. At several places gently dipping beds of younger formations are present a few thousand feet east of nearly vertical outcrops of Laramie.

The sharp bend in the formation, indicated by the change in dip, may partly account for the difference in thickness of the Laramie at the outcrop, where it is about 600 feet thick, and in the subsurface in the eastern part of the quadrangle, where it is nearly 1,000 feet thick. The great stress that must have accompanied this bending possibly caused plastic flowage of the claystone with a consequent thinning. The difference in thickness could also be due to more erosion in the west, to original thickening of deposits toward the center of the basin, or to a combination of all three factors.

The contact between the Laramie and the underlying Fox Hills varies from an abrupt lithologic change to a gradual change from fissile shale and grayish-orange sandstone in the Fox Hills to blocky claystone and light-gray sandstone in the Laramie. At different places Laramie rocks at the contact may be either sandstone or claystone on either sandstone or shale. There was undoubtedly some erosion as the sea retreated from the area and as rivers flowed out across the vacated sea bottom. Any such erosion was probably minor, however, and the boundary is probably best described as transitional rather than unconformable.

AGE

No fossils from the Laramie were collected during the present investigation although many leaf fragments were seen. Horn cores of the dinosaur *Triceratops* have been reported by Brown (1943, p. 69); *Ostrea glabra* were found in the lower part, and *Unio* sp.? at higher horizons by Eldridge (Emmons and others, 1896, p. 77). A comprehensive report on the Laramie flora of the Denver basin by Knowlton (1922) lists over 100 species of fossil plants. The fossils indicate a Late Cretaceous age.

ORIGIN

The coal beds in the lower part of the Laramie were formed in swamps in an area of low relief and sluggish drainage. According to Knowlton (1922, p. 99) the plants grew in a warm humid climate.

SECTION G24-C.—*Laramie Formation*

[Measured in a series of prospect trenches at locality G24 in the SW¼ sec. 28, T. 3 S., R. 70 W. (fig. 3). It is continuous with a section of the Fox Hills Sandstone and the lower part of the Arapahoe Formation measured at this same locality]

		Thickness (ft)
Laramie Formation:		
107.	Claystone, medium- to light-gray (*N*5 to 7), silty	13.7
106.	Sandstone, light-gray (*N*7), fine-grained, silty, limonite-stained	1.4
105.	Claystone, medium-gray (*N*5), silty, slightly calcareous	22.9
104.	Sandstone, grayish-orange (10*YR* 7/4), fine-grained, silty, limonite stained	.3
103.	Claystone, medium-gray (*N*5), silty, slightly calcareous	3.7
102.	Covered	23.9
101.	Claystone, medium-gray (*N*5), silty	4.8
100.	Sandstone, light-gray (*N*7), very fine grained, silty	4.9
99.	Covered	43.0
98.	Claystone, medium-gray (*N*5), silty; streaked by very light gray calcium carbonate	11.0
97.	Covered	28.1
96.	Claystone, medium- to light-gray (*N*5 to 7), silty. Attitude N. 13° W., 85° W	3.7
95.	Claystone, medium- to light-gray (*N*5 to 7), silty; greatly stained by very light gray calcium carbonate and grayish-orange limonite streaks. Unit contains organic matter and is slightly coaly at the base	30.2
94.	Sandstone, light-gray (*N*7), fine-grained, silty; moderately stained by calcium carbonate and limonite	2.1
93.	Claystone, medium-gray, silty; greatly stained by calcium carbonate and limonite	8.4
92.	Siltstone, light- to medium-gray (*N*7 to 5); greatly stained by calcium carbonate	14.4
91.	Claystone, medium-gray (*N*5), silty; greatly stained by calcium carbonate and limonite	4.9
90.	Sandstone, grayish-orange (10*YR* 7/4), fine-grained silty	7.0
89.	Claystone, medium-gray (*N*5); greatly stained by calcium carbonate and limonite	2.3
88.	Siltstone, light-gray (*N*7), sandy; moderately stained by calcium carbonate	2.0
87.	Claystone, medium-gray (*N*5), silty; moderately stained by calcium carbonate and limonite	2.1
86.	Claystone, medium-gray (*N*5); and interbedded light-gray (*N*7) siltstone	3.8
85.	Siltstone, light-gray (*N*7), thin, wavey-bedded; and minor amounts of interbedded medium-gray (*N*5) silty claystone	28.8
84.	Covered	175.5
83.	Sandstone, light-gray (*N*7), fine-grained, silty; moderately streaked by calcium carbonate	10.6
82.	Claystone, medium-gray (*N*5); moderately stained by calcium carbonate and limonite	6.6
81.	Sandstone, grayish-orange (10*YR* 7/4), medium-grained; moderately stained by limonite. Contains a minor amount of dark-gray mineral grains	1.5
80.	Claystone, medium-gray (*N*5). Contains a 1-ft and a 0.5-ft-thick grayish-orange limonite stained zone near the top and a 1-ft-thick light-brown bed near the middle	6.3
79.	Siltstone, medium-gray (*N*5)	.4
78.	Claystone, medium-gray (*N*5), silty	1.8
77.	Siltstone, medium-gray (*N*5). Lower half is stained grayish orange by limonite and contains plant fragments	2.0

Laramie Formation—Continued	Thickness (ft)
76. Claystone, medium-gray (*N*5), silty	3.2
75. Sandstone, light-gray (*N*7) to grayish-orange (10*YR* 7/4), fine-grained; and interbedded light-gray siltstone and medium-gray silty claystone	9.2
74. Sandstone, light-gray (*N*7), medium-grained; moderately stained by limonite. Attitude N. 20° W., 89° W	23.7
73. Claystone, medium-gray (*N*5), silty; upper 0.6 ft greatly stained by limonite. Contains a few 0.1-ft-diameter limonite concretions	6.9
72. Claystone, dark-gray (*N*3). Contains a moderate amount of organic material including plant fragments	10.6
71. Claystone, medium-gray (*N*5); and thin beds of fine-grained, grayish-orange sandstone	1.8
70. Claystone, medium-gray (*N*5); slightly stained by limonite	2.9
69. Sandstone, light-gray (*N*7), medium-grained, even-bedded. Attitude N. 23° W., 78° W	4.7
68. Claystone, dark-gray (*N*3). Contains abundant plant fragments	2.4
67. Sandstone, light-gray (*N*7), medium-grained; greatly stained grayish orange by limonite. Contains abundant plant fragments in lower 2 ft	5.2
66. Claystone, medium-gray (*N*5); moderately stained grayish orange by limonite. Contains moderate amount of plant fragments	5.1
65. Siltstone, light-gray (*N*7), clayey; moderately stained by limonite	5.1
64. Claystone, medium-gray (*N*5), silty. Contains several zones of abundant plant fragments, and two thin coal beds	10.3
63. Sandstone, grayish-orange (10*YR* 7/4), medium-grained	1.6
62. Claystone, light-gray (*N*7)	9.8
61. Sandstone, light-gray (*N*7), medium-grained; contains minor amounts of dark-gray grains. Lower part is greatly stained dark yellowish brown and has concretions 3–5 ft in diameter and small wormlike concretions. Attitude N. 25° W., 73° W	10.5
60. Claystone, medium-gray (*N*5)	9.1
59. Sandstone, light-gray (*N*7), medium-grained	10.1
58. Claystone and thin coal bed	2.0
57. Sandstone; bottom surface stained reddish brown and contains plant fragments	5.5
56. Claystone, medium-gray (*N*5)	1.6
55. Sandstone, light-gray (*N*7), medium-grained. Contains a few plant fragments and a 0.5-ft-thick medium-gray claystone bed	3.0
54. Claystone, medium-gray (*N*5)	4.9
53. Sandstone, light-gray (*N*7), medium-grained; lower 2 ft stained grayish orange by limonite. Contains minor amount of dark mineral grains	26.4
52. Sandstone, light-gray (*N*7), fine-grained	8.7
51. Claystone, light-gray (*N*7)	3.7
50. Siltstone, light-gray (*N*7)	1.9
49. Sandstone, light-gray (*N*7), medium-grained, greatly stained grayish orange by limonite	7.6
48. Covered	13.7
47. Claystone, medium-gray (*N*5), silty	1.2
46. Sandstone, light-gray (*N*7), medium-grained, mottled grayish orange. Contains a few 0.1-ft-diameter limonite concretions	1.7
45. Claystone, medium-gray (*N*5), silty. Attitude N. 25° W., 65° W	3.0
44. Sandstone, very light gray (*N*8), medium-grained	5.4
43. Claystone, light-gray (*N*7), silty	1.3
42. Sandstone, very light gray (*N*8)	2.6
41. Claystone, light-gray (*N*7)	2.6
40. Sandstone, light-gray (*N*7), medium- to coarse-grained, greatly stained grayish orange by limonite. Attitude N. 26° W., 79° W	27.1
39. Claystone, medium-gray (*N*5), mottled reddish brown	.9
38. Sandstone, grayish-orange (10*YR* 7/4), fine-grained	.3
37. Claystone, medium-gray (*N*5), mottled reddish brown	.6
36. Sandstone, grayish-orange (10*YR* 7/4), fine-grained	.3
35. Claystone, medium-gray (*N*5), mottled reddish brown	.3
34. Sandstone, light-gray (*N*7), medium-grained	4.2
Total Laramie Formation	733.2

ARAPAHOE FORMATION

The Arapahoe Formation, like the underlying Laramie, is principally composed of discontinuous beds of sandstone and claystone. In the Golden quadrangle the base is marked by a poorly exposed or discontinuous conglomerate and the top by the appearance of the andesitic debris in the Denver Formation. The Arapahoe Formation underlies most of the northeastern three-fourths of the quadrangle, where it forms small isolated exposures. The Arapahoe, as used in this report, follows the definition of Eldridge (1889, p. 97–99), for reasons explained on page 43. The Arapahoe is 400–500 feet thick.

North of Ralston Creek the lower contact of the Arapahoe Formation was seen at only two places in the field. The location of the contact is based on three criteria: outcrops of conglomerate in the roadcut for State Highway 93 on the north side of Ralston Creek and in the NE¼NE¼ sec. 7, T. 2 S., R. 69 W. (Louisville quadrangle); electric well logs 500 feet south of the N¼ cor. sec. 29, T. 2 S., R. 69 W. (log interpreted by George H. Chase of the U.S. Geol. Survey) and another 800 feet east of Hyatt Lake; and interpolation of subsurface contours drawn on the base of the Laramie Formation (fig. 49). Analysis of these data indicated that the Laramie-Arapahoe contact should be near the surface in the eastern parts of the valleys of Woman and Leyden Creeks. Some corroboration for locating the contact here was obtained in that the contact is just below a hard conglomerate bed in the center of sec. 23, T. 2 S., R. 70 W. and a conglomeratic sandstone 1,000 feet south of the NE. cor. sec. 31, T. 2 S., R. 69 W. In addition, no conglomerate was found stratigraphically lower than the contact shown on the map, although conglomerate beds are present above the contact at several places. These data have required a revision of the location of the lower contact from that shown previously (Van Horn, 1957b).

The Arapahoe Formation is poorly exposed in this area. The most complete exposure is on the campus of the Colorado School of Mines in Golden: the basal conglomerate is exposed in the abandoned claypits south of the athletic field, progressively younger conglomerate and sandstone beds are discontinuously exposed adjacent to the curving road just east of the claypits, and gray sandy claystone and thin sandstone are exposed in an artificial cut 500 feet due east of the claypit symbol. Andesitic-debris-bearing beds of the Denver Formation were temporarily exposed in the excavation for a new gymnasium (not shown on the map of Van Horn, 1972) at the north corner of 14th and Maple Streets (on the map, 700 ft east of the claypit symbol). The basal conglomerate of the Arapahoe is also exposed in two prospect trenches west of Golden and north of Clear Creek. (See measured section at locality G24–D.) The basal conglomerate forms a low mound at a few places between Golden and Van Bibber Creek. The only other outcrop of unequivocal basal Arapahoe conglomerate is on the west side of a deep highway cut east of Ralston Reservoir on the north side of Ralston Creek. Here the basal conglomerate is a weakly cemented pebbly sandstone about 15 feet thick.

Isolated exposures of the Arapahoe north and northeast of North Table Mountain are principally of sandstone and conglomeratic sandstone, although many temporary exposures and a few natural cuts indicate that the formation is principally a sandy or silty claystone. Of nearly 100 sandstone outcrops seen in this area, roughly 50 percent are noncalcareous sandstone, 15 percent are calcareous sandstone, and 35 percent are conglomeratic sandstone. Most of the conglomeratic sandstone occur in outcrops presumably near the base of the Arapahoe but a few are in the middle or upper part. Several outcrops of a coarse conglomeratic sandstone are present near the junction of Van Bibber Creek and McIntyre Street. At several places calcareous sandstones are 100–200 feet higher than the presumed base of the formation, and only a few are in the upper part. Noncalcareous sandstone is present throughout the formation.

The sandstone in the Arapahoe ranges from light gray to moderate yellowish brown; most beds have a brownish or yellowish tinge. The sand grains are generally subangular to subround and consist principally of quartz although small amounts of dark-gray chert are present. The grain size within a single sample generally varies widely, and the different beds range from predominantly very fine grained to conglomeratic. The matrix is generally clay or silt and at many places it forms as much as 50 percent of the rock. At some places very little matrix is present, resulting in a very porous rock. Pebbles in the conglomerate and conglomeratic sandstones were derived from both metamorphic and sedimentary rocks. Quartz, feldspar, and chert are most common—the feldspar appears altered and silicified at many places—but some metamorphic rock and sandstone generally are present. The beds are generally massive but at some places are thin bedded or crossbedded.

The claystone is light to dark gray or brown and generally silty or sandy. Black carbonaceous fragments of fossil plants are present locally. The coarse fraction of the claystone is predominantly quartz. At places thin beds of siltstone are interbedded with the claystone.

The presence of thin conglomerate layers just below the main Arapahoe conglomerate at Golden led Brown (1943, p. 68) to believe that the contact of the Arapahoe with the underlying Laramie was erosional, but transitional. For this and other reasons Brown believed that the erosion did not require a great lapse of time.

AGE

The only fossils from the Arapahoe that were identified during this investigation consisted of several thin, round, calcareous, waferlike freshwater sponges, 1–3 inches in diameter, which were found in a claystone on the north side of the railroad cut in the SW¼SW¼ sec. 23, T. 2 S., R. 70 W. The fossils were identified as *Spongillidae* Gray, 1867, by Richard Rezak of the U.S. Geological Survey (written commun., Jan. 4, 1957). According to Rezak this family ranges in age from Jurassic to Holocene. Very few other fossils have been reported from the Arapahoe. Four species of dinosaurs from the Arapahoe were reported in Emmons, Cross, and Eldridge (1896, p. 227), and the presence of dinosaurs from the Arapahoe near Golden was reported by Brown (1943, p. 70). The dinosaurs are referable to the Cretaceous. No flora from undoubted Arapahoe beds have been identified. Knowlton (1922, p. 102–104) stated that only one of two previously believed Arapahoe floral collections was possibly from the Arapahoe. The beds from which this possible Arapahoe flora came have recently been mapped as Dawson Arkose by Scott (1963b). The distinction between Arapahoe and Dawson is, perhaps, a fine point inasmuch as the two formations interfinger, and the collection was probably made from a horizon equivalent to the Arapahoe. Brown (1943) pointed out that the flora and meager fauna of the Laramie, Arapahoe, and lower Denver Formations are similar, and they are of Cretaceous age.

ORIGIN

The fossil dinosaur, sponges, and leaf fragments and the conglomerates indicate the terrestrial origin of the formation.

SECTION G24-D.—*Arapahoe Formation (part)*

[Measured in a series of prospect trenches at locality G24 in the SW¼ sec. 28, T. 3 S., R. 70 W. It is continuous with a section of the Fox Hills Sandstone and Laramie Formation measured at this same locality].

Arapahoe Formation:	Thickness (ft)
112. Covered.	
111. Claystone, medium-gray (*N*5), silty; mottled by limonite stains	44.5
110. Sandstone, light-gray (*N*7), very fine grained, silty; mottled by limonite stains. Contains discontinuous streaks and lenses of claystone	11.3
109. Claystone, medium-gray (*N*5), silty. Becomes lighter in color and sandier toward base. Grades into underlying sandstone	9.9
108. Sandstone, grayish-orange (10*YR* 7/4), medium-grained, conglomeratic, friable. Pebbles are predominantly gray chert and minor amounts of red chert, pink and gray granite, and sandstone. Attitude N. 10° W., 90°	20.6
Total Arapahoe Formation measured	86.3
Laramie Formation, unit 107.	

CRETACEOUS AND TERTIARY

Although the Cretaceous–Tertiary boundary is shown on the map (Van Horn, 1972) in the lower part of the Denver Formation, the two parts of the formation are not discussed separately. Both parts are similar in lithology, and probably are not separable where paleontologic determinations are lacking. At the west, south, and east sides of North Table Mountain the Cretaceous part of the Denver is 257, 260, and 200 feet thick, respectively, and the Tertiary part, below the base of the capping lava flows, is 380, 500, and 380 feet thick, respectively.

DENVER FORMATION

The distinguishing characteristic of the Denver Formation in the Golden quadrangle is the presence of volcanic debris. The base is "determined by the first appearance of eruptive material among the particles derived from the crystalline or older sedimentary rocks" (Emmons and others, 1896, p. 160). The Denver Formation is present in the southern part of the Golden quadrangle. It crops out at many places in Golden, on North and South Table Mountains, and at a few places south of Clear Creek in the eastern part of the quadrangle. Three lava flows occur in the upper part of the formation. The part of the formation that presumably extended above the highest lava flow has been removed by erosion in this area, and less than 800 feet of the formation remains.

The Denver is composed of light-gray to brown tuffaceous silty claystone, tuffaceous arkose, and andesitic conglomerate. The base is marked by the first appearance of volcanic material, composed of angular fragments and euhedral crystals of hornblende, augite, white feldspar (probably andesine), and magnetite. Rounded quartz grains are present in the lower 200 feet of the formation but above this are rarely present. The amount of angular volcanic debris increases rapidly in progressively younger beds; also, within a few hundred feet of the base and continuing to the highest exposures, there are many beds that contain rounded pebbles and cobbles of andesite (Cross, in Emmons and others, 1896, p. 315).

The claystone and siltstone beds in the Denver are similar in gross aspect to those in the Arapahoe. At some places a careful inspection with a hand lens, however, will reveal the presence of short, stubby, dark-colored prismatic crystals (hornblende and augite) typical of the Denver. The residue of a washed sample of the Denver will invariably contain angular to euhedral grains of dark minerals and clear to milky plagioclase feldspar. Montmorillonite-type clay with excessive swelling capabilities occurs in the Denver Formation in the Denver area (Judd and others, 1954, p. 5, 15, 16). In the Golden quadrangle the Denver Formation, as shown by tests, also has excessive swelling capabilities. Montmorillonite is the predominant clay material in the three samples determined by Gude (1950, table3).

Tuffaceous arkose, as used in this report, consists predominantly of sand-sized feldspar of volcanic origin, although part of the material may have been reworked by streams or wind. The tuffaceous arkose is nearly quartz-free, except in the lower 200 feet of the Denver which may contain as much as 50 percent quartz grains.

The tuffaceous arkose is light gray to light brown and contains characteristic angular broken fragments and euhedral crystals of dark minerals and white to milky plagioclase feldspar. Quartz, if present, occurs as subround to subangular grains in sharp contrast to the feldspar and dark minerals. The particles larger than 0.074-mm diameter from washed samples of the tuffaceous arkose show a great variability in mineral content when examined under a binocular microscope. (See table 5.) In general, more than one-half the particles are fresh, angular, clear to milky plagioclase. About 5 percent are dark, angular, prismatic fragments and euhedral crystals of hornblende and augite, but the amount ranges from a trace to 37 percent. The mafic minerals or the plagioclase may be present in about equal quantities, or either may be greatly predominant over the other. Generally, there is less than 1 percent small euhedral magnetite octahedrons, many of which have rounded corners. Less than 1 percent biotite is also present in most samples. At places cryptocrystalline altered glass was seen adhering to crystals of plagioclase and to the augite or hornblende. The tuffaceous arkose beds are generally massive although at a few places they are crossbedded. The lack of rounding of the crystals and the bedding indicate that fluviatile transportation was at a minimum.

TABLE 5.—*Lithology (in percent) of fragments larger than 0.074 mm in washed samples of the Denver and Arapahoe Formations*

[...., absent; Tr., Trace; Ka, Arapahoe Formation of Cretaceous age; Kdv, Denver Formation (lower part) of Cretaceous age; Tdv, Denver Formation (upper part) of Tertiary age. a, above the contact; b, below the contact. ss, sandstone; st, siltstone; ta, tuffaceous arkose].

Locality No	Section Ravine[1]			U.S. Highway 6[2]					[3]G23					[4]G28				
Sample No	L39	L38	L37	L8	L35	L34	L7	L6	U-1	U-2	U-10	U-11	U-67	U-2	U-6	U-12	U-13	U-14
Formation	Ka	Kdv	Kdv	Ka	Kdv	Kdv	Kdv	Kdv	Ka	Kdv	Tdv	Tdv	Tdv	Kdv	Tdv	Tdv	Tdv	Tdv
Stratigraphic distance (in feet) from Ka-KDV contact	b50	a50	a75	b25	a75	a275	a350	a400	b2	a2	a303	a318	a593	a177	a270	a378	a403	a468
Rock Type	ss	ta	ta	ss	ta	ta	ta	ta	st	st	st	ta	ta	ta	ta	ta	ta	ta
Aggregates of silt and clay	....	....	....	....	....	....	56	10	80	50	85	40	....	70	....	....	....	....
Rounded pink feldspar	....	....	....	55	....	....	....	25	....	....	....	Tr.	Tr.	....	....	....	....	....
Rounded quartz	60	20	30	40	Tr.	....	3	15	20	47	....	....	....	5	Tr.	Tr.	Tr.	....
Rounded white feldspar	1	....	....	5	....	....	....	....	....	....	....	....	90	....	....	....	....	....
Unclassified rounded grains	1	....	....	....	....	....	....	6	....	....	....	....	....	....	....	....	....	....
Rounded black minerals	1	....	....	Tr.	....	....	....	....	Tr.	....	....	....	....	....	....	....	....	....
White cementing material	35	30	35	....	30	....	....	5	....	....	....	....	....	....	55	....	....	....
Rounded andesite(?)	....	5	....	....	....	58	....	....	....	....	....	....	Tr.	....	....	....	....	....
Angular white feldspar	....	35	30	....	60	....	30	30	....	....	10	50	5	20	40	95	60	80
Angular hornblende or augite	....	5	....	....	5	40	2	5	....	2	5	9	2	5	2	5	39	19
Angular magnetite	....	....	....	....	1	.2	10	1	....	.5	....	1	1	Tr.	Tr.	Tr.	1	....
Biotite	1	1	5	....	Tr.	....	1	3	....	....	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	1	Tr.

[1]NE¼NW¼ sec. 25, T. 4 S., R. 70 W., Morrison quadrangle.
[2]SE¼SE¼ sec. 3 and SW¼SW¼ sec. 2, T. 4 S., R. 70 W., Morrison quadrangle.
[3]NW¼NE¼ sec. 21, T. 3 S., R. 70 W., Golden quadrangle.
[4]Center N½ sec. 27, T. 3 S., R. 70 W., Golden quadrangle.

Grain mounts and thin sections of several samples of the Denver were examined microscopically. The white to milky subangular feldspar is probably andesine, some of which appears to be altering to clay. The subangular to euhedral mafic minerals are principally black to light-green hornblende, black to reddish-brown basaltic hornblende, and black to dark-green augite. Hornblende appears to predominate in the lower part of the Denver, but augite occurs in progressively greater amounts toward the upper part where the two are about equal. Biotite is generally present in small amounts.

At places the tuffaceous arkose is composed principally of cryptocrystalline grains of lathlike minerals in a cryptocrystalline groundmass. At other places the rock is a crystal tuff principally composed of unattached subhedral to euhedral crystals in a cryptocrystalline groundmass. The cryptocrystalline material is generally altered but at a few places appears fresh. A sample of the tuffaceous arkose of unit 40, of the measured section at locality G23, is a lithic tuff (Williams and others, 1958, p. 151, fig. 48c). A thin section of this sample contains cryptocrystalline altered glass, plagioclase, and an opaque mineral, probably magnetite. About 20 percent of the thin section is composed of rounded to angular sand-sized grains, each consisting of many minute plagioclase laths. Each grain forms a faint but distinct unit, being slightly darker than the surrounding matrix under optimum light conditions. These grains may have been expelled from a volcanic vent as discrete glassy globules. Another 20 percent of the thin section is composed of randomly oriented discrete laths of plagioclase and black blebs of the opaque mineral. The remaining 60 percent of the thin section is a cryptocrystalline altered glass matrix. The matrix is a very finely comminuted dust that probably settled out of the atmosphere with the discrete grains.

The conglomerate beds range from a normal conglomerate, composed principally of pebbles in a sandy matrix, to a rock consisting of scattered pebbles and boulders in a clayey matrix. The pebbles consist almost entirely of a porphyritic volcanic rock that ranges from nearly aphanitic to coarsely porphyritic. The many petrographic determinations made by Cross (Emmons and others, 1896, p. 315) indicate that the pebbles are principally andesites of many different kinds. A few pebbles of metamorphic rock were found in these conglomerates in the Golden quadrangle. The euhedral crystals and angular crystal fragments of plagioclase and hornblende or augite, typical of the Denver, are almost everywhere visible in the matrix.

The normal conglomerate ranges from cemented pebbles in a sand or silt matrix to pebbly tuffaceous arkose. The pebbles generally are 1–2 inches in diameter, but a boulder about 2 feet across is present in a bed underlying the lowest lava flow on North Table Mountain. The conglomerate beds are generally massive, but at a few places are crossbedded. The conglomerate looks very much like the Quaternary alluvium but is darker in color and finer grained. Conglomerates of this type were, no doubt, deposited as alluvium by streams.

The pebbly mudstone is very different in appearance. The pebbles, and locally cobbles and small boulders, are sparsely scattered throughout a clayey or silty matrix.

Generally there is a crude gradation in size, the coarser material being in the lower part of the beds. Locally petrified logs stand erect in the beds and apparently are in their position of growth. The enclosing material is poorly sorted and massive. At a few places the pebbly mudstone beds are underlain by thin ashy-appearing deposits. The pebbly mudstone beds fit the criteria outlined by Mullineaux and Crandell (1962) for volcanic mudflows. The probable origin of these mudstone beds was first called to my attention by G. E. Lewis and verified by D. R. Crandell, both of the U.S. Geological Survey, from exposures on Green Mountain a few miles south of Golden.

The highest beds in the Denver Formation in the Golden quadrangle underlie the lava flows of North and South Table Mountains. Any Denver or other Tertiary deposits that may have originally overlain these flows have been removed by erosion.

The nature of the contact of the Denver with the underlying Arapahoe Formation is not clearly established. There is a change in lithology that is probably gradational within 100 feet. According to Brown (1943, p. 84), the fauna and flora of the Laramie continue into the Arapahoe and the lower part of the Denver. In the Golden quadrangle the contact is exposed only in a small cut near the base of the west side of North Table Mountain (west of the 67° dip symbol on the map; Van Horn, 1972) in the NW¼NE¼ sec. 21, T. 3 S., R. 70 W. Here a yellowish-gray sandy siltstone of the Arapahoe is overlain, with no evidence of unconformity, by a pale-yellowish-brown siltstone of the Denver. (See measured section G23.) In an Arapahoe hand specimen a few very fine rounded quartz grains are visible, whereas in a Denver specimen a few small, black subhedral crystals are visible. Samples of each were washed through a No. 200 U.S. Standard Sieve and examined with a binocular microscope. (See table 5, samples U-1 and U-2, locality G23.) The Arapahoe residue contained about 80 percent aggregates of silt and very fine sand particles; 20 percent white to clear, subangular to rounded, predominantly unfrosted quartz; and traces of mica and a black mineral. The sample was leached with hydrochloric acid to free more of the grains, and a few particles of white feldspar and subround, elongate, grains of a black mineral were noted. The residue from the Denver sample contained 50 percent aggregates of silt- and clay-sized particles; 47 percent white to clear, subangular to rounded quartz; 2 percent green and reddish-brown broken subhedral to euhedral crystals; 0.5 percent black euhedral magnetite octahedra (the corners are slightly rounded); and a trace of mica. When the sample was leached with hydrochloric acid about 3 percent of a weathered white feldspar was seen. The black mineral in the Arapahoe appears to be abraded, whereas the fresh angular surfaces and crystal faces of the green and reddish-brown minerals in the Denver have undergone little wear. X-ray examinations of the clay-sized fraction of beds on both sides of this contact show no significant differences (table 4). This inconspicuous contact gives little hint of the drastic change in mineralogy and mode of deposition that followed the accumulation of the Arapahoe Formation. The contact between the Arapahoe and Denver probably is transitional.

AGE

The tuffaceous beds of the Denver Formation provided excellent conditions for the preservation of fossils, which reveal that the lower part of the Denver is Cretaceous in age and the upper part Paleocene. Over 200 species of fossil plants were listed by Johnson (1931, p. 370–374) as having been reported from the Denver. He also listed five species of dinosaurs, two of turtles, one of fish, one of crocodile, several mammalian teeth and bones, and five freshwater species of invertebrates.

A bone fragment was found in dark-brown tuffaceous arkose in the irrigation ditch in the SW¼SW¼ sec. 28, T. 3 S., R. 69 W., Arvada quadrangle, at an altitude of 5,520 feet. The fragment was tentatively identified as "dinosaurian" by G. E. Lewis of the U.S. Geological Survey (written commun., April 29, 1954). Thus, this tuffaceous arkose and underlying rocks are tentatively of Cretaceous age.

A few fossils, mostly leaves, were collected in the Golden quadrangle. Several fossil plant localities were reported earlier (Van Horn, 1957b); since then two additional localities have been found—one on the north side and one on the west side of North Table Mountain. The northern locality, at an altitude of 6,250 feet, is in the NW¼SW¼ sec. 15, T. 3 S., R. 70 W. The western locality (unit 18, measured section G23), at an altitude of 6,160 feet, is along the road shown ascending the west side of North Table Mountain. Both localities contain *Allantodiopsis erosa* (Lesquereux) Knowlton and Maxon and the northern locality also contains *Ficus planicostata* Lesquereux. The fossils were identified by R. W. Brown of the U.S. Geological Survey (written commun., Sept. 28, 1953), who indicated that they were of Paleocene age.

The Cretaceous–Tertiary boundary occurs in the lower part of the Denver Formation. Its location is based principally on paleontologic data supplemented by a color change of questionable value. The Cretaceous–Tertiary boundary does not form a satisfactory formational boundary in the Golden quadrangle, and the line shown on the geologic map (Van Horn, 1972) should be used with discretion. The best exposure of the boundary is at the section measured by Brown (1943, p. 74) at the southeast corner of South Table Mountain just south of the Golden quadrangle. Here the boundary is at the base of a thick light-colored zone overlying a thick brown zone. On the north side of South Table Mountain and on North Table Mountain a light-colored zone associated with the boundary is split by a 10- to 20-foot-thick light-brown zone, and the boundary is put at the base of the lower light-colored zone. (See fig. 15.) Unfortunately, these beds cannot be traced continuously, owing to poor exposures.

ORIGIN

The Denver Formation seems to have been deposited on a gently sloping surface of low relief and, as indicated by the abundant flora, in a climate that was wetter and warmer than the present-day climate. Brown (1962, p. 96) stated that the Rocky Mountains and Great Plains were in a general area of warm temperate climate with a medium amount of precipitation. A study of pollen and spores from beds of the southeast corner of South Table Mountain indicates a vegetation dominated by subtropical elements but also containing temperate elements (E. B. Leopold, written commun., Oct. 22, 1957).

The vitric and crystal tuff beds are predominantly pyroclastics and show little evidence of reworking by streams. The rounded andesite pebbles in many of the conglomerate beds, however, show that west of the Golden quadrangle streams were actively eroding and abrading their beds. The volcanic mudflows indicate that the source of the andesitic debris was relatively near the west edge of the present deposit. The general lack of material other than volcanic, as first noted by Cross (1889), indicates that the older beds to the west were mainly covered by volcanic deposits. As shown by the fact that beds of equivalent age to the south, the upper part of the Dawson Arkose, have little andesitic debris, the volcanic cover was probably of local extent in a topographically higher area west of Golden and Morrison. No potential source dikes for the volcanic cover have yet been found in this area. Possibly, however, the Precambrian rocks to the west are intruded by andesitic dikes similar to the one in the Kassler quadrangle reported by Scott (1963b, p. 106–107).

SECTION G23.—*Denver Formation*

[Measured at locality G23 along the road to the top of North Table Mountain in the NE¼ sec. 21, T. 3 S., R. 70 W.]

Denver Formation:

Unit	Description	*Thickness (ft)*
83.	Latite of lava flow 3, dark gray (*N*3); weathers yellowish gray (5*Y* 7/2); dense. Contains phenocrysts of black augite and clear to white feldspar	(1)
82.	Siltstone, greatly baked, sandy; contains a few pebbles and cobbles of latite and altered andesite(?). It has been burned various shades of red and gray. The upper contact is slightly baked and slopes S. 8°. The lower contact is also baked	5.5
81.	Siltstone, baked, sandy; contains a few scattered pebbles and cobbles of rounded latite, some of which are greatly altered. This appears to be a large mass of Denver Formation included in unit 80. (See fig. 18.)	

See footnote on p. 41.

Denver Formation—Continued

Unit	Description	*Thickness (ft)*
80.	Pebbles, cobbles, and boulders of angular latite (similar to unit 83) in a matrix of vesicular volcanic froth. It contains many pockets and thin skewed bands of baked Denver Formation, and includes unit 81	22.1
79.	Tuffaceous arkose, light-gray (*N*7), fine-grained; contains very light gray feldspar and a dark mineral, probably augite. Appears to have been cut by erosion associated with the overlying unit	4.0
78.	Claystone, moderate-reddish-brown (10*R* 4/6) (dry), silty; contains a few pebbles and cobbles of greatly altered andesite. Most of the outcrop has a strongly baked appearance. At places it is greatly fractured and slickensided	12.0
77.	Conglomerate, very pale orange (10*YR* 8/2) to dark-yellowish-brown (10*YR* 4/2); composed of cobbles and boulders of latite with many augite crystals in the matrix. A medium-grained tuffaceous arkose is at the top in places. Forms hard, rounded outcrop	8.5
76.	Claystone, grayish-black (*N*2), pebbly; baked appearance. Lies at base of a channel cut into the latite and may be a mudflow	.6
75.	Latite of lava flow 2, dark-gray (*N*3); weathers yellowish gray (5*Y* 7/2); dense. Contains phenocrysts of black augite and clear to white feldspar. Augite crystals not as prominent as flow 1. A channel cut into unit 75 is filled by units 76 to 82	[1]53.5
74.	Conglomerate, moderate-yellowish-brown (10*YR* 5/4) (dry); contains pebbles and boulders of latite. The matrix contains many large, loose augite crystals similar to those in the ledge south of Castle Rock on South Table Mountain. The top 2-12 in. is baked black. Forms hard, rounded outcrop	10.3
73.	Tuffaceous arkose, very light gray (*N*8) (dry), fine-grained; contains some coarse augite and andesite grains. Forms hard, cliffy outcrop	1.4
72.	Tuffaceous arkose, pale-yellowish-brown (10*YR* 6/2) to light-gray (*N*7), coarse-grained, conglomeratic; contains augite or hornblende and latite or andesite grains. Pebbles are strongly altered latite	4.6
71.	Tuffaceous arkose, very light gray (*N*8) to light-gray (*N*7), medium-grained, conglomeratic. Contains interbedded claystone. Contains fossil wood. Forms hard, cliffy outcrops	7.1
70.	Claystone and siltstone, very light gray (*N*8) to grayish-orange (10*YR* 7/4); in 1- to 6-in. beds. Forms hard, cliffy outcrop. Locality of fossil fern leaf (Eg-53-18) determined by R. W. Brown to be Paleocene in age (table 4, locality G23, unit 70)	7.0
69.	Siltstone, dark-yellowish-brown (10*YR* 4/2) (dry), sandy. Contains many subround pebbles of latite or andesite. Sand grains are very light gray feldspar and augite or hornblende. Forms hard, cliffy outcrops	4.2
68.	Claystone, pale-yellowish-brown (10*YR* 6/2) (dry), silty. Forms hackly slope	9.2
67.	Tuffaceous arkose, moderate-yellowish-brown (10*YR* 5/4) to dark-yellowish-orange (10*YR* 6/6); stained a dark-yellowish-brown (10*YR* 4/2) at places; silty. Contains very light gray feldspar, andesite, augite or hornblende, and minor amounts of pale-pink feldspar and bentonite(?). Forms hard, cliffy outcrops (table 5, locality G23, unit 67)	5.3
66.	Siltstone, light-gray (*N*7) (dry), sandy. Sand grains are principally quartz, very light gray feldspar, augite or hornblende. Cliff former	1.7

See footnote on p. 41.

Denver Formation—Continued

	Thickness (ft)
65. Tuffaceous arkose, pale-yellowish-brown (10*YR* 6/2) (dry), silty, crossbedded; conglomeratic at places. Channels into unit 64. Pebbles are greatly altered andesite which at a few places appeared to be vesicular. Forms hard, rounded outcrop	8.3
64. Tuffaceous arkose, very light gray (*N*8) to light-gray (*N*7), silty, very fine grained. Broken by nearly vertical, north-trending fault with 1-ft displacement. Cliff former	4.6
63. Tuffaceous arkose, yellowish-gray (5*Y* 8/1) (dry), stained grayish-orange (10*YR* 7/4) (dry), fine- to coarse-grained; contains quartz and very light gray feldspar with minor amounts of dark-gray to black minerals. Forms hard cliffy outcrops. Attitude N. 50° E., 2° S.	1.7
62. Siltstone, dark-yellowish-brown (10*YR* 4/2) (damp) to yellowish-gray (5*Y* 8/1) (dry), sandy. Forms slope of hackly fragments	2.3
61. Tuffaceous arkose, very light gray (*N*8) to light-gray medium-grained, conglomeratic, massive; contains quartz, very light gray feldspar, augite or hornblende, and minor biotite. Contains many pebbles and cobbles of altered latite which do not appear to have the large phenocrysts of latite flow 1. Forms hard, rounded outcrop	2.3
60. Siltstone, brownish-gray (5*YR* 4/1) (dry), sandy	13.3
59. Sandstone, very light gray (*N*8), massive, medium-grained. Contains quartz, biotite, augite or hornblende, and minor amounts of pale-pink and very light gray feldspar. The top is displaced 8 in. by a fault with attitude N. 3° W., 70° E.	5.3
58. Sandstone, very light gray (*N*8) (dry), silty, fine-grained; contains quartz, biotite, augite or hornblende, and minor amounts of pale-pink and very light gray feldspar	5.0
57. Covered	11.3
56. Sandstone, very light gray (*N*8) (dry), silty, fine-grained; contains quartz, biotite, augite or hornblende, and minor amounts of pale-pink and very light gray feldspar; bentonitelike clay stringers skewed to bedding. It is massive to wavy bedded and near the base it contains a few latite cobbles. Outcrops form small cliffs, rounded knobs, and thinly covered slopes	11.6
55. Latite of lava flow 1, dark-gray (*N*3); weathers yellowish gray (5*Y* 7/2); dense. Contains phenocrysts of black augite and clear to white feldspar. Augite crystals are very prominent—more so than in any other latite flow in Table Mountain or monzonite in Ralston dike. The middle part is covered by slope wash. The top 4 ft is pale yellowish brown (10*YR* 6/2) to pale brown (5*YR* 5/2) and vesicular	[1]58.3
54. Conglomerate, dark-yellowish-orange (10*YR* 6/6), cobbly; cemented with silt and clay. Some of the pebbles and cobbles are similar to the underlying tuffaceous arkose and others to the overlying latite, but are well rounded. Most are so weathered that they were unidentifiable other than being igneous. The largest boulder seen was 2 ft long. This bed is the basal Denver Formation of Reichert (1954)	5.8
53. Tuffaceous arkose, very pale orange (10*YR* 8/2) (dry), coarse- to fine-grained; contains quartz, very light gray and pink feldspar, and black minerals	5.6

[1]Not part of Denver Formation and thickness not included in total thickness of Denver.

Denver Formation—Continued

	Thickness (ft)
52. Siltstone, pale-brown (5*YR* 5/2) (damp) to grayish-orange-pink (5*YR* 7/2) (dry). Forms hard sloping outcrop	2.3
51. Tuffaceous arkose, light-gray (*N*7) (damp), very light gray (*N*8) (dry), fine-grained. Forms hard, rounded outcrop	3.3
50. Siltstone, medium-light-gray (*N*6) (damp) to light-gray (*N*7) (dry); massive. Forms hard, hackly fragmented sloping outcrop	.7
49. Tuffaceous arkose, light-gray (*N*7) (damp) to very light gray (*N*8) (dry), fine-grained, massive. Contains pink and very light gray feldspar and minor amounts of a black mineral. Stained moderate greenish yellow (10*Y* 7/4) at places. Forms hard, rounded to sloping outcrop. Massive	1.5
48. Siltstone, medium-light-gray (*N*6) (damp) to light-gray (*N*7) (dry); massive. Forms hard, hackly fragmented sloping outcrop	3.3
47. Tuffaceous arkose, light-gray (*N*7) (damp) to very light gray (*N*8) (dry); fine-grained. Forms hard, rounded outcrop	.9
46. Siltstone, medium-light-gray (*N*6) (damp) to light-gray (*N*7) (dry), massive. Forms hard, hackly fragmented sloping outcrop	1.0
45. Tuffaceous arkose, light-gray (*N*7) (damp) to very light gray (*N*8) (dry), fine-grained, massive. Contains pink and very light gray feldspar and minor amounts of a black mineral. Stained moderate greenish yellow (10*Y* 7/4) at places and has a one-half-in. dark-reddish-brown (10*R* 3/4) band parallel to bedding at middle. Forms hard rounded to sloping outcrop	11.3
44. Siltstone, light-gray (*N*7) (damp) to very light gray (*N*8) (dry)	.5
43. Tuffaceous arkose, yellowish-gray (5*Y* 8/1), conglomeratic; contains quartz and andesite pebbles. Sand-sized fraction contains pink and very light gray feldspar and minor amounts of black minerals	2.6
42. Siltstone, light-gray (*N*7) (damp) to very light gray (*N*8) (dry). Two 6- to 8-in.-thick grayish-orange-pink (5*YR* 7/2) siltstone beds are near the base. Forms hard, sloping outcrop	4.3
41. Siltstone, pale-brown (5*YR* 5/2) (damp) to grayish-orange-pink (5*YR* 7/2) (dry). Forms hard sloping outcrop	3.5
40. Tuffaceous arkose, yellowish-gray (5*Y* 8/1); conglomeratic contains quartz and andesite pebbles. Sand-sized fraction contains pink and very light gray feldspar and minor amounts of black minerals. Clay binder is white but mostly altered to yellowish gray. Massive with occasional crossbedding. Forms, hard, rounded outcrop	3.5
39. Tuffaceous arkose, light-gray (*N*7); lithology similar to unit 33. The basal half is medium grained to conglomeratic. The unit is cut out at south end of the outcrop by a channel fill of the overlying unit	1.3
38. Siltstone, medium-light-gray (*N*6) (damp) to light-gray (*N*7) (dry), massive. Forms hard, hackly fragmented sloping outcrop	2.7
37. Tuffaceous arkose, light-gray (*N*7); lithology similar to unit 33. The basal half is medium grained to conglomeratic	.8
36. Siltstone, medium-light-gray (*N*6) (damp) to light-gray (*N*7) (dry), massive. Forms hard, hackly fragmented sloping outcrop	4.3

Denver Formation—Continued

	Thickness (ft)
35. Tuffaceous arkose, light-gray (*N*7); lithology similar to unit 33. The basal half is massive, medium-grained to conglomeratic sandstone. The upper half is crossbedded in thin beds, fine-grained sandstone. Forms hard, rounded outcrop	7.8
34. Claystone, pale-brown (5*YR* 5/2) (damp) to grayish-orange-pink (5*YR* 7/2) (dry), silty. Forms hard, rounded outcrop	3.7
33. Tuffaceous arkose, light-gray (*N*7) (damp) to very light gray (*N*8) (dry), massive. Principally quartz and very light gray feldspar and minor amounts of pale-pink feldspar and a black mineral. Forms hard, rounded outcrop	3.8
32. Claystone, very light gray (*N*8) (dry) and light-gray (damp)	1.9
31. Tuffaceous arkose, very light gray (*N*8)	1.2
30. Tuffaceous arkose, light-gray (*N*7), silty	2.1
29. Claystone, grayish-orange-pink (5*YR* 7/2)	1.0
28. Tuffaceous arkose, very light gray (*N*8); stained moderate yellow (5*Y* 7/6) at places	.3
27. Claystone, very light gray (*N*8)	.3
26. Siltstone, very light gray (*N*8)	.6
25. Tuffaceous arkose, very light gray (*N*8)	.8
24. Conglomerate, very light gray (*N*8) to light-gray (N7); composed chiefly of andesite pebbles of very light gray (*N*8) feldspar, augite or hornblende, and biotite. Sand size has these minerals plus quartz. Forms hard, rounded outcrop	4.7
23. Tuffaceous arkose, light-gray (*N*7) to very light gray (*N*8), fine- to medium-grained, even-bedded to massive. Contains very light gray and pale-pink feldspar, quartz, biotite, and augite or hornblende. Conglomeratic at places. The pebbles are mainly andesite but two 6-in. cobbles were of Precambrian orgin. One was biotite granite gneiss and the other was composed of very light gray feldspar and biotite. Forms hard, rounded outcrop	7.2
22. Conglomerate, light-olive-gray (5*Y* 5/2), silty, massive. Pebbles are light-gray andesite. The sand-size fraction contains quartz and biotite and minor amounts of very light gray feldspar and hornblende or augite. Forms hard, rounded outcrop	1.2
21. Tuffaceous arkose, dusky-yellow (5*Y* 6/4), silty, crossbedded; lithologically similar to unit 20. Has 1- to 2-in-wide zones of calcium carbonate mixed with opal which crosscut bedding planes. Forms hard, rounded outcrop. Attitude N. 4° W., 8° E.	5.3
20. Tuffaceous arkose, light-olive-gray (5*Y* 5/2), silty; composition similar to unit 19 but also contains some andesitic material. Conglomeratic at places with strongly weathered light and very light gray andesitic pebbles. Forms hard, rounded outcrop	2.7
19. Siltstone, olive-gray (5*Y* 3/2), sandy. Sand grains are biotite and very light gray feldspar with minor quartz and hornblende or augite	1.1
18. Tuffaceous arkose, very light gray (*N*8), medium-grained; contains quartz, very light gray feldspar, black augite or hornblende, and very minor biotite. Conglomeratic at places. Forms hard, rounded outcrop. Fossil leaf fragments are present locally. (Table 4, locality G23, unit 18.)	5.6
17. Claystone, dark-gray, contains phenocrysts of unidentified black mineral	.5
16. Tuffaceous arkose, very light gray (*N*8) to light-gray (*N*7), medium-grained; crossbedded at places; contains quartz, pink feldspar, unidentified black mineral and some very light gray feldspar and andesitic material at base; grades up into light-olive-gray (5*Y* 6/1) silty sandstone. Entire section below top of this unit has weathered into thinly covered steep slope	3.2
15. Siltstone, pale-brown (5*YR* 6/2), sandy	1.1
14. Tuffaceous arkose, very light gray (*N*8) to light-gray (*N*7), medium-grained; crossbedded at places. Contains quartz, pink feldspar, unidentified black mineral, and some very light gray feldspar and andesitic material. A fault (attitude of N. 1° E., 84° W.) displaces the top of the unit 18 in. Forms a hard, rounded outcrop	.8
13. Siltstone, pale-brown (5*YR* 5/2), clayey; contains a few quartz sand grains and thin seams of moderate-yellow (5*Y* 7/6) and light-olive and brown (5*Y* 5/6) bentonitic-appearing clay with a greasy luster	1.0
12. Tuffaceous arkose, very light gray (*N*8) to light-gray (*N*7), medium-grained; crossbedded at places with quartz, pink feldspar, and unidentified black mineral. Contains lenses of conglomerate and clayey silt. Conglomerate pebbles are badly weathered to very light gray (*N*8), pale red purple (5*RP* 6/2), grayish red purple (5*RP* 4/2), pale pink (5*RP* 8/2), and light gray (*N*7). They appear to be composed of very light gray and pale-pink feldspar with a black mineral which is either hornblende or augite. Attitude N. 40° E., 12° E.	29.6
11. Tuffaceous arkose, very light gray (*N*8) to light-gray (*N*7), medium-grained; crossbedded at places, containing light-gray feldspar, pink feldspar, and unidentified black mineral. Hard, rounded outcrop but breaks into 2-in. blocks. (Table 5, locality G23, unit 11.)	15.0
10. Siltstone, light-olive-gray (5*Y* 5/2); sandy with limonite staining near top. Attitude N. 5° E., 20° E. (Table 5, locality G23, unit 10.)	3.3
9. Covered	25.0
8. Tuffaceous arkose, yellowish-gray (5*Y* 7/2), medium-grained; contains light-gray feldspar, andesite, and minor pink feldspar. Evenly and thinly bedded. Attitude N. 5° W., 29° E.	5.3
7. Siltstone, brownish-gray (5*YR* 4/1), sandy with a few noncalcareous white spots, massive. Fault N. 12° W., 84° W., near top of bed with minor displacement and 1 in. of gouge	4.6
6. Siltstone, dusky-yellow (5*Y* 6/4), sandy, massive	3.0
5. Siltstone, light-olive-gray (5*Y* 6/1), massive. The base of this bed is about the base of the Tertiary part of the Denver Formation	4.9
4. Tuffaceous arkose, moderate-olive-brown (5*Y* 4/4), fine-grained, massive, silty; contains light-gray feldspar, andesite, and pink feldspar. Attitude N. 2° E., 26° E.	5.0
3. Covered	250.0
2. Siltstone, pale-yellowish-brown (10*YR* 6/2); contains a few black subhedral crystals. Attitude N. 4° W., 67° E. (Tables 4 and 5, locality G23, unit 2.)	2.0
Total Denver Formation	634.0

Arapahoe Formation:

	Thickness (ft)
1. Siltstone, yellowish-gray (5*Y* 7/2). (Tables 4 and 5, locality G23, unit 1.)	2.0
Total Arapahoe Formation measured	2.0

LARAMIE, ARAPAHOE, AND DENVER BOUNDARY PROBLEMS

The Laramie, Arapahoe, and Denver Formations are not readily distinguishable at many places; therefore, the boundaries between them have been shown differently by various workers. The major changes of the stratigraphic position of the boundaries and the different nomenclature are shown in figure 13. After examining the various proposed contacts I decided that the original formational contacts which were established by Emmons, Cross, and Eldridge (1896), and which were used in reports by Van Horn (1957b, 1972) and Smith (1964), are workable at most places, and therefore, their usage is followed in the present report.

Dissatisfaction with the designation of Laramie, Arapahoe, and Denver has been expressed by several geologists who have studied these formations in the Denver area (Johnson, 1930b, p. 14; 1931, p. 368; Brown, 1943, p. 77; LeRoy, 1946, p. 101; Reichert, 1954, p. 17; 1956, p. 110). Johnson believed that the Arapahoe and Denver as originally defined should be combined into one formation. Brown believed that the Laramie should be expanded to include the Arapahoe and the Cretaceous part of the Denver; the basal conglomerate of the Arapahoe was designated as the Arapahoe Conglomerate Member of the Laramie Formation, and the name Denver was restricted to the beds above the Cretaceous-Tertiary boundary. LeRoy, in partial agreement with Johnson, believed that the Arapahoe and Denver should be combined into one

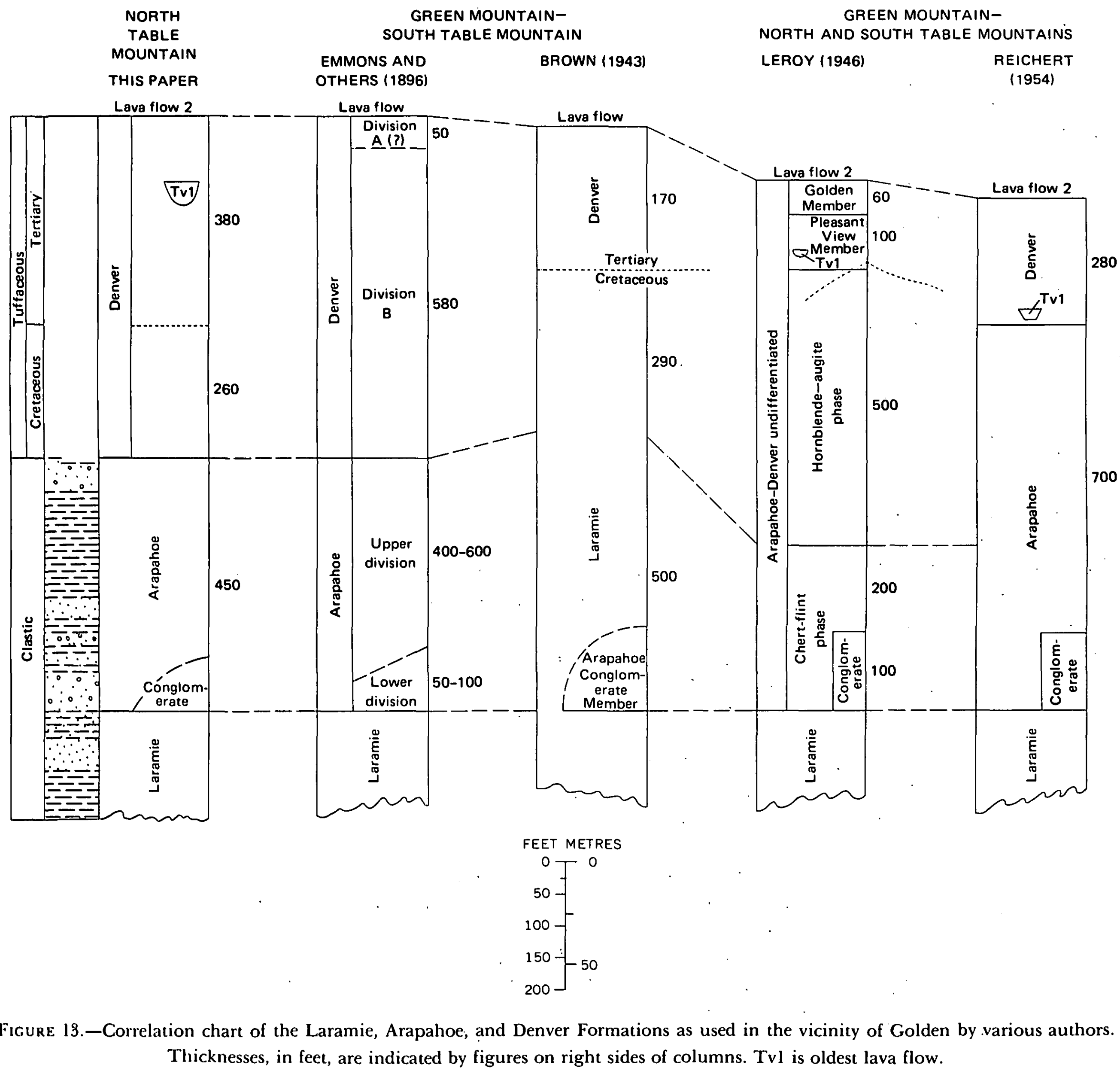


FIGURE 13.—Correlation chart of the Laramie, Arapahoe, and Denver Formations as used in the vicinity of Golden by various authors. Thicknesses, in feet, are indicated by figures on right sides of columns. Tvl is oldest lava flow.

unit; he also named and defined two members in the Tertiary part of the combined Arapahoe–Denver. Reichert recognized the Arapahoe but placed the upper boundary at the base of a basalt–andesite conglomerate bed in the Cretaceous part of the Denver.

The boundary between the Laramie and Arapahoe Formations is retained in this report as originally defined because of the persistent nature of the lithologic change and the conglomerate at the base of the Arapahoe. All the authors cited placed a contact at this stratigraphic position although Brown considered it as only a boundary between members. The subtle lithologic differences between the rocks on each side of this boundary seem to justify retaining the formations as originally defined.

The conflicting views on the Arapahoe and Denver Formations are more difficult to resolve. Johnson wanted to combine the two formations because he believed they were defined because of a misconception as to the age of the Denver (Johnson, 1930b, p. 14). He also pointed out a similarity of contained fossils and origin of the formations. In the original definition, Cross (1889, p. 122) stated, "The independence of the [Denver] formation was first established by the character of the materials in its sediments." This is certainly a valid reason for establishing a formation. LeRoy, like Johnson, also combined the Arapahoe and Denver in spite of recognizing a distinctive difference in lithology—the contact between his flint-chert and hornblende-augite phases is the contact between the Arapahoe and Denver Formations. In recognizing this significant lithologic change LeRoy (1946, p. 103) stated, "the mineralogic break between these two phases on the west slope of Green Mountain is of considerable magnitude and may be placed within several feet." In spite of this, LeRoy stated (1946, p. 101), "From lithic evidence the Arapahoe–Denver boundary as originally placed by Cross and Eldridge is very indefinite." LeRoy presumably concluded that the two formations should be combined because he saw the contact at only one place, on the west slope of Green Mountain.

Although the Denver–Arapahoe contact is rarely exposed, there are several places where abrupt changes from normal sedimentary to volcanic mineralogy take place. (See table 5.) A break of considerable magnitude is exposed on the southwest side of Green Mountain in the SE¼SW¼ sec. 24, T. 4 S., R. 70 W., Morrison quadrangle. This is probably the Section Ravine of Emmons, Cross, and Eldridge (1896, p. 160–161). Here the strata change is marked by the abrupt appearance of volcanic debris within a few feet. The abrupt appearance of volcanic debris is also seen in exposures on the west side of U.S. Highway 6 in the SE¼SE¼ sec. 3, T. 4 S., R. 70 W., Morrison quadrangle, where the highway changes direction from N. 40° W. to N. 80° W. A washed sample of the Arapahoe from just west of the curve contained about 55 percent weathered pink feldspar, 40 percent subangular to round quartz, 5 percent subangular to subround white feldspar, and a trace of magnetite and mica (table 5, sample L8). The next exposure to the southeast, part way up the hill on the west side of the road, is of Denver Formation. A washed sample from this exposure contained 60 percent of white angular to subangular feldspar with many crystal or cleavage faces; 5 percent of black and light-green, angular to euhedral crystals of hornblende or augite; 1 percent of magnetite in very small irregular black blebs; and a trace of reddish-brown biotite crystals (table 5, sample L35). Other beds on the east side of the highway are similar to the last described bed. Two other examples of abrupt appearance of volcanic debris have been described in the sections of this report on the Arapahoe and the Denver Formations. Although the upper part of the Arapahoe and the lower part of the Denver are exposed together at very few places, the difference in lithology is enough to establish the validity of separate formational status for both of them. The contact shown on the map (Van Horn, 1972) may not be exact at all places but is well within the accuracy of generally accepted geologic map standards.

The problem of the Denver–Arapahoe contacts that Brown (1943), LeRoy (1946), and Reichert (1954) placed within the Denver Formation as originally described is somewhat more complex. (See fig. 14.) It should first be pointed out that the lithology of beds above and below these proposed contacts is the same. The beds range from claystone to conglomerate and are composed dominantly of volcanic debris. Neither Brown, Reichert, nor LeRoy questioned this. Brown established his boundary (the Cretaceous-Tertiary boundary) first, and in this area it was based on a single, well-described exposure on South Table Mountain. LeRoy, though not accepting Brown's boundary as a formational boundary, did accept it as the lower boundary for a member of the Denver that could be recognized only on North and South Table Mountains (LeRoy, 1946, p. 103, 104). By thus defining the Pleasant View Member of the Denver, LeRoy virtually recognized Brown's Cretaceous-Tertiary boundary as a mappable contact around North and South Table Mountains. Reichert did not accept Brown's boundary as a mappable contact but did relate his own Arapahoe–Denver contact to Brown's boundary by using the base of the highest dinosaur-bearing bed (a conglomeratic sandstone) of Brown's South Table Mountain exposure for the Arapahoe–Denver contact. Reichert stated that this bed is the lowest, thickest, and most prominent basalt-andesite conglomerate in the area and that it can be traced from Golden to Colorado Springs (Reichert, 1954, p. 21). Scott (1962, 1963b) did not mention this bed in either the Littleton or Kassler quadrangle although he did mention that a tongue of Denver in the Littleton quadrangle has andesitic sandstone. During a field conference in 1953, Brown pointed out two places on the north side of South Table Mountain where he had found Paleocene fossils. During this conference we located the Cretaceous–Tertiary boundary on the

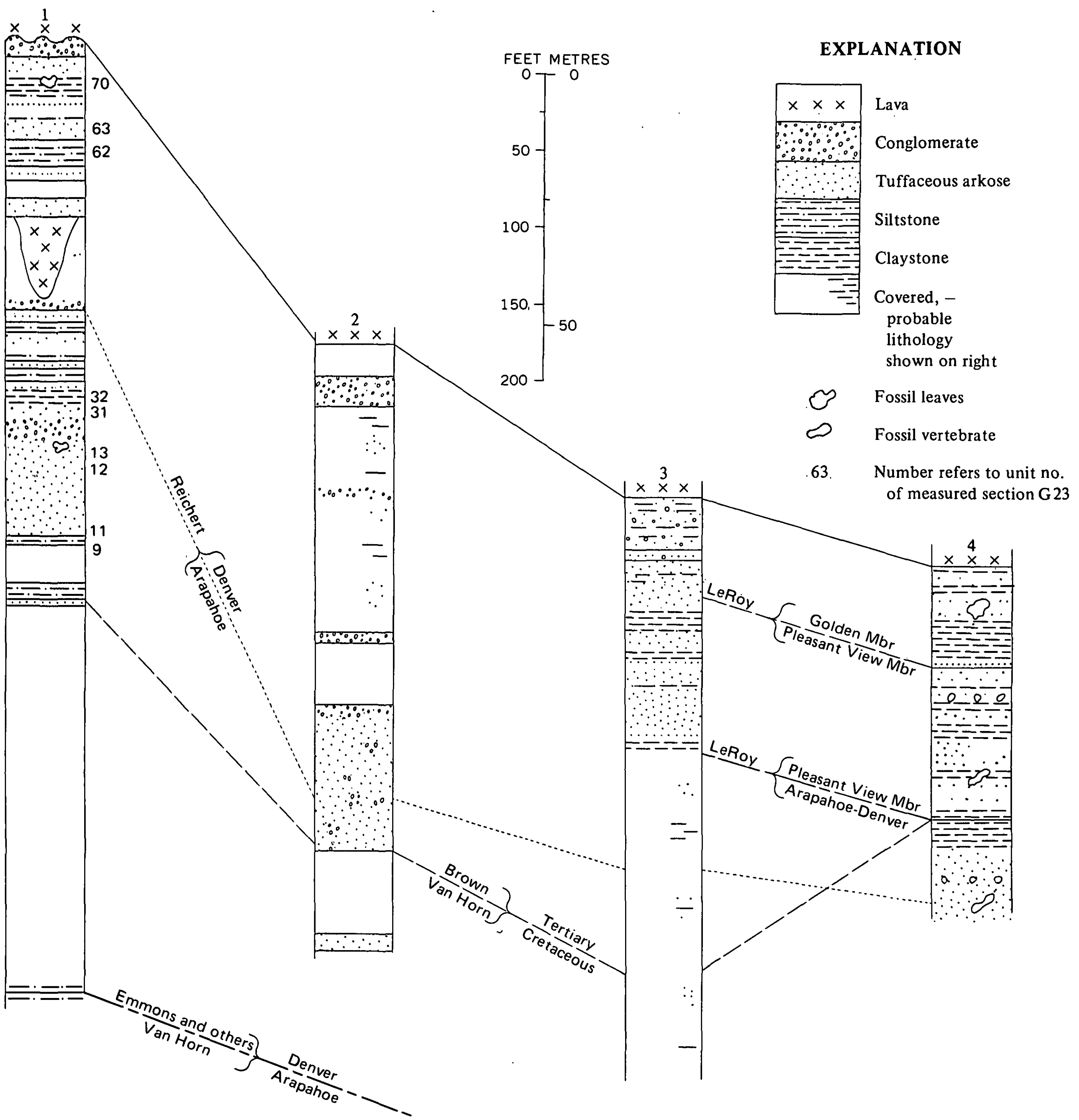


FIGURE 14.—Correlation chart of the Denver Formation as used in the vicinity of Golden by various authors. (1) West side North Table Mountain (G23), NE¼ sec. 21, T. 3 S., R. 70 W.; (2) northwest corner South Table Mountain, SE¼ sec. 27, T. 3 S., R. 70 W.; (3) northeast corner South Table Mountain, NE¼ sec. 26, T. 3 S., R. 70 W.; (4) southeast corner South Table Mountain, NW¼ sec. 31, T. 3 S., R. 70 W. (Morrison quadrangle). The sections are from Emmons, Cross, and Eldridge (1896), Brown (1943), LeRoy (1946), and Reichert (1954).

south side of North Table Mountain. Using these data and some later collections, I mapped the Cretaceous–Tertiary boundary at the base of a thick sequence of light-colored beds in accordance with Brown's criteria (1943, p. 74).

The three boundaries on the Table Mountains established by LeRoy, by Reichert, and by Brown and me were not in accordance. At the southeast corner of South Table Mountain, where the relations are clear, the contacts established by LeRoy and Brown coincide and are about 70 feet above the contact established by Reichert (fig. 14, sec.

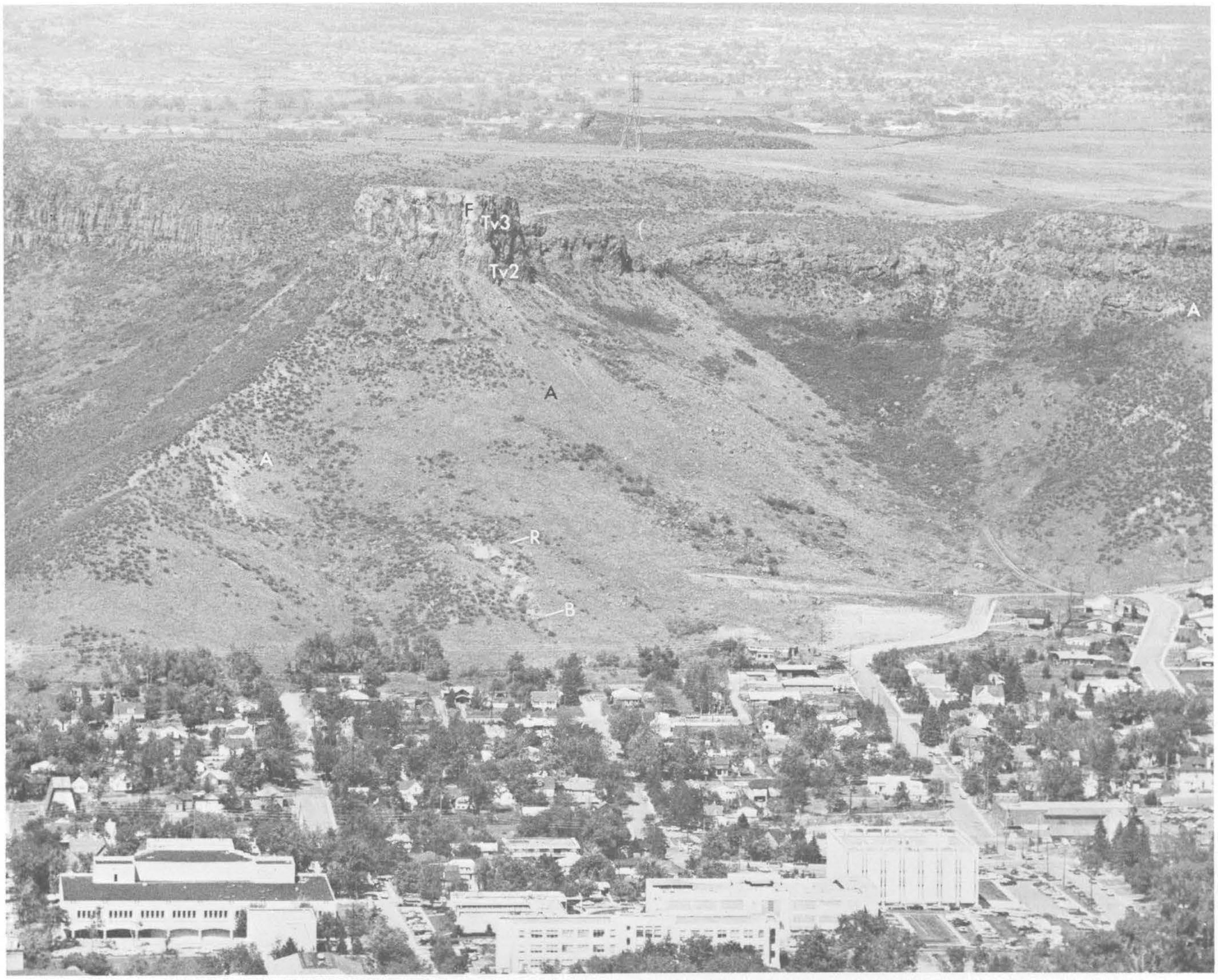


FIGURE 15.—Latite lava flows (Tv2 and Tv3) and the underlying Tertiary and Cretaceous Denver Formation exposed at Castle Rock on the east side of Golden. (See fig. 14.) The Cretaceous-Tertiary boundary (B) is at the base of the light-colored beds near the bottom of the slope. The Denver-Arapahoe boundary established by Reichert (R) (1954) is farther up the slope at the top of the light-colored beds. Outcrops of andesitic conglomerate (A) occur at several places. The one at the upper right is truncated by flow 2 a mile south of the pictured area. The vesicular zone between the two lava flows is near the base of the cliff. The light-colored vertical scar on Castle Rock (F) marks the site of the 1958 rockfall, debris of which can be seen on the slope to the right of the scar. Photograph by H. E. Malde, U.S. Geological Survey.

4). On the northeast corner of South Table Mountain the Cretaceous-Tertiary boundary established by Brown and me is about 150 feet lower than the presumably same boundary established by LeRoy (fig. 14, sec. 3). Reichert's contact is about midway between these two boundaries; it has moved from 70 feet below the Cretaceous-Tertiary boundary to 70 feet above it in a distance of about 2 miles. LeRoy's boundary, which supposedly coincides with the Cretaceous-Tertiary boundary, has moved to a position 150 feet above it.

On the northwest side of South Table Mountain, below Castle Rock, the position of LeRoy's boundary could not be established. Reichert, however, showed his boundary to be at 5,850 feet altitude which is at the base of a dark-colored sequence of beds and overlies a light-colored sequence. (See figs. 14 and 15, sec. 2.) I believe the Cretaceous-Tertiary boundary to be at the base of this light-colored sequence at 5,820 feet altitude. Thus Reichert's boundary is here 30 feet above the Cretaceous-Tertiary boundary.

A similar relation prevails on North Table Mountain where Brown and I established the Cretaceous-Tertiary boundary near the southwest corner at about 150 feet below the base of the lowest lava flow. The position of LeRoy's boundary is not clear on North Table Mountain but he stated that sandstones in the lower third of his Pleasant View Member are contemporaneous with the lowest lava flow. Reichert was more definite and placed his boundary at the base of a conglomerate 10 feet below the base of the lowest lava flow, on the west side of North Table Mountain (fig. 14, section 1). Reichert's contact here, at about the same position as LeRoy's boundary, is approximately 140 feet above the Cretaceous–Tertiary boundary.

After recognizing these relationships I walked completely around both North and South Table Mountains. The results, as might be expected, were far from satisfactory because of the thick colluvial deposits and many landslides. Neither LeRoy's, Brown's, nor Reichert's units could be traced. The conglomerate beds are not persistent and are present at many different positions. Brown's contact is not satisfactory because there are several different horizons where light-colored beds overlie dark-colored beds. Without distinctive fossils I could not pick the proper horizon. At this point I decided that the boundaries described by Emmons, Cross, and Eldridge (1896), which are based on distinctive mineralogic or compositional differences, were the most practical formation boundaries. Although the Cretaceous–Tertiary boundary is also shown, it is essentially a paleontologic boundary and is only approximately located.

TERTIARY IGNEOUS ROCKS

Lava flows interbedded with the Tertiary part of the Denver Formation, and irregular intrusive bodies and dikes that intrude the Pierre Shale, constitute the Tertiary igneous rocks in the Golden quadrangle. Sills of similar material intrude the Fort Hays Limestone Member of the Niobrara Formation in the adjoining Ralston Buttes quadrangle (Van Horn, in Sheridan and others, 1967). These rocks, formerly classed as diorite and basalt, were determined to be mafic monzonite and its extrusive equivalent, mafic latite, by W. T. Pecora of the U.S. Geological Survey (written commun., May 11, 1955). Although Waldschmidt (1939) and Cross (in Emmons and others, 1896) both recognized that potassic feldspar is present in these rocks, they did not realize that it exceeded the amount of plagioclase feldspar. The large amount of potassic feldspar is shown by the high potassium oxide content of the rock (table 6) and by the thin sections analyzed (table 7).

Both intrusive and extrusive rocks are composed principally of potassic feldspar (probably sanidine), plagioclase (andesine-labradorite), and augite. Olivine, magnetite, biotite, and apatite are present in smaller amounts. (See table 7.) The potassic feldspar occurs as large, poorly defined, colorless grains containing inclusions of plagioclase and other minerals. Cross indicated that potassic feldspar also occurs in the groundmass (Emmons and others, 1896, p. 303). The plagioclase forms sharply

TABLE 6.—*Chemical analyses (in percent) of monzonite, latite, and tuffaceous rocks of, and interbedded with, the Denver Formation*

[Samples were analyzed by P. L. D. Elmore, K. E., White, and S. D. Botts by methods similar to those described by Shapiro and Brannock (1956)]

Locality No (fig. 3)	G31	G30	G32	G22	G7	G62	G65	G66	G68
Lab. No.	149006	149007	149008	149010	149012	149013	149014	149015	149016
SiO_2	49.2	53.2	54.1	54.0	52.4	60.3	54.2	56.1	50.6
Al_2O_3	15	16.4	16.8	17	15.2	17.6	15.2	18.8	20.6
Fe_2O_3	6.9	5.1	4.6	4.1	4.4	4.4	8.6	5.2	6.8
FeO	3.5	3.8	3.8	4.2	4.5	.31	2	.68	1.8
MgO	6.2	3.6	3.2	3.2	6.8	.75	2.3	1.1	1.2
CaO	6.5	6.7	6.4	6.2	7	1	5.4	5.2	2.1
Na_2O	2.3	3.2	3.2	3.5	2.7	1.7	2.3	3.1	3.1
K_2O	3.6	4.6	4.7	4.7	3.3	9.1	4	2	4.2
TiO_2	1	.86	.82	.82	.82	1	.98	.54	.96
P_2O_5	.78	.58	.54	.56	.45	.06	.57	.24	.32
MnO	.28	.16	.16	.16	.15	.02	.12	.11	.08
H_2O	4.7	2	1.6	1.3	2.2	3.7	3.9	6.5	9
CO_2	.08	.20	.08	.05	.08	.08	<.05	<.05	.06
Sum	100	100	100	100	100	100	100	100	101

SAMPLE DESCRIPTION AND LOCALITY

Golden quadrangle, T. 3 S., R. 70 W.

G31. Latite from middle of lowest flow in the SW¼NW¼ sec. 14.
G30. Latite from middle of intermediate flow in the SW¼SW¼ sec. 14.
G32. Latite from lower part of highest flow in the SE¼NE¼ sec. 21.
G22. Monzonite from south of Ralston dike in the NW¼SE¼ sec. 9.
G7. Monzonite from Ralston dike in the NE¼NE¼ sec. 5.

Morrison quadrangle, SW¼NW¼ sec. 31, T. 3 S., R. 69 W.

G62. Tuffaceous claystone from Cretaceous part of Denver Formation.
G65. Tuffaceous sandstone from Cretaceous part of Denver Formation.
G66. Tuffaceous sandstone from Tertiary part of Denver Formation.
G68. Tuffaceous sandstone from Tertiary part of Denver Formation.

TABLE 7.—*Modal analyses, in volume percent, of Tertiary intrusive and extrusive rocks in the Golden quadrangle and vicinity*

[The Tv1 samples are from North Table Mountain and the Tv2 and Tv3 samples are from North and South Table Mountains. The Leyden sill locality is in the NW¼SW¼ sec. 29, T. 2 S., R. 70 W., Ralston Buttes quadrangle. The Green Mountain locality is in the SW¼NE¼ sec. 12, T. 4 S., R. 70 W., Morrison quadrangle, and according to Smith (1964) is equivalent to Tv3. Analyst: Barrie H. Bieler. About 2,000 points counted per thin section]

Location	Number of samples	Potassic feldspar	Plagioclase feldspar	Augite	Olivine	Biotite	Magnetite	Apatite
Leyden sill....	1	46.9	32.9	11.8	1.9	2.4	4.0	0.1
Ralston dike	6	35.8	28.1	23	4.1	1.9	6.0	1.2
Tv1	5	34.8	30.7	22.5	6.8	.1	4.8	.3
Tv2	4	37.4	32.5	18.1	3	.2	7.4	1.2
Tv3	6	38.2	36.4	15.8	2.7	.5	5.2	.8
Green Mountain..	1	38.7	33.1	19.7	3.4	.4	4.5	.2

defined colorless grains both as phenocrysts and in the microcrystalline groundmass. The augite forms large sharply defined to ragged, pale-brown to pale-green phenocrysts that contain inclusions of magnetite, apatite, biotite, and plagioclase. The augite also occurs as small somewhat irregular grains. Olivine is present as small or large, rather irregular, yellowish-brown to dark-green phenocrysts, and generally is greatly altered. Magnetite forms black irregularly rounded to nearly square small to medium size grains. Apatite is in short stubby crystals or as rounded to nearly square, small, gray grains. The biotite phenocrysts are strongly pleochroic from light yellowish brown to dark orange and are generally small and ragged. Much of the rock shows signs of slight alteration but not enough to significantly affect its physical properties. According to Schlocker (1947), alteration products in these rocks are composed of clay minerals of the montmorillonite-nontronite group.

MONZONITE

The monzonite intrusives are west of, or associated with, the Golden fault. In the Golden quadrangle the monzonite intrudes only the Pierre Shale and is not known to intrude any younger rock in the vicinity. Ralston dike, the largest of the intrusives, forms the large hill southeast of Ralston Reservoir. Two thin intersecting dikes northwest of Ralston dike are visible on the northwest side of Ralston Reservoir only when the water is at a low stage. They can be traced only a short distance and neither seem to be connected to Ralston dike at the surface. Southeast of Ralston dike are 10 irregularly shaped intrusive bodies that range in shape from thin tabular to roughly circular.

In hand specimen the monzonite intrusives are very dark gray rocks composed of short stubby phenocrysts in an aphanitic groundmass. The phenocrysts, of glassy feldspar and very dark green to almost black augite, generally are only a few millimetres long. At one place on Ralston dike, however, a single plagioclase crystal 3 cm long and an augite crystal 2 cm long were seen. The groundmass weathers to a medium gray or moderate brown from which the almost black augite grains stand out in sharp contrast. Rounded knobs, as much as 1 foot in diameter, due to spheroidal weathering are present at several places.

A few small xenoliths were found enclosed by the monzonite. On Ralston dike one was of metamorphic rock and another was of sandstone. A quartzite xenolith was found near the center of the largest intrusive southeast of Ralston dike. The metamorphic rock and the quartzite undoubtedly came from the Precambrian basement but the sandstone could not be identified as to source. None of the xenoliths have been appreciably metamorphosed by the monzonite.

Ralston dike, about 7,500 feet long and 2,000 feet wide, is canoe shaped, with a hollowed-out center occupied by Upper Long Lake. The west side is about 400 feet above the lake but the east side is only 20–50 feet above the lake. The lake occupies an undrained basin that has been increased in volume by two small artificial dams on the east side. Eldridge (in Emmons and others, 1896, p. 282) reported the presence of outcrops of Pierre Shale on the west side of the basin and concluded that the entire basin area was of shale. Whitman Cross (unpub. notes) also examined the basin; he did not find any shale, but concluded that shale probably underlies the basin because of the depression. Later, when the lake was at a low level, the area was investigated by Waldschmidt (1939, p. 11), who was not able to find any shale. No evidence of shale was found during my investigation of the basin. From outcrops now available the basin walls appear to be principally brown colluvium containing abundant monzonite fragments. In the lower part of the basin the colluvium is overlain by 1–2 feet of pale-brown loess. Outcrops of monzonite extend down to the shore of Upper Long Lake at a few places. The absence of gravel around the margin of the lake indicates that the part of the basin lower than the adjoining Rocky Flats Alluvium has been formed since Nebraskan time; the part lower than the base of the dams, the original undrained depression, must have been excavated by wind erosion—the depth of the erosion is not known.

The joint system developed in Ralston dike was not studied; there are, however, three sets of conspicuous joints. The most persistent set strikes nearly east and dips a few degrees to either side of vertical. A second strikes approximately north and dips 20°–70° E. A third set, which is generally less well developed than the others, strikes from a few degrees west of north to northeast and dips 18°–60° W. A tabular platy structure is developed at several places; at the north end of the dike the plates are parallel to the first joint set described, but in the abandoned quarry on the northwest side they are parallel to the third joint set. At two places a vertical pseudocolumnar structure is faintly developed.

No obvious evidence of multiple intrusion was seen at Ralston dike. The rock, however, is not entirely uniform. Several samples taken from the water tunnels driven into the dike and from the quarries show minor differences in the size of phenocrysts and the quantity of some of the minerals. These differences could be due to multiple intrusions of slightly different character or to differentiation within a single intrusion.

The contact of Ralston dike with the enclosing Pierre Shale is discordant and ranges from gently undulatory to sharply irregular. The contact is clearly exposed in the inlet and outlet tunnels of Upper Long Lake and at a few places in surface outcrops. On the west side of Ralston dike the contact dips 50°–60° E., about 10° gentler than the shale. In the abandoned quarry on the northwest side the contact is very irregular with large jagged embayments of monzonite into the Pierre. Only 500 feet north of the quarry, the contact is very smooth and regular. Here, however, the Pierre is brecciated for 6 inches and the monzonite for 1 foot on either side of the contact. The shale within 2 inches of the contact appears baked and is abnormally hard, brittle, and fractured for several feet to the west. Both the brecciated and normal monzonite are slickensided. In the tunnel through the west side of the dike the contact is gently undulating; it strikes N. 22° E. and dips 61° E., whereas the Pierre strikes N. 3° W. and dips 69° E. Here, a strongly developed east-striking vertical joint system in the monzonite is also present, though less strongly developed, in the shale. Several small faults with thin gouge zones are present in the shale.

On the east side of Ralston dike the contact between the monzonite and Pierre Shale dips about 45° W., whereas the shale dips from vertical to 70° W. (overturned). At the abandoned quarry on the northeast side, the contact is gently rolling and the shale is bleached and hardened for many feet east of the contact. Both the monzonite and shale are cut by slickensided faults of small displacement. The outlet tunnel under Upper Long Lake contains an interesting exposure of the contact. (See fig. 16.) Here the contact, though very irregular, dips about 45° W. The monzonite apparently follows fractures in the shale, and the contact consists of many short, nearly straight segments. Some of these segments intersect at angles approaching 90°, such as the one at the top of figure 16 above the point of the pick. Thin fingers of shale extend into the monzonite shown in the upper right of the figure, and a small finger of monzonite shown just above the pick is entirely surrounded by shale. The monzonite is strongly brecciated for 6 feet west of the contact. The shale, though strongly jointed, is not obviously brecciated. Slickensided surfaces with many different orientations are abundant in both shale and monzonite.

The baking of the shale on both sides of Ralston dike, the transection of shale stratification by the monzonite, the monzonite embayments, and interfingering into the shale show the intrusive nature of Ralston dike. The commonly shared slickensides and joint pattern record tectonic movement of both shale and monzonite at some time after solidification of the monzonite. Similar features, though not so well displayed, indicate that the irregular-shaped monzonite intrusives southeast of Ralston dike underwent a similar sequence of events.

The monzonite bodies that intrude the Pierre Shale southeast of Ralston dike are texturally and mineralogically similar to Ralston dike. The western three irregular-shaped bodies are roughly alined along a major fault. A short thin tabular dike is present just west of the southernmost body. One large and five small intrusives are east of the fault. A small body of Pierre Shale (not shown in Van Horn, 1972) is apparently enclosed by monzonite near the southwest corner of the largest of these intrusives. The monzonite of this large intrusive is coarser grained than most of the other intrusives. The large number and close grouping of these intrusives indicate to me the possibility that they are cupolas and all merge into a single large mass within a few hundred feet of the ground surface. (See Van Horn, 1972, cross section *B–B′*.) The monzonite dikes all have similar composition and probably are of nearly the same age.

Some of the intrusives seem to be related to a late stage of movement on the Golden fault. Displaced fossil zones in the Pierre Shale indicate that a major fault strikes into the north end of Ralston dike where a strongly brecciated zone of Pierre is exposed in a roadcut just north of the dike and just east of the Ralston Reservoir dam. A similar major fault is indicated by displaced fossil zones southeast of Ralston dike along the line of smaller intrusives. These faults line up with the axis of the shallow basin occupied by Upper Long Lake. If a major displacement had affected Ralston dike it would have resulted in obvious offset of the east and west parts because of the converging dips of the contacts. On the other hand, minor tectonic movement of the dike is recorded by the slickensided surfaces and the joints that cross the monzonite contact and by the zone of weakness indicated by the presence of the Upper Long

FIGURE 16.—Contact between Pierre Shale (P) and monzonite (M) in the water outlet tunnel on the east side of Ralston dike. Photograph by L. M. Gard, U.S. Geological Survey.

Lake basin. Thus, Ralston dike seems to have been intruded during the late stages of movement of the Golden fault.

LATITE

North and east of Golden, latitic lava flows are interbedded with the rocks of the Tertiary part of the Denver Formation. These lavas are divisible into three separate flows, which Waldschmidt (1939, p. 16) called basalt flows 1 (oldest), 2, and 3 (youngest). All three flows are similar in composition to the Tertiary intrusives just described and are classified as latite in this report. The vesicular top of the two oldest flows are still preserved at most places, but the top of the youngest flow is everywhere eroded.

Flow 1, although similar to the other flows, contains noticeably larger and more abundant phenocrysts of augite than the others. It is texturally similar to the coarse monzonite of the largest intrusive southeast of Ralston dike. The lava was not extruded as a broad blanket but was confined to several tongues, which probably occupied shallow depressions on the ground surface. These tongues are about 60 feet thick in their central parts but thin laterally. The lower 3–5 feet of the large flow on the west side of North Table Mountain consists of an angular, vesicular clinkery mass typical of aa. The flow apparently caused little disturbance to the underlying conglomerate bed. The massive lava above the base shows no flow structure except for a nearly vertical tubular opening, probably caused by rising gas. The vesicular top, which is as much as 20 feet thick in better exposures, consists of many small to large circular openings, some of which are elongate upward. Many of these openings are filled with

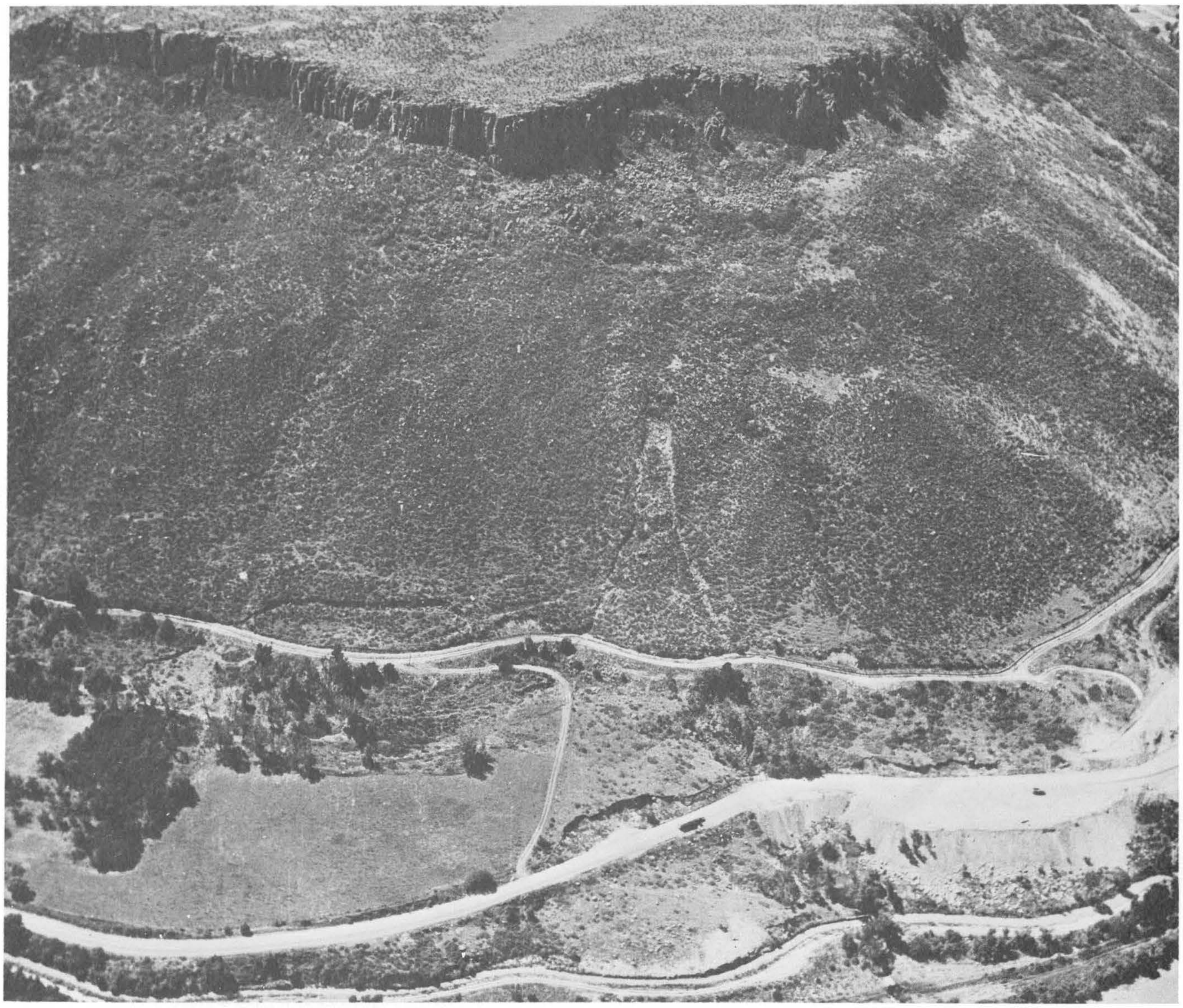


FIGURE 17.—Well-developed columnar structure in latite of lava flows 2 and 3 on the north side of South Table Mountain. The vesicular zone between the flows is near the base of the cliffs. Debris from fallen columns litters the colluvial and landslide slopes of the base of the cliff. Two active landslides are formed on the flanks of older slides that reach to the base of the lava. The base of Castle Rock and part of Golden are visible at the extreme upper right of the picture. Photograph by R. B. Colton and J. H. Hartshorn, U.S. Geological Survey.

weathered zeolites. These flows are underlain by as much as 200 feet of the Paleocene part of the Denver Formation, and are overlain by 120 feet (west) to 200 feet (east) of the Paleocene part of the Denver, which is in turn overlain by flow 2.

Flow 2 apparently thickens eastward and northward. It is about 45 feet thick on South Table Mountain but on North Table Mountain it is 70 feet thick at the southwest corner, 100 feet thick at the southeast corner, and 125 feet thick at the northeast corner. The upper part has been removed by erosion on the south part of South Table Mountain. Hand-level elevations of 10 points at the base of the flow show that the northern part slopes southeast at about 150 feet per mile, but the slope is much less near the east end of South Table Mountain (fig. 19). Part of this slope is probably due to uplift of the western part.

The basal few feet of flow 2 may be either massive and dense or moderately vesicular latite. Above this the flow is hard dense latite. At most places a well-developed columnar structure is visible in the latite. (See fig. 17.) The columns are 3–20 feet across, but most are about 12 feet. Locally a poorly developed horizontal sheeting intersects the columnar structure and causes the latite to break into thin tabular plates. At many places the columns are intersected by randomly oriented, moderately dipping joints. Where these joints dip toward the face of clifflike outcrops they form planes of weakness leading to rockfalls.

The top 20–40 feet of flow 2 is vesicular, some of the vesicles being several feet long. At many places these vesicles are filled with zeolites, most of which are weathered. Many large and beautiful crystal clusters of fresh zeolites have been collected, in years past, from this zone in several now-abandoned quarries on both North and South Table Mountains. The zeolites have been well described by several authors (Cross and Hillebrand, 1882, p. 452, 458; Emmons and others, 1896, p. 292–298; Waldschmidt, 1939, p. 31–38). Waldschmidt included an excellent summary of the existing literature on zeolites in this area.

The Denver Formation between flows 1 and 2 thickens eastward on North Table Mountain. On South Table Mountain from Castle Rock southeastward, beds of the Denver underlying flow 2 are cut out. The prominent outcrop below the latite cliff just visible at the right side of figure 15 is a Denver Formation conglomerate containing augite crystals. The conglomerate is 14 feet below the latite and was traced southeastward into the Morrison quadrangle, where it converges with the latite. At a few places as much as 1 foot of the Denver Formation underlying flow 2 has a black, burned appearance. This is presumably due to combustion of vegetation on the ground surface that was overwhelmed by the hot lava flow.

The upper vesicular zone is the little-eroded original top of flow 2. In most exposures flow 3 lies directly on the vesicular top of flow 2. A single outcrop, however, on the quarry road on the west side of North Table Mountain (measured section G23) gives evidence of deposition of sediments between flows 2 and 3 (fig. 18). At this locality a stream eroded a steep-walled channel about 50 feet into flow 2. Sediments deposited in this channel include conglomerates, sandstone, and possibly volcanic mudflows. The earliest sediment (unit 76, fig. 18) may have been a volcanic mudflow—possibly hot. It consists of a black baked-appearing pebbly claystone 2–8 inches thick that follows the convolutions of the underlying latite surface. The pebbly claystone is overlain by about 8 feet of a stream-deposited bouldery conglomerate (unit 77) containing many loose augite crystals. The conglomerate is overlain by a probable volcanic mudflow (unit 78) about 12 feet thick, composed of sparse andesitic pebbles and cobbles in a silty claystone matrix. At places the mudflow has been altered to shades of yellow and red by later steam explosions or hot-water solutions. This mudflow rises high on the north side of the channel where it abuts against the smooth surface of the eroded latite of flow 2. Near the middle of the

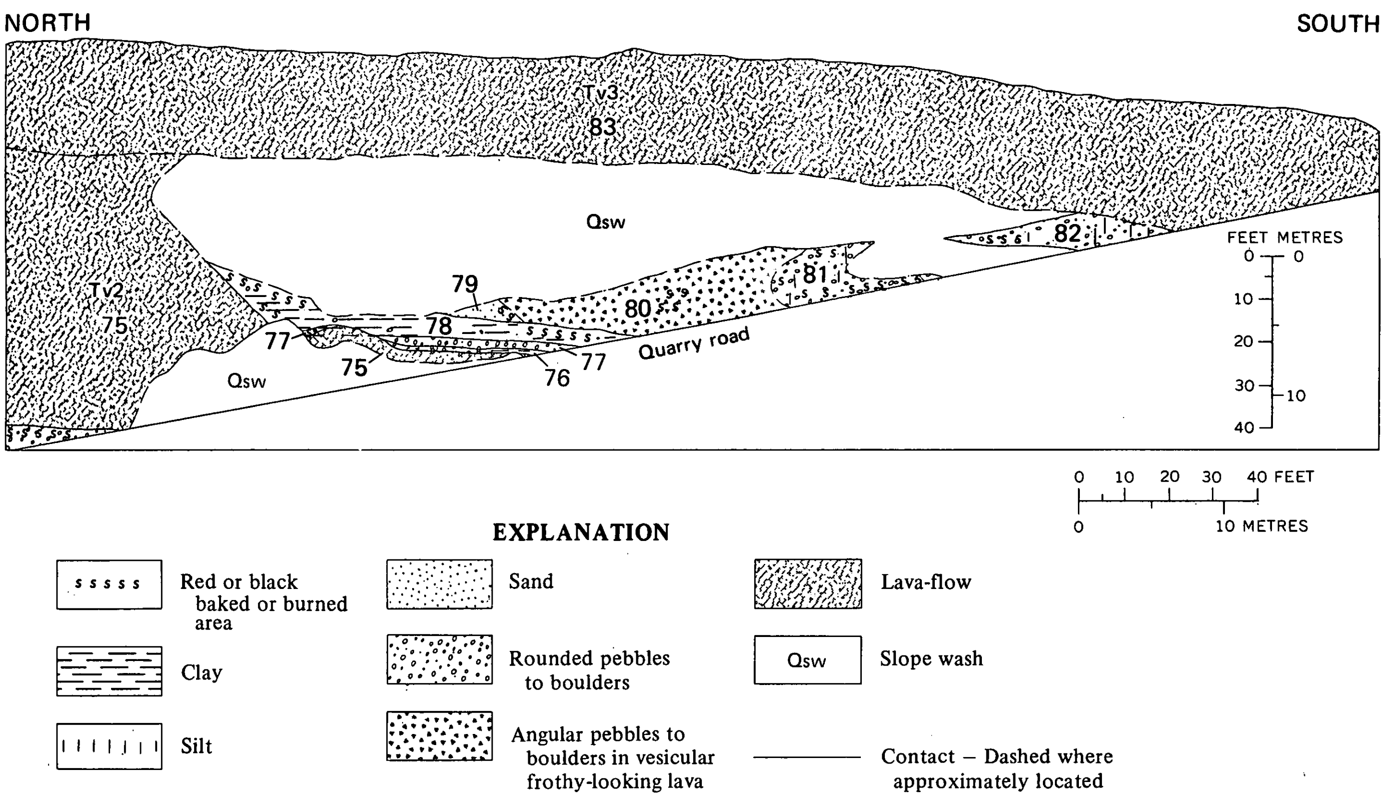


FIGURE 18.—Section exposed along the road to the quarry at the west side of North Table Mountain, showing sedimentary rocks between the two youngest lava flows (Tv3 and Tv2). The numbered units are keyed to the numbers in measured section G23 of the Denver Formation.

channel a small patch of tuffaceous arkose (unit 79) overlies the mudflow. Overlying and to the south of the arkose is a breccia of pebble- to boulder-sized angular pieces of latite and Denver Formation in a matrix of vesicular volcanic frothy-looking rock (unit 80). This frothy-looking rock is exposed for about 22 feet vertically and for about 50 feet west of the tuffaceous arkose where it appears to contain a large mass of Denver Formation (unit 81). The frothy-looking rock is present above and south of unit 81 where it underlies a conglomeratic sandy siltstone (unit 82), which at the south end of the exposure is overlain by massive latite of flow 3 (unit 83). The frothy deposit is probably the result of a leading tongue of flow 3 moving into the stream channel and encountering water-saturated sediments. The water vaporized suddenly, causing the molten latite to practically explode and also bringing about the oxidation and burned appearance of nearby sediments. After the water had all vaporized, the massive latite of flow 3 was able to fill and overflow the old channel in a normal manner.

Flow 3 is the thickest of the latite flows. The top has everywhere been eroded off, so the total thickness is not known. On the west side of North Table Mountain, however, 172 feet of the flow still remains. The remaining thickness at other places on North Table Mountain is considerably less and is generally 50–90 feet. On South Table Mountain flow 3 is 50–60 feet thick on the north side, but has been removed by erosion on the south side. It is a hard dense latite similar to the other Tertiary igneous rocks. No vesicular zone is now present in the upper part. The well-developed columnar structure is similar to that described for flow 2 and, where joints dip toward vertical faces, flow 3 is also subject to rockfalls.

The similarity of the Tertiary extrusive and intrusive igneous rocks indicates that all were emplaced at about the same time. If it were otherwise, magmatic differentiation in the source chamber would probably have produced different kinds of rock. Some authors have indicated that the series of conical hills near the west side of North Table Mountain represent the original vent from which the lava flowed. The abundant tabular plates at this place are probably the result of flow structure, but they also can be seen on higher parts of the flow at the southwest and the northeast corners of North Table Mountain. Dikelike features at the conical hills appear to be case-hardened joints rather than dikes. The similarity in texture of the intrusive and extrusive rock probably indicates that the intrusive rock was relatively close to the then-existing surface. This is further borne out by the inverted cone shape of Ralston dike which indicates it may have been expanding as it approached the earth's surface. In addition, the projected contours of the base of flow2 pass about 500 feet above the high part of Ralston dike. (See fig. 19.) The trend of these contours of the base of flow 2 pass about 500 feet above the high part of Ralston dike. (See fig. 19.) The trend of these contours is at 90° to a line drawn from the center of Ralston dike to the east part of North Table Mountain. Thus, the source of the lava flows was probably one or more of the monzonite intrusives northwest of North Table Mountain.

QUATERNARY DEPOSITS

The Quaternary deposits form the most important known economic resource in the area and are the most widespread material of concern to the construction industry. Deposits of Quaternary age in the Golden quadrangle include alluvium, colluvium, loess, transported mantle, artificial fill, and landslides. The age assigned to the deposits has a fivefold basis: topographic position, contained volcanic ash, relict soils, stratigraphic position, and contained fossils. The topographic position of the various terrace deposits is the principal means of identifying relative ages of the terraces; within any one valley the higher terraces are the oldest. Correlation between valleys and with glaciations was possible because a volcanic ash similar to and considered to be of equivalent age to the Pearlette Ash Member of the Sappa Formation (Condra and others, 1950, p. 22) is incorporated in the terrace deposits in the valleys of Clear and Ralston Creeks. (See fig. 20.) Degree of development of relict soils was used extensively to correlate the Louviers Alluvium and younger terrace deposits between valleys but was used very cautiously for the older deposits. The use of soils as stratigraphic markers is more completely explained in the section on soils on page 93. The superposition of deposits was used at a few places for determining relative age of adjoining deposits. Fossil vertebrates and invertebrates at a very few places served to corroborate in a general way the correlation of deposits with glacial stages arrived at by other means. Other, more intangible, criteria which were useful for distinguishing the younger from older deposits were color, grain size, and degree of coherence. Most of the locality numbers mentioned in the text are plotted on the preliminary surficial geologic map of Van Horn (1968) and all are shown in figure 3. Deposits less than 3 feet thick are not shown on the geologic map.

The Unified Soils Classification[2] (U.S. Bureau of Reclamation, 1960, p. 379–400) is used at several places in the following text to describe the various surficial deposits. This classification has value in predicting the physical properties and some possible construction uses of surficial deposits (Van Horn, 1968b).

[2]The letter symbols of the Unified Soil Classification indicate the kind of material contained in the class. The first letter indicates the grain size and inorganic or organic character of the material: G is gravel, S is sand, M is silt (nonplastic fines), C is clay (plastic fines), O is organic silt or clay, and Pt is peat and other highly organic material. The second letter indicates some other property of the material: W is well graded (engineering sense), P is poorly graded (engineering sense), M is silty, C is clayey, L is low liquid limit, and H is high liquid limit. Soils that fall on or near the boundary between two classes are designated by the combined and hyphenated symbols of the two classes, such as CL-ML.

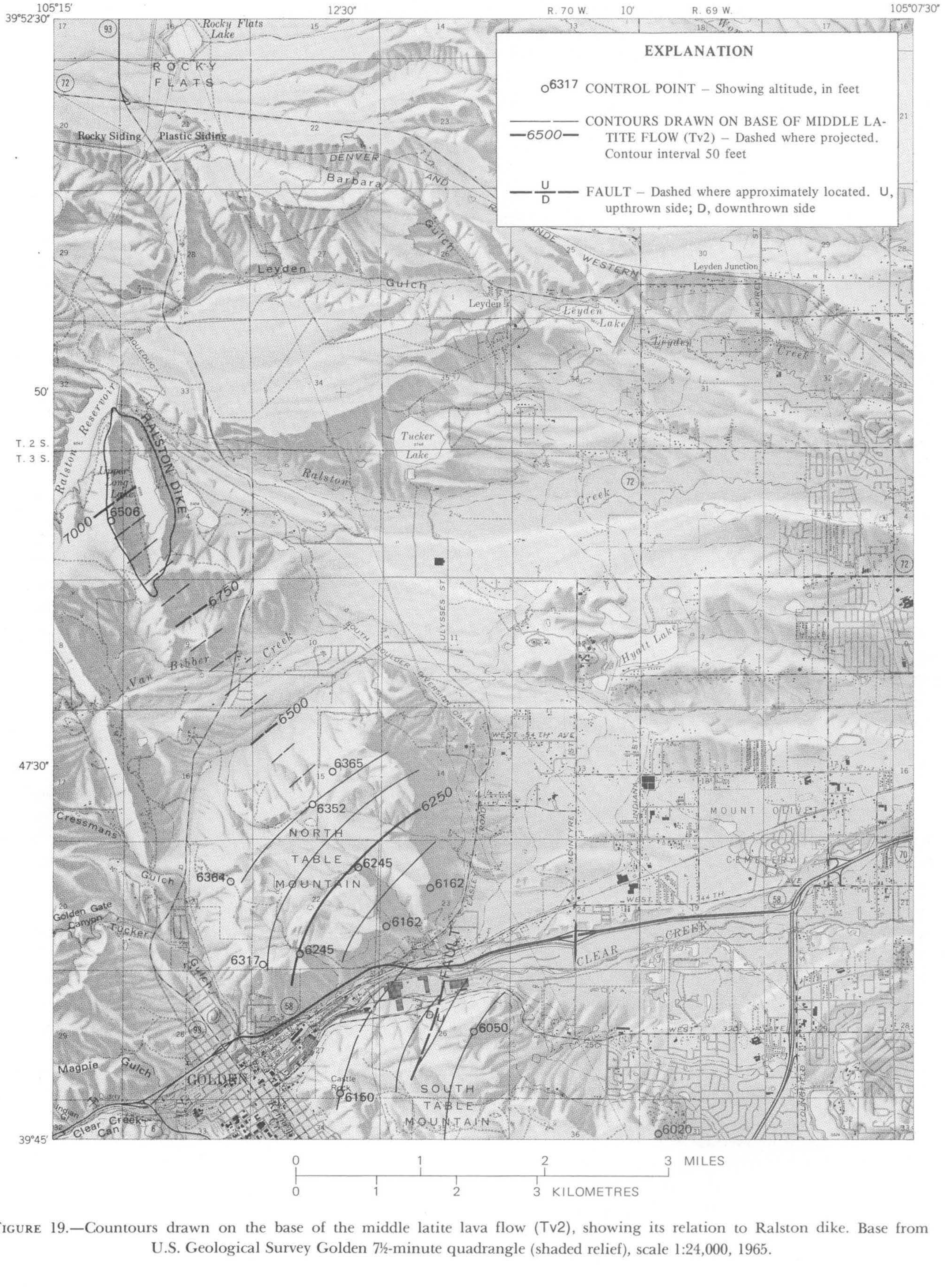


FIGURE 19.—Countours drawn on the base of the middle latite lava flow (Tv2), showing its relation to Ralston dike. Base from U.S. Geological Survey Golden 7½-minute quadrangle (shaded relief), scale 1:24,000, 1965.

ALLUVIUM

The sand and gravel of the alluvial deposits have certain similarities that are common to all such deposits and thus need not be repeated. Alluvial deposits are lenticular in cross section and elongate in longitudinal section. Each deposit is thickest near the center of the valley and thins toward the valley sides. In the older deposits, the central part (near the center line of the present valley) has been removed by erosion to leave terraces at various heights above the modern streams. The deposits are generally thin at the mountain front but thicken rapidly as they pass into the foothills; they seem to maintain a roughly consistent thickness downstream, but some, particularly those along the smaller streams, become slightly thinner downstream.

The sand and gravel in the alluvial deposits are generally coarser near the mountain front, where boulders commonly occur, but become finer eastward. At a few places, however, large boulders are present several miles east of the mountains. The larger streams generally contain the coarsest material; the youngest deposits—those of Pinedale and Holocene age—are generally finer grained than older deposits at similar distances from the mountain front.

The lithology of the gravel in the stream deposits reflects the lithologic types of bedrock found upstream from the deposit. The gravel in all stream deposits is almost entirely derived from the Precambrian rocks in the mountain area, although the Tertiary monzonite and latite make up a small part of deposits that are downstream from the Table Mountains and the Ralston dike.

Pebble counts of flood-plain deposits west of the mountain front (see table 8) show that deposits of several streams are readily distinguishable. Clear Creek and Mount Vernon Creek (south of the quadrangle) both contain many recognizable and distinctive pebbles and cobbles of very light granitic rock not found in any of the other streams. Gravel from Coal Creek (north of the quadrangle), which contributed the deposit on Rocky Flats, contains a distinctively high proportion of quartzite from Coal Creek. The term "quartzite from Coal Creek" here refers to distinctive bluish-gray quartzite pebbles and cobbles derived from Precambrian rocks named the Coal Creek Quartzite by Boos and Boos (1934, p. 306; 1957, p. 2612) and referred to as the quartzite-schist sequence (a localized lithologic facies of the Idaho Springs Formation) by Wells, Sheridan, and Albee (1964, p. O2). This

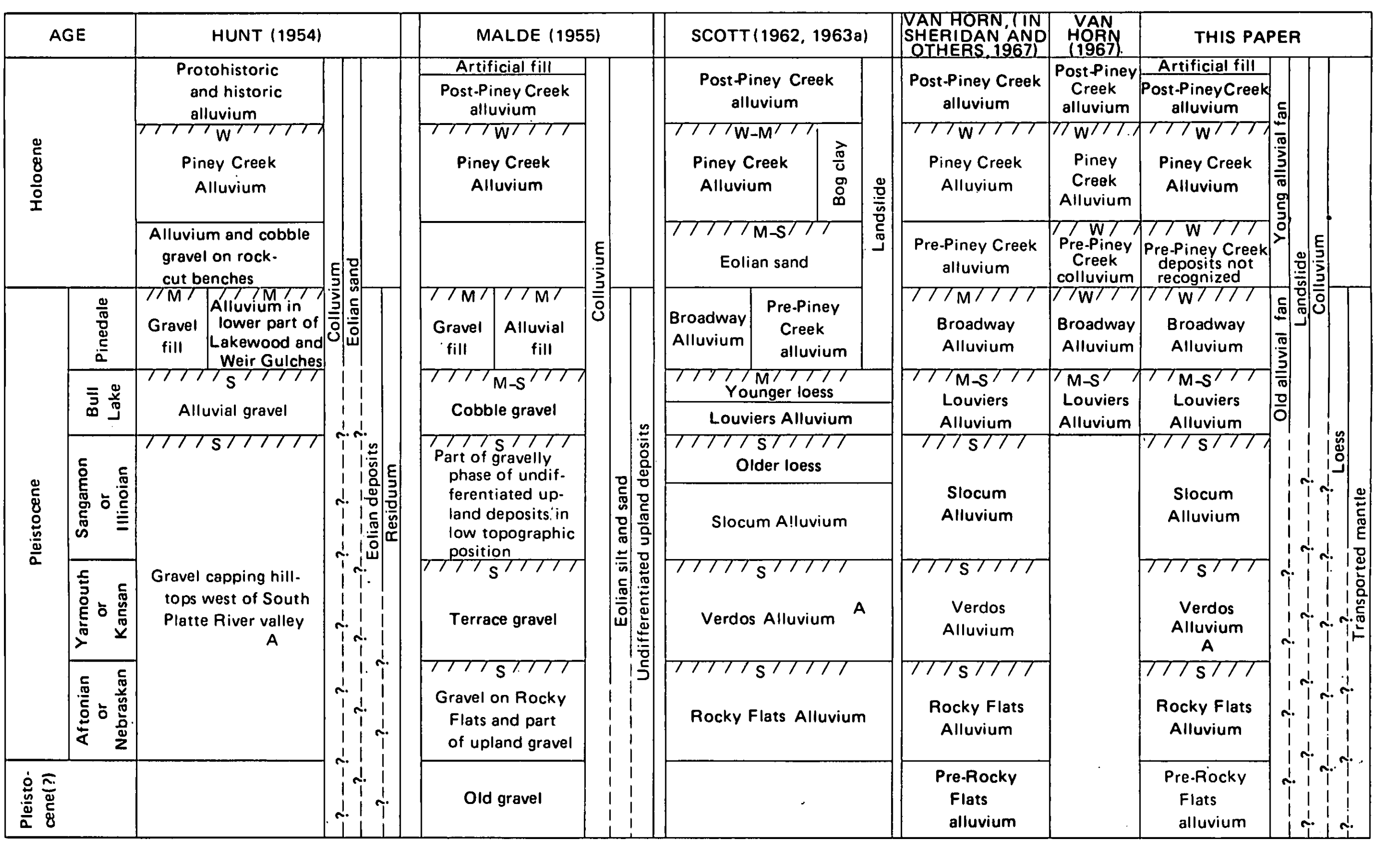


FIGURE 20.—Correlation of Quaternary formations as used in the vicinity of Golden by various authors, showing the time of formation and relative development of old soils. Not all age equivalents are those assigned by the original author. The symbol / / / S / / / indicates time of formation of a soil and the degree of development: S, strong; M, moderate; W, weak. A indicates rhyolitic volcanic ash.

TABLE 8.—*Pebble counts from alluvial deposits in the Golden and adjacent quadrangles*

[The figures are in percent of particles larger than one-quarter inch. About 150 pebbles were counted for each sample. Within each drainage basin the samples farther to the right are farther east of the Front Range. ...., not present. Qr, Rocky Flats Alluvium; Qpr, pre-Rocky Flats alluvium; Qpp, post-Piney Creek alluvium; Qb, Broadway Alluvium; Qv, Verdos Alluvium; Qlo, Louviers Alluvium; Qof, old alluvial fan deposit; Qs, Slocum Alluvium; re, transported mantle]

Drainage basin	Coal Creek		Ralston Creek				Van Bibber Creek				Tucker Gulch	Clear Creek						Mount Vernon Creek
Field locality	G143	R46	R40	R28	G101	G111c	G114	R41	R39	G109	R42	R43	G95	G99	G48	G82	G85	R44
Formation symbol	Qr	Qpr	Qpp	Qb	Qv	Qlo	re	Qpp	Qv	Qb	Qpp	Qpp	Qof	Qof	Qlo	Qs	re	Qpp
Pegmatite	....	....	29	41	17	7	16	37	11	39	17	16	11	27	9	5	15	23
Granitic	5	....	15	6	7	29	39	5	....	29	20	25	32	45	21	52	49	48
Granodiorite	....	....	6	....	6	1	1	2	....	2	3	16	....	....	42	4	11	....
Quartzite	....	....	9	29	6	4	7	23	33	3	3	8	....	....	....	7	15	3
Quartzite[1]	80	27	9	....	6	....	....	....	....	....	....	....	....	....	....	....	....	....
Gneiss and schist	10	....	27	24	52	52	27	26	45	12	52	31	56	27	15	21	8	26
Sedimentary	5	73	6	....	2	4	1	....	....	8	....	....	....	....	....	....	1	....
Latite or monzonite	....	....	....	....	1	....	....	....	....	5	....	....	....	....	....	1	1	....
Syenite	....	....	....	....	....	....	....	....	....	....	....	4	....	....	....	....	....	....
Unidentified	....	....	....	....	3	4	9	7	11	3	3	2	....	....	12	10	....	....
Total	100	100	101	100	100	101	100	100	100	101	98	102	99	99	99	100	100	100

[1]Quartzite from Coal Creek.

SAMPLE LOCALITIES

G143. NE¼SW¼ sec. 21, T. 2 S., R. 70 W., Golden quadrangle.
R46. NE¼NW¼ sec. 29, T. 2 S., R. 70 W., Ralston Buttes quadrangle.
R40. NW¼SE¼ sec. 31, T. 2 S., R. 70 W., Ralston Buttes quadrangle.
R28. SE¼SE¼ sec. 6, T. 3 S., R. 70 W., Ralston Buttes quadrangle.
G101. NW¼SE¼ sec. 33, T. 2 S., R. 70 W., Golden quadrangle.
G111. NW¼NE¼ sec. 11, T. 3 S., R. 70 W., Golden quadrangle.
G114. NW¼NE¼ sec. 6, T. 3 S., R. 69 W., Golden quadrangle.
R41. NE¼SE¼ sec. 7, T. 3 S., R. 70 W., Ralston Buttes quadrangle.
R39. NE¼NW¼ sec. 8, T. 3 S., R. 70 W., Ralston Buttes quadrangle.
G109. NE¼SE¼ sec. 13, T. 3 S., R. 70 W., Golden quadrangle.
R42. NW¼SE¼ sec. 20, T. 3 S., R. 70 W., Golden quadrangle.
R43. NE¼NE¼ sec. 32, T. 3 S., R. 70 W., Golden quadrangle.
G95. NW¼SE¼ sec. 28, T. 3 S., R. 70 W., Golden quadrangle.
G99. NW¼NW¼ sec. 34, T. 3 S., R. 70 W., Golden quadrangle.
G48. SW¼SW¼ sec. 27, T. 3 S., R. 70 W., Golden quadrangle.
G82. SW¼NW¼ sec. 24, T. 3 S., R. 70 W., Golden quadrangle.
G85. NW¼NE¼ sec. 16, T. 3 S., R. 69 W., Arvada quadrangle.
R44. NW¼SE¼ sec. 17, T. 4 S., R. 70 W., Morrison quadrangle.

unit crops out west and northwest of the Golden quadrangle in Coal Creek valley and on the north side of Ralston Creek valley. Gravel from Ralston Creek has a mixture of quartzite from Coal Creek and other less distinctive metamorphic rocks. Deposits of Van Bibber Creek and Tucker Gulch are mostly metamorphic gneiss and schist with no readily distinctive rock type, which is in itself a distinctive characteristic. Streams such as Woman Creek (which heads in Rocky Flats Alluvium from Coal Creek) and Leyden Creek (which heads in Rocky Flats and Verdos Alluvium from Coal and Ralston Creeks) assume the lithologies of these alluviums.

Alluvial deposits in each valley become younger with decreasing height above the valley floor. At most places it appears that each alluvium was deposited on a stream-cut bedrock floor, only to be cut through and partially removed during the next erosion cycle. The remnants at the sides of the valley were left as terraces. (See fig. 21.) The new bedrock floor was then covered by a younger alluvium. This process was repeated several times during the Pleistocene. However, it is possible that alluvium underlying the flood plains of some creeks was deposited in late Pleistocene time and that subsequent erosion has not yet cut down to bedrock.

LONGITUDINAL STREAM AND TERRACE PROFILES

Longitudinal stream and terrace profiles (pl. 1) were prepared for Clear, Van Bibber, Ralston, and Leyden Creeks, and Tucker Gulch. Each stream valley was divided into three to five fairly straight sections and the profile laid out along the approximate center of each section. The stream and terrace elevation at right angles to this line were then projected to the centerline. No allowance was made for the valleyward slope of some of the terraces or for slight deviation in direction of some of the Pleistocene valleys from the modern valley. The latter is the reason for the anomalous difference in altitude of the two differently oriented projected slopes of the Verdos Alluvium of Ralston Creek between the first and second bends from the west. Here the upper terrace surface was projected along lines greatly skewed from the earlier direction of streamflow. The small segment of Van Bibber Creek that joined Clear Creek near the present locality of Mount Olivet Cemetery during Pleistocene time is plotted separately.

The profiles show reasonably well the slope and continuity of the terraces, the relation of younger to older terraces, and the approximate amount of erosion that occurred between periods of deposition. The profiles show that the terrace segments along any particular valley fall

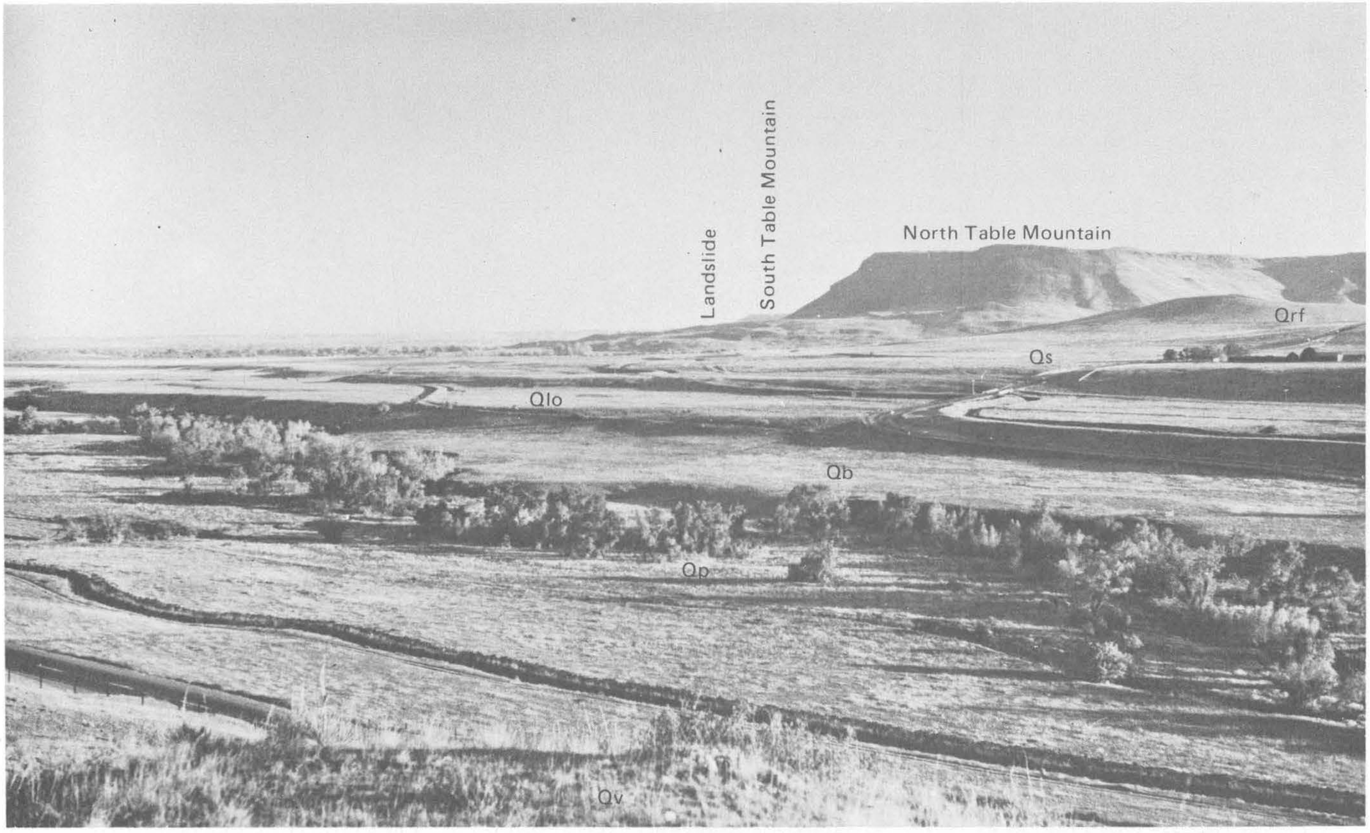


FIGURE 21.—Alluvial terraces in the valley of Ralston Creek. From oldest to youngest: Rocky Flats Alluvium (Qrf), Verdos Alluvium (in foreground) (Qv), Slocum Alluvium (Qs), Louviers Alluvium (Qlo), Broadway Alluvium (Qb), and Piney Creek Alluvium (Qp). The hummocky ridge extending northeast (to the left) from North Table Mountain is a large landslide. The paved road in the lower left has now been destroyed by a landslide. View is southeast from the Verdos surface east of State Highway 93.

along the same generally eastward-sloping plane and, therefore, provide supplemental evidence for correlation of the segments. The profiles also show the way in which the transported mantle and colluvium cut across, and are generally steeper than, the main terraces.

The stream and terrace profiles generally are concave up. Clear and Van Bibber Creeks, however, show slightly bimodal profiles. The junction of the two concave profiles of Clear Creek is near the easternmost bend of the profile (pl. 1*F*). The apparently slower rate of incision of the creek indicated by this junction may be due to the creek's having to remove recurring landslide debris shed from the Table Mountains. Van Bibber Creek shows a more distinctly bimodal character; the junction of the two concave segments is just west of the intersection with profile *E* near Ulysses Street (pl. 1*C*, *E*).

A smoothly concave profile, without bimodal character, results if the profile west of Ulysses Street is joined to the profile from Ulysses Street to Mount Olivet Cemetery (pl. 1*E*). It thus seems that Van Bibber Creek originally flowed directly into Clear Creek in the vicinity of the cemetery. The bimodal character of the present course probably indicates that the lower part of the Van Bibber Creek was captured by a more vigorously eroding stream tributary to Ralston Creek during or shortly after the deposition of the Broadway Alluvium in Pinedale time.

PLEISTOCENE(?) DEPOSITS

PRE-ROCKY FLATS ALLUVIUM

One small deposit of pre-Rocky Flats alluvium south of Rocky siding in the northwest part of the quadrangle is probably the correlative of the old gravel described by Malde (1955, p. 223). The deposit slopes east-northeast about 250 feet per mile and is 250 feet higher than Leyden Creek. The ground surface is littered with cobbles and small boulders.

The deposit is a moderate-reddish-brown, coarse, poorly sorted, bouldery sand and gravel in a clayey sand matrix. The common large size of the boulders is about 3 feet in diameter; the largest boulder seen was 6 feet in diameter. The coarse material is predominantly sandstone and some conglomerate (73 percent), and quartzite from Coal Creek (27 percent). Not present in the pebble count sample but found elsewhere were small amounts of granitic rocks, some of which are rotten, and metamorphic rocks. About 50 percent of the deposit is clayey sand. (See fig. 22.) Much of the clay is in silt- and sand-sized aggregates. The thickness of the deposit ranges from 6 to 15 feet. The contact with the underlying Pierre Shale is gently rolling.

Until some distinctive fossils are found, the age of the pre-Rocky Flats alluvium must remain in doubt, although I believe the age is probably early Nebraskan. This belief is based on the topographic position of this alluvium, which is about 1,000 feet below the late Tertiary surface in the mountains to the west (Van Horn, in Sheridan and others, 1967, p. 51) but only 50 feet higher than the nearby Rocky Flats Alluvium.

PLEISTOCENE DEPOSITS

NEBRASKAN OR AFTONIAN

ROCKY FLATS ALLUVIUM

Deposits of Rocky Flats Alluvium derived from Coal, Ralston, and Clear Creeks are present in the area. The deposit from Coal Creek is in the northwestern part of the quadrangle although Coal Creek itself is north of the quadrangle. This deposit has the shape of a broad gently rounded and eastward-sloping alluvial fan. The deposit from Ralston Creek, on the south side of Ralston dike, forms a terracelike eastward-sloping plane. The deposit from Clear Creek, not shown on the map, is a small irregular outcrop high on the south valley wall.

Coal Creek

The Rocky Flats Alluvium derived from Coal Creek, the most extensive of the three Rocky Flat deposits, is in the northwest part of the quadrangle. The upper surface is very even and slightly concave up (pl. 1*A*). The easterly slope is about 120 feet per mile along the west edge of the quadrangle and 80 feet per mile near the eastern part of the deposit. The upper surface is 220–300 feet above Leyden Creek. The alluvium on Rocky Flats is generally about 40 feet thick but ranges from 0 to at least 50 feet.

In the western part of the area the relatively smooth upper surface is broken only by a few shallow longitudinal drains that carry water only during the infrequent heavy rains. The eastern part of the deposit is deeply and intricately dissected by intermittent streams that have cut through the alluvium into the underlying bedrock. The ground surface at Rocky Flats is littered with cobbles and pebbles of quartzite. At some places small hillocks of fine-grained material, similar to mima or soil mounds, rise above the general level of the surface. The mounds are about 25 feet in diameter and 1–2 feet high. No mounds are present on the Rocky Flats Alluvium south of Rocky Flats.

The character of the cut surface on bedrock underlying

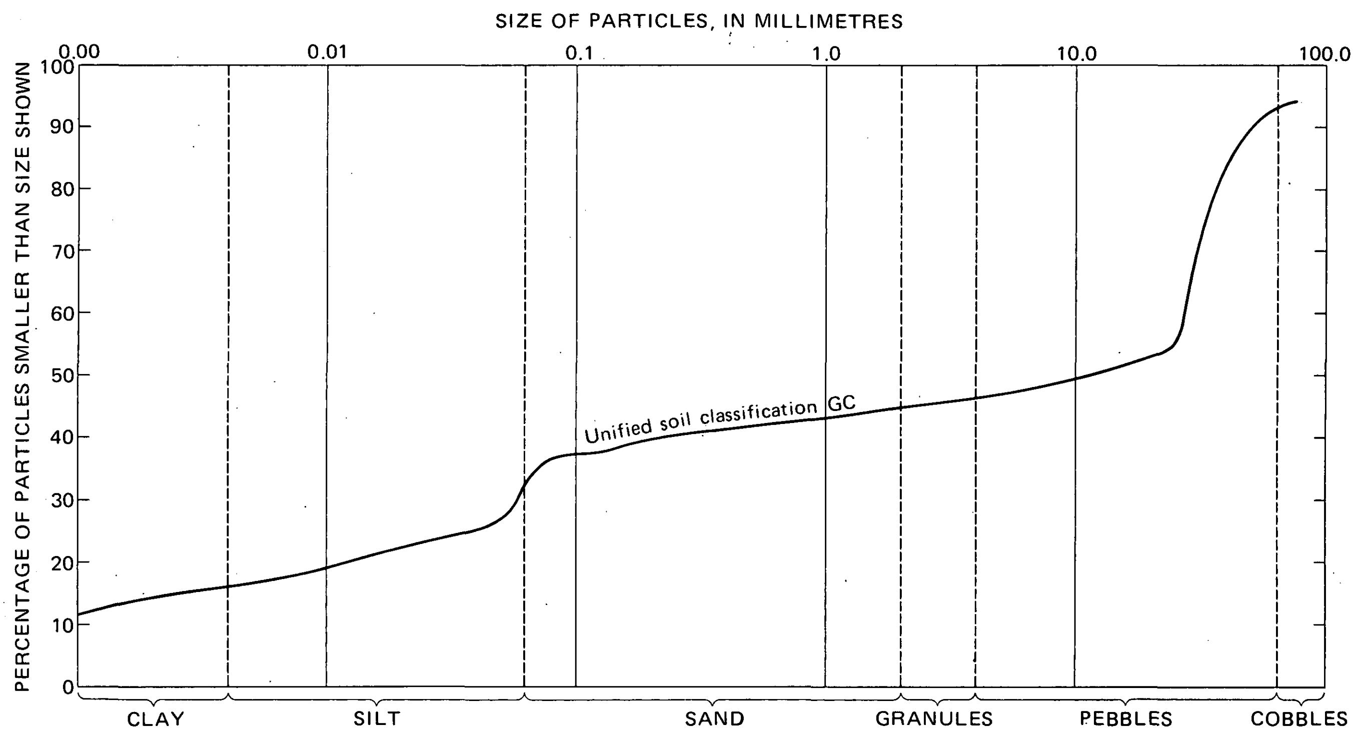


FIGURE 22.—Cumulative curve showing the size distribution of sample R46 of pre-Rocky Flats alluvium. Sample from the NW¼ sec. 29, T. 2 S., R. 70 W. (Ralston Buttes quadrangle).

the alluvium is not very well known. The lower part of the Laramie Formation appears to form a nearly continuous north-trending ridge transverse to the east-sloping Rocky Flats surface. Outcrops, shallow prospect pits, and clay mines show that the top of the ridge is at or just below the top of the alluvium at most places where it crosses Rocky Flats. Geologic mapping, well logs, and geophysical surveys show that the alluvium has its normal thickness of about 40 feet within a few hundred feet both east and west of the ridge. This indicates that the erosion surface under the Rocky Flats Alluvium is composed of two concave-up sections, separated by the north-trending ridge of Laramie Formation.

Near the junction of State Highways 72 and 93 the alluvium is a poorly sorted coarse sand and gravel, whereas 2 miles eastward it is a pebbly coarse sand. The size distributions of several samples are shown in figure 23. The pebbles and cobbles are subround to subangular. Boulders as much as 2 feet in diameter are present at many places in the Rocky Flats Alluvium. The largest boulder seen in the area is near the base of the deposit, about 500 feet north of Plastic siding. The exposed part of the boulder is 15 by 21 feet, attesting to the power of the mudflow, or possibly a stream that moved it at least 2 miles. The coarse fraction of the alluvium is predominantly quartzite from Coal Creek, but it also contains small amounts of sedimentary, metamorphic, and granitic rocks (table 8). The upper 3 feet commonly contains a clayey sand and gravel, silty sand, or the clayey B horizon of a pre-Bull Lake soil. Some of this material is undoubtedly younger than Aftonian inasmuch as it overlies a pre-Bull Lake soil and bears a post-Pinedale soil. The amount of this material, however, is small and generally less than 3 feet thick, so it was not mapped.

Ralston Creek

A small deposit of Rocky Flats Alluvium transects the south end of Ralston dike. Remnants of this deposit extend east of State Highway 93. The top of the deposit forms an inclined plane that slopes eastward about 140 feet per mile. At its east end the deposit is about 350 feet higher than Ralston Creek. The west end of the deposit heads just east of a wind-gap cut in the Dakota Group. The deposit is about half a mile south of, and 250 feet higher than, the present valley of Ralston Creek through the Dakota. During Rocky Flats time the Rocky Flats Alluvium extended through and west of the wind gap. This deposit of Rocky Flats Alluvium has been truncated by a younger northeast-sloping deposit of Verdos Alluvium derived from Van Bibber Creek (Van Horn, in Sheridan and others, 1967).

The Rocky Flats Alluvium from Ralston Creek, about 30 feet thick, consists of coarse sand and gravel containing boulders as large as 2 feet in diameter. At places the deposit contains appreciable clay. The rocks are principally metamorphic and consist of schist, gneiss, and a

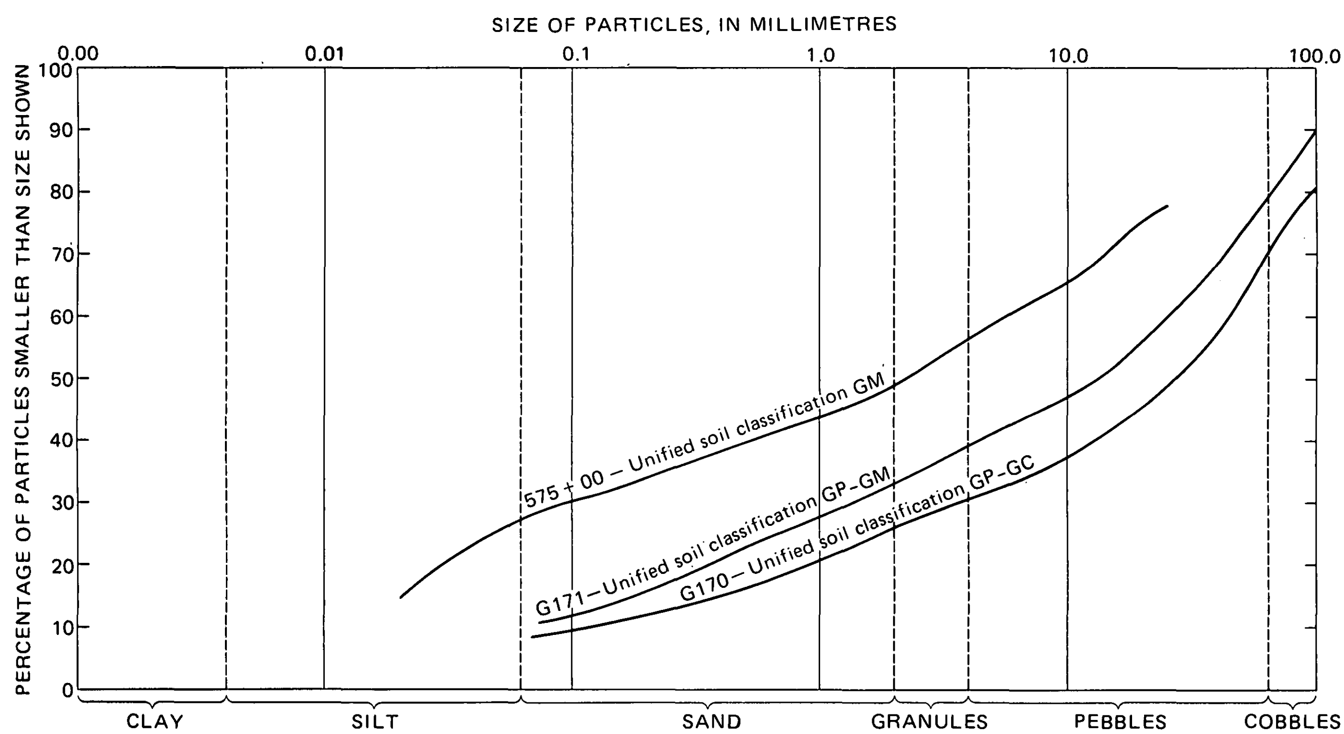


FIGURE 23.—Cumulative curves showing the size distribution of samples of Rocky Flats Alluvium. Samples 575+00 from SW¼NW¼ sec. 21, G171 from NW¼SW¼ sec. 23, and G170 from SW¼NW¼ sec. 21, all T. 2 S., R. 70 W.

bluish-gray quartzite like the quartzite from Coal Creek. The pebbles and cobbles are subround to subangular. Southwest of Ralston dike the upper part of the alluvium is moderately cemented by calcium carbonate; the cemented zone is overlain by 1.5 feet of fine-grained alluvium. The calcium carbonate may represent the Cca horizon of a pre-Bull Lake soil. The overlying fine-grained alluvium is probably the result of sheetwash reworking the older alluvium. The mineralogy of the calcium carbonate in the soil was not determined.

The Rocky Flats Alluvium south of Ralston dike was probably derived from Ralston Creek. The bluish-gray quartzite from Coal Creek crops out no farther south than the north side of the valley of Ralston Creek in the Ralston Buttes quadrangle and, no doubt, served as the source of the bluish-gray quartzite in the alluvium. Therefore, the alluvium must have come, at least in part, from Ralston Creek. The profile drawn along the crestline of the hogback formed on the Dakota Group (fig. 24) in the Ralston Buttes quadrangle indicates that during Nebraskan time the low point in the valley may have been farther south than at present. Upstream from the point of crossing the Dakota hogback, the valley of Ralston Creek has changed very little from its position in Nebraskan time. The presence of the broad shoulder and the Rocky Flats Alluvium on the south side of Ralston dike and the absence of both on the north side of the dike lead me to suspect that Ralston Creek was confined to the area south of Ralston dike during Nebraskan time. It probably joined Clear Creek at some place east of North Table Mountain.

Clear Creek

A small deposit of bouldery and cobbly sand and gravel, too small to be shown on the map, is exposed on the steep northeast flank of Mount Zion just south of Clear Creek at the southwest corner of the Golden quadrangle at an altitude of about 6,050 feet, about 350 feet above Clear Creek. The deposit consists principally of subround cobbles and small boulders that contain the very light gray granitic rock typical of alluvium along Clear Creek. It is overlain by 7 feet of colluvium, the lower 3 feet of which is strongly impregnated by calcium carbonate that represents a pre-Bull Lake Cca soil horizon. The upper 4 feet has no soil and is colluvium of Holocene age. The sand and gravel deposit is probably a remnant of a once much larger deposit of Rocky Flats Alluvium.

Soil

At a few places the remnant of a once thick, strongly developed soil is exposed along the margins of or in cuts into the Rocky Flats Alluvium. This soil is similar to and correlative with the pre-Bull Lake soil of Hunt (1954, p. 126) and Malde (1955, p. 247). An excellent exposure of the soil on Rocky Flats, which was measured on the east bank of the South Boulder Diversion Canal between State Highways 72 and 93, is shown in the following section G143. Malde (p. 250) also indicated a low-lime facies of this soil west of the center of sec. 15, T. 2 S., R. 70 W., but this facies is not apparent in the Golden quadrangle, probably because of poor exposures.

Section G143.—*Soil on Rocky Flats Alluvium*

[Measured on east bank of South Boulder Diversion Canal, between State Highways 72 and 93, NE¼SW¼ sec. 21, T. 2 S., R. 70 W.[1] [2]]

	Thickness (ft)
1. Spoil from canal	4.0
2. Clayey sand, dark-brown (7.5*YR* 3/2), nonclacareous, poorly sorted.[3] Contains some pebbles and cobbles. Gradational into unit 3	.2
3. Clayey sand, dark-brown (7.5*YR* 3/2), noncalcareous, medium subangular blocky, pH 6.9.[3] Contains ⅛-in. and smaller blebs of reddish-brown clay similar to 4. Contains some pebbles and cobbles. Gradational into unit 4	.6

See footnotes at end of stratigraphic section.

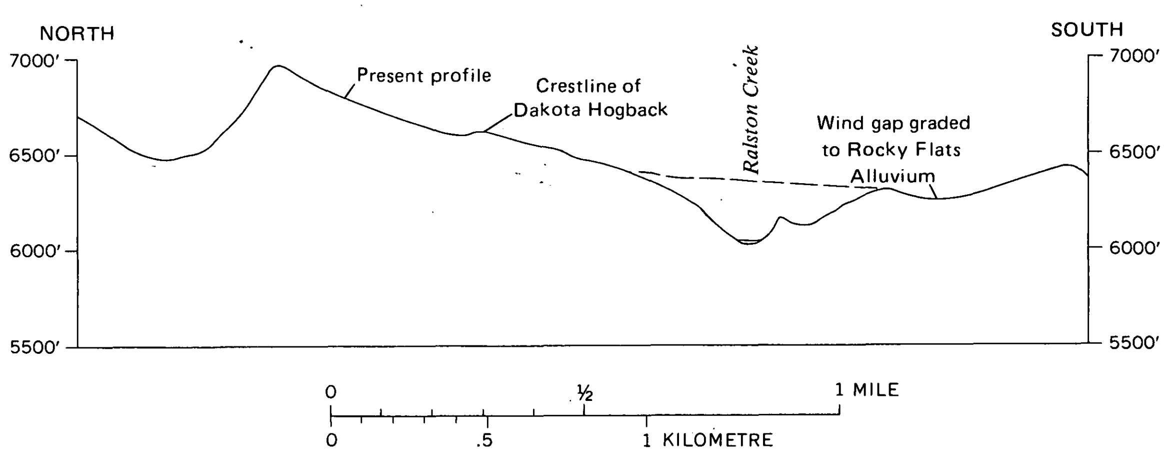


Figure 24.—Profile of the crestline of the hogback formed by the Dakota Group in the vicinity of Ralston Creek in the Ralston Buttes quadrangle, just west of the Golden quadrangle. The dashed line is the inferred crestline profile during Nebraskan and Aftonian time.

	Thickness (ft)
4. Sandy silty clay, reddish-brown (2.5*YR* 3/2), noncalcareous, angular blocky to prismatic, pH 6.5.[3] Contains some pebbles and cobbles. Grades into unit 5	2.2
5. Sandy silty clay, yellowish-red (5*YR* 4/6), noncalcareous, angular blocky to prismatic, pH 6.5.[3] Contains some pebbles and cobbles. Sharp to gradational uneven contact with unit 6	1.5
6. Silty to cobbly sand and gravel, pinkish-white (7.5*YR* 8/2), strongly calcareous, moderately to strongly cemented caliche. Maximum size is 2 ft and common large size is 10 in.[3] The coarse fraction is about 80 percent quartzite from Coal Creek, 10 percent metamorphic, 5 percent granitic, and 5 percent sedimentary (table 8). Base not exposed	3.0

[1]Mechanical analyses of the units in this exposure shown in Van Horn (1968) do not include pebbles larger than 1 in.

[2]The U numbers in Van Horn (1968) correspond to the next highest unit number in this measured section, thus U1 of Van Horn (1968) corresponds to unit 2 of the measured section, and U2 to unit 3, and so forth.

[3]See table 12, fig. 48, and Van Horn (1968, sample G143).

At places as much as 6 feet of unit 6 is exposed; northward, toward the flume, the heavy caliche gradually changes to a poorly defined thin layer of calcium carbonate stringers and blebs under the thick clay layers. Pebbles and cobbles of bluish-gray quartzite from Coal Creek are present throughout this section but are much more common toward the base. A change in the clay minerals is indicated by the mica-to-montmorillonite ratio which decreases abruptly between units 3 and 4 (table 12).

Unit 2 of the section is probably an A horizon of Holocene age; similar horizons are present at the top of all deposits in the area except for the post-Piney Creek deposits. Unit 3 is a B horizon, probably of post-Pinedale age, that has developed on an older B horizon or on a now-unrecognizable Pinedale deposit. A similar horizon is described in the section of the Louviers Alluvium along Clear Creek. The small reddish-brown blebs of clay in this horizon probably were in the process of being changed to dark brown when the soil-forming period ended. The abrupt change in the mica-to-montmorillinite ratio from about 6/1 to 1/4 may also indicate that a long hiatus existed between the formation of units 3 and 4. The difference in the soils is attributed to the fact that different kinds of soil develop under different climatic and biologic conditions. Units 4 and 5 are the B1 and B2 horizons of a pre-Bull Lake soil, and unit 6 is the Cca horizon.

Age and Correlation

The Nebraskan or Aftonian age of the Rocky Flats Alluvium is inferred from the volcanic ash that is similar to, and correlated with, the Pearlette Ash Member of the Sappa Formation of Kansan age which is contained in the next lowest alluvium about a mile south of Rocky Flats.

Origin

The alluvium on Rocky Flats has the shape of a gently eastward-sloping alluvial fan with its apex at the mouth of Coal Creek Canyon. Prior to Kansan time it was undoubtedly much more extensive than it is at present. It probably extended eastward to the South Platte River and may have joined with other similar deposits to the north and south in much the same way that the modern flood plains of adjacent valleys join. The thickness of the deposits and the possible presence of bedrock interfluves indicate that most of the Rocky Flats Alluvium in the Golden area is the result of alluviation, although the lower few feet may be the result of pedimentation. Pediment gravels which are associated with lateral planation are generally only a few feet thick (Denny, 1965, p. 21, 58). Although lateral planation was no doubt an important factor in shaping the bedrock surface underlying the Rocky Flats Alluvium, it seems rather unlikely that a stream with the small drainage area that Coal Creek has would be able to plane the bedrock effectively while distributing a surficial load of 40 feet of coarse alluvium. Pediment gravel originating from Coal Creek, a small stream, probably would be present only in the lower few feet of the existing deposit. The remainder of the deposit, then, is the result of alluviation.

Two major inferences about the origin of the Rocky Flats Alluvium, mostly based on indirect evidence, are possible. First, the Rocky Flats Alluvium is principally a product of processes other than pedimentation in the Golden quadrangle, as discussed above. Second, it is very likely that interfluves of Cretaceous and Paleocene bedrock separated most segments of the valleys of Coal, Ralston, and Clear Creeks within the limits of the Golden quadrangle; so the deposits were probably confined within the limits of separate valleys.

The Rocky Flats Alluvium south of Ralston dike appears to have been deposited in a relatively narrow valley between Ralston dike on the north and the large irregular intrusive on the south. The presence of a bedrock interfluve between Ralston and Clear Creeks is partly suggested by the absence of Van Bibber Creek from this area until after Kansan time. During Kansan and earlier time Van Bibber Creek joined Ralston Creek near Ralston Reservoir (Van Horn, in Sheridan and others, 1967, p. 57). For the lower segment of Van Bibber Creek to have captured the upper segment south of Ralston Reservoir it must have been cutting easily eroded material, such as the soft Cretaceous and Paleocene deposits. The hard sandstones of the Laramie Formation and Dakota Group are broken by faults, which would locally permit the relatively easy removal of those otherwise resistant rocks. The lack of any deposits or bedrock benches west of North Table Mountain or north of Ralston dike at the proper level for Rocky Flats Alluvium may also indicate former bedrock interfluves in these areas.

If these former bedrock interfluves of this old narrow valley were present they were formed principally of soft Cretaceous and Paleocene rocks that have since been almost completely eroded away, and the topography has been reversed. The old alluvium now forms an interfluve extending a short distance east of the mountains. In this context the alluvium seems to be a terrace deposit. The Rocky Flats Alluvium and the bedrock interfluves were eroded prior to the deposition of the next younger Verdos Alluvium.

KANSAN OR YARMOUTH

VERDOS ALLUVIUM

The Verdos Alluvium, which contains a rhyolitic volcanic ash member probably equivalent to the Pearlette Volcanic Ash Member of the Sappa Formation of Kansan age, is present at several places in the quadrangle. The largest deposit of Verdos Alluvium is north of Ralston Creek between Leyden and Ralston Reservoir. The several isolated hills north of Leyden Creek and west of Leyden are capped by Verdos Alluvium derived from Ralston Creek, as are several ridges extending east of Rocky Flats. The long east-trending ridge north of Leyden Lake is capped partly by Verdos Alluvium and partly by transported mantle derived from the Verdos Alluvium. The bedrock knoll west of Hyatt Lake probably was once part of the surface on which the Verdos was deposited. The higher knolls on the ridge south of Van Bibber Creek are capped by transported mantle deposits probably derived from Verdos Alluvium. Several isolated deposits of Verdos Alluvium are on the north side of Clear Creek at Golden. Volcanic ash was found in the Ralston and Clear Creek drainages.

RALSTON CREEK

Adjacent to Ralston Creek the upper surface of the Verdos Alluvium is 170–200 feet above the creek, and about 170 feet below the upper surface of the Rocky Flats Alluvium. The Verdos slopes 80–70 feet per mile slightly north of east, in the general direction of Standley Lake. The physiographic relations indicate that the Verdos at Leyden Junction and east of Rocky Flats was deposited by an ancestral northeast-flowing Ralston Creek.

The character of the bedrock surface beneath the Verdos is poorly known. The general eastward slope of the surface is interrupted by the north-trending ridge of the lower part of the Laramie Formation, which rises to or near the upper surface of the Verdos at several places. The alluvium resumes its normal thickness to the east and to the west of this transverse ridge of the Laramie, thus giving the lower surface of the Verdos a bimodal character. An apparent northward slope of the lower surface is exposed in a cut for State Highway 93, made about 1960, north of Ralston Creek. Additional evidence for a northerly component of slope of the lower surface is the southward thinning of the deposit between Ralston Reservoir and Tucker Lake (Van Horn, 1972). The northerly slope indicates that the original southern limit of the deposit probably was not very far south of the present southern limit.

This poorly sorted alluvium ranges in thickness from 0 to at least 40 feet and averages about 30 feet. It ranges from a cobbly sand and gravel to a pebbly sand. The size distribution of a sample from locality G101 on the east side of State Highway 93 near the middle part of the deposit is shown in figure 25. The Verdos is extremely variable in size gradation within short distances but in general is finer grained toward the east. The coarse fraction is principally of granitic rock, gneiss, and pegmatite but includes quartzite, schist, granodiorite, sandstone, and conglomerate. North of Ralston Reservoir the alluvium is complexly mixed with old alluvial fan deposits. Here it contains appreciably greater amounts of silt and sedimentary rock fragments. Several species of Foraminifera reworked from the Cretaceous bedrock are present at places in the deposit. Rock fragments below a depth of 3 feet generally are sound; above this, however, fragments commonly are rotten, and appreciable interstitial clay is present.

At places the upper 2–5 feet has a poorly to strongly cemented caliche layer. In the large borrow pit north of Ralston Reservoir the caliche is in several layers 1–2 feet thick separated by 1- to 2-foot-thick layers of silty to clayey sand or gravel and sand. At other places in the pit there is only one caliche layer. A measured section along the south side of the borrow pit follows.

SECTION GF5.—*Verdos Alluvium*

[Measured along the south side of borrow pit north of Ralston Reservoir, SE¼NE¼ sec. 32, T. 2 S., R. 70 W.]

	Thickness (ft)
1. Clayey to cobbly sand, red (10*R* 4/6). At places upper 1 ft has thin calcium carbonate stringers	4.0
2. Silty to cobbly coarse sand and few small boulders, white (10*YR* 8/2) at top to very pale brown (10*YR* 7/4) at base. Upper 3 ft is well cemented with calcium carbonate, but lower 4 ft is only moderately to weakly cemented	7.0
3. Silty to pebbly coarse sand, very pale brown (10*YR* 8/2); some narrow stringers of calcium carbonate. Contains fossil gastropods *Oreohelix* sp. indet., *Pupilla muscorem* (Linné), *Vallonia gracilicosta* Reinhardt, and *Zonitoides arboreus* (Say)	2.5
4. Silty coarse sand, light-reddish-brown (5*YR* 6/4). Persistent zone of calcium carbonate concretions as much as 4 in. in diameter at top. Base covered	3.0
Total thickness measured	16.5

The fossils in unit 3 were identified by A. B. Leonard of the Kansas Geological Survey (written commun., Jan. 15, 1953). Other collections from this pit identified by Leonard include *Pupilla blandi* Morse and *Deroceras laeve* (Müller). The faunule is terrestrial and indicates a woodland–plains border area. The *Oreohelix* suggests montane conditions, which is not surprising in view of the 6,100-foot altitude and the nearness to the Front Range.

Deposits in the measured section probably include a soil profile. Unit 1 may have been a B horizon that was extensively reworked by streams that incorporated much additional material into a new deposit. If so, unit 1 is younger than Yarmouth. The thin calcium carbonate zone in the upper part of this unit is probably the result of a post-Sangamon soil-forming period. The lower units seem to be an undisturbed pre-Bull Lake Cca horizon, impregnating sand and gravel of Kansan or Yarmouth age.

At the west end of the pit is a small lenticular deposit of silt containing about 10 percent rhyolitic volcanic ash shards (tables 10 and 11, locality G31). (See fig. 26.) The lens is about 30 feet long and 1-1.5 feet thick. It is very light gray where dry and grayish orange where damp. The lens is principally composed of silt-sized, rounded, and frosted quartz grains and aggregates of clay particles but includes small amounts of mica and dark mineral grains. The volcanic ash shards are clear to pitted, curved fragments that are mostly pieces of bubble junctures but include a few nearly complete bubbles. A few slender dark-brown crystals of chevkinite attached to the volcanic glass shards were identified by H. A. Powers of the U.S. Geological Survey (oral commun.). Analyses of specially cleaned glass shards (table 11) show marked similarity to analyses of the Pearlette Ash Member at the type locality of the Sappa Formation in Nebraska (Miller and others, 1964, p. 26).

About 10 feet of Verdos Alluvium mixed with an old alluvial fan deposit overlies the volcanic ash. The top of the mixed deposit is marked by as much as 2 feet of very light gray poorly cemented caliche (fig. 26). The gently undulating top of the caliche, probably the roots of a pre-Bull Lake Cca soil horizon, is unconformably overlain by 1-2 feet of younger colluvium.

The several isolated deposits of Verdos Alluvium north of Leyden Creek are eroded remnants of the large deposit north of Ralston dike. These isolated deposits are similar to the main deposit but probably contain more quartzite derived from reworking of the adjacent Rocky Flats Alluvium.

The Verdos Alluvium on the long ridge extending east from Leyden Junction is a continuation of the Verdos Alluvium north of Ralston dike and undoubtedly was originally continuous with it. Much of the quartzite in the alluvium on the ridge probably was derived from reworking the Rocky Flats Alluvium. Volcanic ash has been reported from this gravel (George Chase, U.S. Geol. Survey, oral commun.) but was not seen during the present study. The eastern part of this ridge is covered by as much as 5 feet of loess but it thins westward, and although present at the west end it is not mapped there. A slightly lower terracelike surface north of the ridge is underlain by a transported mantle deposit probably derived from the Verdos Alluvium.

Clear Creek

North of Clear Creek at Golden, three isolated deposits of Verdos Alluvium contain thin deposits of volcanic ash probably equivalent to the Pearlette Ash Member of the

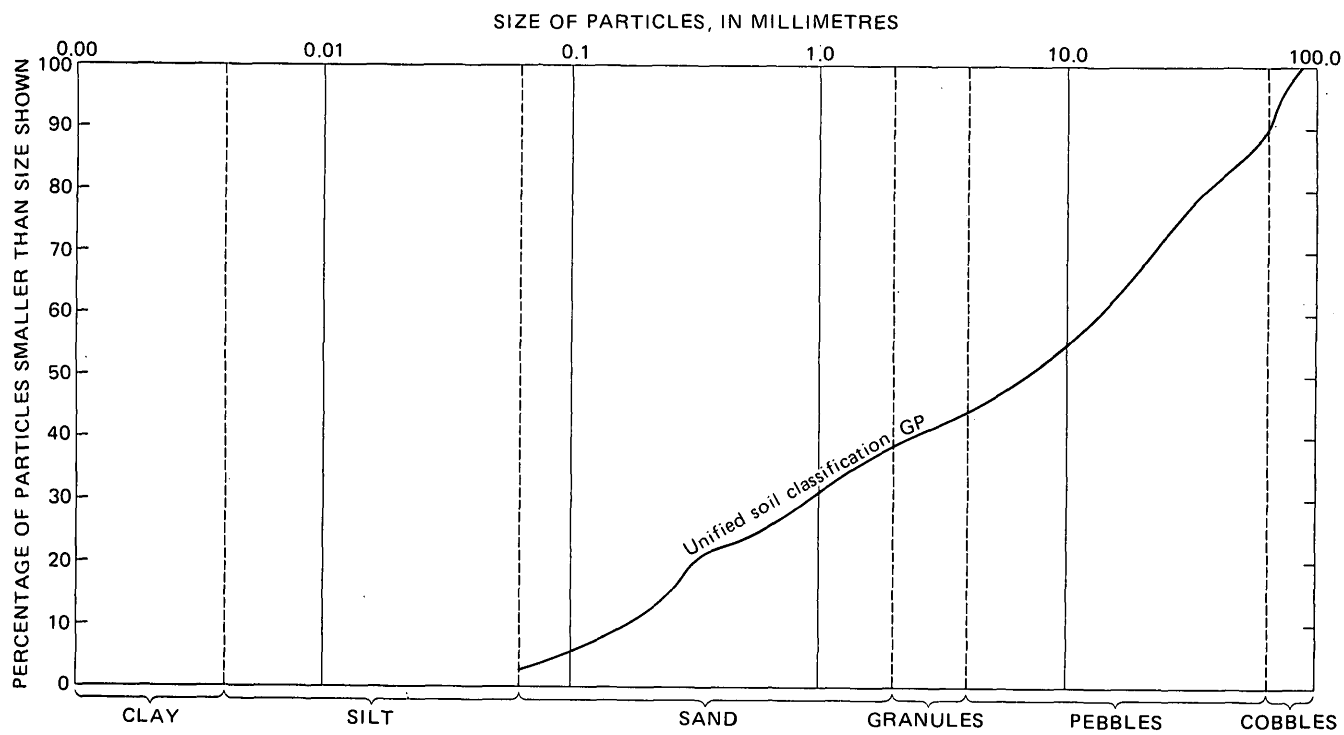


FIGURE 25.—Cumulative curve showing the size distribution of a sample of Verdos Alluvium from locality G101. Sample is from the NW¼SE¼ sec. 33, T. 2 S., R. 70 W.

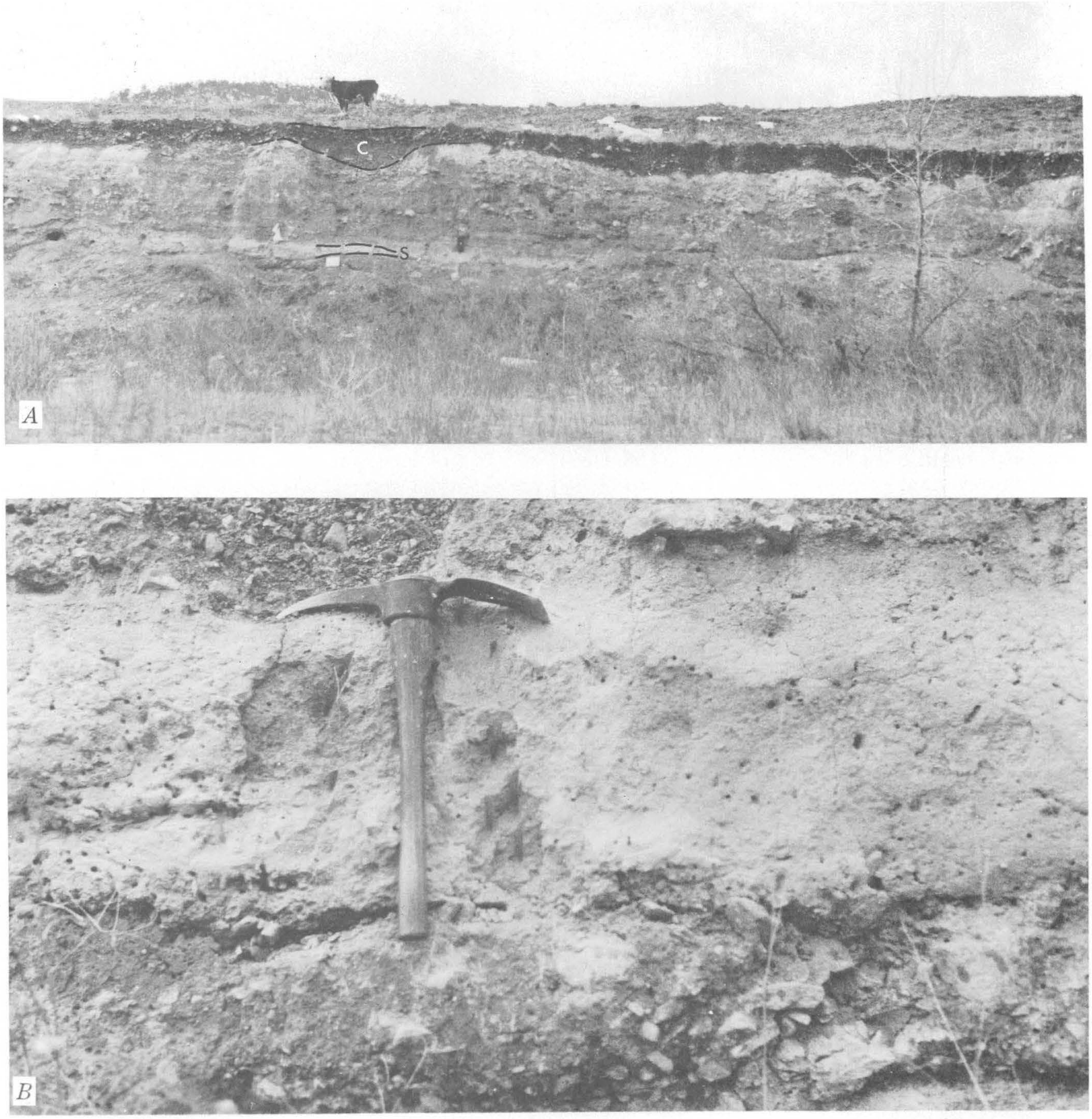


FIGURE 26.—Crudely stratified deposit of mixed Verdos Alluvium and old alluvial fan in the NW¼NE¼ sec. 32, T. 2 S., R. 70 W. (locality G31). *A*, Far view. The lenticular silt bed (S) contains about 10 percent rhyolitic volcanic ash probably equivalent to the Pearlette Ash Member of the Sappa Formation. The thin light-colored caliche bed just below the top of the excavation is probably the basal part of a pre-Bull lake Cca soil horizon. Unconformably overlying the caliche is colluvium (C) of Holocene age. The low grassy slope behind the cow is a spoil bank from the South Boulder Diversion Canal. *B*, Closeup of the volcanic-ash-bearing silt bed (S) and part of the mixed Verdos Alluvium and old alluvial fan deposit.

Sappa Formation. The westernmost deposit, which is not shown on the geologic map, is exposed in the westernmost prospect trench in the NE¼SW¼ sec. 28, T. 3 S., R. 70 W. (locality G24). A fourth deposit, also not shown on the map, has been overridden by a landslide that lies athwart the east boundary of sec. 28, T. 3 S., R. 70 W. (locality G94). (See fig. 42.) These four deposits do not now form a flat surface but are undoubtedly erosional remnants of a former terrace deposit that sloped about 60 feet per mile eastward between the Table Mountains. The deposit in the terrace was at least 40 feet thick. No deposit of Verdos Alluvium attributable to Clear Creek was found south of the creek.

The nearly circular deposit of Verdos capping the hill in northeast Golden (Graveyard hill) contains a 2-foot-thick deposit of rhyolitic volcanic ash in the lower part. The Verdos overlying the ash consists of about 40 feet of poorly sorted interbedded sand and cobbly sand and gravel. The coarse material contains a large proportion of light- to medium-gray granitic rock derived from the Silver Plume Granite in the headwaters of Clear Creek. The Verdos exposed in the prospect trench is of similar lithology, as are the other two deposits. In the prospect trench more than 3 feet of cobbly alluvium is overlain by rhyolitic volcanic ash, which in turn is overlain by colluvium. The deposit overridden by the landslide contains many cobbles and boulders of latite in addition to the granitic rock. The volcanic ash and topographic position relative to other nearby alluvial deposits indicate that these four isolated deposits are Verdos Alluvium.

Volcanic Ash Member

Volcanic ash in the Verdos Alluvium is a distinctive marker and forms a basis for correlating deposits in the Golden quadrangle with deposits elsewhere in the Denver area (Scott, 1962, 1963a; Hunt, 1954). The mineralogy and chemical composition of this ash strongly indicate that it is equivalent to the Pearlette Ash Member of the Sappa Formation and therefore is of late Kansan age.

The ash deposits range from light gray to white and have a fluffy or powdery texture. The tiny, broken shards are visible with a hand lens and create a myriad of brilliant bluish-white sparkles when viewed in strong light. When examined through a microscope the shards are seen to be mainly curved plates of clear to cloudy glass. Many of the plates are strongly pitted and the pits filled with a white clay mineral. (These fillings are removed by ultrasonic cleaning before the ash is analyzed chemically.) Many broken bubble junctions with jagged edges and a few unbroken bubbles are present in the ash. The chemical composition of ultrasonically cleaned shards (table 10, sample E1818) is similar to that of a rhyolite. Tiny crystals of brown chevkinite and green ferroaugite, some with particles of glass still attached to them, are an integral part of the ash. E. J. Young, of the U.S. Geological Survey, identified these minerals in samples from the two westernmost deposits at Golden (table 9), and H. A. Powers, also of the U.S. Geological Survey, identified chevkinite in the sample from north of Ralston Reservoir (oral communs.).

A possible extension of the Pearlette Ash Member into Colorado and other Western States was indicated by Powers, Young, and Barnett (1958). Powers (1961, p. B261–B263; fig. 111.1) subsequently proposed that the Pearlette Ash had 0.12–0.15 percent chlorine and 0.12–0.17 percent fluorine and that it differed from several other silicic ash deposits in these constituents. The volcanic ash deposits in the Golden area fall within the limits assigned to the Pearlette (table 10). The partial composition of the

TABLE 9.—*Minerals in samples of volcanic ash from near Golden, Colo.*
[Mineral identification by E. J. Young, U.S. Geological Survey. X, present; ..., absent; ?, identification not certain]

Locality No.	G24	G93
Serial No.	263316	280636
Chevkinite	X	X
Green ferroaugite	X	X
Magnetite	X	X
Hematite	X	....
Ilmenite	X	X
Quartz and feldspar	X	....
Blue-green hornblende	....	X
Green hornblende	X	....
Red-brown hornblende	....	X
Brown hornblende	X	X
Biotite	X	X
Zircon	X	X
Tourmaline	?	X
Sillimanite	?	X
Fayalite	?	....
Garnet	?	X
Hypersthene	....	X
Apatite	....	X
Sphene	....	X
Monazite	....	?

SAMPLE LOCALITIES

G24. NE¼SW¼ sec. 28, T. 3 S., R. 70 W., Golden quadrangle.
G93. Center sec. 28, T. 3 S., R. 70 W., Golden quadrangle.

TABLE 10.—*Complete and partial rock analyses (in percent) of volcanic ash samples from near Golden, Colorado*

Locality No.	[1]G24	[2]G93	[3]G31	[3]MS33
Serial No.	E1818	G 2860	E2073	E2072
SiO_2	72.91	....	....	....
Al_2O_3	11.86	....	....	....
Fe_2O_3	.58	....	....	....
FeO	.83	....	....	....
MgO	.06	....	....	....
CaO	.51	....	....	....
Na_2O	3.21	....	3.27	3.01
K_2O	5.17	....	5.11	5.17
H_2O-	.16	....	....	....
H_2O+	3.98	....	....	....
Total H_2O	....	....	4.10	4.03
TiO_2	.10	....	....	....
P_2O_5	.02	....	....	....
F	.17	0.122	.17	.15
Cl	....	.130	....	....
MnO	.04	....	....	....
Subtotal	99.60			
less O	.07			
Total	99.53			

[1]Analyst: Paula Montalto.
[2]Analysts: E. L. Munson and V. C. Smith.
[3]Analyst: D. F. Powers.

SAMPLE LOCALITIES

G24. NE¼SW¼ sec. 28, T. 3 S., R. 70 W., Golden quadrangle.
G93. Center sec. 28, T. 3 S., R. 70 W., Golden quadrangle.
G31. NW¼NE¼ sec. 32, T. 2 S., R. 70 W., Golden quadrangle.
MS33. SE¼ sec. 3, T. 4 S., R. 70 W., Morrison quadrangle.

Pearlette Ash Member at the type locality of the Sappa Formation, and at several other places in Kansas and Nebraska, was published by Miller, Van Horn, Dobrovolny, and Buck (1964, p. 26–28). The volcanic ash from the Golden area (table 11) is chemically similar to the ash from the other areas. Of the 24 elements determined in most of the samples from near Golden, 18 are within the limits shown for the Kansas and Nebraska samples. The other six elements are all present in higher percentages in one or more of the Golden area samples than in the Kansas and Nebraska samples. The small and inconstant differences, however, do not appear to be significant: boron, beryllium, and manganese are high in samples from localities G31 and MS33; cobalt and strontium were high in locality G24; fluorine is high in samples from localities G24 and G31, but still within the limits shown by Powers (1961); zirconium is high in all four of the samples from the Golden area. The ash at locality G24 is the type O Pearlette and is about 0.6 million years old, according to G. A. Izett of the U.S. Geological Survey (oral commun., July 1975).

Soil

The original soil developed on the Verdos Alluvium has been largely eroded at most exposures I examined. At some places only a caliche layer, which probably is the Cca horizon of a pre-Bull Lake soil, is present. This layer ranges in thickness from 0 to 7 feet but is absent at many places. In the deep cut for State Highway 93 north of Ralston Creek, a thick reddish-brown clayey gravel overlies a thick moderately cemented caliche zone, as shown in the following measured section.

SECTION G101.—*Soil on Verdos Alluvium*

[Measured in the east bank of highway cut in the NW¼SE¼ sec. 33, T. 2 S., R. 70 W.]

	Thickness (ft)
1. Spoil and old road fill	2.2
2. Clayey sand and gravel, dark-reddish-brown (2.5*YR* 3/4), noncalcareous; no soil structure. The pebbles and cobbles are stained dark reddish brown and many are rotten. The matrix is damp sandy clay. Grades into unit 3[1]	.9
3. Clayey sand and gravel, dark-red (2.5*YR* 3/6) mottled dark-reddish-brown (2.5*YR* 3/4), noncalcareous, no soil structure. Similar to unit 2 except for color; grades into unit 4[1]	1.4
4. Cobbly sand and gravel, clayey at top to silty at base, pinkish-gray (5*YR* 7/2), strongly calcareous. Calcium	

[1] See footnote at end of stratigraphic section.

TABLE 11.—*Quantitative spectrographic analyses (in percent by weight) of glass shards from volcanic ash samples near Golden, Colo., and Orleans, Nebr.*

[Samples were disaggregated and the glass shards were cleaned with an ultrasonic transducer; shards were separated from contaminants by use of an electromagnet; and analyses were made by generally accepted spectrographic methods. Reported results have an overall accuracy of ±15 percent, except that they are less accurate near limits of detection]

Locality No	[1] G31	[1] G24	[2] G93	[1] MS33	Type section of the Sappa Formation[3]			
Serial No	E2073	E1818	G2860	E2072	G2861	G2862	G2863	G2864
Element[4]								
Ag	([5])	([5])	< 0.00005	([5])	< 0.00005	< 0.00005	< 0.00005	< 0.00005
B	0.003	0.002	< .001	0.003	< .001	< .001	< .001	< .001
Ba	.016	.021	.032	.016	.017	.018	.016	.016
Be	.0017	.0010	.0007	.0013	.0009	.0006	.0009	0006
Co	.0001	.0002	< .0001	< .0001	< .0001	< .0001	< .0001	< .0001
Cr	.0001	.0001	< .0001	.0001	< .0001	< .0001	< .0001	< .0001
Cu	.0006	.0005	.0004	.0008	.0004	.0004	.0003	.0002
Fe	1.2	([6])	1.1	1.3	.93	.84	.92	.91
Ga	.0026	.0026	.0024	.0027	.0023	.0022	.0023	.0022
La	.011	.012	.013	.014	.014	.011	.010	.010
Mn	.034	([6])	.026	.032	.023	.022	.024	.020
Mo	.0006	.0006	.0005	.0005	.0003	.0005	.0005	.0004
Nb	.008	.007	.007	.008	.007	.005	.005	.005
Ni	< .0004	< .0003	< .0002	< .0004	< .0002	< .0002	< .0002	< .0002
Pb	.005	.004	.004	.005	.004	.004	.005	.004
Sc	< .0003	.0003	< .0005	< .0003	< .0005	< .0005	< .0005	< .0005
Sn	.0011	.0011	.001	.0009	.001	.001	.001	.001
Sr	.0014	.0084	< .001	.0020	< .001	< .001	< .001	< .001
Ti	.077	([6])	.087	.084	.082	.076	.074	.078
V	< .0003	.0003	< .0005	< .0003	< .0005	< .0005	< .0005	< .0005
Y	.011	.012	.009	.013	.010	.008	.009	.008
Yb	.0010	.0011	.0010	.0011	.0010	.0010	.0010	.0010
Zr	.030	.029	.030	.036	.027	.021	.020	.021

[1] Analysts: P. R. Barnett, N. M. Conklin, and J. C. Hamilton.
[2] Analyst: P. R. Barnett.
[3] Analyses from Miller and others (1964, p. 26, 27).
[4] Also looked for in all samples but not detected: As, Au, Bi, Cd, Ge, In, Pt, Sb, Ta, Th, Tl, U, W, and Zn.
[5] Also looked for but not detected.
[6] Not determined.

SAMPLE LOCALITIES

G31. NW¼NE¼ sec. 32, T. 2 S., R. 70 W., Golden quadrangle.
G24. NE¼SW¼ sec. 28, T. 3 S., R. 70 W., Golden quadrangle.
G93. Center sec. 28. T. 3 S., R. 70 W., Golden quadrangle.
MS33. SE¼ sec. 3, T. 4 S., R. 70 W., Morrison quadrangle.
G2861-64. SE¼NE¼ sec. 11, T. 2 N., R. 20 W., Stamford Quadrangle, Nebraska.

Unit 4.—Continued	Thickness (ft)
carbonate forms a moderately to weakly cemented zone at the top but decreases to slender stringers and small blebs toward base. Some pebbles and cobbles have a thick rind of hard caliche. Contains a few rotten schist pebbles[1]	2.2
5. Silty to cobbly sand and gravel and interlensing silty sand, reddish-yellow (5*YR* 6/6). Pebbles and cobbles are principally metamorphic and granitic rocks similar to post-Piney Creek alluvium of Ralston Creek.[1] (See table 8.) The largest rock seen is 2 ft in diameter and the common large size is 6 in. (See sample G101 of Van Horn (1968) for mechanical analysis.) Seeps are present at the base of the thickest part at the bedrock contact. Unconformably overlies the Arapahoe and Laramie Formations	15 to 30

[1]See table 12.

Units 2 and 3 of the measured section are B horizons of a pre-Bull Lake soil. No soil structure was found but the large number of pebbles and cobbles and the high moisture content would probably tend to obscure any structure. Well-developed clay skins coat the pebbles and cobbles. The Cca horizon (unit 4) is thin for a pre-Bull Lake soil, but Cca horizons, because of their variability owing to local conditions, are not dependable criteria for use in soil stratigraphy. The A horizon and upper part of the B horizon have been removed by erosion.

At many places along the excavation for the aqueduct north of Ralston Reservoir the Cca horizon is overlain by 1-3 feet of moderate-reddish-brown silty to cobbly sand and gravel. The contact between the two is very sharp and uneven. This seems to indicate that the upper part of the Verdos Alluvium has been reworked and that some of the B horizon of the original soil has been incorporated into the younger deposit overlying the caliche.

Age and Correlation

The age of the Verdos Alluvium is believed to be Kansan and Yarmouth chiefly because of the contained volcanic ash that is correlated with the Pearlette Ash Member of late Kansan age. The ash and underlying deposits of Verdos Alluvium are Kansan. The alluvium overlying the ash as well as the eroded soil profile may be of late Kansan or early Yarmouth age. The soil represented by the reddish-brown B horizon or the eroded Cca horizon probably developed during Yarmouth time.

The correlation of the volcanic ash in the Golden quadrangle with the Pearlette Ash Member of the Sappa Formation forms the main basis for the ages assigned to the terrace deposits in the Golden quadrangle. This correlation is corroborated by the topographic position of the terrace and the soil: the next younger terrace deposit also has a pre-Bull Lake soil, but the next one younger than that does not. Hence, the Verdos is the next to the youngest pre-Bull Lake deposit and is therefore consistent with a Kansan and Yarmouth age assignment.

ILLINOIAN OR SANGAMON

SLOCUM ALLUVIUM

The most continuous deposit of Slocum Alluvium is on the south side of Ralston Creek, but smaller deposits are adjacent to Clear Creek and Standley Lake. The Slocum borders valleys in the area and has a definite terrace aspect. It is the oldest terrace deposit that at places is overlain by a younger terrace deposit within the limits of the Golden quadrangle. It is as much as 40 feet thick.

Ralston Creek

The upper surface of the Slocum south of Ralston Creek slopes southeastward about 100 feet per mile. The Slocum is about 200 feet lower than the Rocky Flats Alluvium east of Ralston dike and about 100 feet lower than the Verdos Alluvium north of Ralston Creek. A low ridge at the south side of the surface south of Ralston Creek is thinly veneered with gravel and separates the Ralston Creek drainage from the Van Bibber Creek drainage.

The Slocum Alluvium adjacent to Ralston Creek is a poorly sorted, silty to cobbly sand and gravel that is 10–30 feet thick. The proportion of silt and clay increases outward from the center of the valley as the thickness of the deposit decreases. At places the upper 3 feet contains some rotten cobbles, mostly of schist.

Northeast of North Table Mountain the Slocum deposit is crossed obliquely by the present course of Van Bibber Creek. On the south side of the creek it continues southeastward to the vicinity of West 54th Avenue and McIntyre Street where it forms a terrace just a few feet above the next youngest terrace of Louviers Alluvium. Prior to deposition of the Louviers the Slocum probably continued southeastward and merged with the Slocum from Clear Creek. It may still be present under the Louviers, which has, however, obscured the relation between the deposits in this area. The Slocum south of Van Bibber Creek probably was deposited in part by Van Bibber Creek. The deposit is lower than the adjoining large deposit of Slocum to the northwest (pl. 1*G*). This is probably a result of erosion of the deposit south of Van Bibber Creek, although possibly the latter deposit has been miscorrelated and should be included in the Louviers Alluvium.

Clear Creek

The Slocum Alluvium adjacent to Clear Creek comprises five terrace remnants that are located on both sides of the creek. The upper surfaces slope eastward 55 feet per mile, are about 150 feet below the Rocky Flats Alluvium, 70 feet below the Verdos, and 75 feet above Clear Creek. The alluvium is a cobbly sand and gravel that contains very little silt or clay. It is poorly to normally sorted as determined by the sorting coefficient of Trask (1932, p. 72). The deposit contains pebbles and cobbles of Silver Plume Granite that distinguish alluvium of Clear Creek. Except for a few small remnants, the Slocum has been eroded from the valley of Clear Creek. The deposits at Golden generally are less than 10 feet thick (see measured soil section G72) and probably represent the thin edge of the deposit near the valley walls.

The base of the deposit is exposed at the west end of a gravel pit south of Fairmount School, in the NW¼ sec. 24, T. 3 S., R. 70 W. At the west end of the pit the contact with the underlying Denver Formation is about 10 feet higher than the top of the nearby Louviers Alluvium of Bull Lake age. The bedrock surface slopes eastward and in the eastern part of the gravel pit is not exposed even though the pit has been excavated almost to the same level as the top of the Louviers Alluvium. This thickness of gravel indicates that at least part of the valley in which Louviers was deposited had been eroded by Illinoian time. One mile east of the pit the upper surface of the Slocum Alluvium slopes under, and is buried by, the Louviers Alluvium. This superposition of alluvium is the oldest example found in the Golden quadrangle where a younger alluvium physically overlies an older alluvium rather than being in a valley incised below the base of the older deposit.

The Slocum at the pit near Fairmount School is 20–35 feet thick and, besides the typical Clear Creek clasts, it contains pebble- to boulder-sized fragments of latite. The silt-sized fraction contains small amounts of augite, hornblende, magnetite, and white feldspar derived from the Denver Formation. The largest boulder seen was 4 feet in maximum dimension. The common large size is 0.6 foot. Figure 27 shows the size distribution of a sample from locality G82 of this deposit. Rotten cobbles are present throughout the deposit but increase in number toward the top where they make up about 10 percent of the deposit. They account for 20 percent of the pre-Bull Lake soil that is present at a few places on the deposit.

Standley Lake

The Slocum north of Standley Lake is a silty to cobbly gravel that is more than 15 feet thick. The cobbles are principally quartzite from Coal Creek. The deposit is capped by a calcium carbonate zone 0–7 feet thick that may be the Cca horizon of a pre-Bull Lake soil. At places it forms a strongly cemented caliche as much as 3 feet thick.

Soil

The soil seen on the Slocum Alluvium is everywhere partly eroded and generally only a Cca horizon 1–7 feet thick is present. Even the Cca horizon is completely eroded at many places. The calcium carbonate of the Cca horizon may either form a strong hard cement or be loosely disseminated throughout the zone. At a few places as much as 6 inches of moderate-reddish-brown clayey B soil horizon overlies the Cca. An eroded soil on the Slocum (described in the following measured section) was exposed at locality G72 in the excavation for the metallurgical building of the Colorado School of Mines northwest of the corner of 15th and Arapahoe Streets in Golden.

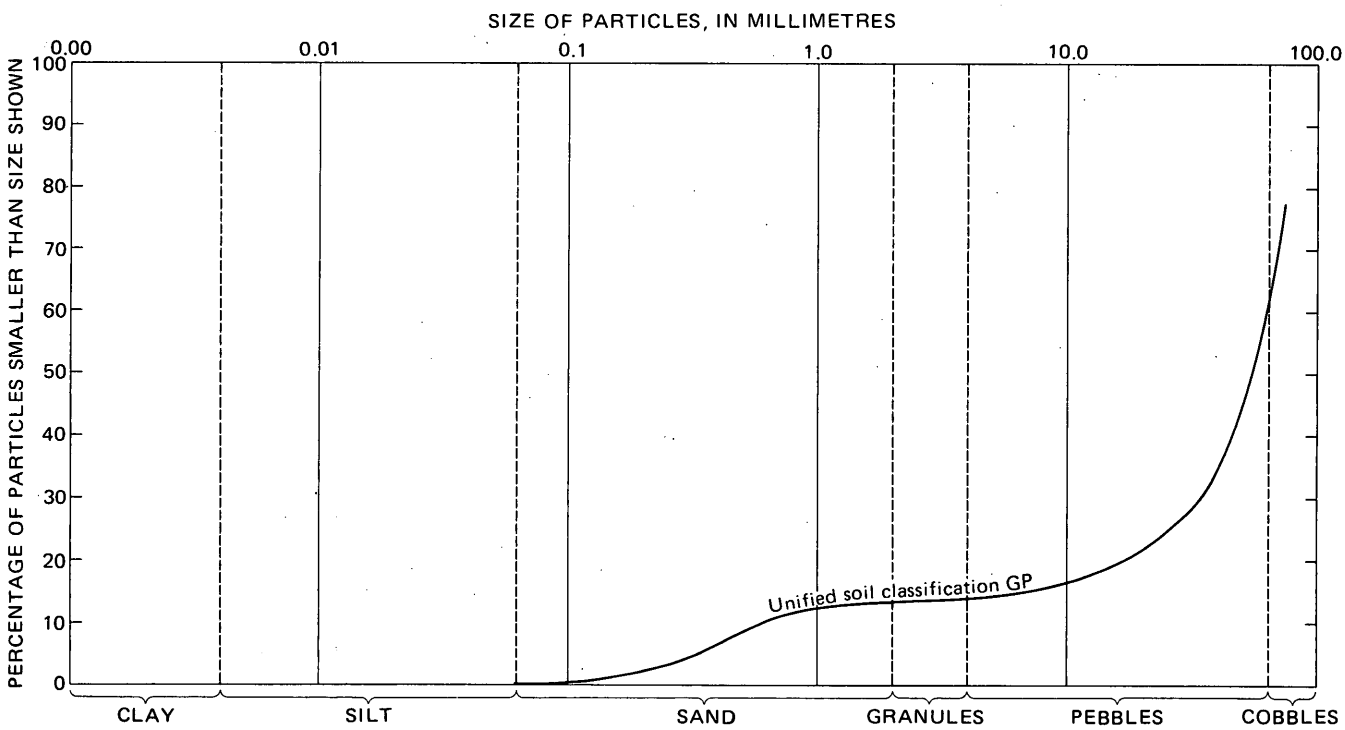


FIGURE 27.—Cumulative curve showing the size distribution of a sample of Slocum Alluvium from locality G82, SW¼NW¼ sec. 24, T. 3 S., R. 70 W.

SECTION G72.—*Eroded soil on Slocum Alluvium*

[Measured in the excavation for the Colorado School of Mines metallurgical building in NW¼NW¼ sec. 34, T. 3 S., R. 70 W.]

	Thickness (ft)
1. Clayey silt, grayish-black. Probably artificial fill	0.5
2. Clayey to cobbly sand, moderate-reddish-brown (10*R* 4/6). Many light-gray rounded granite cobbles, some rotten. Forms discontinuous layer	0–1.5
3. Silty to cobbly sand and gravel, very light gray, zone of calcium carbonate accumulation. Forms discontinuous layer	0–1.5
4. Cobbly sand and gravel, yellowish-gray (5*Y* 8/1). Common large size of rounded cobbles is 8 in. Many pebbles and cobbles of light-gray granite	3.5–5
5. Claystone of Denver Formation	6.0

Unit 2 of this section is probably the B or Bca horizon of a pre-Bull Lake soil. No soil structure was noted and possibly it is merely a reworked B horizon. The Cca horizon, unit 3, is very thin, which may also indicate that the overlying unit is a reworked deposit. The rounded cobbles of light-gray granite which distinguish this as an alluvium deposited by Clear Creek are in sharp contrast to the angular pebbles and cobbles of gneiss and schist in the adjoining old alluvial fan.

A roadcut south of Ralston Creek and 1½ miles east of Ralston dike exposed 2 feet of reddish-brown pebbly to clayey silt overlying Slocum Alluvium. The silt has well-developed prismatic structure with clay skins on the prism faces. Clay skins have also formed around the pebbles. The silt overlies 1–2 feet of strongly cemented pebbly to cobbly caliche, which overlies a cobbly sand and gravel. The exposure is poor but appears to be of a strongly developed pre-Bull Lake soil on Slocum Alluvium.

AGE AND CORRELATION

The Illinoian or Sangamon age of the Slocum Alluvium is established by the volcanic ash in the next highest (older) alluvium, by the strongly developed pre-Bull Lake soil on the deposit, and by the fact that the overlying alluvium is capped by a well-developed soil of probable post-Bull Lake age.

ORIGIN

East of North Table Mountain the lower surface of the Slocum slopes eastward and passes below the upper surface of the next younger Louviers Alluvium. Exposures and well logs are not good enough to permit tracing the contact between the two alluviums for any distance. However, part of the alluvium under the Louviers terrace almost certainly is Slocum, and part of the thick alluvium under the flood plain of Clear Creek possibly is Slocum. If the latter could be proved it would indicate deep erosion by Illinoian time and extensive alluviation during Illinoian time. No evidence to support such an extensive fill terrace has yet been found in the deep gravel pits in the flood plain.

BULL LAKE AND PINEDALE

The deposits of Bull Lake and Pinedale age were formerly shown as being of Wisconsin age in the Denver area. Because of nomenclature changes it has become more appropriate to refer to their age as Bull Lake and Pinedale, even though this represents no change in their chronologic placement. The former usage and the usage of the present report are as follows:

Former usage	Usage of the present report
Recent	Holocene
Post-Wisconsin	post-Pinedale
Late Wisconsin	Pinedale
Mid-Wisconsin	post-Bull Lake
Early Wisconsin	Bull Lake
Pre-Wisconsin	pre-Bull Lake

The Louviers Alluvium of Bull Lake age and the Broadway Alluvium of Pinedale age are both present in this area. This twofold division of the Bull Lake and Pinedale was not recognized by Hunt (1954) or Malde (1955), although they did recognize more than one deposit of Bull Lake and Pinedale age. They both used the soil developed on the Pinedale deposits to delineate the Bull Lake and Pinedale deposits at most places. Locally they correlated the strong soil developed on the Louviers Alluvium with a pre-Bull Lake soil and, thus, included part of the Louviers in their pre-Bull Lake deposits.

The soil of post-Bull Lake age described by Malde (1955, p. 252) and by Hunt (1954, p. 109) appears to be the same as the late Pinedale and superimposed early Holocene soils of the present report and of my earlier report (Van Horn, 1967). This soil appears to be the same as the early Holocene soil developed on the pre-Piney Creek alluvium exposed only along small tributary streams described by Scott (1962, 1963a). I correlate all alluvial deposits that bear this soil and are younger than Louviers with the Broadway Alluvium (Van Horn, 1967).

LOUVIERS ALLUVIUM

The Louviers Alluvium, of Bull Lake age, forms broad, well-defined terraces in the southern and eastern parts of the quadrangle. It is present in the valleys of all major streams except Leyden Creek. The upper surface slopes eastward 50–100 feet per mile, and in most places is about 40 feet above stream level. The deposit is generally a coarse cobbly sand and gravel that is normally to poorly sorted. There generally is less than 10 percent silt and clay in the deposit, except for the soil horizon, which contains more than 10 percent. The largest deposits are adjacent to Clear and Ralston Creeks.

CLEAR CREEK

In the valley of Clear Creek the Louviers is present in the vicinity of 8th Street in north Golden and also under the main business district of Golden near 13th and Washington Streets. Here the pebbles and cobbles are subround to round and are predominantly of granitic rock typical of Clear Creek. The deposit is normally sorted. Boulders as large as 1 foot across are present, but the common large size is 6 inches (fig. 28). The size distribution of a sample from this locality, G48, is shown in figure 29. Where the gravel is at the surface in the excavation a few feet west of the area shown in figure 28 the upper 2 feet is stained brown by iron oxide and appears strongly weathered, but no soil structure was seen in the excavation. A coarse cobbly sand and gravel that underlies the brewery just east of Kenneys Creek is probably Louviers; the upper part, however, has been so extensively reworked during construction of the brewery that it has been mapped as artificial fill.

The lower part of the young alluvial fan deposit shown at the mouth of Tucker Gulch in north Golden was probably deposited at the same time as the Louviers Alluvium in the vicinity of 8th Street. The upper part of the fan is much younger, and has been covered by recent floods.

Farther east, the Louviers exposed in the valley across the creek from the Golden Sewage Disposal plant (NE¼ sec. 27, T. 3 S., R. 70 W.) is coarse cobbly sand and gravel. The owner of a well drilled in this deposit reported 47 feet of sand and gravel. The well bottomed in clay, presumably Denver Formation. East of the Table Mountains the Louviers is marked by broad terraces of cobbly sand and gravel on both sides of Clear Creek. On the north side, near the corner of West 44th Avenue and McIntyre Street, the deposit is more than 20 feet thick. It is probably much thinner east of Mount Olivet Cemetery. It is about 10 feet thick on the south side of Clear Creek except near West 32d Avenue and Youngfield Street, where locally it is more than 20 feet thick, and at places is almost entirely composed of sand. At many places near West 32d Avenue and Youngfield Street the Louviers is overlain by a thin silt layer that locally may be as much as 20 feet thick. This may be loess although it is crudely bedded and appears to grade into the colluvium on the flanks of South Table Mountain. At a few places the top of the gravel underlying the silt is marked by a moderate to strong accumulation of calcium carbonate, probably a Cca soil horizon.

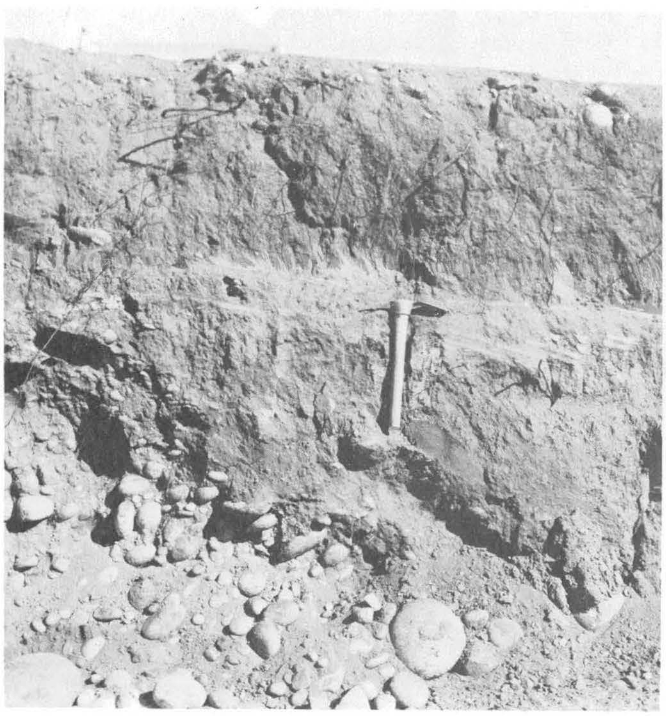


FIGURE 28.—Normally sorted Louviers Alluvium deposited by Clear Creek at locality G48 is shown at the lower left of the photograph. Behind the pick, unconformably overlying the Louviers, is dark-brown silty sand of the Broadway Alluvium deposited by Kenneys Creek. The Broadway is inconspicuously overlain by an artificial fill of very dark brown sandy silt above the pick head. The upper 2–6 inches of the exposure is spoil from the excavation. The eroded surface of the Louviers trends N. 30° W. The exposure was in an excavation along the south side of 13th Street, between Jackson and Ford Streets, in Golden. The pick handle is 1.5 feet long; the view is to the northwest.

Gravel Pits In Clear Creek Flood Plain

East of North Table Mountain, exposures in several sand and gravel pits and prospect pits in the flood plain of Clear Creek show as much as 60 feet of cobbly sand and gravel, overlain in most places by 3–4 feet of fine- to coarse-grained alluvium. The cobbly sand and gravel is massive to poorly bedded and contains lenses of pebbly sand. A few boulders of granite and latite were as much as 5 feet in diameter. At places small amounts of gold are extracted as a byproduct of the gravel production.

No indications of major unconformities were seen in the sand and gravel. Locally the upper few feet of the deposit is iron stained and contains partially rotten cobbles of granite, but the staining and rotting both decrease with depth. No zones of calcium carbonate accumulation were seen. No evidence for the age of the cobbly sand and gravel was found, but it is presumed to be at least as old as the Louviers Alluvium and is shown as Louviers(?) on the geologic map (Van Horn, 1972). The overlying 3–4 feet of alluvium is mapped as post-Piney Creek alluvium.

Ralston Creek

The other major deposit of Louviers Alluvium is on the south side of Ralston Creek. The thickness of this deposit is not known but it is probably less than 20 feet at most places. This deposit of coarse cobbly sand and gravel (fig. 30) has a very indefinite east boundary. The main body probably occupied the position of the present valley of Ralston Creek north of the bedrock ridge in secs. 5 and 6, T. 2 S., R. 69 W. A smaller body may once have existed south of this ridge. Both, however, have been completely removed by erosion.

The two deposits of transported mantle shown on the north side of Ralston Creek near Ralston Church (sec. 31,

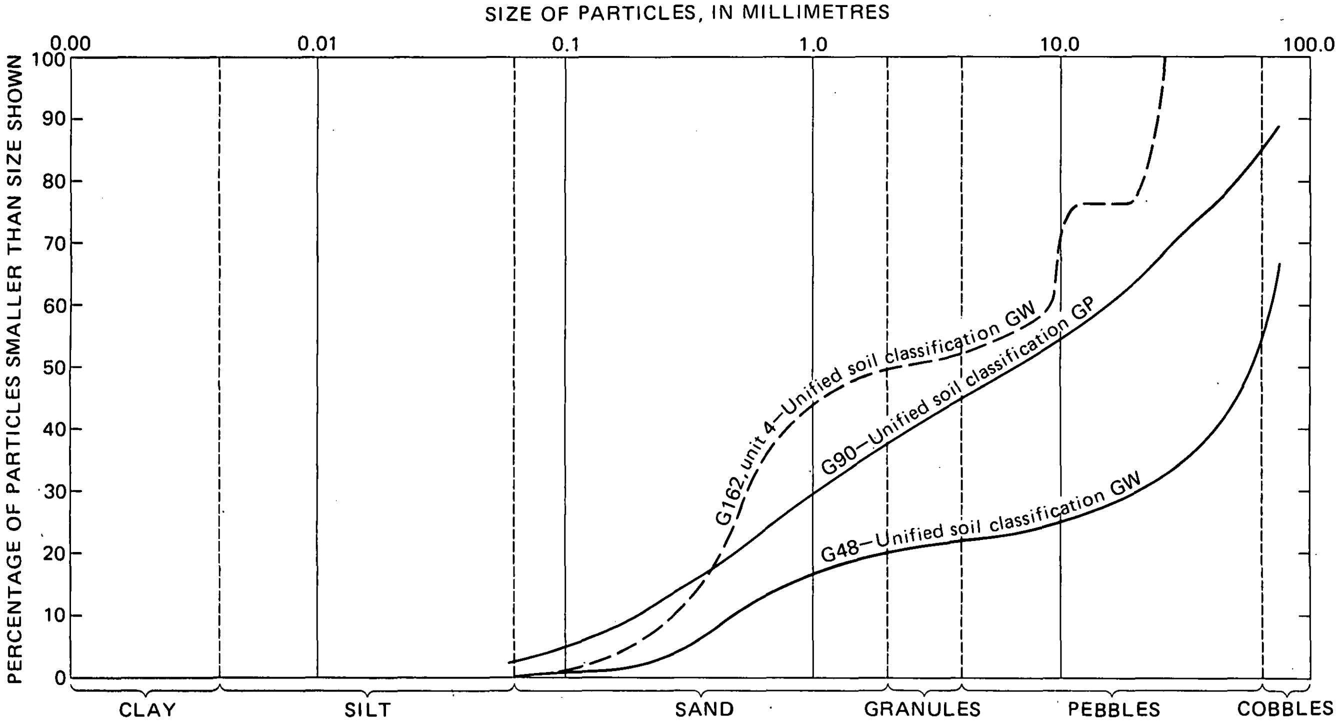


FIGURE 29.—Cumulative curves showing the size distribution of samples of Louviers Alluvium deposited by Clear Creek. Sample G48 is from the SW¼SW¼ sec. 27, T. 3 S., R. 70 W.; G162, from the NE¼SW¼ sec. 19, T. 3 S., R. 69 W.; and G90, from the NW¼NE¼SW¼ sec. 29, T. 3 S., R. 69 W.

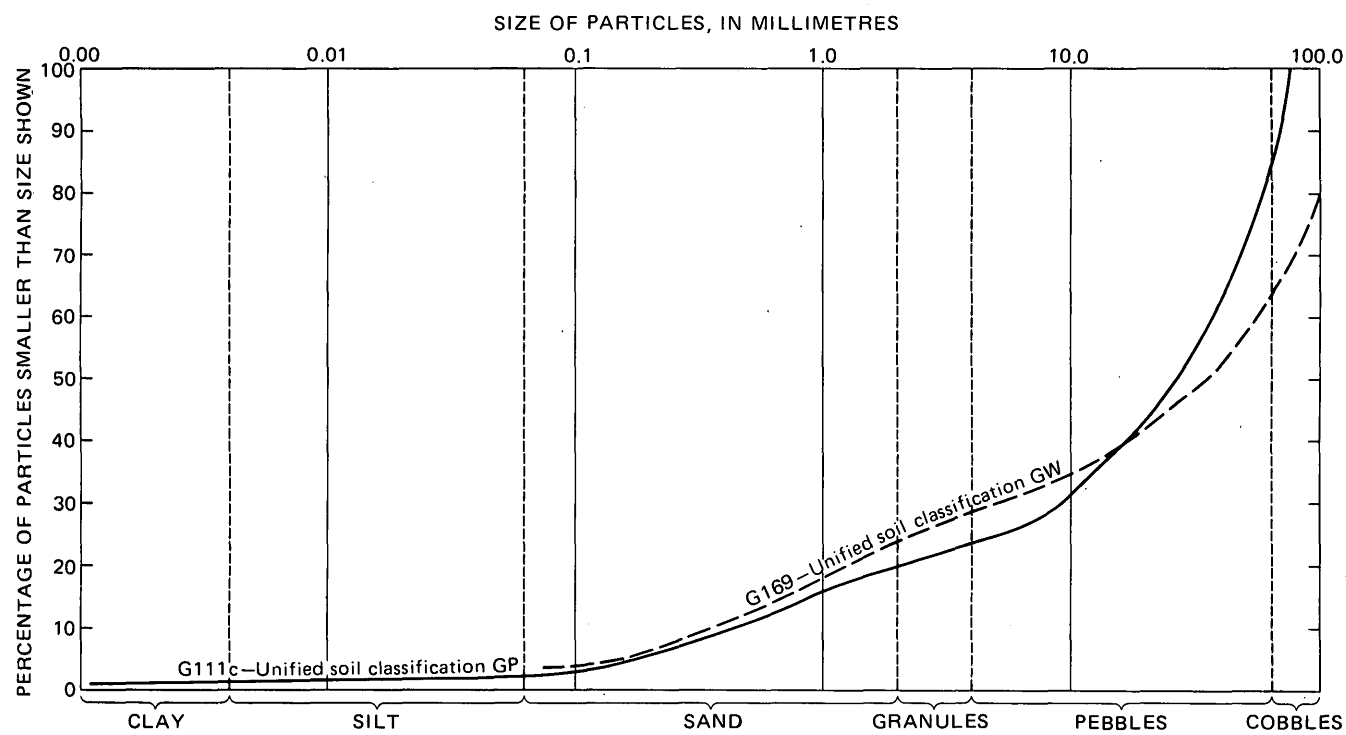


FIGURE 30.—Cumulative curves showing the size distribution of samples of Louviers Alluvium deposited by Ralston Creek. Sample G111C is from the NW¼NE¼ sec. 11 and G169 from the NE¼SE¼ sec. 1, T. 3 S., R. 70 W.

T. 2 S., R. 69 W.) are graded to about the same level as the Louviers. These deposits may be about the same age as the Louviers but they have more silt- and clay-sized material and grade imperceptibly upward to a level higher than the adjacent Louviers.

Standley Lake

Louviers Alluvium in the large area near the northeast corner of the quadrangle is probably less than 10 feet thick at most places. This coarse cobbly sand and gravel is principally composed of quartzite reworked from the Rocky Flats Alluvium. The small patch of Louviers(?) shown northwest of Upper Twin Lake marks an early course of the stream now occupying the valley to the north. The valley was probably cut during the early erosional stages of Bull Lake time and abandoned before the main body of alluvium was deposited.

Van Bibber Creek

A small deposit of Louviers near the corner of 54th Avenue and McIntyre Street was deposited by Van Bibber Creek as shown by the fact that it contains no light-gray granite. The lack of any deposits of Louviers in the present valley of Van Bibber Creek east of McIntyre Street probably indicates that Van Bibber Creek was flowing south of its present course and joined Clear Creek in the vicinity of Mount Olivet Cemetery throughout Bull Lake time. The Louviers was not recognized in the area north of North Table Mountain although it may be present under a thin cover of younger alluvium. The old fan deposit east of the Dakota hogback may be equivalent to the Louviers. It is not mapped as Louviers because of the coarse angular nature of the material in the deposit, and because of the fanlike shape.

Soil

Like most Pleistocene soils in the area, the soil on the Louviers has been mostly removed by erosion. The thickest soil seen on the Louviers is in a sand and gravel prospect, locality G111, in the Ralston Creek drainage (fig. 31, samples G111A, G111B; fig. 30, sample G111C). Here the B horizon is 1.5 feet thick. The top 0.5 foot is dark reddish-brown, silty sand and gravel which overlies 1 foot of dark-brown silty and pebbly sand. Samples for clay mineralogy determinations (fig. 48, table 12) showed that the upper 0.5 foot contained 20 percent clay-sized material and the lower 1 foot contained 10 percent. The Cca horizon in the prospect pit consists of 0–2.5 feet of sand and gravel moderately cemented by very light gray calcium carbonate.

The B horizon of the post-Bull Lake soil of the Golden area is characterized by a well-developed prismatic structure. Illuviated clay has formed coatings on the prism faces and around pebbles and cobbles. The horizon is generally noncalcareous. It is mostly dark brown but may have a reddish cast in the upper part. It was recognized only on alluvial deposits, where it is as much as 1.5 feet thick. The calcium carbonate in the Cca horizon is so variable in amount and thickness that it is not useful for recognizing this soil.

Age and Correlation

The Bull Lake age of the Louviers Alluvium is established by the topographic position of its terrace and by the relative degree of development of the soil formed on it. The Louviers forms the second terrace below the volcanic-ash-bearing Verdos Alluvium of Kansan or Yarmouth age. The soil is not as strongly developed as the pre-Bull Lake soils, but is more strongly developed than the soil on the next youngest terrace deposit, the Broadway Alluvium. Thus, the soil on the Louviers fits into the soil-stratigraphic succession outlined by Morrison and Frye (1965). (See p. 93.)

BROADWAY ALLUVIUM

The Broadway Alluvium, of Pinedale age, is generally a fine-grained alluvium and consists of silty to pebbly sand. At a few places in the western part of the quadrangle it is a coarse cobbly sand and gravel. Examples of the coarse phase are exposed adjacent to Clear Creek east of North Table Mountain and along Ralston Creek east of State Highway 93. The deposits of Broadway Alluvium are probably less than 10 feet thick at most places. The major deposits were formed by Ralston and Van Bibber Creeks. Smaller deposits are present west of Standley Lake and adjacent to Clear Creek.

Clear Creek

Only two small areas of Broadway Alluvium were found along Clear Creek. The only exposure of the deposit seen in Golden had no soil developed on it but showed the stratigraphic relation of the Broadway Alluvium overlying and cutting into the underlying Louviers Alluvium (fig. 28). The Broadway Alluvium shown in figure 28 was probably derived from Kenneys Creek and is a fine-grained facies at the edge of the deposit. This terrace of Broadway Alluvium is 5–10 feet above Clear Creek and 10–15 feet below the top of the Louviers Alluvium.

The other deposit of Broadway Alluvium, east of North Table Mountain, is about 10 feet above Clear Creek and 40 feet below the top of the Louviers Alluvium. Here the Broadway is a poorly sorted cobbly sand and gravel with a moderately developed soil on it. The A horizon of the soil consists of 0.2 feet of a very dark grayish brown humic, friable, silty coarse sand. This is underlain by 1.5 feet of dark-brown B horizon that is noncalcareous and has thin clay skins on the faces of the fine subangular blocky soil peds (individual natural soil aggregates). The B horizon is a cohesive, plastic clayey coarse sand that grades into the overlying A horizon and the underlying cobbly gravel. No zone of calcium carbonate accumulation (Cca horizon) was found. Pebbles and cobbles of the light-gray granitic rock typical of Clear Creek deposits predominate, but no bedding characteristics were visible in the limited exposure. The coarse cobbly alluvium seems to extend entirely down the terrace scarp to the level of the modern flood plain of Clear Creek.

Van Bibber Creek

The Broadway Alluvium adjacent to Van Bibber Creek grades rapidly eastward from a coarse cobbly sand and gravel to a fine sand (fig. 32, sample locality G109, unit 7). The greatest thickness of the alluvium seen was 6 feet. The alluvium probably is no more than 15 feet thick in the western part of the quadrangle and may be less than half that thick in the eastern part.

Along the western part of Van Bibber Creek the Broadway Alluvium is a coarse cobbly sand and gravel with subangular particles. It forms a terrace about 20 feet above the modern stream. North of North Table Mountain this terrace is only about 5–10 feet above stream level and is at about the same level as the adjacent Piney Creek Alluvium—at places 1–2 feet of Piney Creek overlies the Broadway. During the early part, if not all, of Pinedale time Van Bibber Creek flowed southeast from the northeast corner of North Table Mountain toward Mount Olivet Cemetery. The alluvium deposited in this gently sloping valley segment is a silty to pebbly sand. It was deposited in a broad shallow valley that was cut a few feet into the Louviers Alluvium. At places deep cuts reveal that the Broadway is underlain by a coarse cobbly sand and gravel that has a strong calcium carbonate zone.

When the Broadway Alluvium was deposited by Van Bibber Creek, Clear Creek must have been depositing its gravel at a lower level. Van Bibber Creek probably joined Clear Creek southeast of Mount Olivet Cemetery. The channel Van Bibber Creek cut through the Louviers Alluvium also must have been southeast of Mount Olivet Cemetery. Erosion has removed any direct evidence of this old channel as well as the eastern end of the Broadway Alluvium of Van Bibber Creek. This segment of Van Bibber Creek was abandoned in the latter part of Pinedale or early Holocene time when Van Bibber Creek was captured by a tributary of Ralston Creek at about the point where Ulysses Street crosses the creek.

Only one small deposit of Broadway Alluvium was found in the postcapture segment. It could not be determined if this was deposited before or after the capture. I suspect, but can find no evidence to prove, that the large area of Piney Creek Alluvium near the east border of the quadrangle in the present valley of the creek is underlain by Broadway Alluvium.

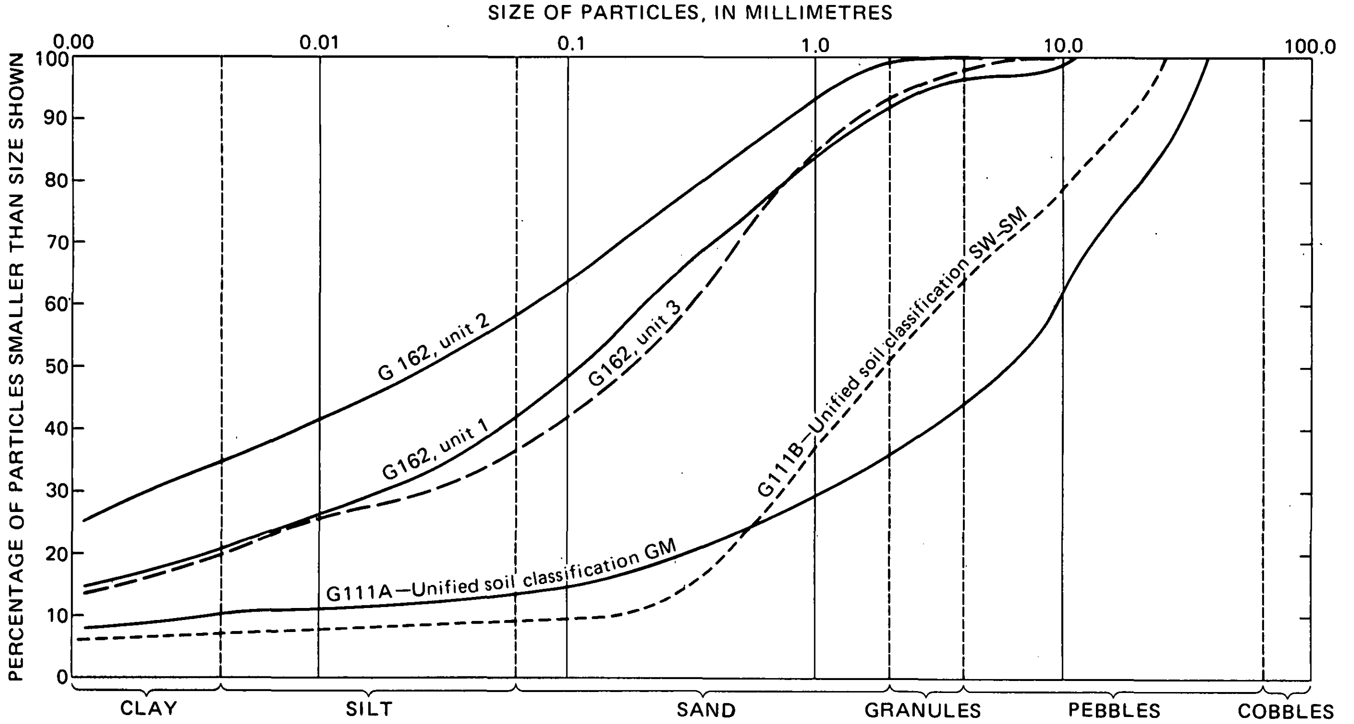


FIGURE 31.—Cumulative curves showing the size distribution of samples from soil horizons developed on Louviers Alluvium. Sample G162 is from the NE¼SW¼ sec. 19, T. 3 S., R. 69 W.; unit 1 is from the A horizon, unit 2 the B1 horizon, and unit 3 the B2 horizon. Samples G111A and G111B are from the NW¼NE¼ sec. 11, T. 3 S., R. 70 W.; G111A is from the B1 horizon and G111B the B2 horizon.

Ralston Creek

The Broadway Alluvium along Ralston Creek is a coarse cobbly sand and gravel in the western part of the quadrangle. Here it is about 20 feet above the Piney Creek Alluvium and nearly 30 feet above Ralston Creek. To the east the Broadway becomes much finer grained and its terrace converges with the terraces of the younger Piney Creek Alluvium until the Broadway is only a foot or so higher than the Piney Creek and is covered by a veneer of younger alluvium. Local residents report that prior to construction of the Ralston Reservoir dam the bigger floods would submerge areas above the level of the Broadway terrace. These exceptional floods, and similar ones that would presumably have occurred in Piney Creek time, would account for the veneer of younger alluvium overlying the Broadway Alluvium. In the eastern part of the quadrangle the lower part of the Broadway is a light-yellowish-brown silty sand. This is overlain by an upper part of dark-gray slightly calcareous sandy clay as much as 3 feet thick. The soil developed on the sandy clay has 0.2 foot of very dark gray friable, humic sandy silt. This is underlain by a B horizon consisting of 0.6 foot of very dark gray noncalcareous sandy clay that has clay skins coating the medium to fine angular blocky peds.

Leyden Creek

A small terrace deposit of moderate-yellowish-brown sandy silt at the town of Leyden is the only Broadway Alluvium found along Leyden Creek. The soil developed on the deposit is similar to that on other deposits of Broadway Alluvium. Near the crossing of Alkire Street and Leyden Creek a soillike horizon on a terrace deposit superficially resembles soils developed on Broadway Alluvium but lacks the usual soil structure found in the B horizon. It was therefore included with the Piney Creek Alluvium.

The Broadway Alluvium found along Leyden Creek is the oldest alluvium in the valley directly attributable to Leyden Creek. The narrow, unterraced, V-shaped valley indicates that most of the cutting in this valley is not very old and probably occurred between Illinoian and Pinedale time.

Standley Lake

The Broadway Alluvium west of Standley Lake is principally yellowish-brown sandy silt or sand. A cobbly sand and gravel unit is present at a few places but appears to be lenticular. The coarse fraction is mainly quartzite from Coal Creek. The deposit forms a terrace about 20 feet above the modern streams and 30 feet below the Louviers Alluvium.

The B horizon of the soil on the Broadway is as much as 0.5 foot thicker in this area than elsewhere. Where the B horizon is thick, the Cca horizon is thin or absent. According to Joseph B. Brown of the U.S. Department of Agriculture (oral commun.) the unusual thickness of the B horizon may be due to the lack of calcareous material in the parent material, which is principally quartzite. Because the downward-percolating water is not clogged with calcium carbonate the B horizon of a soil tends to develop more rapidly.

Soil

The soil generally found on the Broadway Alluvium is a moderately well developed pedocal, which I believe was formed mainly during two separate soil-forming intervals (Van Horn, 1967). The earlier interval followed the deposition of the Broadway Alluvium, forming the post-Broadway Alluvium soil, and the later interval followed the deposition of lower Holocene terrestrial deposits and formed the early Holocene soil. Soils which probably are equivalent to either the post-Broadway or early Holocene soil have been described previously (Van Horn, in Sheridan and others, 1967, p. 56, 57). A similar soil has developed on a fine-grained alluvium in the SW. cor. NW¼NW¼ sec. 24, T. 2 S., R. 70 W., in the Golden quadrangle. Here the soil consists of 2 feet of dark-grayish-brown to black clayey to sandy silt that contains threadlike streaks of very light gray calcium carbonate. It is overlain by 3 feet of colluvium. The relation of this soil and the alluvium to other alluviums is not known. I believe it is either the post-Broadway or the early Holocene soil.

Where the upper surface of the Broadway Alluvium has been continuously exposed since the end of deposition, as it has at most places in the Golden quadrangle, it is capped by a dark-gray to dark-grayish-brown, humic, massive to thin platy A horizon about 0.5 foot thick. This overlies a 0.5- to 1-foot-thick B horizon, generally with a sharp contact. The B horizon is dark brown, prismatic, noncalcareous, and moderately plastic. The prism faces contain faint to moderately well developed clay skins. Clay skins also are present around pebbles found in this horizon. At places the lower part of the B horizon is slightly to moderately calcareous and contains light-gray calcium carbonate in thin stringers and as coatings along prism and joint faces. The B horizon grades into the underlying Cca horizon which is 0.5–3 feet thick. The Cca horizon does not have a cemented caliche zone such as may occur in the older soils. The calcium carbonate is generally present as coatings along joint faces and on the underside of pebbles or as tiny spots disseminated throughout the deposit. The clay mineralogy, size gradation, and other materials tests results are shown in figures 33 and 48, and in table 12, and in Van Horn (1968).

The following section, locality G109, showing a moderately well developed soil on Broadway Alluvium from Van Bibber Creek, was exposed in an excavation for a greenhouse northwest of the corner of 50th Avenue and Indiana Street in the NE¼SE¼ sec. 13, T. 3 S., R. 70 W. (figs. 32 and 33).

SECTION G109.—*Soil on Broadway Alluvium*

[Measured in an excavation at the northwest corner of 50th Avenue and Indiana Street, Golden, NE¼SE¼ sec. 13, T. 3 S., R. 70 W.]

	Thickness (ft)
1. Spoil. Clayey to pebbly silt. Base nearly level but has minor undulations	0.5
2. A horizon and plowed layer. Dark-grayish-brown (2.5*Y* 4/2), massive to faintly thin, platy, silty sand and a few pebbles. The unit has fair dilatancy, slight plasticity, and low dry strength. Base forms sharp level contact with unit 3 just below top of ruler in figure 32[1]	.5
3. B horizon. Dark-yellowish-brown (10*YR* 4/4) mottled dark-brown (10*YR* 4/3), noncalcareous clayey sandy silt and a few pebbles. The ped faces of the poorly to moderately developed, fine, angular, blocky to prismatic structure contains a moderate accumulation of clay skins in the upper part. The unit has low dilatancy, moderate plasticity, and high dry strength. Grades into unit 4[1]	.3
4. Bca horizon. Light-olive-gray (5*Y* 6/2), ranging from dark-yellowish-brown at top to light-gray at base, massive, slightly to moderately calcareous, clayey to silty sand. The unit has fair dilatancy, moderate plasticity, and moderate dry strength. The contact with unit 5 is gradational	.3
5. Clca horizon. Light-gray (5*Y* 6/2), massive, strongly calcareous, silty sand and some pebbles. It contains abundant calcium carbonate mostly disseminated throughout the deposit but concentrated at a few places into thin white streaks and as rinds on the bottoms of a few pebbles. The unit has fair dilatancy, moderate plasticity, and low dry strength. It grades into the underlying unit[1]	.4
6. C2ca horizon. Yellowish-brown (10*YR* 6/8), moderately to strongly calcareous, massive silty sand and a few pebbles. The unit has good dilatancy, slight plasticity, and low dry strength. It grades into the underlying unit	.5
7. C3 horizon, alluvium. Dark-yellowish-brown (10*YR* 4/4), massive, silty, fine- to medium-grained sand and a few pebbles. The alluvium has good dilatancy, slight plasticity, and low dry strength. The base is not exposed[1]	.5

[1]See table 12 and figures 33 and 48.

AGE AND CORRELATION

The Broadway Alluvium is considered to be of Pinedale age. The moderately well developed soil formed on the deposit is similar in degree of development to the early Holocene soil of Scott (1962, 1963a), which he said had developed on the pre-Piney Creek alluvium of the tributary valleys in the Kassler and Littleton quadrangles, Colorado. New exposures in these quadrangles resulting from the Plum Creek floods of 1965 have provided evidence that terrace deposits Scott had correlated with the pre-Piney Creek alluvium are probably Broadway Alluvium and that the moderately well developed soil was formed only on the Broadway Alluvium and not on younger deposits (Van Horn, 1967). The deposit also occupies a stratigraphic position similar to that of the upper part of the deposit which caps the Broadway terrace and which was considered by Hunt (1954, p. 104) to be Pinedale in age.

FIGURE 32.—Soil developed on Broadway Alluvium at locality G109 northwest of 50th Avenue and Indiana Street, Golden, NE¼SE¼ sec. 13, T. 3 S., R. 70 W. The material above the top of the 20-inch ruler is the A horizon.

HOLOCENE DEPOSITS

PRE-PINEY CREEK ALLUVIUM(?)

Deposits of pre-Piney Creek alluvium were not mapped or definitely recognized in the Golden quadrangle although they are present in the adjoining Ralston Buttes quadrangle.

At two places west of Standley Lake a black, massive silty clay, about 2 feet thick, underlies Piney Creek Alluvium. The contact is conformable at both places. In the SW¼NW¼ sec. 24, T. 2 S., R. 70 W., cobbly sand and gravel underlying the black silty clay yielded a metacarpal bone identified by G. E. Lewis of the U.S. Geological Survey as *Bison* cf. *B. bison* (Linnaeus). It is probably of post-Mankato (post-middle Pinedale) age. The black bed, although its origin is not clear, may represent a humified surface horizon formed during a period of slope stability between the pre-Piney Creek alluvium (Scott, 1962, p. 30) and deposition of the Piney Creek Alluvium. If so, the cobbly sand and gravel underlying the black silty clay is probably pre-Piney Creek alluvium. A similar bed was reported (Van Horn, in Sheridan and others, 1967, p. 56–57) in the Ralston Buttes quadrangle. These beds may be equivalent to a very dark gray humic soil horizon, about 2 feet thick, that caps a terrace deposit about 20 feet above stream level near the Kassler quadrangle (Van Horn, 1967).

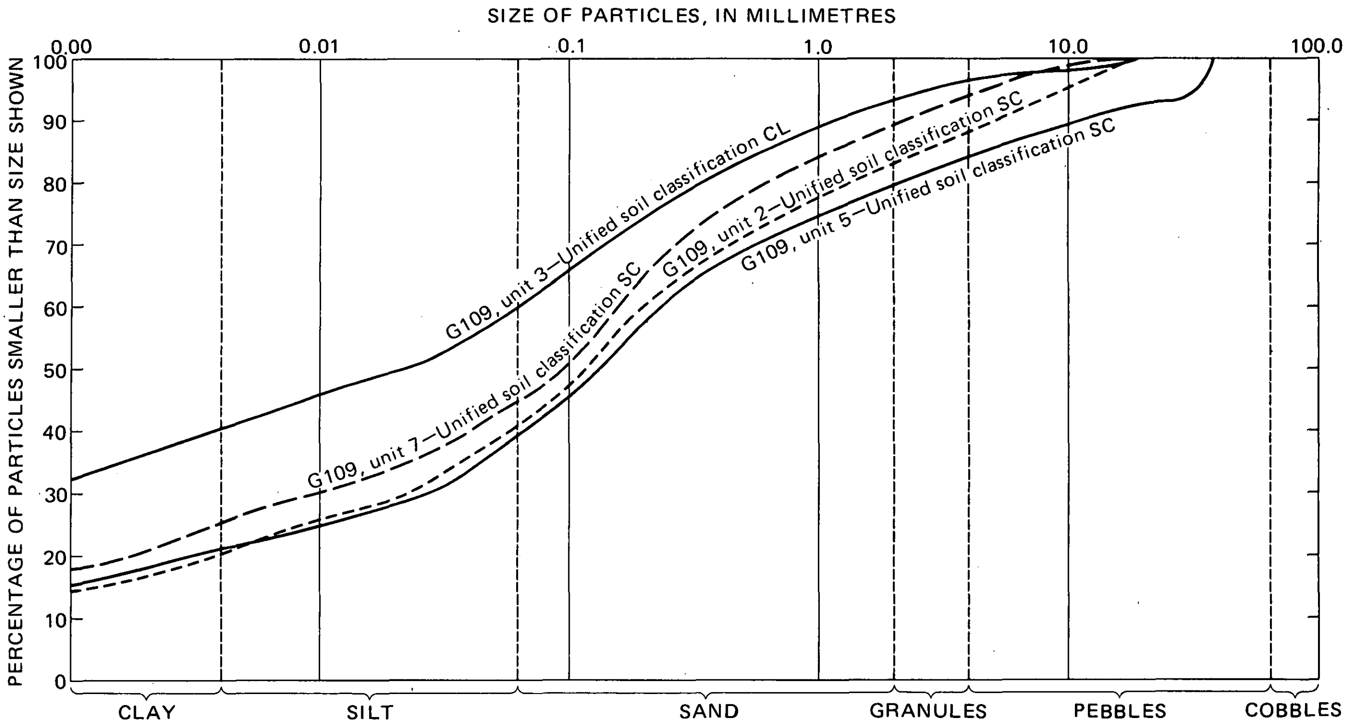


FIGURE 33.—Cumulative curves showing the size distribution of samples from soil horizons developed on Broadway Alluvium at locality G109, NE¼SE¼ sec. 13, T. 3 S., R. 70 W. Units 2, 3, 5, and 7 are described in the accompanying measured section at locality G109.

PINEY CREEK ALLUVIUM

The Piney Creek Alluvium generally is crudely to moderately well-bedded, dark-gray to dark-brown sandy silt or silty sand. The upper part usually contains much humic material. A very weak azonal soil is developed on the Piney Creek at several places. In the western part of the quadrangle lenses of gravel and sand locally are present in the lower part of the deposit. In the eastern part of the quadrangle the deposit contains more clay, and tends to stand in nearly vertical banks where gullied. The size distribution curve of a sample of Piney Creek Alluvium adjacent to Leyden Creek is shown in figure 34. The material is a silty clay of low plasticity. The Piney Creek was not recognized in the valley of Clear Creek, although it is present in all the other stream valleys.

In the western part of the area the Piney Creek forms a terrace 6–10 feet above the present streams and below the terrace composed of Broadway Alluvium. Farther eastward along most streams, the two terrace surfaces merge and in the eastern parts of Van Bibber and Leyden Creeks the Piney Creek Alluvium appears to overlie the upper terrace surface of the Broadway Alluvium. In these places the Piney Creek is probably very thin, perhaps only 3–4 feet thick. In the valley of Ralston Creek the Broadway forms a terrace a few feet above the Piney Creek, but the Broadway has a thin layer of younger alluvium over it. This younger alluvium probably represents flood deposits of Piney Creek and possibly post-Piney Creek age. In the vicinity of Indiana Street, probably as a result of a post-Piney Creek flood, Ralston Creek left the valley it had followed in Piney Creek time and cut a short stretch of new channel into the Broadway Alluvium, in which it is now flowing.

SOIL

The soil developed on the Piney Creek is a very weak azonal soil. At most places the A horizon consists of 0.2–0.6 foot of noncalcareous, slightly platy dark-grayish-brown sandy silt. At a few places this is underlain by as much as 1 foot of slightly calcareous sandy silt that contains some widely disseminated pinhead-size spots and vertically oriented threadlike streaks of a white salt—probably calcium carbonate. No zone of clay accumulation was seen.

AGE AND CORRELATION

The alluvium is correlated with the Piney Creek because of the thin azonal soil developed on the alluvium and because the younger deposits bear no soil. The age is post-Mankato (post-middle Pinedale) as shown by the bison found in the pre-Piney Creek alluvium(?) underlying the Piney Creek west of Standley Lake, and from Holocene fossils found in the Piney Creek in the adjoining Ralston Buttes quadrangle (Van Horn, in Sheridan and others, 1967, p. 54).

POST-PINEY CREEK ALLUVIUM

Post-Piney Creek alluvium is present in the beds of most of the streams in the area but is very thin. It is

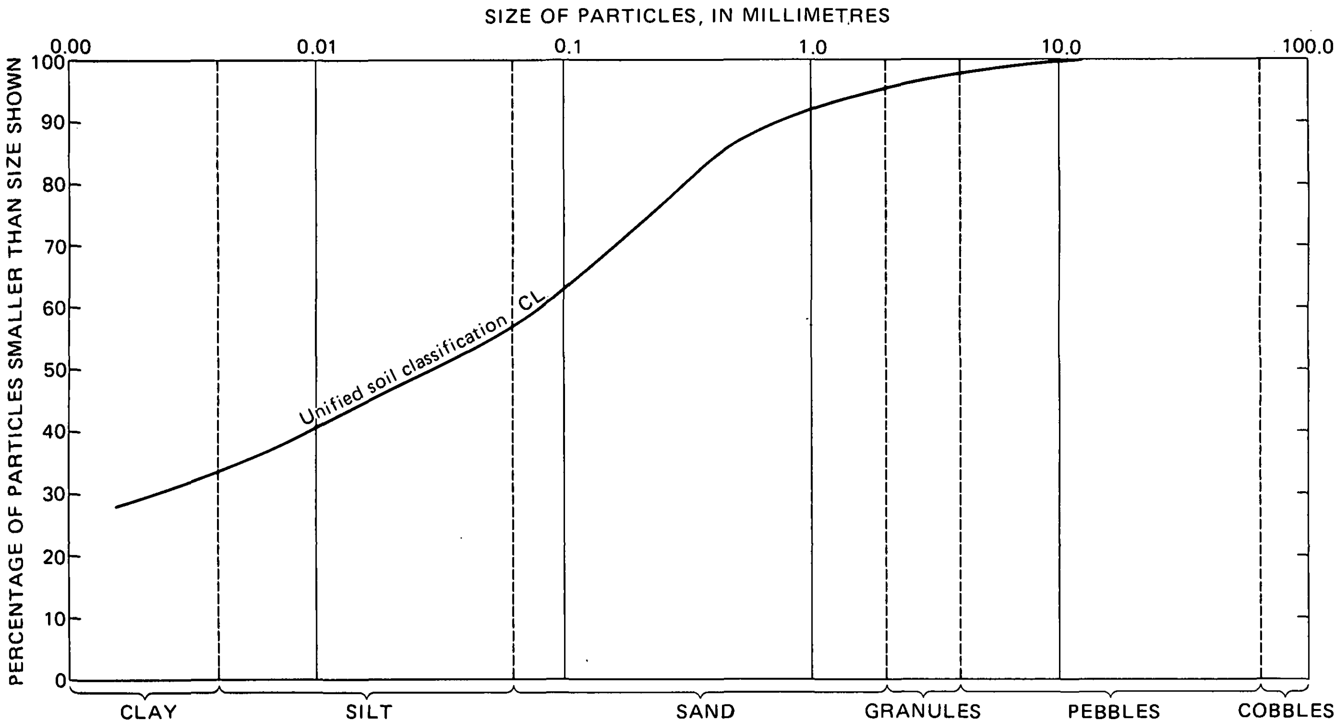


FIGURE 34.—Cumulative curve showing the size distribution of a sample of Piney Creek Alluvium from locality 842+00 (Van Horn, 1968) adjacent to Leyden Creek in the NE¼NE¼ sec. 36, T. 2 S., R. 70 W.

mapped only along Clear Creek and Tucker Gulch in the southern part of the quadrangle where the deposits are thickest. The size distribution curves of samples collected near the mountain front from the major streams in the vicinity of the Golden quadrangle are shown in figure 35. No soil or soil structure was found on the post-Piney Creek alluvium. Exposures are rare inasmuch as the present streams have cut into this deposit at very few places.

CLEAR CREEK

The post-Piney Creek alluvium in the western part of the quadrangle is a coarse cobbly sand and gravel. West of the mountain front boulders are common in the streambed. Mechanical analysis of a gravel bar in the stream in this area shows that the material is poorly sorted and contains less than 1 percent silt and clay (fig. 35). Within the city limits of Golden the flood plain has been greatly restricted by artificial fill dumped on the alluvium.

East of a small dam near the east end of North Table Mountain, Clear Creek has made a shallow cut into the post-Piney Creek alluvium. At the base of the cut is 2–4 feet of cobbly sand and gravel that may be an older alluvium. This is overlain by 1–5 feet of silty sand with no obvious stratification. The silty sand is overlain by 0.2 foot of concrete that appears to have been dumped as waste material from construction of the nearby dam. The concrete is overlain by 0.4 foot of silty sand similar to the material under the concrete. The top of the upper silty sand is level with the adjacent terrain and this sand is assumed to represent postdam flood deposits. No soil or evidence of weathering was found in any of the beds.

East of North Table Mountain exposures in several sand and gravel pits and gravel prospect pits show 3–4 feet of fine to coarse alluvium overlying a thick cobbly sand and gravel. The cobbly sand and gravel is presumed to be Louviers Alluvium. The overlying fine to coarse alluvium ranges from black or dark-brownish-gray clayey to sandy silt, near the edge of the valley, to a brown silty cobbly sand and gravel, near the middle of the valley. No soil was found on this material. Near the east boundary of the quadrangle are several 1- to 2-foot-high, northeast-trending terracelike scarps. The dark-brown, pebbly to silty sand exposed on the surfaces adjacent to these scarps has no soil developed on it.

TUCKER GULCH

The only other significant deposit of post-Piney Creek alluvium is in Tucker Gulch. Here the alluvium is coarse cobbly to bouldery sand and gravel (fig. 35). Many of the fragments are subangular. The not-uncommon historic torrential floods have deposited an unknown thickness of this material in the steeply sloping narrow valley downstream from the Front Range. At a few places upstream from the mountain front the post-Piney Creek has been entirely removed by erosion and the stream has cut down to bedrock (Van Horn, in Sheridan and others, 1967, p. 56, pl. 1). Near the mouth of Golden Gate Canyon a cut in this alluvium shows 5 feet of cobbly sand and gravel.

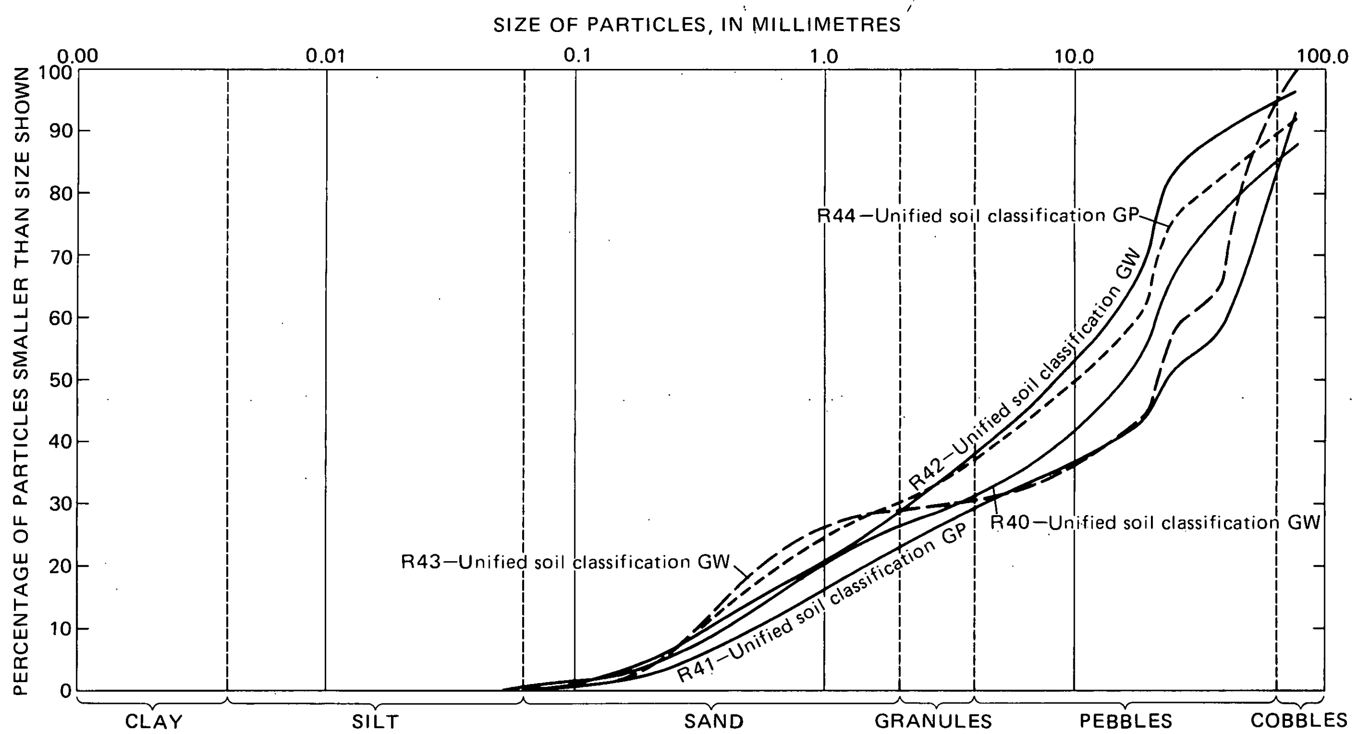


FIGURE 35.—Cumulative curves showing the size distribution of samples of post-Piney Creek alluvium. Sample R40 is from Ralston Creek, NW¼SE¼ sec. 31, T. 2 S., R. 70 W. (Ralston Buttes quadrangle); R41 from Van Bibber Creek in the NE¼SE¼ sec. 7, T. 3 S., R. 70 W. (Ralston Buttes quadrangle); R42 from Tucker Gulch in the NW¼SE¼ sec. 20, T. 3 S., R. 70 W. (Golden quadrangle); R43 from Clear Creek in the NE¼NE¼ sec. 32, T. 3 S., R. 70 W. (Golden quadrangle); R44 from Mount Vernon Creek in the NW¼SE¼ sec. 17, T. 4 S., R. 70 W. (Morrison quadrangle).

OTHER CREEKS

The post-Piney Creek alluvium is poorly exposed in the other creeks of the Golden quadrangle. Where exposed it generally is gray to brown crudely bedded sand and sandy silt that contains pebbles and cobbles at a few places. At most places the alluvium is in the bottoms of valleys cut into the Piney Creek Alluvium, although at a few places there is a veneer of overbank flood deposits of post-Piney Creek alluvium overlying the terrace of Piney Creek Alluvium. West of Ralston Reservoir the post-Piney Creek alluvium in Ralston Creek is coarse sand and gravel. (See fig. 35.)

A stream cut in the NW¼NW¼ sec. 25, T. 2 S., R. 70 W. reveals 2 feet of crudely bedded post-Piney Creek alluvium unconformably overlying an older fine-grained alluvium that is presumed to be Piney Creek. A bone found 0.4 foot below the top of the post-Piney Creek alluvium was identified by G. E. Lewis of the U.S. Geological Survey as probably *Bos tauras*, the domestic cow. This would indicate that the upper part of the section was deposited after 1850.

Additional evidence of the age of post-Piney Creek alluvium was found on the south bank of Van Bibber Creek where it crosses the hogback of the Dakota Group. Here a scattering of chips and broken points showed the presence of Indian occupation of this bank that is about 6 feet above the creek bottom. A prominent dark-gray silty sand layer about 2 feet below the top of the bank contained charcoal. A 150-pound sample from this layer yielded 10.2 grams of charcoal, which was dated at 1,050±200 years before present (Rubin and Alexander, 1960, p 156, sample W–616).

The coarse fraction of the same sample contained a few dozen rodent pellets, some of which appeared charred, about 10 pounds of angular to subangular rock fragments as much as one-half inch in diameter, several bone fragments, a few flakes of chert and one of obsidian, and one side-notched point that is 2.05 cm long and 1.1 cm wide just forward of the notch. Mr. Arnold Withers of the University of Denver identified the point as a side-notched point possibly of a Late Woodland culture. (The point is in the Denver University collection under accession No. K–4–11.) The deposit was originally believed to be Piney Creek Alluvium but the radiocarbon date, the side-notched point, and the lack of a soil on the deposit all indicate that the deposit is post-Piney Creek. Because of its small areal extent and thinness, however, the deposit is included in the Piney Creek on the geologic map.

In 1966 the site was studied by Nelson (1969), who concluded that there are three separate cultural layers at the site that range in age from 800 to 2,140±145 years before present.

The foregoing bits of information seem to indicate that post-Piney Creek alluviation started prior to the year 200 B.C. and that a period of erosion started some time after this. A second, and perhaps equally plausible, interpretation is that this area has been undergoing erosion since the end of Piney Creek alluviation and that the thin, relatively minor amounts of post-Piney Creek alluvium found in this area are only the overbank flood deposits of the present streams. Evidence supporting this interpretation was seen south of Denver where the 1965 flood of Plum Creek deposited as much as 1 foot of nearly continuous sand on the thin humic A horizon of the terrace 8 feet above the flood plain, and a thin discontinuous layer of sand on the thick humic A horizon of the terrace 25 feet above stream level. A list of 19 floods that occurred in the vicinity of the Golden quadrangle during 26 of the years between 1878 and 1914—an average of almost one every year—has been made in this report. (See p. 108.)

PLEISTOCENE AND HOLOCENE DEPOSITS

Several different kinds of deposits of Pleistocene, Holocene, or undifferentiated Pleistocene and Holocene age shown on geologic map (Van Horn, 1972) consist of alluvial fan deposits, transported mantle, colluvium, loess, artificial fill, and landslides. Some of these deposits grade into each other and into the various alluvial deposits described earlier; others have sharp boundaries. Only broad age distinctions have been made within these deposits, although finer subdivisions are possible at some places.

ALLUVIAL FAN DEPOSITS

Alluvial fan deposits are a heterogeneous mixture of particles ranging from boulders to clay. In plan view the deposits generally have the shape of a partially opened fan, with the narrow, or handle, end pointing upstream and the wide, lobate end downstream. They are stream deposits brought about by a sudden lessening of the carrying power of a stream. This is generally caused by a flattening of the gradient of a stream or by a stream in a narrow valley issuing onto a wide flat plain, or both. The lithology of the deposits reflects the bedrock in the valley from which they originate. Two ages of alluvial fans are distinguished on the geologic map (Van Horn, 1972); geomorphic relations of deposits was the main criterion used in establishing the relative age, and the degree of soil development was used to a much lesser degree. The old alluvial fans are of Bull Lake age or older, whereas the young alluvial fans are of Pinedale age or younger.

OLD ALLUVIAL FAN DEPOSITS

The old alluvial fans that debouch from the mountains are poorly sorted bouldery sand and gravel near the mountain front but rapidly grade to finer grained sand and gravel away from the mountains. Beds of clayey to sandy silt are present near the terminal end of some deposits.

The old fan in the south part of Golden was deposited on a very irregular surface. Near Washington Avenue beds of brown sandy silt as much as 5 feet thick overlie clean sand. (See sample G99, fig. 36.) Other exposures in this same area show subangular silty to cobbly sand and gravel, containing boulders as much as 2.5 feet in diameter, resting on the Denver Formation. At some places many of the cobbles and small boulders in the upper part of the deposit are rotten. Although no well-developed soil was found on the deposit, a calcium carbonate cemented zone as much as 3 feet thick locally is present in the top part. At a few places this zone has been eroded and younger alluvium or colluvium has been deposited in channels cut in the old fan.

Other old fan deposits are similar but exposures are generally poor. An excellent exposure of the terminal end of a fan is exposed in the gravel pits just north of the Louviers Alluvium along 8th Street in Golden (NW¼SE¼ sec. 28, T. 3 S., R. 70 W.). Here the fan deposit has been truncated by erosion before deposition of the Louviers. The upper surface of the fan is at the same height as the adjacent Slocum Alluvium and is probably of the same age. The old fan deposit is composed of material from the small canyon north of Clear Creek and contains none of the light-colored granite so typical of Clear Creek. The deposit is poorly sorted cobbly sand and gravel (G95, fig. 36) that is horizontally and evenly, though somewhat crudely, bedded. The bedding gives the impression of a terrace alluvium constructed by Clear Creek but the shape and lithology indicate alluvial fan deposition. At this place the deposit probably resulted from a mixing of the two processes. A few hundred feet uphill from the north edge of this fan a thin deposit of cobbly sand and gravel from Clear Creek is overlain by Pearlette-like volcanic ash. This material no doubt was once part of an extensive alluvial fill of Verdos Alluvium that was mostly eroded away before the old fan alluvium was deposited.

A small remnant of a still older fan is preserved on the small knoll one-half mile north of Clear Creek and just east of the Front Range. The older fan probably was graded to the level of the Verdos Alluvium. Both fan deposits are as much as 20 feet thick.

The large old alluvial fan near Van Bibber Creek northwest of North Table Mountain may be intermediate between a fan and a terrace deposit. This fan deposit is poorly exposed, but it appears to be composed of silty to bouldery sand and gravel, coarser at the west end. The soil that formed on it has been removed by erosion except for a strong accumulation of calcium carbonate. This deposit probably resulted when Van Bibber Creek left the relatively confined valley west of the Dakota Group and debouched into the wide valley east of the Dakota. It is tentatively correlated with the Louviers Alluvium because

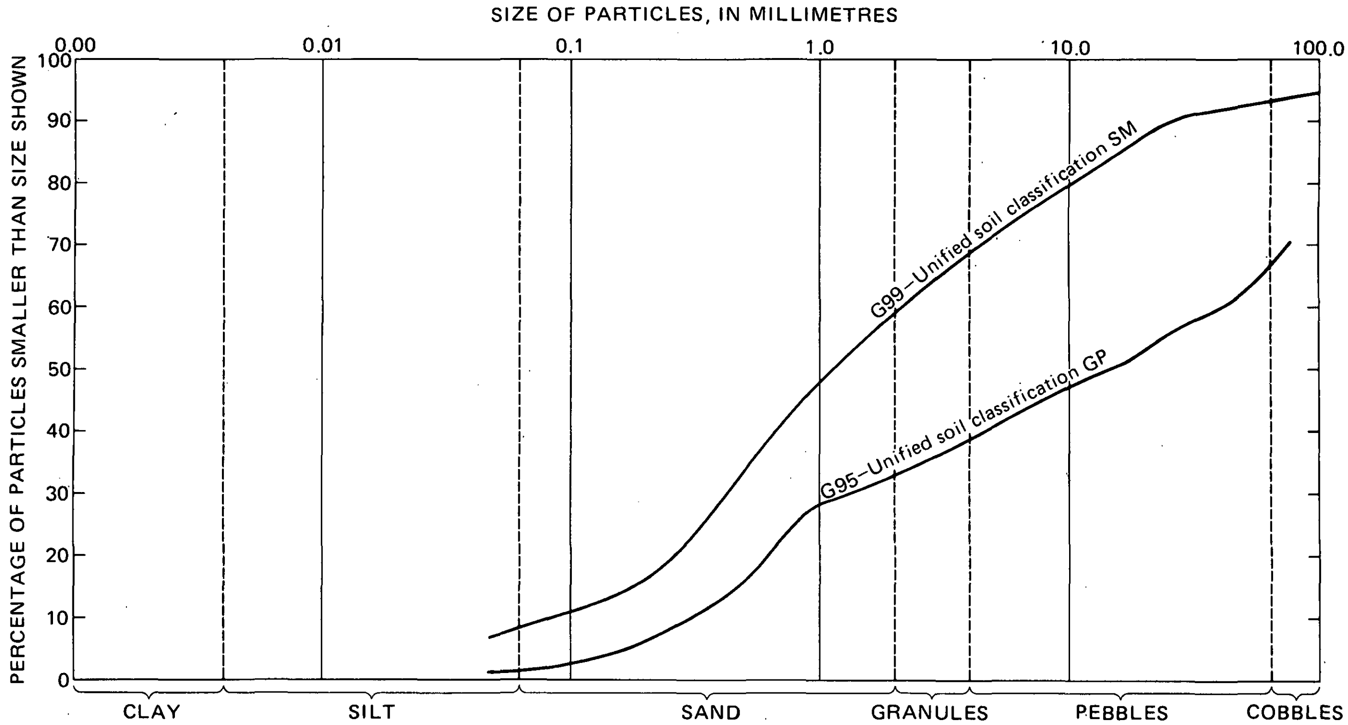


FIGURE 36.—Cumulative curves showing the size distribution of samples of old alluvial fan deposits. Sample G99 is from the NW¼NW¼ sec. 34, and sample G95 is from the NW¼SE¼ sec. 28, T. 3 S., R. 70 W.

it is about the same height above stream level as the Louviers terrace to the west and because the oldest alluvium that truncates the fan is probably the Broadway Alluvium.

The old fans north of Ralston Reservoir appear to merge and interfinger with the Verdos Alluvium. At a few places the old fans are cut by small channels filled with younger material. The old fan alluvium contains much silt and calcium carbonate where exposed east of the South Boulder Diversion Canal (fig. 26).

YOUNG ALLUVIAL FAN DEPOSITS

Included as young alluvial fan deposits are all the fan deposits that are younger than Bull Lake. The fans west of the longitude of Golden are a silty to cobbly sand and gravel, whereas the fans east of Golden appear to have more silt- and clay-sized material and fewer cobbles. The upper few feet of most young fans is clayey silt grading downward into a coarser material. At places the bottoms of cobbles and pebbles in the upper part of the coarser material have a thin calcium carbonate rind, probably part of the Cca horizon of a soil. No well-preserved recognizable soil was found on any of the young fan deposits. Their age was determined by their relation to terrace deposits they truncate or overlie. Most of these young fans probably were formed before deposition of the Piney Creek Alluvium, but sediment is still being deposited on many of them.

The young fan formed at the mouth of Tucker Gulch near its junction with Clear Creek is intermediate between an alluvial fan and a terrace deposit. It has the shape of an alluvial fan and is composed of poorly sorted sand and gravel that contains many subangular cobbles and boulders. The material is principally from Tucker Gulch although some is from Clear Creek. It resembles a terrace deposit in that the upper surface is gently sloping and bulges only slightly above the upper surface of the Louviers Alluvium deposited by Clear Creek. The fan deposit probably resulted from the loss of carrying power where Tucker Creek encountered the flatter gradient of Clear Creek. Several historic floods have added material to the upper part of the deposit. The lower part of the deposit probably is equivalent to the old alluvial fan deposit.

TRANSPORTED MANTLE

Transported mantle, as the name implies, is surficial material that has been moved and deposited by a combination of processes. It seems to be partly alluvium and partly colluvium. The deposits consist of a mixture of boulder- to clay-sized material that underlies planar surfaces that slope more steeply than stream terraces (pl. 1). It ranges from a clayey to cobbly sand and gravel to pebbly sandy silt. At many places the deposits become coarser grained downslope. The upper few feet of the transported mantle commonly has abundant calcium carbonate and may contain some reddish-brown to brown

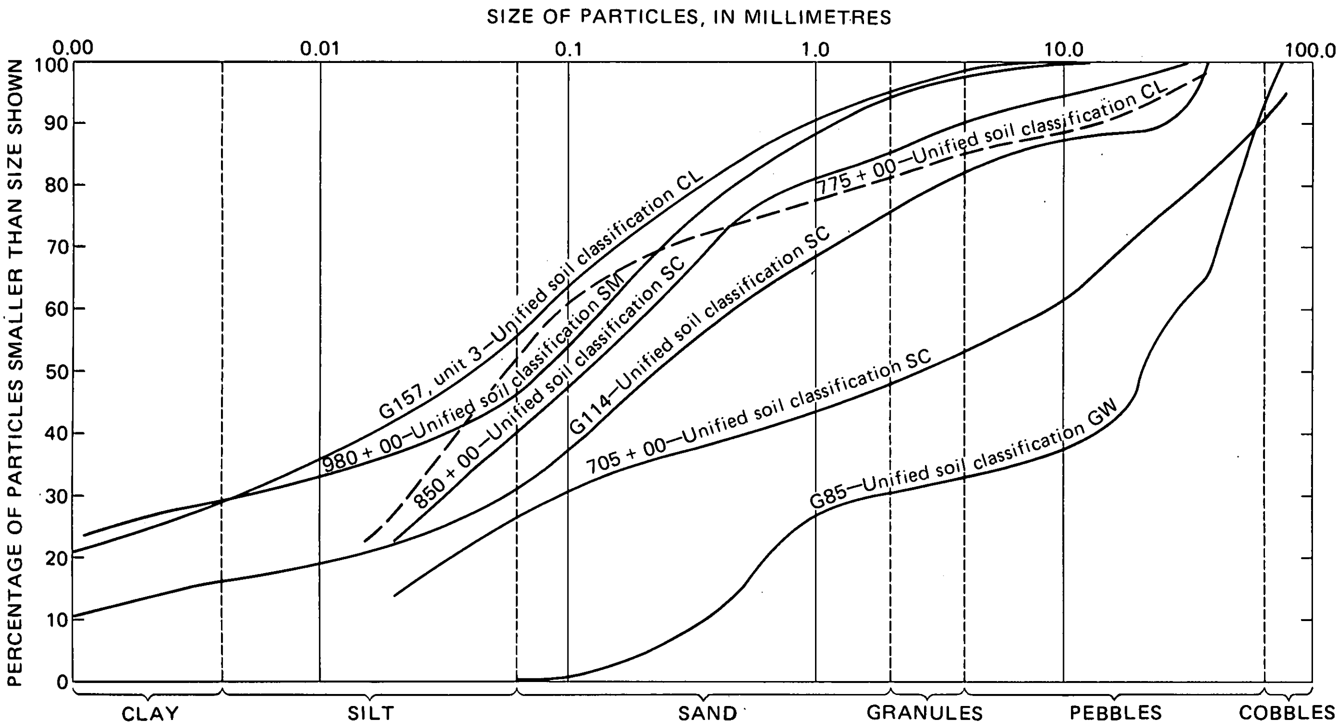


FIGURE 37.—Cumulative curves showing the size distribution of samples of transported mantle. Sample 705+00 is from the NE¼SW¼ sec. 23, T. 2 S., R. 70 W.; 775+00 from SW¼NE¼ sec. 25, T. 2 S., R. 70 W.; 850+00 from SE¼NE¼ sec. 36, T. 2 S., R. 70 W.; 980+00 from NW¼NW¼ sec. 8, T. 3 S., R. 69 W.; G114 from NW¼NE¼ sec. 6, T. 3 S., R. 69 W.; G157 from NW¼SW¼ sec. 9, T. 3 S., R. 69 W.; G85 from NW¼NE¼ sec. 16, T. 3 S., R. 69 W. (Arvada quadrangle).

clay. At a few places the lower part is made up of clean cobbly sand and gravel. The gravel clasts are well rounded and predominantly of Precambrian rocks derived from the Front Range. In general it is coarser and less plastic than colluvium and finer and more plastic than alluvium (fig. 37). The transported mantle is 0–15 feet thick. It is equivalent to similar deposits mapped as residuum by Hunt (1954, p. 101) and Van Horn (1968) and as undifferentiated upland deposits by Malde (1955, p. 233). Scott (1962, 1963a) has included similar deposits in the Littleton and Kassler quadrangles with the next lowest terrace or pediment alluvium. Wells (1967) may have mapped some of these deposits as colluvium.

Transported mantle deposits generally head at an isolated hill, although some form slopes between alluvial terraces or between a terrace and the adjacent flood plain. The downstream ends of transported mantle deposits generally tend to merge with topographically lower (younger) alluvial terraces. But some of the transported mantle surfaces, if projected upstream from the headward end, will rise above much older terrace surfaces. The transported mantle on the ridge north of Leyden is an example (pl. 1*A*): it starts below an obvious break in slope at the eastern end of the Rocky Flats Alluvium and maintains an even slope eastward to the narrow remnant of the Verdos Alluvium east of Indiana Street (State Highway 72). This segment of transported mantle probably was formed and deposited mainly by Ralston Creek during an erosional period between deposition of the Rocky Flats and Verdos Alluviums. Later, after deposition of the Verdos Alluvium by Ralston Creek, another deposit of transported mantle lying east of Indiana Street and north of the narrow ridge of Verdos, was formed on a surface cut by Ralston Creek. The two transported mantle deposits merge and the boundary between them is indistinguishable. Thus, this seemingly continuous deposit of transported mantle is actually two deposits of different ages.

Similar deposits of transported mantle southeast of Leyden are graded to the Louviers Alluvium and are probably pre-Bull Lake in age (pl. 1*A*). The large deposit of transported mantle south of Van Bibber Creek near the east boundary of the quadrangle has been truncated by the Louviers Alluvium deposited by Clear Creek (pl. 1*C*). It may be pre-Slocum in age. The uphill part, forming the present divide between Clear and Van Bibber Creeks, is very close to the altitude expectable for the Verdos Alluvium from which the transported mantle probably was derived. Sample G85 (fig. 37) was collected from this deposit just east of the quadrangle.

The large body of transported mantle in secs. 7, 8, and 9 just north of Van Bibber Creek at the east boundary of the quadrangle appears to be graded to the level of the Piney

Creek Alluvium at the low end of the deposit, and to a level above the Louviers Alluvium from Ralston Creek at the high end (pl. 1*B*). Exposures 30 feet above the Piney Creek terrace of Van Bibber Creek show 1 foot of strongly calcium-carbonate-impregnated silty to clayey sand, overlain abruptly by 0.6 foot of clayey material that has prismatic structure and poorly developed clay skins. Farther uphill a similar sequence shows 2.5 feet of dark-brown, slightly plastic, clayey to pebbly coarse sand (locality G157, fig. 37) overlying a strongly calcium-carbonate-impregnated silty sand and gravel. The upper part of the coarse sand has some clay skins developed around the pebbles, and the lower part has sparse ⅛–1 inch spots of calcium carbonate. The underlying strongly calcium-carbonate-impregnated zone in both of these exposures is probably the Cca horizon of a soil developed on transported mantle. The soil is the same age as, or older than, the soil developed on the Louviers Alluvium. The overlying material is probably colluvium bearing a soil equivalent to the soil formed on the Broadway Alluvium. Both deposits probably extend under the Piney Creek Alluvium in Van Bibber Creek. If so, the eastern part of Van Bibber Creek valley must have been excavated to about its present depth before Pinedale time at the latest. This deepening may have been related to the erosion that removed the Louviers Alluvium of Ralston Creek east of Hyatt Lake.

Transported mantle deposits are overlain by a thin cover of colluvium or, at a few places, by loess. They are generally underlain by bedrock. The following section describes the soil horizons at locality G55.

SECTION G55.—*Soil on transported mantle deposit*
[Measured on east side of a roadcut in the SW¼NW¼ sec. 29, T. 2 S., R. 69 W]

	Thickness (ft)
1. A1 horizon. Very dark brown, weakly calcareous, very finely prismatic, sandy silt; friable, contains many roots	0.2
2. A3 horizon. Very dark gray brown, noncalcareous, very finely prismatic, sandy silt; friable, contains many roots	.4
3. B horizon. Dark-brown, noncalcareous, medium angular blocky, sandy to silty clay. Clay skins are present on vertical faces. Grades into unit 4	1.2
4. Cca horizon. Dark-brown, moderately calcareous, massive, sandy silt. Contains lenses and streaks of light-gray calcium carbonate. The material on which this soil formed is probably loess. This unit truncates the next two underlying units	.9
5. IIBb horizon. Yellowish-red, moderately calcareous to noncalcareous, coarse angular blocky, clayey sand. Clay skins are present on vertical faces. Moderately calcareous in areas where thin streaks of calcium carbonate extend downward from the overlying unit, noncalcareous where these streaks are not present. Grades into underlying unit	1.3
6. IIC1ca horizon. Pinkish-white, strongly calcareous, massive, cobbly to sandy silt	1.3
7. IIC2ca horizon. Grayish-brown, strongly calcareous, massive, cobbly sand and gravel. Base covered	2.0

Units 1–4 of this section probably are loess and they extend across a bedrock ridge. Units 6 and 7, consisting of transported mantle, lie in a channel cut into the bedrock. After the transported mantle was deposited a soil formed on it. This soil was truncated and loess was deposited on the truncated surface. A later soil formed on the loess. The older soil is probably pre-Bull Lake in age and the younger soil is probably equivalent to the soil formed on the Broadway Alluvium. Unit 5 is a B horizon formed on the transported mantle.

AGE

The soil formed on transported mantle is mostly eroded. Generally only the remnants of a Cca horizon are found although at some places the reddish-brown or brown clay in the upper part may represent a Bca soil horizon. This soil is probably no younger than the soil formed on the Louviers Alluvium. No younger soils were found on transported mantle.

The transported mantle deposits were formed at different times prior to Pinedale time. The relation of some deposits to the terrace gravels both upslope and downslope indicates the age of the deposit.

ORIGIN

The origin of the transported mantle is complex but streams and slopewash seem to be the two major processes involved. I visualize one way the deposits may have formed as follows. The broad flood plains of the Pleistocene streams (fig. 38*A*) were eroded between major periods of alluviation. This erosion formed steeply sloping valley sides adjacent to the newly eroded valleys (fig. 38*B*). As the flood plains were gradually incised they were left as terraces. Downstream the meanders of the stream were wider, perhaps controlled by gently dipping bedrock, and by erosion-planed slopes that were not as steep as the terrace scarps but were steeper than the old flood plain. The resulting surface sloped less steeply than the sides of the incised valley upstream, but more steeply than the original terrace (or old flood plain) surface. The streams, though dominantly eroding, left a thin deposit of alluvium, mostly reworked from older terraces and colluvium, on the eroded bedrock surfaces. Colluvium that accumulated on the slopes was reworked by rill wash and by the streams. Because the transported mantle deposit was thin and the slopes were moderately steep, some fine-grained material from the underlying bedrock was also incorporated into the deposit.

COLLUVIUM

Colluvium consists of material that has been moved down steep slopes by creep and sheet wash and, at a few places, a few minor alluvial deposits formed by short, steep-gradient streams that flow only during and shortly after rainstorms. The colluvial deposits grade into, and interfinger with, alluvial terrace deposits and transported

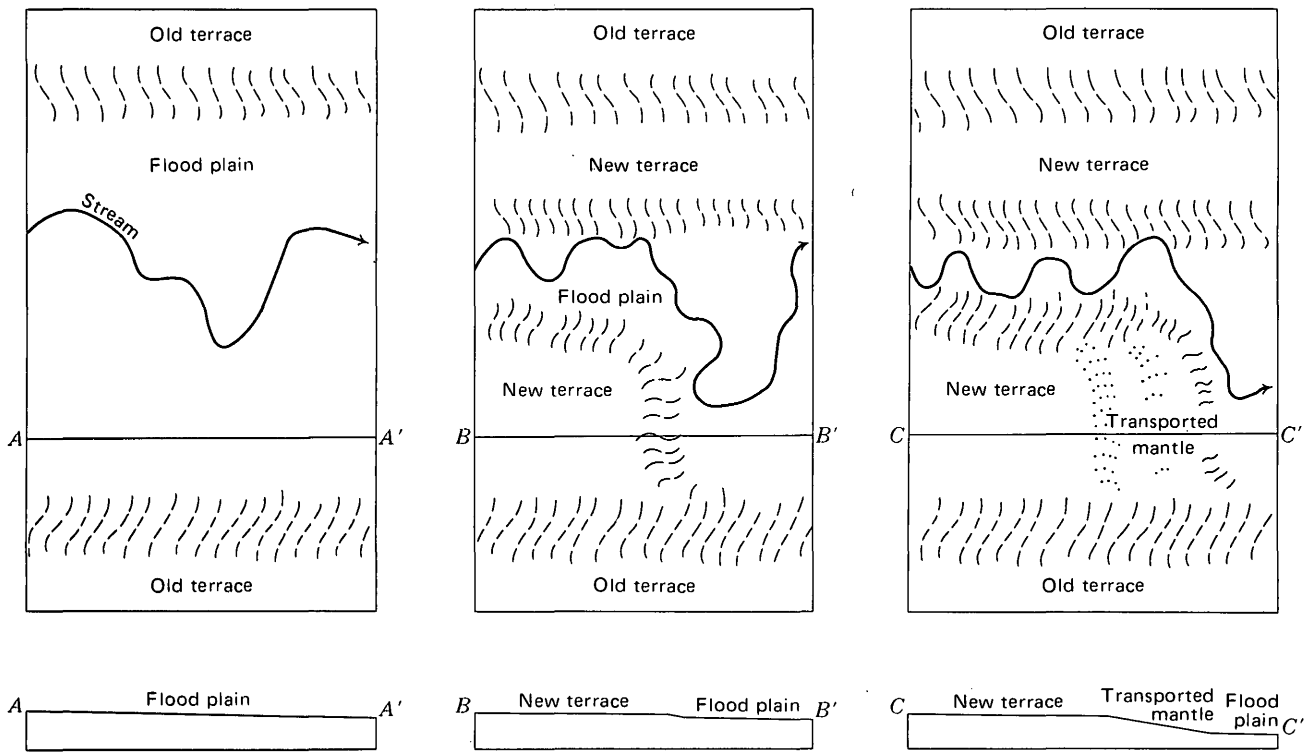


FIGURE 38.—The development of transported mantle surfaces by stream erosion: *A*, the original flood plain; *B*, and intermediate stage after incision of the flood plain and formation of terrace remnants, a narrow upstream valley, and a wide downstream valley; *C*, the transported-mantle surface.

mantle. The material composing the colluvium is derived from both bedrock and surficial deposits. Colluvium is mostly a massive to crudely bedded clayey to sandy silt but locally either the sand or the clay can predominate. At places a predominantly silty upper part grades downward into a predominantly sandy lower part. Colluvial deposits on the flanks of the mountains and hogbacks locally contain boulders (fig. 51). Slopes below alluvial terraces may have an appreciable percentage of rounded cobbles and pebbles. The size distribution curves for several samples of colluvium are shown in figure 39.

Colluvial deposits generally overlie very irregularly sloping bedrock surfaces. At many places the bedrock projects upward nearly through the colluvium. The thickness of the colluvium ranges from a few inches to 20 feet; on gentle slopes it is generally less than 10 feet. Large changes in thickness can be found within a few hundred feet; thus, predictions about the depth of colluvium are unreliable, and probably some colluvium that is shown on the map is less than 3 feet thick.

The deposition and history of colluvium and landslides, particularly on the Table Mountains, are intimately related. All the landslides mapped have moved some colluvium, and some of the older landslides may have been covered by deposits of younger colluvium. Where the topography indicates a former landslide, the deposit has been mapped as a landslide regardless of the amount of postlandslide colluvial cover. Such a colluvial deposit was temporarily exposed in a pipeline trench that traversed the upper part of an old landslide on the north side of South Table Mountain in sec. 36, T. 3 S., R. 70 W. The trench, about 6 feet deep, is 100 feet west of the powerline shown on the map (Van Horn, 1972). The deposit exposed in the trench from the Welch Ditch to the base of the lava flow capping the mountain consists of moderate-yellowish-brown clayey silt of colluvial origin. The uphill end of the deposit has many subangular cobbles and boulders of latite which decrease in number toward the downhill end, where there are only a few. About a third of the way up the trench is a one-quarter-inch-thick reddish-brown nearly horizontal layer with several discontinuous nearly horizontal fractures; the contact with the overlying material is a smooth slickensided surface, possibly a slip plane. This surface may be the bottom of the landslide, in which case a similar (but steeply dipping) slip plane would be expected in the upper part of the trench, at the uphill end of the landslide. No such slip plane was found in the upper part of the trench, but it may have been covered by postlandslide colluvium to a depth greater than the depth of the trench.

At many places the Piney Creek Alluvium merges headward into a colluvial slope. The western part of Leyden

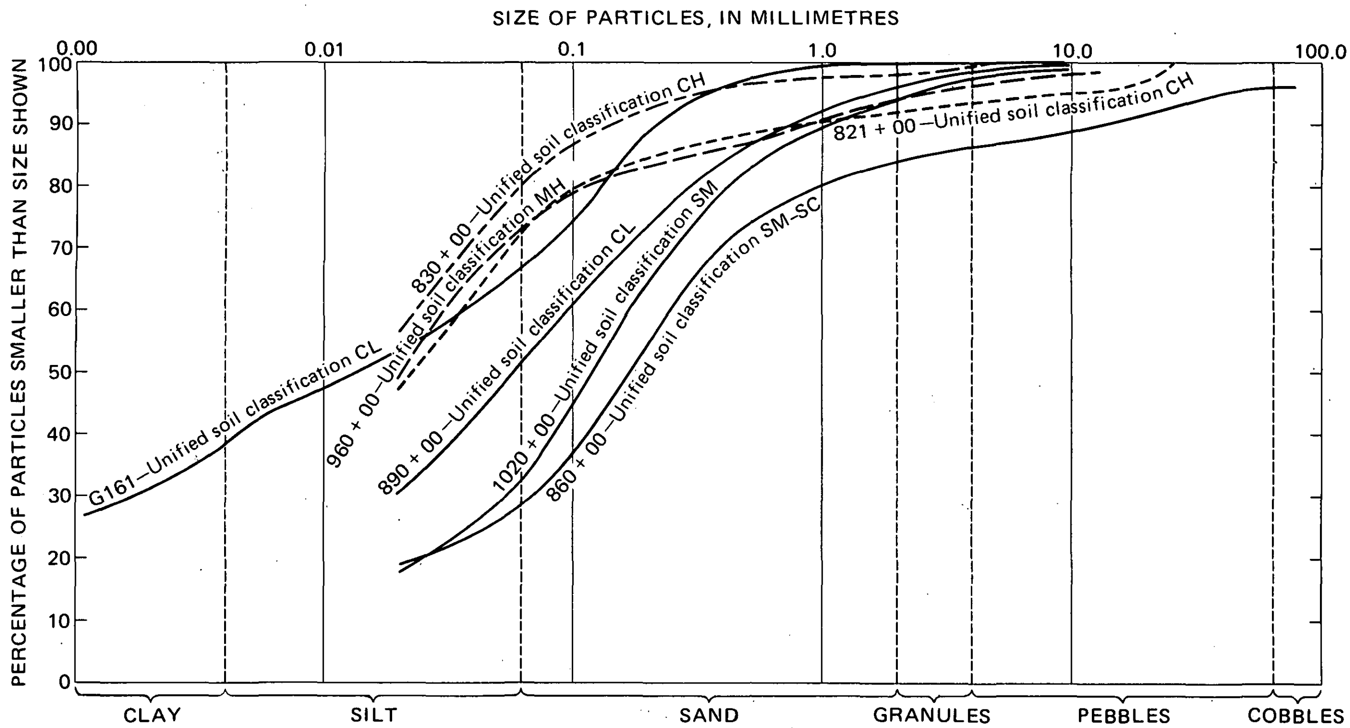


FIGURE 39.—Cumulative curves showing the size distribution of samples of colluvium. Sample 821+00 is from the SE¼SE¼ sec. 25, 830+00 from NE¼NE¼ sec. 36, and 860+00 from NE¼SE¼ sec. 36, all from T. 2 S., R. 70 W.; sample 890+00 is from NE¼NE¼ sec. 1, T. 3 S., R. 70 W.; sample 960+00 is from NW¼NE¼ sec. 7; 1020+00 from SE¼SE¼ sec. 5, G161 from NE¼SW¼ sec. 7, all from T. 3 S., R 69 W.

Gulch has many such examples, indicating colluvial activity during alluviation.

Soils that form on colluvial deposits are in general poorly developed. They tend to be destroyed even as they are formed by the slow downward movement and by deposition of material in the upper part of the deposit. No well-developed soil was found on the colluvial deposits although at several places there are weathered zones believed to be comparable with the soil formed on the Broadway Alluvium. Locally thick accumulations of calcium carbonate indicate that parts of the deposits are probably pre-Bull Lake in age.

LOESS

Loess—wind-deposited silt and sandy silt—forms a widespread, but generally thin, layer over much of the quadrangle. At places it overlies alluvial deposits ranging in age from Nebraskan to Bull Lake. Loess shown on the geologic map is at least 3 feet thick. Thinner loess occurs west to the mountain front, but probably no farther. It is as much as 2½ feet thick on the transported mantle east of Rocky Flats (see measured section G55, p. 82) and 1½ feet thick on the Verdos Alluvium east of Ralston Reservoir.

The loess that overlies the Verdos Alluvium in the NW¼NW¼ sec. 33, T. 2 S., R. 69 W. is typical of most loess in the area. It is a pale-brown inorganic sandy silt. Bedding is not visible except at a few places near the base of the deposit. Vertical jointing is present at most exposures but is not always obvious. At many places a few pebbles are widely scattered through the deposits. The loess generally is less than 10 feet thick.

At locality G173 (fig. 40), where the loess is 3 feet thick, the bottom 2 feet was sampled for laboratory tests. Possibly some alluviated clay from the soil, equivalent to the soil formed on the Broadway Alluvium, was included in the sample. The grain size distribution of both this sample and a sample from modified loess on the side of the valley (loc. G172, fig. 40) is similar to that of sandy loess in central Nebraska and to that of some of the colluvium in the Golden quadrangle.

The thickest loess is in the northeast part of the quadrangle in the small valley in the S½ sec. 33, T. 2 S., R. 69 W. Here the loess probably was partly reworked into modified loess. The material is a pale-brown inorganic sandy silt to silty sand. Crude horizontal bedding is visible on a few wind-etched surfaces on the outcrop. No vertical jointing is apparent. The deposit is coarser, better sorted, and much thicker than the loess overlying the Verdos Alluvium. In the railroad cut just east of the quadrangle it was more than 25 feet thick (sample G172, fig. 40). This material was probably reworked by slope wash during deposition and is, therefore, a modified loess; the modification by slope wash probably accounts for the crude bedding. The coarseness indicates that it must have been derived from a

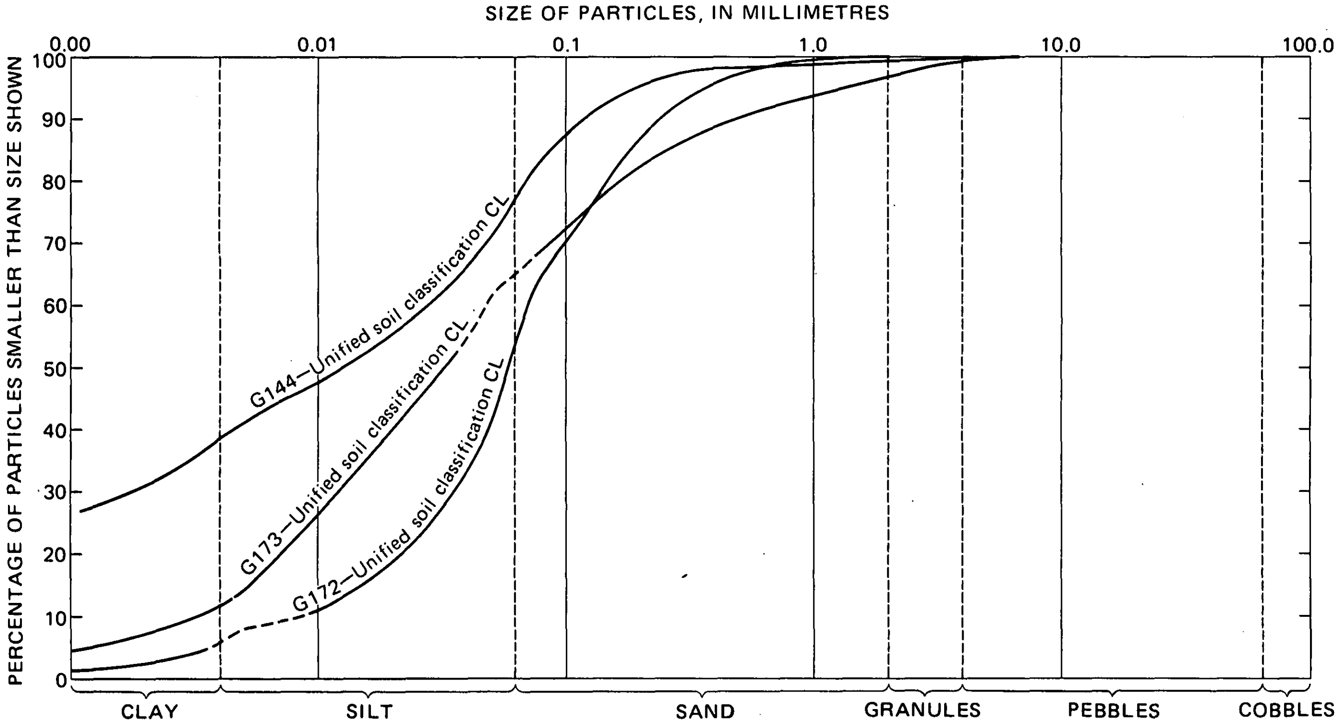


FIGURE 40.—Cumulative curves showing the size distribution of samples of loess. Sample G172 is from the SE¼SW¼ sec. 33 (Arvada quadrangle), G173 from NW¼NW¼ sec. 33, and G144 from NE¼NW¼ sec. 33 (Arvada quadrangle), T. 2 S., R. 69 W.

nearby source, possibly from alluvium along Leyden and Ralston Creeks.

The youngest alluvium on which loess was definitely recognized is the Louviers. A loesslike deposit, too small to be shown on the map, is included in the colluvium south of, and slightly higher than, the small patch of Broadway Alluvium one-half mile northwest of Upper Twin Lake. The loesslike deposit is of sandy silt and is 1.5 feet thick.

SOIL

The soil developed on the loess is comparable to the soil formed on the Broadway Alluvium. It consists of the ubiquitous 0.5 foot of A horizon, about 1 foot of dark-brown, noncalcareous, blocky clayey B horizon, and as much as 1.5 feet of calcareous Cca horizon with the calcium carbonate present as small pods and streaks along joints (measured section G55, units 1–4, p. 82). At places where the loess is thin the Cca horizon extends down into the top of underlying older deposits or soil horizons. No deposits were found overlying the loess.

Where loess overlies Louviers Alluvium, in some places separate soils seem to be developed on the silt and on the alluvium. At most such places the silt has a soil similar to that on the Broadway Alluvium with a moderately calcareous Cca horizon. This soil is underlain by a pebbly to cobbly gravel with a strong caliche zone in the top. The change is abrupt and at places is marked by a layer of cobbles or by channels cut into the caliche and filled with uncemented material. Such a change occurs at the locality (G62) photographed in figure 41 and is described in the following measured section.

SECTION G62.—*Soil on loess deposit*

[Measured in a south-trending gully (shown in fig. 41) between the stream and the unimproved road in the SE¼SE¼ sec. 13, T. 2 S., R. 70 W.]

	Thickness (ft)
1. A horizon; dark-grayish-brown (10*YR* 4/2), noncalcareous, thin platy, sandy silt. Grades into unit 2	0.3
2. B horizon; dark-brown (10*YR* 3/3), noncalcareous, medium subangular blocky, clayey to sandy silt. Grades into unit 3	.8
3. Cca horizon; yellowish-brown (10*YR* 5/4), moderately calcareous at top to strongly calcareous at base, massive, sandy silt. Calcium carbonate is in scattered lenses, 2–5 mm long, at top but becomes disseminated toward base. Abrupt unconformable contact with unit 4	1.3
4. IIC1ca horizon; pinkish-white (5*YR* 8/2), very strongly calcareous, massive, silty to cobbly sand and gravel. Calcium carbonate forms moderately cemented caliche at places. The pebbles and cobbles generally have a 1-mm-thick rind of calcium carbonate. Below and to right of the pick shown in figure 41 a narrow vertical walled channel, filled with cobbly sand and gravel, is cut into the upper part. The pebbles and cobbles in the channel are coated with calcium carbonate but are not cemented	1.8
5. IIC2ca horizon; yellowish-brown (10*YR* 5/4), calcareous massive, silty sand. Calcium carbonate forms numerous hard nodules, 2–5 mm in diameter Base covered	1.0

FIGURE 41.—Loess with a moderately well developed soil unconformably overlying the Cca soil horizon developed on Louviers Alluvium in the SE¼SE¼ sec. 13, T. 2 S., R. 70 W. The numbers refer to the unit numbers on the accompanying measured section at locality G62.

This sequence of deposits probably contains two separate soil profiles. Unit 1 is a humic A horizon of Holocene age. Units 2 and 3 are the B and Cca horizons of a soil similar to that formed on the Broadway Alluvium. They are developed on silt that is probably loess. There is a somewhat greater than normal amount of calcium carbonate in unit 3 for the soil developed on the Broadway Alluvium, but not excessively so. This unit is only 1.3 feet thick, the upper part of which is low in calcium carbonate. The concentration of calcium carbonate may be due to deposition in a thinner than usual zone and also because there was more free calcium carbonate available in the parent material of the loess which consisted partly of the underlying older soil. The undulating top of unit 4 and sand- and gravel-filled channels cut into it represent an erosional unconformity. Malde (1955, fig. 54 and p. 236) indicated that units 4 and 5 are pre-Bull Lake (pre-Wisconsin) soils, but I interpret them as the Cca horizon of a moderate or strong soil of indeterminate age; judging from their topographic position I believe them to be the post-Bull Lake soil developed on Louviers Alluvium.

AGE AND CORRELATION

A Pinedale age for the loess in the Golden quadrangle is indicated by its position overlying strong calcium carbonate accumulations on terraces no younger than Louviers Alluvium, and by the soil developed on the loess, which is comparable to the soil on the Broadway Alluvium. Although some of the loess may be older than Pinedale no strongly developed soil was found on or within the loess. The loess is probably correlative with the eolian silt and sand of Malde (1955, p. 240), the eolian deposits of Hunt (1954, p. 108), and the younger loess of Scott (1962, 1963a), although all three believed the loess to be of Bull Lake age. The soils on the loess described by Malde and by

Hunt are similar to the soil on the loess in the Golden quadrangle.

LANDSLIDES

Landslides are most common on the flanks of North and South Table Mountains but also are present on many other steep slopes in the quadrangle. Bedrock formations involved in landsliding are Pierre Shale, Laramie Formation, Arapahoe Formation, Denver Formation, and rocks of Precambrian age. Colluvium is the principal surficial deposit affected by landslides, although the Verdos Alluvium is overridden by one slide; flood-plain alluvium and presumably the underlying Louviers(?) Alluvium are reported to have been involved in another (Van Horn, 1954, p. 15). Most landslides in this area are of the slump type in which the upper surface of the sliding block rotates backward relative to the direction of movement. At places the rotation is not obvious and the slides appear to be slow debris slides. Rockfall is another common landslide type, but no rockfall deposits have been mapped. A small incipient block-glide landslide is forming in Precambrian rocks west of Golden.

The summary of historical geologic events (p. 108) is an annotated list of landslides, floods, and other geologic phenomena of the Golden area that have been reported in the Golden Globe newspaper for 26 of the years between 1878 and 1914. These records show that 25 landslides, seven of them rockfalls and 15 other types of slides, had been reported. It can safely be assumed that there were other landslides that were not reported, because none of the five landslides that were active during the first half of 1968 were reported in the local newspapers. If only half the active landslides have been reported in the Golden Globe, it would indicate that there are at least two active landslides per year.

The landslides shown on the geologic map (Van Horn, 1972) are differentiated only by the quality of the evidence for movement, as follows: (1) All slides for which I have seen compelling evidence of movement, including plainly visible bounding faults and scarps, dislocation of structures, and younger material overridden by older material are shown with a triangular pattern. (2) The large masses that have been inferred, by interpretation of their topography, to be landslides, are shown without a pattern.

The evidence for mapping the landslides shown in the Golden quadrangle (Van Horn, 1972) consists of: discordant, short, terracelike landforms that lack terrace gravels; active slides reported by residents of the area and in old newspaper accounts; and the presence of one outcrop showing a slide plane under an old slide. The topography of most slides consists of an abrupt flattening of a normally steep slope at the head of the landslide. Where erosion has not completely obliterated it, a nearly vertical scarp is visible just above the landslide. At many places the head of the slide has a slight slope backward toward the main hillside, caused by rotation of the landslide block. On large slides or at a common junction of several smaller slides a small undrained depression exists at the head. Below the head, the body of the slide is a steeply sloping, hummocky, irregular surface. This surface was probably caused by what originally were minor scarps, or perhaps separate smaller slides. Many of the large slide areas appear to be a composite of many small, but now indistinct slides (fig. 21). A cursory inspection of the sides of North and South Table Mountains gives the impression of a series of terracelike levels. Close examination of these levels, however, reveals that they are at many different altitudes and that they slope toward the mountainside at many places, and no rounded stream sand and gravel nor isolated pebbles were found on them.

The toes of old slides are generally obscure. The toes of active slides behave in various ways. At places the toes form nearly vertically rising transverse ridges as much as 10 feet above adjoining undisturbed surfaces. (See fig. 44.) The material exposed in the scarps formed by the rising toe rapidly ravels to form flatter slopes, which may be covered by vegetation within a few years if no new movement takes place. At one place a transverse ridge of this type is reported to have formed in the modern channel of Clear Creek (Van Horn, 1954, p. 15). The creek was dammed for a few hours but quickly eroded the obstruction. At other places the toes merely slide over downhill slopes. At some places the toes move into artificial excavations and commonly are removed as the slides slowly advance. One such place is along the Farmers Highline Canal north of the sewage disposal plant (sec. 27, T. 3 S., R. 70 W.). Here the water in the ditch is able to carry away the fine material, but cobbles and boulders of latite accumulate in the ditch and must periodically be removed. According to Mr. Stott of the ditch company (oral commun.) pilings from the railroad 100 feet uphill have been found in the uphill bank of the ditch. Mr. Stott stated that in most years evidence of movement of the uphill bank of the canal was noticeable during the spring and summer. The downhill bank appears to be stable. When examined in April 1961, the railroad tracks, normally straight, had bulged about 3 feet downhill and had vertical waves of long wavelength and small amplitude. Telephone poles above the canal leaned at various angles, some uphill and others downhill. The highway above the railroad, originally constructed with an even grade, had several large sags.

The only place that an unequivocal slide plane was found exposed in an old slide was in a residential section in the northeast part of Golden (fig. 42), described in the following measured section.

FIGURE 42.—An old landslide at Plateau Parkway in Golden in the SE¼NE¼ sec. 28, T. 3 S., R. 70 W., showing a disoriented mass of Denver Formation (unit 2) that has overridden Verdos Alluvium (unit 6). The Denver Formation has moved southward along the slide plane (unit 3) from the flank of North Table Mountain which is to the left of the area pictured. The numbers refer to unit numbers in the accompanying measured section at locality G94. View toward the east.

SECTION G94.—*Landslide in Golden*

[Measured behind a house in the SE¼NE¼ sec. 28, T. 3 S., R. 70 W.]

	Thickness (ft)
1. Colluvium; clay to boulders as much as 3 ft in maximum dimension	3.0
2. Sandstone and claystone; bedding greatly fractured and disrupted (but appears to dip steeply north)	10
3. Silty clay, dark-brown, slickensided; strikes N. 70° E., dips 12° N. Striations plunge 8° N. 30° E	.1
4. Silty sand light-olive-gray; appears to be a mixture of debris from the Denver Formation and alluvium of Clear Creek. A prominent light-gray, 0.5-ft-thick calcium-carbonate-impregnated layer is in upper foot	1–2.5
5. Clayey sand, moderate-yellowish-brown; similar to unit 4	3
6. Cobbly sand and gravel; cobbles predominantly rounded, of Precambrian origin, and typical of alluvium from Clear Creek. Also contains many subangular cobbles and boulders of latite. The deposit partially cemented by light-gray calcium carbonate. Top of this unit is about level with base of the volcanic ash in the Verdos Alluvium ¼ mile to the east. Base not exposed	6

Unit 1 is colluvium that is mixed with debris from old rockfalls. Unit 2 is a badly fractured mass of Denver Formation that has slid over the underlying Pleistocene deposits on the slickensided slide plane (unit 3). Units 4 and 5 are probably prelandslide colluvium. The calcium carbonate in unit 4 does not represent a soil zone. No bedding was seen in units 4 and 5 and they do not appear to have been particularly affected by the overriding landslide. Unit 6 is a stream-deposited sand and gravel that is almost certainly a remnant of the Verdos Alluvium. The calcium-carbonate-cemented layer in unit 6 is probably the eroded Cca horizon of a pre-Bull Lake soil. The landslide occurred after the formation of the pre-Bull Lake soil and before the accumulation of as much as 3 feet of colluvium of probable Holocene age (unit 1). No indisputable evidence of present activity of the landslide was found. The telephone pole and the fence visible in the picture are not out of line, and no surface cracks had opened in the excavation or uphill from the toe. Some cracks occurring in nearby buildings may be due to expansive clay in the Denver Formation or to settling that is normal in new structures. The area uphill from this landslide is a gently sloping terracelike plane. It is similar in shape and general aspect to the other old landforms on the flanks of North and South Table Mountains that have been mapped as landslides.

The largest landslide in the area, at the northeast corner of North Table mountain (figs. 21 and 43), covers about three-quarters of a square mile. A hand-dug cistern 12 feet

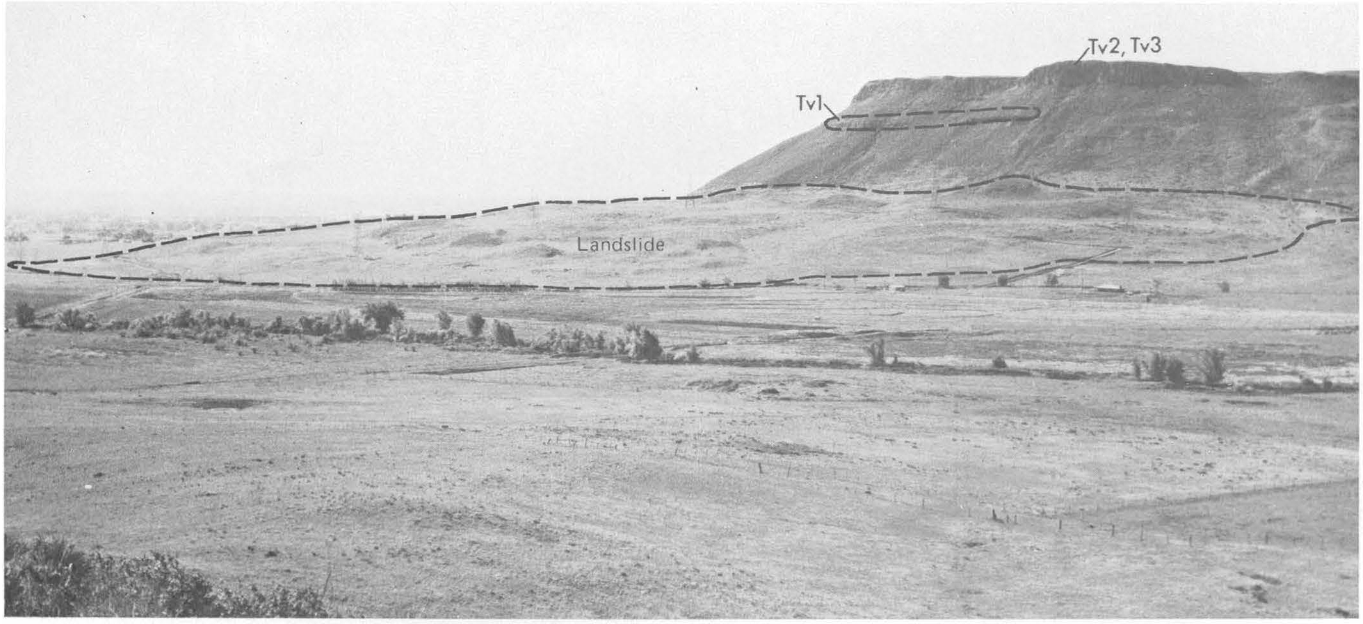


FIGURE 43.—A large composite landslide with a typically hummocky surface at the northeast corner of North Table Mountain. No historic movement has been reported on this landslide, but a horse tooth found in the landslide deposit may indicate some movement since A.D. 1500 Lava flows 2 (Tv2) and 3 (Tv3) cap North Table Mountain and lava flow 1 (Tv1) fills an old channel in the Denver Formation part way down the slope. Photograph, toward the southeast, by H. E. Malde, U.S. Geological Survey.

deep located in the upper part of this landslide showed 10 feet of hard silty clay overlying claystone of the Denver Formation. A tooth was collected by the owner of the property in the cistern from near the base of the silty clay. The tooth was identified as an upper molar of *Equus* sp. by the late Mrs. Jean Hough of the U.S. Geological Survey. Mrs. Hough (written commun., Nov. 25, 1953) stated that the tooth was not fossilized and was probably of Holocene age. This would mean that the horse died some time after A.D. 1500 when the horse was beginning to be reestablished on this continent by Spanish importation. The burial of the tooth almost certainly would not be due to historic accumulation of 10 feet of colluvium; therefore a more reasonable explanation for the burial of the tooth is that it had been washed into a deep crack, probably resulting from landslide movement, which has now healed and is no longer visible. There is no other evidence indicating movement of this landslide in historic time.

Landslides are forming at present, and two landslides on South Table Mountain became active in 1967 and were still moving in 1968. One of these, in the SW¼NW¼ sec. 25, T. 3 S., R. 70 W., is between the Welch and Agricultural Ditches. (See fig. 44.) Prior to the formation of this landslide in 1967 the ground had not shown signs of movement. There is no indication of any disturbance occurring within the past few years that might have triggered movement of this landslide. The slope, therefore, must have been in a potential state of imbalance for many years, and the pressure generated by the mass of the slide finally overcame the coefficient of friction of the material in the slide, perhaps aided by a gradually increased water content. The other slide, in the SW¼ of the same section, is in the lower end of an ancient landslide. This ancient landslide became activated shortly after material had been excavated from the toe of the slide. During 1968 three older slides in the NE¼ sec. 27, T. 3 S., R. 70 W., were also active; two on South Table Mountain involved a highway (fig. 17), and one on North Table Mountain was at the former junction of State Highway 58 and Easley Road, about 500 feet north of the Golden Sewage Disposal plant.

A new landslide adjoining an old landslide occurred on the north side of a cut for the relocated State Highway 58 in the NW¼NE¼ sec. 27, T. 3 S., R. 70 W. on North Table Mountain. I first saw this landslide in December 1969 shortly before the highway was completed. The landslide involved the upper part of the cut and slowly moved toward the highway. There was no apparent rotation of the mass and it appeared to be a slow debris slide. Several additional units slid downhill before the entire new landslide was removed by excavation in about March 1970.

Rockfalls, though not frequent, occur with great rapidity. Seven of the slides reported in the newspapers (p. 108) probably were rockfalls. Two small rockfalls from South Table Mountain were investigated shortly after their occurrence. They both came from the west side of the latite flows capping Castle Rock (fig. 15). The first, of about 400 cubic yards, happened at 5:20 a.m. on a foggy Sunday morning, March 23, 1958. The roar, like a blast of dynamite, awakened a few light sleepers and startled a passing newspaper delivery boy. The temperature was

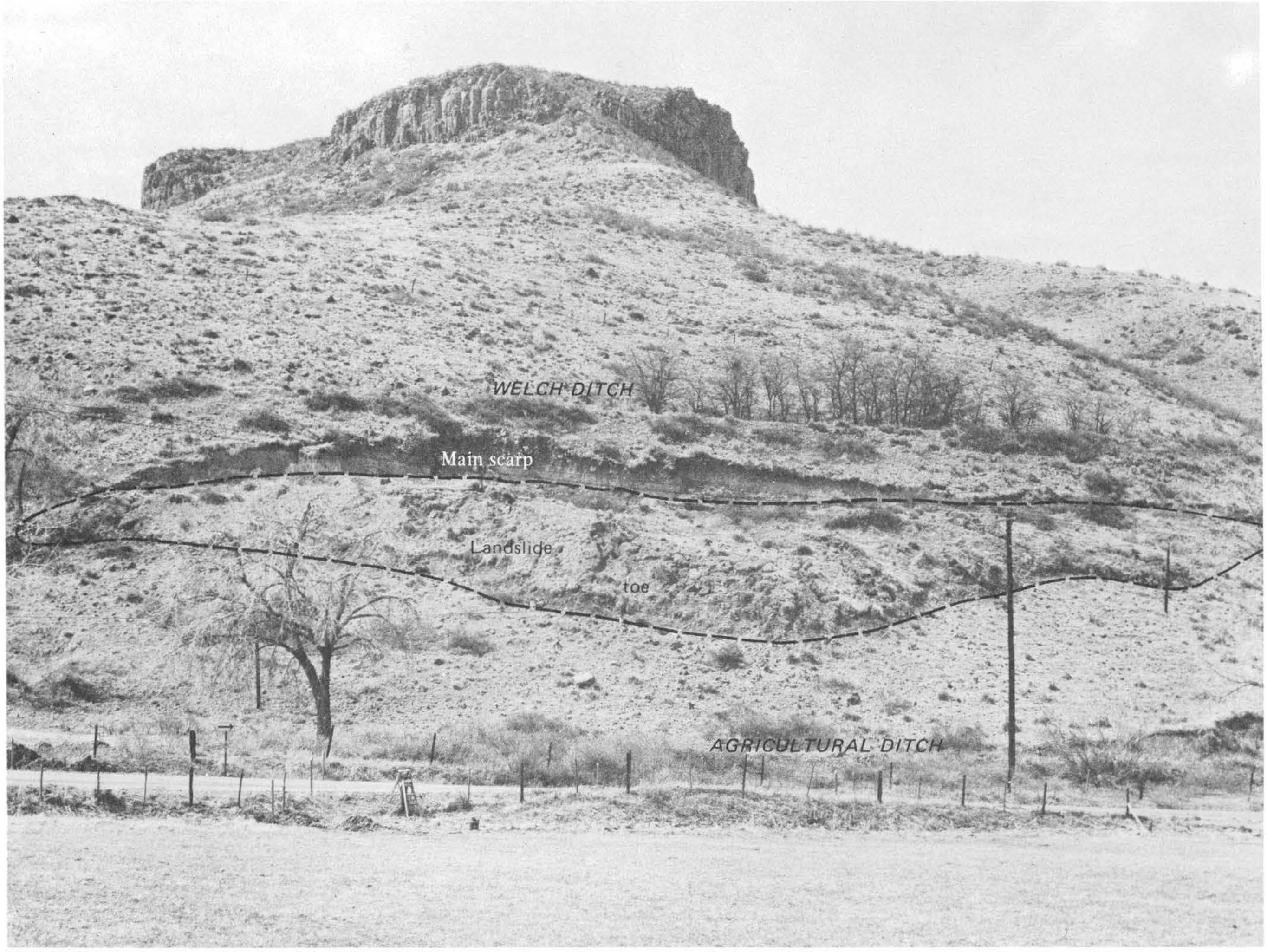


FIGURE 44.—An active slump landslide in the SW¼NW¼ sec. 25, T. 3 S., R. 70 W. The head of the slump has dropped down and the toe is bulging up indicating rotational movement. The Welch Ditch is just above the nearly vertical main scarp of the landslide. The toe of the landslide has bulged upward about 10 feet. The most recent movement is indicated by the raw dirt scarp at the base of the toe. The landslide started in 1967; the photograph was taken in 1971 by H. E. Malde, U.S. Geological Survey. Note the columnar jointing in the latite lava flow capping South Table Mountain, and the numerous boulders of latite on the slope.

close to freezing and the relative humidity was 100 percent. When the area was examined 2 days later it was determined that a single 100-foot-high column of latite, about 15 by 8 feet wide at the base and 18 by 5 feet wide at the top, had collapsed. A 6-foot-deep pile of freshly broken rock of many sizes formed a fan-shaped deposit which extended about 100 feet out from the original base of the column. This pile of debris contained many precariously perched boulders. Extending about 100 feet horizontally southwest from the debris was a zone of pulverized earth that was liberally sprinkled with freshly broken flat rock fragments as much as 6 inches across. A few trails, consisting of gouges and furrows, extended from the zone of pulverized earth to the bottom of the steep slope about 500 feet from the column. At the base of the steep slope were rectangular blocks of freshly broken rock about 12 inches across. One rectangular block 4 by 3.5 by 2.5 feet moved a distance of 900 feet before sliding to a stop in a driveway about 50 feet from a house. The tracks of this block were plainly visible for several hundred feet upslope. The last big bound of this boulder was 24 feet long and occurred not more than 75 feet from its final resting point. The freshly broken rock had an angular blocky appearance and is marked by many very light yellowish gray percussion points. When examined 4 years later these percussion points were still visible but were medium gray and the rock no longer had the original freshly broken appearance.

A second but smaller rockfall, in February 1962, consisted of about 32 cubic yards of latite that fell from the recess formed by the fall of March 1958. The rock followed the same course as the earlier fall. One block about 3 by 3 by 2 feet rolled and bounded about 500 feet out from the base of the latite cap.

Concentrations of similar blocky boulders around the

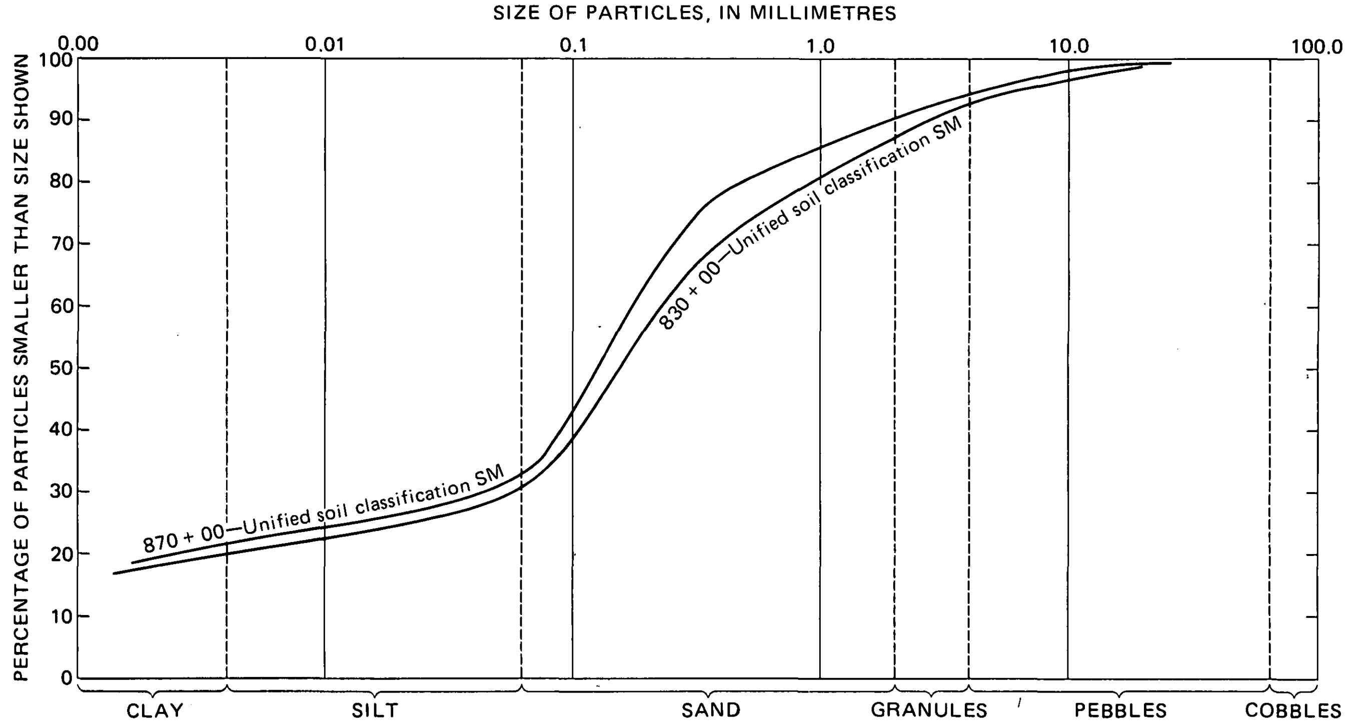


FIGURE 45.—Cumulative curves showing the size distribution of two samples of artificial fill. Sample 830+00 is from the NE¼NE¼ sec. 36 and sample 870+00 is from the SE¼SE¼ sec. 36, T. 2 S., R. 70 W.

flanks of North and South Table Mountains indicate that rockfalls have been numerous. The strongly jointed vertical columns are poorly supported at many of the high vertical faces around the mountains. Frost action during each winter tends to open the joints a small amount, and to push the columns outward. Colluvial action tends to move material downward away from the base and to leave the columns unsupported. When the column reaches a position of imbalance, it falls and cascades down the slope with great rapidity. Many of the boulders visible on the flanks of North and South Table Mountains (fig. 44) undoubtedly are the result of rockfalls.

The third type of movement, block glide, was found only near the SE. cor. sec. 29, T. 3 S., R. 70 W. This slide is uphill from a steep quarry face and was probably initiated by the quarrying. The quarry, started in 1948 or 1949 at the site of an older quarry, was excavated rapidly into the mountain. By September 1951 a single large crack outlining the shape and maximum size of the slide had developed several hundred feet uphill from the quarry face. By 1953 the main crack had branched at the east end and several small transverse cracks had developed between the quarry and the main crack. During July 1953 the surface of the slide was 4 feet lower than the adjacent undisturbed surface and was separated from it by a crack 10 feet deep and 6 feet wide. In 1959 the crack was nearly filled with debris but the head of the slide was about 10 feet below the undisturbed colluvium of the crown. No further change has been noted in this slide.[3] The slide involves both Precambrian bedrock and surficial colluvium. The slide plane was not located although it probably is present in the steep quarry face and in the cutbank above U.S. Highway 6. Rotational movement of the slide is not apparent; rather, the slide mass seems to have very slowly glided down a fractured surface or joint plane.

ARTIFICIAL FILL

Artificial fill ranges from well-compacted layers of silt and gravel in structures like Ralston Reservoir dam to uncompacted, uncontrolled gully-fill dumps of tree stumps, grass clippings, boulders, and miscellaneous dirt and trash like the fill east of the County Hall of Justice in Golden (sec. 34, T. 3 S., R. 70 W.). Artificial fill ranges in thickness from 150 feet at Ralston Reservoir dam to a few inches around building sites. Only areally large fills more than 3 feet thick were mapped (Van Horn, 1972). The well-compacted fills include the many highway and railroad fills, dams, and fills around large buildings. Most of these fills are of selected material, principally poorly sorted sand containing small amounts of pebbles, silt, and clay. The size distribution of two samples that were collected from highway fills is shown in figure 45. The sample from locality 870+00 contained fragments of "red dog," an oxidized clinker commonly found on coal mine dumps.

[3]In June 1973, as this manuscript was being prepared, new cracks could be seen above the original main scarp and a longitudinal crack had opened on the east side downslope from the original main scarp.

FIGURE 46.—Poorly compacted fill in abandoned clay pits of the Laramie Formation west of the Colorado School of Mines campus, sec. 33, T. 3 S., R. 70 W. Apartment buildings behind the fill are founded on the sandstone ribs that form the walls of the clay pits. Photograph, toward the southeast, by H. E. Malde, U.S. Geological Survey.

Parts of the highway and railroad fill are cobbly sand and gravel. Partly compacted fills include controlled city and county dumps that are burned and then compacted with bulldozers and industrial dumps such as the one extending west of Golden on the north side of Clear Creek. The city and county dumps are a chaotic mixture of organic and inorganic debris that is generally covered by a few feet of locally derived gravel and silt. The industrial dump principally consists of locally derived earth materials from excavations, but it also may contain broken pottery and porcelain. Poorly compacted fills, which generally occur in gullies used as dumps, are similar to the partly compacted fills except that in the partly compacted fills some compaction is brought about by trucks crossing the fill to dump at the edge. At irregular intervals the material is pushed over the edge by bulldozers.

The debris filling the old clay pits west of the Colorado School of Mines is a poorly compacted fill (fig. 46). The apartment buildings behind the visible fill were constructed over a well-compacted fill in the same clay pits. The load-bearing members of these buildings were placed on the sandstone ribs that separated the old clay pits. In general this procedure has been satisfactory but a few of the apartments pictured at the left of figure 46 have shown signs of structural distress. At other places the well-compacted fill has settled, forming sags in the otherwise smooth topography.

PLEISTOCENE AND HOLOCENE SOILS

One important criterion used to establish the relative age of the various deposits is the degree of soil development on the deposit. In this report soils or soil profiles are commonly described in three parts (master horizons) which are called the A, B, and C horizons (U.S. Dept. of Agriculture, 1962). The A horizon is usually dark or medium gray. It contains organic and mineral matter, but has been depleted in clay and calcium carbonate. The B horizon underlies the A horizon and is a zone of deposition of clay derived from the A horizon. Calcium carbonate has been partly leached from the B horizon. The C horizon underlies the B horizon (or the A horizon where the B horizon is missing) and is a zone in which some chemical weathering has taken place. The Cca horizon, which is in the upper part of the C horizon, is a zone in which calcium carbonate has been deposited. A number following the master horizon letter indicates that two or more phases of this horizon have been recognized. (See fig. 47.) A Roman numeral (II) preceding the master horizon letter indicates that a lithologic discontinuity overlies the units so designated. Any of these horizons may be absent from a soil profile because of erosion or lack of sufficient soil development. The upper layers have been eroded from many of the older soil exposures. The B and Cca horizons have not yet developed in the youngest soil.

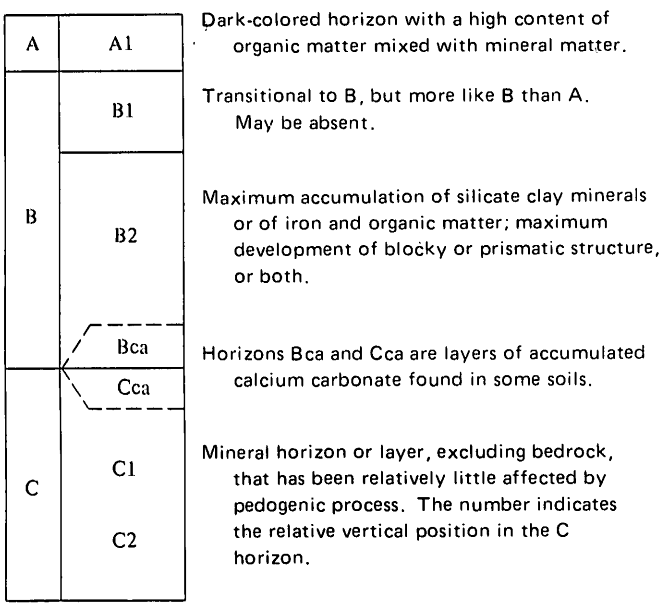


FIGURE 47.—Soil-profile horizon terminology used in this report. Modified from U.S. Department of Agriculture (1951, p. 173; 1962).

The term "degree of soil development" is a general expression for summarizing the differences in thickness of the soil profile, and in thickness and other characteristics of individual horizons (Richmond, 1962, p. 25). It is a convenient method of comparing soils of different ages that have developed on similar parent materials. For instance, a well-developed soil may be thicker or have more clay accumulation in the B horizon than a poorly developed soil.

The extensive sequence of terraces, in which each successive terrace is lower and younger than the adjoining terrace, simplified the comparison of the extent of soil development on the various deposits. The deposits in the flood plain of the existing streams have no soil developed on them. The lowest terrace deposit (Piney Creek Alluvium) has a thin A horizon underlain at a few places by small blebs of calcium carbonate. The next higher terrace deposit (Broadway Alluvium) has a thin but complete soil profile consisting of a thin A horizon, nearly 1 foot of brown B horizon, and a Cca horizon 1.5 feet thick. The next older terrace deposit (Louviers Alluvium) has a soil which is generally eroded but which has as much as 1.5 feet of reddish-brown B horizon overlying as much as 3 feet of Cca horizon. At places this soil is indistinguishable from the older soils.

The pre-Bull Lake alluvial deposits have thick, well-developed soil profiles that have been eroded and were not differentiated. They have reddish- to yellowish-brown B horizons as much as 4 feet thick and Cca horizons as much as 6 feet thick. James Thorp (U.S. Dept. of Agriculture, oral commun.) indicated that the soil on the Rocky Flats Alluvium might be distinguished from other pre-Bull Lake soils by its very red B horizon. The analysis of soil developed on Rocky Flats Alluvium at locality G143 (table 12) shows a much greater amount of montmorillonite than the soil developed on Verdos Alluvium and thus tends to corroborate Thorp's observation.

The soils in the Golden area are in a stratigraphic sequence similar to the sequence outlined by Morrison and Frye (1965). They indicated that three very strongly developed soils of pre-Bull Lake age are followed by a strongly developed soil of post-Bull Lake age which is succeeded by as many as three less well-developed soils.

The differences in degree of soil development were first established along Clear and Ralston Creeks where there are readily distinguishable terrace sequences. These soils were then correlated with soils in adjoining areas where the terrace sequence is not so clear. At a few places younger soils were found stratigraphically overlying older soils. It was found that the B horizon forms the most distinctive and consistently equally developed horizon in any particular soil. The Cca horizon varies greatly in thickness and amount of accumulation of the calcium carbonate in short distances. It is, no doubt, influenced by the amount of limestone or other calcareous rocks in the parent material. There is no way to tell how much of the calcium carbonate may be due to evaporation at the top of some past water table, or how much calcium carbonate has been carried away in solution and did not precipitate. In spite of these difficulties the Cca horizon still provides an indication of the degree of soil development on a deposit and, if used with caution, provides a useful tool in correlating deposits.

In addition to the field criteria just discussed for differentiating soils, X-ray analyses of 30 samples from seven soil profiles of different ages show differences in kind and amount of clays (table 12). These differences persist in

TABLE 12.—*X-ray analyses of soils developed on alluvium in the Golden quadrangle*

[Analyst: Paul Blackmon. Tr., trace; ....., not present]

Soil zone	Locality and sample No.	Estimated parts in 10: Mica	Montmorillonite	Kaolinite	Vermiculite	Mica-montmorillonite	Chlorite	Quartz	Feldspar	Calcite	Total percent clay	Ratio of mica to montmorillonite	Ratio of mica to montmorillonite times 10[1]	Ratio of mica to montmorillonite times percent clay	Percent montmorillonite in total sample in clay-sized fraction	Percent montmorillonite in total sample in silt-sized fraction	Percent montmorillonite in total sample (assuming none is in the sand-sized fraction)	Percent mica in total sample in clay-sized fraction	Percent mica in total sample in silt-sized fraction	Percent mica in total sample (assuming none is in the sand-sized fraction)
										Broadway Alluvium										
A	G109-2	4	1+	1+	Tr.	<1	.....	2	Tr.	.....	21	2.7:1	27	56.7	3.1	0	3.1	8.4	3.0	11.4
B	3	2+	2+	1+	.....	2	.....	1+	Tr.	.....	43	1:1	10	43	10.7	0	10.7	10.8	1.8	12.6
C1ca	5	<1	2+	<1	Tr.	1+	.....	1	.....	4	31	1:5	2	6.2	7.7	.5	8.2	2.3	1.4	3.7
C3	7	<1	4+	1+	Tr.	1	Tr.	1+	.....	1	25	1:9	1.1	2.8	11.2	0	11.2	1.9	1.3	3.2
A	G115-1	4	1+	1+	1	.....	.....	2	Tr.	.....	15	2.7:1	27	40.5	2.0	0	2.0	6.0	1.4	7.4
B1	2	2	3	1	Tr.	1	.....	2+	Tr.	.....	40	1:1.5	6.7	26.6	12.0	0	12.0	8.0	1.3	9.3
B2	3	2	4	1+	.....	1+	Tr.	1+	.....	.....	29	1:2	5	14.5	11.6	0	11.6	5.8	1.9	7.7
A	G113-1	4	<1	2	Tr.	<1	.....	2+	.....	.....	17	5.3:1	53	90	1.3	.5	1.8	6.8	4.6	11.4
B	2	4	1+	2	.....	1	.....	1+	.....	.....	25	2.7:1	27	67.5	3.7	1.3	5.0	10.0	4.3	14.3
C1ca	3	4	1	2	.....	1	.....	2	.....	.....	11	4:1	40	44	1.1	.1	1.2	4.4	1.6	6.0
C2	4	3+	1+	2	.....	1	.....	2	.....	.....	4	2.3:1	23	9.2	.6	0	.6	1.4	1.2	2.6
										Louviers Alluvium										
B1	G111-1	3	2	1	.....	1+	.....	2	Tr.	.....	22	1.5:1	15	33.0	4.4	0	4.4	6.6	.4	7.0
B2	2	3	2	1	.....	1+	.....	2	Tr.	.....	10	1.5:1	15	15.0	2.0	0	2.0	3.0	.3	3.3
C1	3	1	1	<1	.....	1	.....	1	.....	5+	4.1	1:1	10	4.1	.4	.2	.6	.4	1.5	1.9
C2	4	<1	7	1	.....	.....	.....	1+	.....	.....	3.6	.75:7	1.1	.4	2.5	.1	2.6	.3	1.3	1.6
A	G162-1	4	1+	2	.....	<1	.....	2	.....	.....	21	2.7:1	27	56.7	3.1	0	3.1	8.4	1.7	10.1
B1	2	3	2	1+	.....	1	.....	2+	.....	.....	41	1.5:1	15	61.5	8.2	0	8.2	12.3	1.3	13.6
B2	3	2+	2+	1	.....	1+	.....	2+	.....	.....	31	1:1	10	31.0	7.7	0	7.7	7.7	.8	8.5
Cca	4	3	2+	1	.....	1	.....	2	Tr.	.....	5	1.2:1	12	6.0	1.3	0	1.3	1.5	.4	1.9
										Verdos Alluvium										
B1	G101-2	3	1	1+	2	<1	.....	1+	.....	.....	21	3:1	30	63	2.1	0	2.1	6.1	2.8	8.9
B2	3	2+	3+	1+	Tr.	1+	.....	1	.....	.....	25	1:1.4	7.1	17.8	8.8	.7	9.5	6.3	3.0	9.3
C1ca	4	<1	4+	1	.....	1+	.....	1	Tr.	1+	12	1:8	1.3	1.6	5.4	2.7	8.1	.9	1.3	2.2
C2	5	1	5	1	.....	1+	.....	1+	Tr.	.....	9	1:5	2	1.8	4.5	.8	5.3	.9	2.3	3.2
										Rocky Flats Alluvium										
A	*G143-2a	4	<1	2	Tr.	<1	Tr.	2+	.....	.....	8	.....	.....	.....	.....	.....	.....	.....	.....	.....
A	*2b	4	<1	1+	Tr.	<1	.....	3	.....	.....	11	8:1	80	88.0	.7	0	.7	4.4	1.1	5.5
B	*3a	4+	Tr.	3	Tr.	<1	.....	2	Tr.	.....	12	.....	.....	.....	.....	.....	.....	.....	.....	.....
B	*3b	4	<1	2	Tr.	1	.....	3	.....	.....	17	8:1	80	136.0	1.3	0	1.3	6.8	1.3	8.1
IIB1	4	1	4+	1+	Tr.	1	.....	1+	.....	.....	47	1:4.5	2.2	10.4	21.2	0	21.2	4.7	.8	5.5
IIB2	5	1	5	1+	Tr.	1	.....	1+	.....	.....	60	1:5	2	12.0	30	0	30.0	6.0	.4	6.4
IICca	6	<1	4	1+	.....	<1	.....	1+	.....	2	64	1:8	1.3	8.0	25.6	0	25.6	4.8	0	4.8

*Probably a post-Pinedale soil overlying the pre-Bull Lake soil.

[1]The ratio given in the column to the left has been reduced to a common denominator in this column for ease of comparison.

SAMPLE LOCALITIES

G109. NE¼SE¼ sec. 13, T. 3 S., R. 70 W.
G115. SW¼SW¼ sec. 24, T. 3 S., R. 70 W.
G113. NE¼NE¼ sec. 4, T. 3 S., R. 70 W.
G111. NW¼NE¼ sec. 11, T. 3 S., R. 70 W.
G162. NE¼SW¼ sec. 19, T. 3 S., R. 69 W.
G101. NW¼SE¼ sec. 33, T. 2 S., R. 70 W.
G143. NE¼SW¼ sec. 21, T. 2 S., R. 70 W.

spite of different parent materials. Table 8 (p. 56) shows the type of rock in the parent material of various deposits and table 12 shows the kind and approximate quantity of minerals and the mica-to-montmorillonite ratio present in the clay- and silt-sized fractions of seven soil profiles. Three general trends are indicated by the X-ray analyses:

1. The mica-to-montmorillonite ratio generally decreases downward in each soil profile. The ratio is highest in the A horizon, it decreases in the B horizon and is generally lowest in the C horizon.
2. In older soils the mica-to-montmorillonite ratio is less than in comparable horizons of younger soils. Thus, montmorillonite predominates in the B horizon of woil on the pre-Bull Lake deposits and mica predominates in the B horizon of woil on the Bull Lake or Pinedale deposits (table 13). Both trends are apparent in both the numerical average of the ratios and the proportion of samples in which either mica or montmorillonite predominates. Thus, mica is predominant over montmorillonite in only one of four samples from the B horizon of the soil on the pre-Bull Lake deposits but is predominant in three of five samples from the B horizon of the soils in Pinedale deposits. (See table 14.)
3. The C horizon of each soil has the least clay and the B horizon has the most. (See fig. 48.)

Table 13.—*Ratio of mica to montmorillonite, multiplied by 10, of soil samples from the Golden quadrangle*

[The ratio of, for example, the pre-Bull Lake C2 soil horizon is 2 mica to 10 montmorillonite; this ratio multiplied by 10 is 2. For ratios less than 10, montmorillonite is predominant]

Average ratio of mica to montmorillonite multiplied by 10			
Age of deposit on which soil formed	Pinedale	Bull Lake	Pre-Bull Lake
Soil horizon:			
A	47	27	...
B	26	14	10
C	21	11	2
C2	12	1	2

Table 14.—*Number of soil samples from the Golden quadrangle in which the amount of mica was respectively greater (>) or less (<) than the amount of montmorillonite*

Age of deposit on which soil formed			Pinedale	Bull Lake	Pre-Bull Lake
Soil horizon	A	Mica > montmorillonite	4	1	0
		Mica < montmorillonite	0	0	0
	B	Mica > montmorillonite	3	4	1
		Mica < montmorillonite	2	0	3
	C	Mica > montmorillonite	1	2	0
		Mica < montmorillonite	1	0	2
	C2	Mica > montmorillonite	1	0	0
		Mica < montmorillonite	1	1	1

Both the similarities and the differences may be explained by climatic differences and relative grain size of the mica and montmorillonite. The montmorillonite particles are generally smaller than the mica particles and because of this are probably easier to move downward (illuviate) than the mica. This would increase the proportion of montmorillonite in the lower part of the soil. Within any given time span similar climatic conditions within the small area represented by the Golden quadrangle should lead to similar rates of illuviation in deposits of similar texture, thus giving similar mica to montmorillonite ratios in deposits of the same age. Different climatic conditions during successive periods of time (or different length of the soil-forming period) should cause different amounts of illuviation, hence different mica-to-montmorillonite ratios in B horizons of deposits of different ages.

STRUCTURAL GEOLOGY

The dominant structural features of the area are the east-dipping limb of the Front Range anticline and the west-dipping Golden fault, both of which are attributed to the Laramide revolution. The concept of the Front Range anticline has long been accepted by geologists working in the Rocky Mountains. The east limb of the anticline is indicated by the steeply dipping to overturned beds of Paleozoic and Mesozoic age in the western part of the Golden quadrangle. The west limb of this anticline is so far removed from the Golden quadrangle that the east limb of the anticline is herein considered a monocline.

FOLDS

Folds in the area consist of the Front Range monocline and several smaller flexures (fig. 49). The monocline of the Front Range is the dominant fold of the Golden quadrangle. This steeply east-dipping to overturned structure trends slightly west of north along the west edge of the quadrangle. East of the Golden fault the Upper Cretaceous rocks dip vertically downward for hundreds of feet, then abruptly bend eastward to dip gently toward the center of the Denver basin. This abrupt change is shown by the change in dips at the surface on the west side of North Table Mountain.

Another large but less conspicuous fold is present at Golden where the rocks east of the Golden fault on the crenulated limb of the Front Range monocline form a broad overturned to vertically plunging syncline normal to the monocline. One limb of the syncline trends north and the other southeast. It is best outlined by the vertical to overturned beds of the Fox Hills and Laramie Formations; the axis is where the vertically plunging syncline symbol is shown in figure 49 at the contact of the two formations.

Gentle west dips of a few degrees on the east flanks of

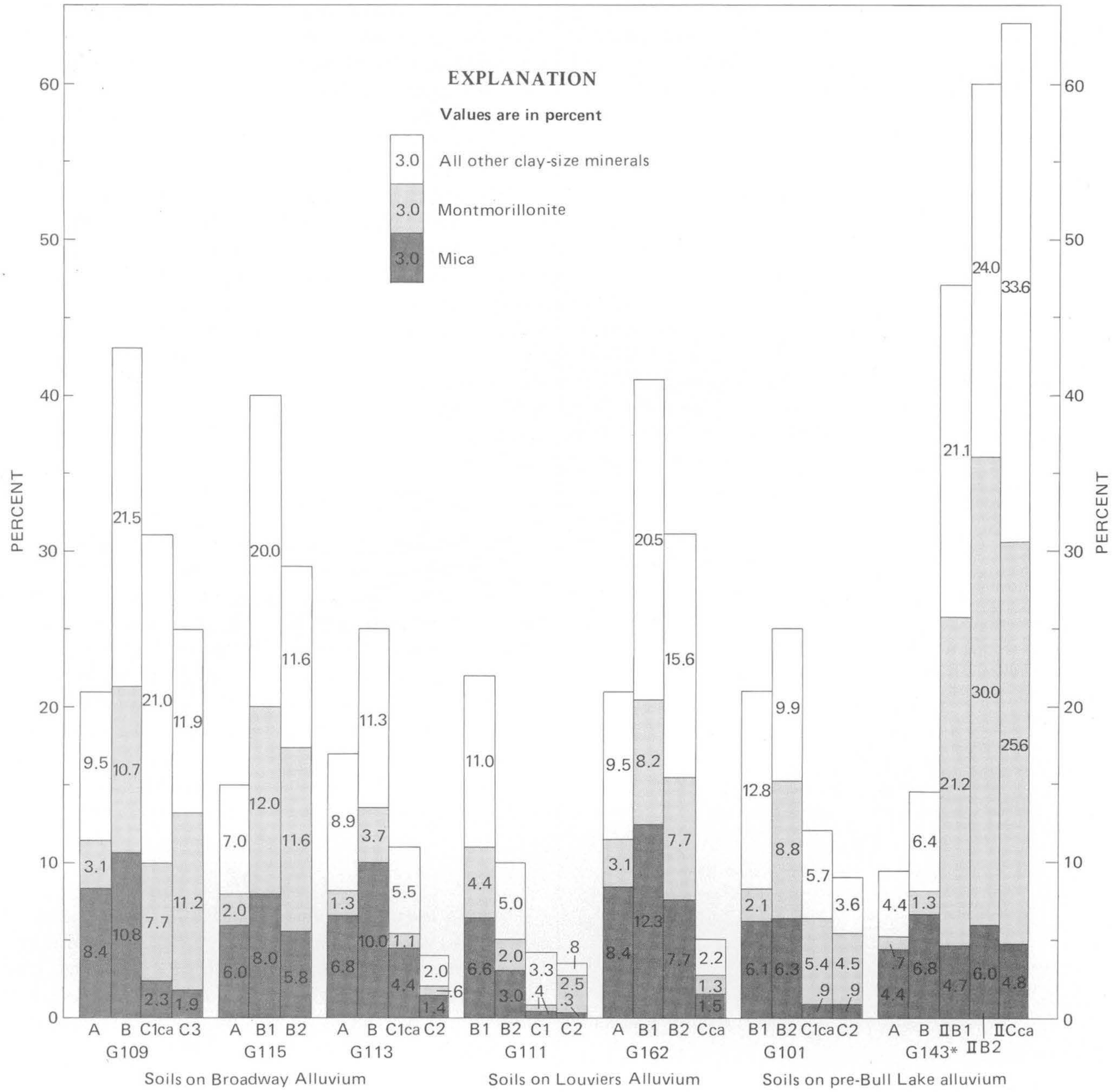


FIGURE 48.—Percentage of clay minerals in the clay-sized fraction of various soils in the Golden quadrangle, Colorado. *, the A and B horizons are probably developed on a thin Pinedale deposit. The localities are given in table 12.

North and South Table Mountains indicate the presence of a broad, shallow syncline under these mountains. The dips are corroborated by subsurface data on the top of the Fox Hills that show a broad gently southeast-plunging anticline that enters the quadrangle north of Leyden (Spencer, 1961) and trends east of the Table Mountains (Stewart, 1955, p. 30). The north end of the west limb of the anticline and the north end of the syncline that trends southward to the Table Mountains are well displayed by structure contours interpolated from altitudes of the coal horizon at various places in the new Leyden Coal mine taken from the files of the Colorado State Bureau of Mines. (See figs. 12 and 49.)

FAULTS

Most of the faults in the Golden quadrangle are related to, or continuations of, faults in the Precambrian terrane to the west. The largest fault in the quadrangle, the Golden fault, probably is a southern extension of the Livingstone fault from the Ralston Buttes quadrangle

(Van Horn, in Sheridan and others, 1967, p. 72). The total amount of displacement along the Golden fault zone is not known but is probably very large. Just north of Golden, at the point of apparent maximum stratigraphic displacement, about 8,800 feet of stratigraphic section has been cut out by the fault. The stratigraphic displacement decreases rapidly to the north, but it is interesting to note that, depending on the attitude of faults and bedding, major movement on the fault could have led to very little apparent stratigraphic displacement.

The Golden fault has been the subject of controversy concerning not only its angle of dip, but also its location and even its existence. In my opinion, the Golden fault is a moderately to steeply west-dipping reverse fault of large displacement. The marked reduction of the geologic section at Golden was noted by A. R. Marvine (in Hayden, 1874, p. 136), who mentioned the possibility of this being the result of faulting or unconformity. He seemed to prefer the unconformity concept inasmuch as no fault is shown on his map (p. 147) or on the atlas map (Hayden, 1877, pl. 12). A similar conclusion was reached by Lakes (1889), although in his section at Clear Creek (pl. 3, p. 58) he strongly supported the possibility of faulting. Eldridge strongly favored an unconformity as the cause of the thin section at Golden (1889; Emmons and others, 1896). The assault on the unconformity concept probably began with Patton's (1905) description of some remarkable faulting in the Dakota Group south of Golden. Work by Richardson (1912, p. 429) several miles south of Golden caused him to question the unconformity concept at Golden, and he suggested that the reduction in section might be due to faulting. Lee (1915, p. 32) also expressed doubt about the proposed unconformity at Golden. The presence of a fault was convincingly argued by Zeigler (1917) to explain the omission of beds at Golden. He believed that the fault was a steep-angle reverse fault and he showed the fault passing west of Ralston dike, but concurred with Eldridge (Emmons and others, 1896, pl. 10) in locating two transverse faults southeast of Ralston dike. Johnson (1925, 1930b) and Van Tuyl and McLaren (1932) agreed with Zeigler. Waldschmidt (1939) was the first to suggest that the fault southeast of Ralston dike was a single fault rather than two transverse faults, and that in the vicinity of Ralston dike it was a low-angle thrust fault. He also believed that there was a fault west of Ralston dike but could find no evidence for it. The low-angle thrust fault concept was later applied to the Golden fault throughout the Golden-Morrison area by Stewart (1952, p. 966). Van Horn (1957b) reverted to the steep-angle reverse fault. The Golden fault was described by Boos and Boos (1957, p. 2640) as a thrust-fault belt consisting of underthrusts. Osterwald (1961, p. 226) and Harms (1961, p. 413) both concluded that the Golden fault is a high-angle reverse fault. Berg (1962, p. 707) concluded that faults in the Golden zone dip 35°–50° SW.

The principal evidence for the steep angle of the fault is found at three places. The first, and southernmost, place is about 9 miles south of Golden, where evidence for the steep angle of the fault was shown in detail by Smith (1964, section *B–B′*). By comparing the logs of wells with the outcrop of the Golden fault, Smith showed that the fault zone dips 50°–60° to the southwest, and that the southwest side has moved up relative to the northeast side. The second place is the south bank of Clear Creek where the fault contact between the Pierre Shale and the overriding Lyons and Fountain is plainly visible from the north side of the creek. Here the apparent dip is more than 45° W. The third place is east of the mouth of Golden Gate Canyon where several boreholes were drilled. D. F. Tobin (oral commun.), who examined the cores from the boreholes, believed that the fault dips in excess of 60°. In addition the displacement of the fossil horizons in the Pierre Shale north of Van Bibber Creek shown by Van Horn (1972) is generally compatible with a west-dipping reverse fault. The beds on the west override and cut out the beds on the east. The salient of Pierre Shale extending eastward near Ralston dike, however, is apparently anomalous.

The only place the Golden fault is known to be associated with a long looping salient eastward is east of the intrusives southeast of Ralston dike. Because of this unique situation the salient seems to be related to the intrusives. Another relationship brought out by the mapping (Van Horn, 1972) is that the number and concentration of the intrusives suggest that they are all part of a single large intrusive lying near the surface. The location of fossil zones in the Pierre Shale suggests that there are two other faults in this area. The westernmost is indicated by the less-than-normal thickness of beds between the *Didymoceras cheyennense* zone and the *Baculites eliasi* zone. The other fault is shown by the repetition of the *Baculites grandis* zone. Fossils typical of the older *Inoceramus typicus* zone are present between the two. Geologic cross section *B–B′* (Van Horn, 1972) is drawn through this area. The attitudes of the faults and beds shown in the cross section are based on meager surface exposures. These relations suggest that the long looping salient of Cretaceous rock is essentially a small upright spoon-shaped overthrust plate that formed during a late stage of activity along the Golden fault. Other theories that were considered to account for the salient required that the salient be part of a syncline, a recumbent anticline, a low-angled Golden fault, two transverse faults, or a landslide. These theories were rejected because they did not fit the observed relations of the beds, the faults, or the intrusives.

A possible interpretation of the sequence of events leading to the formation of the spoon-shaped overthrust plate is that the block west of the main Golden fault moved upward and eastward after the beds had been folded into a nearly vertical attitude. The intrusion then moved up this

FIGURE 49.—Structure contours on the top of the Fox Hills Sandstone in the Golden quadrangle. Map explanation is at top of facing page. Base from U.S. Geological Survey Golden 7½-minute quadrangle (shaded relief), scale 1:24,000, 1965.

EXPLANATION

—*4600*— STRUCTURE CONTOUR DRAWN ON TOP OF THE FOX HILLS SANDSTONE – Dashed where approximately located. Contour interval 100 feet

——— FAULT – Approximately located

ANTICLINE – Showing crestline and direction of plunge. Dashed where approximately located

SYNCLINE – Showing troughline and direction of plunge. Dashed where approximately located

VERTICALLY PLUNGING SYNCLINE

o WELL USED FOR CONTROL

fault zone. As the intrusive approached the surface, pressure generated by the heat, chemical reactions, and the mass of the intrusive exerted strong forces against the adjoining sedimentary rock. This force ruptured and pushed a thin slice of sedimentary rock eastward along a spoon-shaped fault surface. The bottom of the spoon is probably opposite the main body of the intrusive. The large degree of overturning in the overthrust slice may be due to drag or to a preintrusive overturned fold. The western part of the salient was faulted up relative to the eastern part during a late stage of the formation of the salient, thus repeating the *Baculites grandis* zone. All movement stopped when the pressure caused by the intrusive was relieved by the magma reaching the surface. Later erosion left the slice exposed as a long eastward-looping salient of older rocks overlying younger rocks.

Thick slices of sedimentary rock that have been caught in the Golden fault have been reported from localities southeast of Morrison (Berg, 1962), at Tucker Gulch (Van Tuyl and McLaren, 1932), and northwest of the Golden quadrangle in the Livingstone breccia reef (Lovering and Goddard, 1950). Similar slices are exposed in the south valley wall of Clear Creek just west of the Pierre Shale and in Tucker Gulch just east of the Front Range. These slices, though not unique, do reveal something of the mechanics of movement of the fault blocks.

The fault exposed in the north bank of Tucker Gulch is of interest because of the peculiar position of the Benton Shale sandwiched between two older formations (figs. 50 and 51). A bedding plane in the Fountain Formation 20 feet west of the fault strikes N. 5° W. and dips 51° E. The fault, which has a 2-inch-wide gouge zone, strikes N. 20° E. and dips 82° W. A 3-inch-wide bentonite seam in the Benton, 12 feet east of the fault, strikes N. 20° E. and dips 88° E. The Benton is exposed for 61 feet east of the fault and appears to maintain the same attitude. The bentonite beds indicate this may be in the lower part of the Greenhorn equivalent. East of the Benton is 30 feet of colluvium which is followed by beds in the Dakota Group that strike N. 30° W. and dip 51° SW. Exposures in an old prospect shaft nearby indicate that the beds are in the upper part of the Dakota. Dakota outcrops continue another 144 feet to the east where they strike N. 50° W. and dip 70° SW. A small outcrop of Pierre Shale is present 90 feet east of the Dakota exposure; the intervening fault and bedrock are covered by colluvium. The Morrison Formation crops out 400 feet south of the Dakota along the south side of a farm access road on the south side of Tucker Gulch. The attitude of the Morrison is similar to that of the Dakota. Float from the Lykins Formation is present on the south side of the knoll south of the Morrison Formation. These relations suggest that the beds are overturned.

The location of some of the faults in the Pierre Shale north of Ralston dike is uncertain. Most of the area is covered by surficial deposits but possible discrepancies in the fossil zones of the Pierre Shale suggest that faults associated with the Golden and Livingstone faults are present in the area. Several thousand feet of left-lateral displacement along the Livingstone fault is indicated by the offset of the basal Pierre contact between the Ralston Buttes and Eldorado Springs quadrangles (Wells, 1967; Van Horn, in Sheridan and others, 1967). In the Golden quadrangle the most northwesterly fault is part of this system, although here the offset is not so clear cut. South of the junction of this fault with the west-trending fault one-half mile north of Ralston Reservoir the stratigraphic interval between the *Baculites scotti* and the *Didymoceras cheyennense* zones appears to be shorter than normal. This shortening probably indicates deletion of section by reverse faulting. (See Van Horn, 1972, geologic section *A–A′*.) On the next fault to the east, intervals between the fossil zones suggest that nearly 1,000 feet of section has been cut out by reverse faulting. The northward extension of this eastern fault is believed to fade out into bedding-plane faults of unknown displacement and extent. Southward, near Ralston Creek, the faults north of Ralston dike join with the Golden fault and the small overthrust fault that forms the salient southeast of Ralston dike. The junction is covered by surficial deposits and individual displacements are not known. An alternative interpretation based on the same data by Scott and Cobban (1965) shows the Golden fault terminating 2 miles north of Ralston dike and shows no connection with the Livingstone fault.

The southeast-trending fault adjacent to Van Bibber Creek is the extension of a fault mapped in the Ralston Buttes quadrangle, where it appears to offset the Lyons Sandstone. The offset shown in the Dakota Group (Van Horn, 1972) is less certain and probably is smaller than the offset shown for the Lyons. The small faults shown in the Dakota are undoubtedly related to this fault. The Benton Shale appears to be thinner south of the fault than it is to the north. The fault very probably bends to the south and

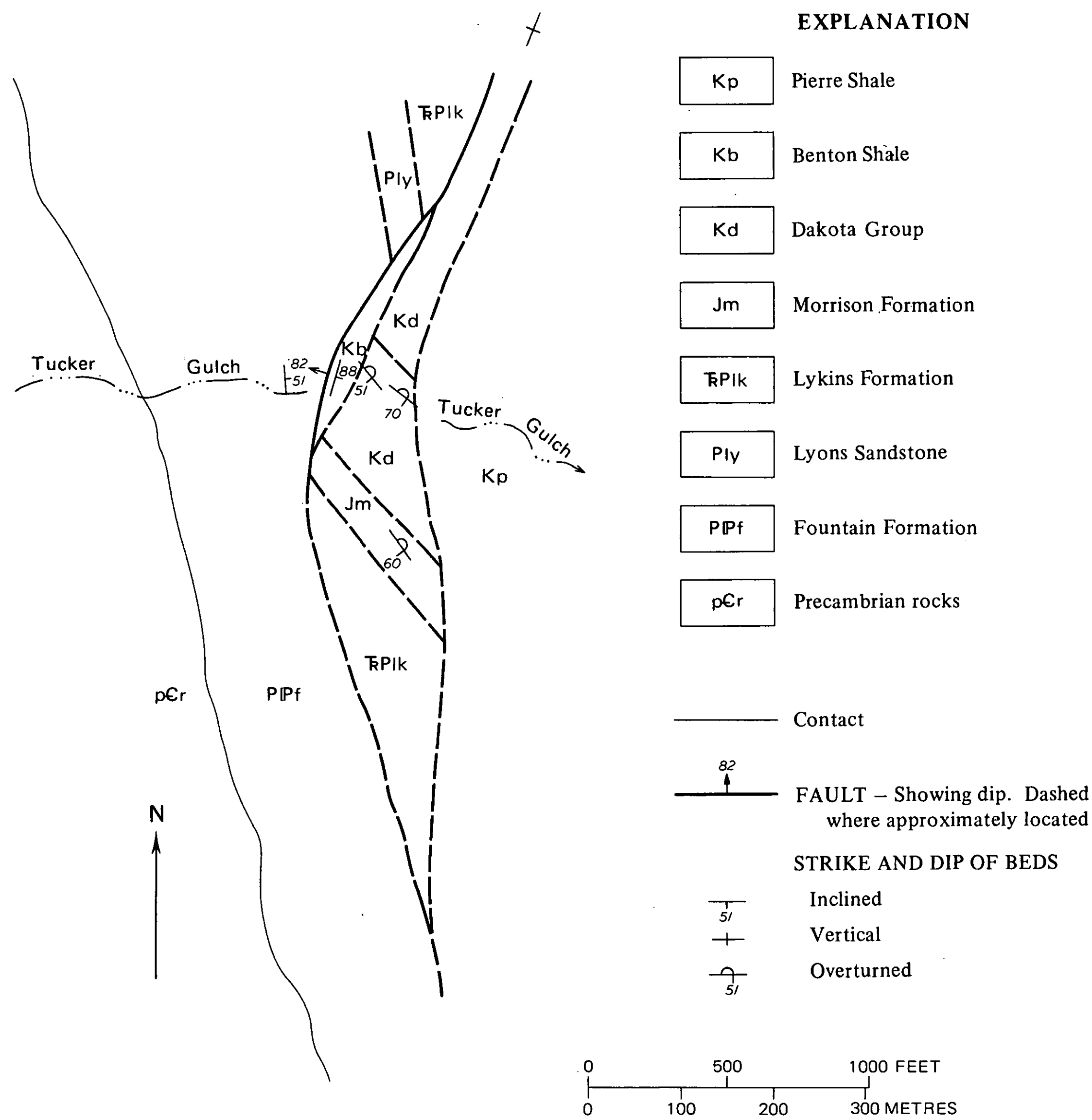


FIGURE 50.—Sketch map of the fault slice in the Golden fault zone at Tucker Gulch in the Golden quadrangle.

becomes a west-dipping, reverse, strike fault that joins the Golden fault to the south. The several small faults in the Dakota north of Tucker Gulch, and the east-trending fault in sec. 21 north of the kilns and east of the Golden fault are all related to the Golden fault. Along the Golden fault zone there are possibly similar faults that are obscured by the surficial deposits.

The south-dipping fault shown passing through the quarry north of Clear Creek in the Precambrian rocks is also a reverse fault as is shown by the offset of the Precambrian-Fountain contact south of the creek's mouth (Van Horn, 1972).

An east-dipping reverse fault in sec. 26, T. 3 S., R. 70 W., on the north flank of South Table Mountain, affected lava flows 2 and 3 and the underlying sedimentary rock of the Denver Formation. It has a throw of 60 feet and a heave of 40 feet; the west side moved down and to the east relative to the east side. The fault could not be traced more than 100 yards.

A graben of Yarmouth(?) or younger age, with 5 feet of displacement, in a trench in the NE¼SW¼ sec. 28, T. 3 S., R. 70 W., was described by Scott (1970, p. C15–C16). It involves the Fox Hills Sandstone, Verdos Alluvium, and colluvium; it is nearly parallel to the strike of the Fox Hills. The relationship of the small downdropped block on the downdropped side of the Golden fault to the Golden fault is not clear. It should be noted, however, that the graben is near the locality of the New (Little) White Ash mine which was reported to have surface subsidence in 1903. (p. 109)

FIGURE 51.—Part of the Golden fault zone in the north bank of Tucker Gulch. The pick is on the Fountain Formation and the hat is on Benton Shale; both formations are dipping east. The fault zone, about 2 inches wide, is marked by the west-dipping white streak just above and to the left of the hat. The bouldery deposit overlying the irregularly eroded bedrock surface is colluvium.

GEOLOGIC HISTORY

Rocks exposed in the Golden quadrangle record events that occurred at times ranging from the Precambrian to the present. The oldest rocks in the area record the accumulation of sedimentary and possibly volcanic rocks in Precambrian time. According to Sheridan, Maxwell, and Albee (1967, p. 73) these rocks were metamorphosed, intruded, and subjected to at least three periods of deformation during Precambrian time.

From some time in the later Precambrian until Pennsylvanian time, erosion dominated the area and created a major unconformity that is marked by the contact between the Precambrian rocks and the terrestrial Fountain Formation. Little is known of events during the time interval represented by this unconformity. Limestone pebbles in the Fountain Formation suggest that sedimentary rocks may have been deposited in nearby areas, but if so they were completely removed by erosion before the Fountain Formation was deposited. Streams flowing over the eroded surface of the folded and faulted Precambrian rocks deposited the sediments of the Fountain Formation on lowlands that bordered a sea to the east. Following deposition of the Fountain, the sea encroached on this land area and the Lyons Sandstone was deposited near the shoreline. Later, as the Permian sea encroached farther on the land, the red mudstones and algal limestones of the Lykins Formation were deposited in shallow water; the limestones may have formed in intertidal zones. Marine conditions probably persisted into Early Triassic time, and then the sea withdrew. Some erosion probably took place during later Triassic and(or) Early Jurassic time.

Sedimentation began again in Late Jurassic time with the deposition of the Ralston Creek Formation (including a basal 5-ft-thick bed of sandstone possibly equivalent to the Entrada Sandstone) and the succeeding Morrison Formation. These fine-grained terrestrial sediments were deposited by sluggish rivers on a low flat plain and in lakes and swamps during Late Jurassic time.

Terrestrial conditions persisted into the Early Cretaceous, when the sea began to readvance on the land. The rocks of the Dakota Group were deposited at the margin of this sea, and with continued encroachment of the sea the succeeding Benton, Niobrara, and Pierre Formations were deposited in deeper waters. According to Lovering and Goddard (1950, p. 58) the uplift of the present Front Range probably began about middle Pierre time, although the Denver basin had been subsiding and filling for some time prior to the uplift. The uplift of the Front Range marked the beginning of the Laramide orogeny, which culminated in early Tertiary time. As a result of this uplift the Paleozoic and Mesozoic formations were bent upward along the mountain front, and movements along the Golden and associated faults occurred in several stages. Volcanism taking place in the rising mountains of the Front Range during Late Cretaceous and early Tertiary time caused the flood of volcanic tuff, mudflows, and tuffaceous terrestrial deposits of the Denver Formation.

Ralston dike and associated intrusives were emplaced during Paleocene time, after most of the Laramide faulting had taken place. The lava flows of North and South Table Mountains probably came from a volcanic vent a short distance above the present crest of Ralston dike. All traces of Tertiary sedimentary rocks younger than the Denver Formation have been eroded from the Golden quadrangle, but erosion surfaces cut during the latter part of the Tertiary are still partially preserved in the mountains to the west (Van Horn, in Sheridan and others, 1967). These younger erosion surfaces, of probable Pliocene age, are about 2,000 feet above the present stream level and 1,500 feet above the lower Pleistocene alluvium (Malde and Van Horn, 1965, p. 42). Thus the erosion between late Tertiary and early Pleistocene time greatly exceeded erosion during the Pleistocene and Holocene.

Quaternary history in the Golden quadrangle is marked by recurrent episodes of erosion, alluviation, and soil formation. During each of the three major pre-Bull Lake glaciations the major streams eroded broad terracelike surfaces on the bedrock. These surfaces were then alluviated by the streams. There is some evidence pointing to the possibility that during early Pleistocene time the stream valleys were separated by interfluves that extended east of the foothills. Clear, Tucker, Ralston, and Coal Creeks all had well-established drainages in about their present location by Nebraskan time, although Ralston Creek occupied a valley on the south side of Ralston dike. During Nebraskan time the Rocky Flats Alluvium, and probably the pre-Rocky Flats alluvium, were deposited on broad, gently sloping surfaces cut by the individual streams. A soil of Aftonian(?) age was then developed on these deposits.

The deposits of Nebraskan age were eroded and the Verdos Alluvium of Kansan age was deposited in valleys cut below the Rocky Flats Alluvium. During Kansan time a rhyolitic volcanic ash, probably equivalent to the Pearlette Ash Member of the Sappa Formation, fell on the area and is locally preserved in the Verdos Alluvium. By Kansan time Ralston Creek was flowing northeastward north of Ralston dike, and across the areas now occupied by Leyden Creek and by Standley Lake. Van Bibber Creek had established its present valley west of Ralston dike by Kansan time but flowed northward to join Ralston Creek west of Ralston dike. A soil of Yarmouth(?) age was developed on the Verdos Alluvium.

The streams again cut into the older deposits and the Slocum Alluvium of Illinoian age was deposited in the new valleys. The area draining into Standley Lake was established as a basin separate from the rest of the Golden quadrangle between Kansan and Illinoian times. Slocum Alluvium was deposited in this basin by a stream originating on Rocky Flats. The basin has been isolated from the rest of the Golden quadrangle since Illinoian time, and at present drains northeastward into the South Platte River. By Illinoian time Ralston Creek had established its present valley east of Ralston dike but may have joined Clear Creek near Mount Olivet Cemetery. Van Bibber Creek established its present valley south of Ralston dike by Illinoian time and probably joined Ralston Creek just north of North Table Mountain. A soil of Sangamon(?) age developed on the Slocum Alluvium.

The Louviers Alluvium was deposited during Bull Lake time in a valley cut into the Slocum. At about this time Ralston Creek shifted its eastern valley about 2 miles northward and joined Clear Creek about 4 miles east of Mount Olivet Cemetery. Van Bibber Creek, however, stayed in the old valley and joined Clear Creek in the vicinity of Mount Olivet Cemetery. The post-Bull Lake soil, a moderately to strongly developed soil, was formed on the Louviers and correlative deposits in the interval between Bull Lake and Pinedale times.

The Louviers Alluvium was then partly eroded and the Broadway Alluvium of Pinedale age was deposited in the newly formed valley. At this time silt blown from the flood plains of streams formed a thin deposit of loess on the older deposits. Van Bibber Creek was captured from the Clear Creek drainage by a tributary of Ralston Creek toward the end of, or shortly after, Pinedale time, at a point northeast of North Table Mountain. At about this same time Van Bibber Creek captured part of the Tucker Gulch drainage in the mountains to the west (Van Horn, in Sheridan and others, 1967, p. 57).

A weak soil, the post-Broadway Alluvium soil, probably formed on the Broadway Alluvium, loess, and other deposits of Pinedale age. Narrow valleys were then eroded into the Broadway Alluvium. It is possible that deposits of pre-Piney Creek alluvium or colluvium were deposited in these valleys, but they have not been recognized in the Golden quadrangle. I believe that a weak soil developed after the pre-Piney Creek deposits formed. This weak soil, where added to an exposed previously developed post-Broadway Alluvium soil, resulted in a moderately well developed soil (Van Horn, 1967). Piney Creek Alluvium, of Holocene age, was deposited in valleys cut into the Broadway Alluvium. A weak soil developed on the Piney Creek. Valleys have been cut into the Piney Creek, and at places post-Piney Creek alluvium is being deposited on the flood plains of the stream.

Leyden Creek, a relatively young stream, was established after Kansan time and prior to Pinedale time. At present its valley heads one-half mile from the point where Coal Creek issues from the foothills in the Eldorado Springs quadrangle. In this area Leyden Creek has incised its valley lower than, and has a steeper gradient than, Coal Creek. These relations indicate that the capture of Coal Creek by Leyden Creek, although not imminent, is possible.

Deposits of alluvial fans, transported mantle, colluvium, and landslide debris probably have been forming continuously throughout Quaternary time. At most places their age was not determined. In 1968, as this report was being written, there were at least five active landslides on the flanks of South and North Table Mountains.

ECONOMIC GEOLOGY

Economic deposits that have been developed in the Golden quadrangle are sand, gravel, limestone, riprap, crushed rock, dimension stone, clay, coal, gold, and feldspar (for ceramic glaze). Potential economic deposits are silica sand, uranium, oil, and gas. There are no known economic metallic ore deposits in the Golden quadrangle although some gold is produced as a byproduct from the mining of sand and gravel. In 1966 only common clay and sand and gravel were produced in the quadrangle.

COAL

Subbituminous coal occurs in several lenticular bodies in the lower part of the Laramie Formation. No coal has been mined from the Golden quadrangle since 1950. The earliest recorded production was in 1873, but some mines were producing 20 years earlier. All mines except the new Leyden mine are in the area of steeply dipping outcrops. The mines near the outcrop were generally worked from vertical shafts sunk about 100 feet west of the outcrop. In most places the coal dipped steeply west (overturned) so a few hundred feet below the surface the coal was within 50 feet of the shaft. In the lower parts of the deeper mines the coal was steeply east dipping. The new Leyden mine, now used for natural gas storage, is in the gently east-dipping strata in the eastern part of the area.

The coal generally is in two beds which are separated by a distance of 10–20 feet: (1) The westernmost (lower) bed, 2–8 feet thick, and (2) the main coal bed, 8–14 feet thick. From the surface downward for about 100 feet the coal is generally fractured and lusterless. Below about 100 feet, however, it is black, lustrous, and hard, and it slacks readily on exposure. The coal has a relatively low ash content. The grade of the coal is better in the steeply dipping rocks than in the gently dipping rocks. Samples from the Leyden No. 3 mine (new Leyden of the present report) show 20 percent moisture, 55 percent fixed carbon, 7 percent ash, 0.7 percent sulfur, and 9,500 Btu (Fieldner and others, 1937).

An estimated 10 million tons of coal has been mined from 13 mines in the quadrangle. Assuming an average thickness of 6 feet of minable coal, 250 million tons of coal still lies within 1,000 feet of the surface.

OIL

Oil seeps occur in and adjacent to the Golden quadrangle but commercial production of oil has not yet been attained. Oil seeps have been reported from Halfmile Gulch (which joins Tucker Gulch from the northwest at the west boundary of the quadrangle) and from the easternmost tunnel on U.S. Highway 6 in Clear Creek Canyon. Both of these occurrences are in Precambrian rocks just west of the Golden quadrangle. Oil seeps have also been reported from a clay mine in the Dakota Group north of Tucker Gulch and from a water well south of the amphitheater in Red Rocks Park (Morrison quadrangle).

Oil possibly is trapped in a zone under the Golden fault, or in small anticlines such as the one east of the Table Mountains. This structure was tested by a well east of Hyatt Lake in 1955. Although the well was drilled into the Lyons Sandstone, no commercial oil shows were found. Possible producing units include the Lyons Sandstone, Dakota Group, the equivalent of the Carlile Shale in the Benton Shale, Fort Hays Limestone Member of the Niobrara Formation, and sandstone or siltstone beds in the Pierre Shale.

URANIUM

A potential economic deposit of uranium occurs in Tucker Gulch where a 6-inch-thick zone of high radioactivity occurs in the Benton Shale just east of the Fountain-Benton fault contact. Radiometric and radiochemical analyses of this material show 0.08 percent equivalent uranium but 0.019 percent uranium. The material that gives the equivalent uranium reading is composed of radioactive disintegration products of uranium, indicating a possibility that commercial deposits of uranium exist at depth.

A uranium prospect in the Laramie Formation at Leyden Creek in the SE¼SW¼ sec 28, T. 2 S., R. 70 W. (Gude and McKeown, 1952) has been abandoned. Several prospects have been driven on faults in the interlayered gneiss in Indian Gulch and one on the south side of Clear Creek. The prospect south of Clear Creek is on a ridge, where a brecciated fault dips 70° S. and gives a scintillometer count of several times the background.

GOLD

Gold was first mined in the Golden quadrangle in 1859 from placer deposits at the site of the town of Arapahoe Bar on the flood plain of Clear Creek near the SW. cor. sec. 24, T. 3 S., R. 70 W. (Henderson, 1926). Placer deposits were subsequently worked along Clear Creek but no large discoveries were made in Jefferson County. From 1858 to 1962, 16,558 fine ounces of gold worth $553,084 was produced in Jefferson County (Prommel and Hopkins, 1964). Much of this came from Clear Creek but part of it came from west of the Golden quadrangle. Since World War II a small, but unrevealed, amount of gold has been recovered in the quadrangle as a byproduct of some of the gravel-mining operations in the flood plain of Clear Creek. The gold is fine grained but is coarser in the lower and upper thirds of the gravel deposits (W. H. Slensker, oral commun.).

CLAY

Clay has been mined from the Fountain, Lykins, Morrison, Benton, Pierre, Laramie, and Arapahoe Formations, and Dakota Group in or near the Golden quadrangle. The principal productive beds are in the Dakota, Laramie, and Benton. Refractory-grade clay occurs in the South Platte Formation of the Dakota Group, and isolated deposits of refractory clay also occur in the Laramie (Waagé, 1952, p. 378, 385). Most of the readily accessible refractory clay has been mined from the area. Substantial reserves of clay are present north of Van Bibber Creek, but they may have a high iron content (Waagé, 1961, p. 88, 89).

Most common clay produced in the area is from the Laramie Formation. The best grades are generally in the lower beds, although most clay beds in the formation are usable. Common clay of the Laramie has been mined in the following areas: Golden, half a mile south of Van Bibber Creek, Leyden Creek to the Denver and Rio Grande Western Railroad, and south of Rocky Flats Lake. Extensive deposits of clay of unknown quality are present in the intervening areas and in the northeastern part of the quadrangle.

Clay from the upper part of the Pierre Shale has been treated and expanded to form a lightweight aggregate. In the Golden quadrangle two pits adjacent to monzonite intrusions produced shale for a short time. In 1964 an area 2 miles north of the quadrangle produced at a rate of a few hundred thousand tons a year (Bush, 1964, p. 200), and this locality was still producing in 1967. Clay from the Benton Shale has a tendency to bloat and is generally blended with other clays. Waagé (1952, p. 388) stated that the Benton might be a source of bloating clay suitable for manufacturing lightweight concrete blocks. Benton Shale has been produced from a small pit west of North Table Mountain and from a pit north of Van Bibber Creek.

SILICA SAND

No quarries developed for silica sand have been noted in the Golden quadrangle, but Argall (1949, p. 355, 357) stated that silica sand has been quarried from the Dakota Group north of Golden and at several other places in Colorado. The Dakota in the Golden quadrangle is similar to these deposits and is a potential source of silica sand.

DIMENSION STONE

Although parts of the Lyons and Lykins Formations and latites of Tertiary age have been used for dimension stone, no quarries in the Lyons or Lykins have been operated in the Golden quadrangle. The Lyons Sandstone exposed in the Golden quadrangle does not have the highly prized pink color of the stone quarried at Lyons, Colo. The crinkled limestone of the Lykins has recently been used for a decorative stone finish on fireplaces in some of the new homes in the Denver area, but it is not used as a structural stone nor is it used on the outside of buildings.

Latite from quarries on North and South Table Mountains has been used as cobblestone and building stone. It made an excellent cobblestone, but this use is outmoded; latite also has had some use as a building stone, but it does not have a pleasing aspect, owing to the somber color.

Sources of lichen-covered field rock (moss rock) for facing include the outcrop areas of rocks of Precambrian age, and the Fountain, Lyons, Morrison, and Laramie Formations, and Dakota Group. Most of these will not break into predictable shapes and are brown or gray.

LIMESTONE

Limestone beds in the Lykins and Niobrara Formations were extensively quarried for mortar and smelter flux many years ago, but limestone no longer is used as a source for this material in the Golden quadrangle. The use of limestone for nonchemical purposes is discussed in the following section.

CRUSHED ROCK

Several quarries have extracted rock from the Precambrian interlayered gneiss and the Tertiary igneous rock exposed in the Golden quadrangle. Both of these materials have been used for concrete aggregate and riprap. Limestone suitable for use as crushed rock is also present in the area.

Interlayered gneiss from a quarry in Clear Creek Canyon, half a mile west of Golden, has been used as concrete aggregate and riprap. The material is fine to coarse grained, harsh (produces very angular fragments when crushed), nonreactive, and sound (Hickey, 1950, p. 10). In addition to concrete aggregate and riprap, it is suitable for railroad ballast, highway base course, and other uses where hard, durable, angular, crushed rock is desired.

Latite has been quarried from North and South Table Mountains, and monzonite from Ralston dike, for use as riprap, concrete aggregate, and road metal. Both rocks are hard, tough, durable, and harsh.

The only limestone quarried in this area in recent years came from a small quarry in the upper part of the "crinkled limestone" (Glennon Limestone Member of the Lykins of LeRoy) in the NE¼ sec. 17, T. 3 S., R. 70 W. This material is used to surface private driveways. It has a pleasing reddish color and should wear well but would probably wear excessively if used on heavy duty roads and highways. A sample of this material from Ralston Reservoir showed 44.0 percent loss in the Los Angeles abrasion test. A sample from the 4-foot-thick dolomitic limestone that underlies this bed showed a 44.7 percent loss in the Los Angeles abrasion test.

The Fort Hays Limestone Member of the Niobrara Formation contains a considerable amount of interbedded shale. A sample of this limestone from Ralston Reservoir showed only 24.4 percent loss in the Los Angeles abrasion test; another sample from the Pueblo area (100 miles south of Golden) gave a loss of 24.7 percent. It is hard, durable, harsh, and tough; it would probably be suitable for mineral aggregate in highway construction. The light color of the Fort Hays would be particularly desirable for the wearing or armor course of asphaltic concrete. Probably neither the Fort Hays nor the Glennon would be suitable for concrete aggregate, although, to my knowledge, no tests for this use have been made.

SAND AND GRAVEL

Sources of sand and gravel include Rocky Flats, Verdos, Slocum, Louviers, and Broadway Alluviums, and transported mantle and alluvial-fan deposits. About 250 million cubic yards of sand and gravel suitable for concrete and mineral aggregate is present in the quadrangle, but urban development is rapidly encroaching on the most desirable deposits and probably only a small part of these deposits will ever be mined. About 7 million cubic yards had been mined in 1964.

The alluvial deposits adjacent to and underlying Clear Creek and the Louviers and Broadway Alluviums adjacent to Ralston Creek are the best sources of concrete aggregate. The material ranges from silt to cobble size and appears to be sound. The lithology of the deposits is shown in table 8. The material has been used locally for both concrete and bituminous aggregate and for many other purposes. Most of the other deposits contain enough silt and clay to make them less desirable for concrete aggregate, although they generally are suitable for use as mineral aggregate. The alluvial fans and other gravelly deposits near the mountain front generally contain a large proportion of boulders. None of the deposits are known to have a harmful amount of deleterious minerals, although bituminous binder might strip from the quartzite in the deposits from Coal Creek. Small amounts of placer gold are extracted as a byproduct from some of the sand and gravel operations on Clear Creek.

Where available the size distribution of the material is shown separately in the present report in the geologic description of each unit. Materials test data consisting of mechanical analyses, coefficient of sorting, Atterburg limits, pH, swell capacity, specific gravity, and soil classification (both Unified and AASHO) of 57 samples from the quadrangle have previously been published (Van Horn, 1968).

ENGINEERING GEOLOGY

An economic and physical relationship exists between man and the different geologic units because of the way in which he uses and builds on them. In general the geologic units have a definite range of physical properties, and their gross reaction to outside forces acting on them is to some extent predictable. The physical character of geologic units has an effect on, among other things, foundation conditions, workability, suitability of septic systems, cutslope stability, and earthquake hazard. Construction materials were discussed in a previous section of this report.

FOUNDATION CONDITIONS

Metamorphic rock, igneous rock, and sandstone (except in the Denver Formation) generally provide good to excellent foundation conditions. The alluvial terrace deposits provide good foundations, but at places high water tables may exist at basement level. Several geologic units provide poor foundation conditions in the quadrangle; these are parts of the Ralston Creek, Morrison, Benton, Pierre, Fox Hills, Laramie, Arapahoe, and Denver Formations, and colluvium, transported mantle, loess, artificial fill, and landslide deposits. In all these units except the last three, swelling clays cause the potentially poor foundation conditions in the area. The chief source of potential failure of foundations in the last three units is differential settlement, and in the event of landslides the entire structure may move laterally. Recognition of these potential hazards can lead to proper foundation design prior to construction.

SWELLING CLAY

Some clay minerals, principally montmorillonite, undergo expansion and contraction related to wetting and drying. Structures built on deposits containing such minerals can be damaged by the alternate swelling and shrinking of the clay. In the Golden quadrangle the Denver Formation contains abundant montmorillonite (table 4), and structures built on the Denver have sustained damage to a greater degree than structures built on other geologic units. This greater amount of damage may be more apparent than real, however, because more than half the structures in the area that are built on potentially expansive formations are built on the Denver. Some damage has also been sustained by structures built on clay and shale beds in the Laramie Formation and the Pierre Shale. Expansive clays may also be found in clay and shale beds in the Arapahoe, Fox Hills, Benton, Morrison, and Ralston Creek Formations, all of which are known to contain montmorillonite. The thick shale and mudstone beds in the Lykins and Fountain Formations are not believed to be expansive but probably should be tested prior to construction of any structure on them.

The presence of montmorillonite does not automatically indicate poor foundation conditions. Ralston Reservoir dam and a tunnel into Upper Long Lake are both in Pierre Shale, which contains abundant montmorillonite. Neither structure has shown any indication of distress caused by swelling clays. The Smoky Hill Shale Member of the Niobrara Formation contains some thin bentonite beds which probably are mainly montmorillonite. Because the beds are thin and widely spaced they probably will have little effect on foundation conditions.

Colluvium, transported mantle, loess, and soils locally contain montmorillonite. Materials tested show that some samples of these deposits show high swell and plasticity indexes (Van Horn, 1968), both of which indicate potentially hazardous swelling properties. Holtz and Gibbs (1954) pointed out that materials having a high plasticity index generally are more expansive than those having a low plasticity index. Further testing is advisable on any material that has a plasticity index of 20 or more before constructing any buildings on it.

DIFFERENTIAL SETTLEMENT

Loess, when saturated with water, tends to settle under heavy loads. The amount of settling frequently is not the same at all places, and consequently may cause unusual stress in the structures. Artificial fill, where poorly compacted, may also settle differentially under heavy loads; it also hides older more stable deposits so that parts of a building founded on fill may inadvertently be partly or entirely supported by the older deposit. (See fig. 52.) This is particularly possible along the outcrop of the Laramie and Arapahoe Formations where abandoned clay pits that are separated by vertical walls of sandstone may be used for dumps. Differential settlement is possible wherever a structure is founded on two different geologic units.

A potential hazard in the area is the surface expression of cave-ins of old mine workings. No such cave-ins were seen in the area but the possibility is present, particularly along the outcrop of the Laramie Formation. These cave-ins tend to become obscure as time passes, and examples of cave-ins reported in the Golden Globe November 29, 1902, and March 14, 1903 (see p. 109) are no longer visible because the surface openings are now filled with debris.

LANDSLIDES

Landslides provide the least stable, and perhaps the least predictable, foundations. The mapping of landslides in a rapidly growing urban area presents delicate economic problems. The property involved in landslides is generally on the higher slopes and is esteemed as view property. At my present state of knowledge I am unable to predict when, or if, any such property located on a landslide, whether old or recent, will move downslope. Consultant engineers can design buildings that will withstand such movement but the cost may be prohibitive, and perhaps unnecessary. The incidence of active slides is not high at present, but when man tampers with the natural slopes by excavating the toe of the slope, or adding abnormal amounts of water from septic tanks and lawn watering, the incidence may increase. Besides, the homeowner who finds himself in possession of part of the "Heartbreak Hills" (Johns, 1958) with his home being torn asunder won't care about the incidence rate of landslides.

FIGURE 52.—Structural distress in an apartment building west of the Colorado School of Mines that was constructed over a well-compacted artificial fill. The load-bearing members of most of the apartment buildings in this area were reportedly founded on sandstone ribs that separated abandoned clay pits (now filled) as much as 50 feet deep, or on caissons to sandstone. The building pictured, however, was reportedly placed on footings 3 feet deep founded on thick artificial fill overlying a clay pit. Photograph by M. M. Lemke, Colorado School of Mines.

The principal areas of unstable slopes are the sides of North and South Table Mountains underlain by the Denver Formation. (See p. 108.) Numerous old landslides and debris from rockfalls can be seen in this area, and several areas on the north side of South Table Mountain have moved in recent years (Van Horn, 1954). These landslides appear to have formed both by rotational movement along a curved slide plane and by debris sliding down a planar slide plane. Several similar, but generally smaller, landslides occur in the lower 1,000 feet of the Pierre Shale and several good examples can be seen on the west side of Ralston Reservoir. The reactivation of an old landslide in 1959 in the basal part of the Arapahoe Formation just north of Ralston Creek forced the relocation of State Highway 93 (fig. 53). Several small slides are in the upper part of the Laramie Formation on the south side of Leyden Creek. Landslides and rockfalls also occur in the Precambrian rocks.

WORKABILITY

The surficial materials and most of the shale, mudstone, and rocks of the Denver Formation (except the latite) can probably be excavated with power equipment. The other rock units locally will require blasting to excavate.

The alluvial deposits, being relatively free of clay, will be easiest to work with power equipment, and colluvium and landslide deposits will probably provide relatively difficult working conditions. On Rocky Flats the alluvial-fan deposits and the Rocky Flats Alluvium contain some very large boulders that will require special handling. The Rocky Flats Alluvium locally contains abundant clay and, as a result, it is more difficult to work with power equipment than are other alluviums.

SEPTIC SYSTEMS

Sewage disposal in much of the quadrangle is by small septic systems. The alluvial deposits provide the best drainage for disposing of the effluent from these systems. Care should be taken to see that the systems are in good condition and are not discharging noxious wastes into the ground water. The many shallow wells in the alluvium could be contaminated by malfunctioning septic systems.

Fine-grained deposits such as colluvium, loess, the Piney Creek Alluvium, parts of the Broadway Alluvium, and transported mantle are less desirable but can be used for septic systems. They do not drain as well as the alluviums. It would be injudicious to allow such systems to discharge into landslide deposits because additional water would only increase the danger of movement. The bedrock formations are not suitable for disposal of septic-system effluent.

CUT-SLOPE STABILITY

The cut-slope stability of the geologic units in the quadrangle differs greatly from one unit to another. In areas of low dip the sandstone beds are stable in nearly vertical cuts. In areas of steeply dipping beds or joints, cuts in any of the bedrock units should be designed for the attitude of the bedding and joints at the particular area, because bedding and joints together may outline blocks of rock that can slide downslope if an artificial cut removes their natural support. The hogback ridges and metamorphic

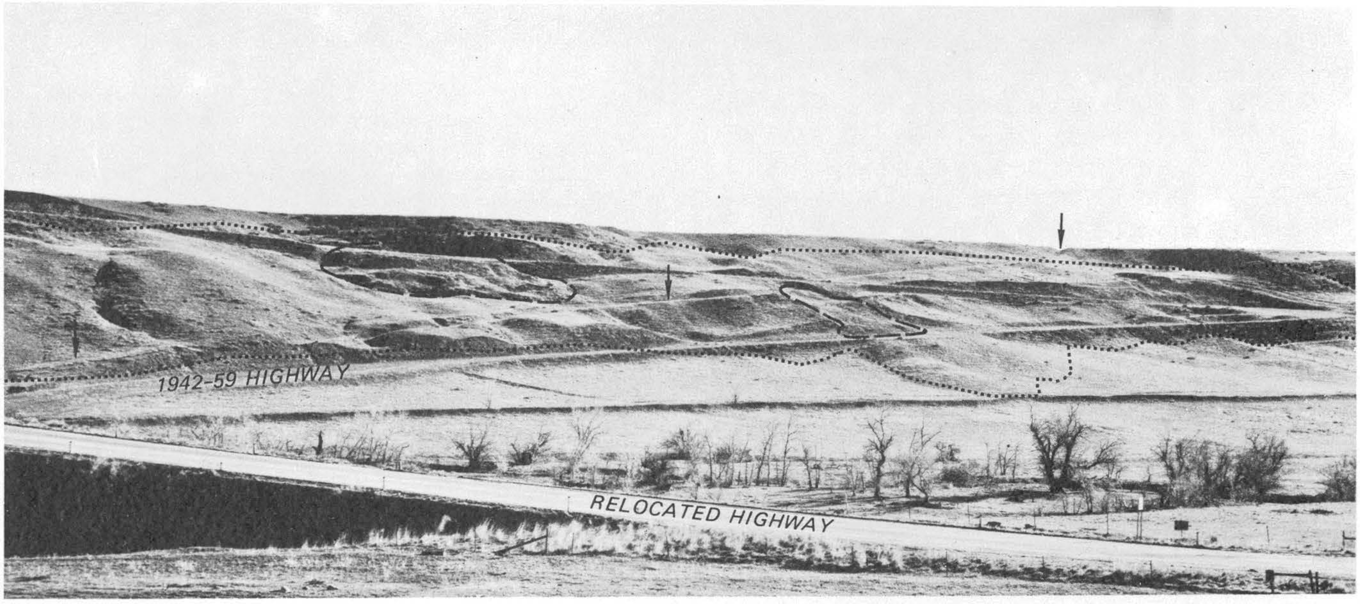


FIGURE 53.—Hummocky topography on an ancient landslide (dotted line) reactivated by highway construction in 1959 on State Highway 93, sec. 33, T. 2 S., R. 70 W. Three generations of highways are visible. The oldest (arrows) forms a faint trace that ascends the slope without a U-turn. It was constructed prior to 1895 on the ancient landslide and had not been broken by landslides until the 1959 reactivation. The highway with the U-turn was constructed prior to 1942 and was widened and rebuilt in 1959. Movement on the landslide started (dashed lines) before construction was completed, and the highway was relocated. The renewed movement also disrupted the trace of the oldest highway. Photograph, toward the northeast, by H. E. Malde, U.S. Geological Survey.

terrane of the mountains are particularly hazardous areas in this respect. Shale and claystone beds are generally weak, and design of cut-slopes should account for strength of the particular beds as well as the attitude of the joints and bedding. Cut-slopes in clay and shale can be unstable in any setting.

The steepness of cut-slopes in the surficial deposits should not exceed the minimum requirements of the Colorado Industrial Commission. Water saturation, which may be found in these units, provides hazardous excavating conditions and calls for extra caution. Cuts into landslide areas should only be made after a thorough slope-stability analysis.

EARTHQUAKE HAZARD

There is no evidence for movement along any of the faults in the Golden area during Holocene time, which encompasses roughly the last 10,000 years. Several of the earthquakes centered around the Denver area since 1962 have been felt in the quadrangle, but, to my knowledge, no structural damage in the Golden area has been caused by these tremors. In the event of strong earthquakes affecting the Golden area, landslides and colluvial deposits would be the least stable material, and bedrock the most stable.

HISTORICAL GEOLOGIC EVENTS AT GOLDEN, COLO., AND VICINITY

This is a summary of historical events with geologic implications that have taken place at and near Golden as recorded in old issues of the Golden Globe that are now kept in the Pioneer Museum at Golden, Colo. The newspapers examined were published during the years 1878–87, 1895 to mid-1903, 1906–11, and 1913–14, a total of 26½ years. The first item is not, strictly speaking, part of this record, but this early notice of a rockfall inspired my search for old records of landslides. The record is not complete, but the dates covered will give some idea of the frequency of the events. Landslides, rockfalls, and floods account for most of the events recorded herein. During the reading of these old papers it became evident that not every slide nor all movements of a particular slide were reported. Judging from inferences read in the old papers and from present-day newspaper standards probably 50 percent or less of the active landslides and rockfalls were reported.

June 22, 1871. An estimated 1,000 tons of rock fell from the south face of North Table Mountain with a roar like an earthquake [reported in the Golden Transcript newspaper column "90 Years Ago Today" for June 22, 1961.]

July 5, 1879. Hailstones as much as 7 inches in diameter caused much damage in Golden.

March 12, 1881. A landslide occurred near the Valley Smelter on the south side of North Table Mountain. The material slid down a wet bedrock surface. Deep cracks formed near the Church Ditch, and a small hill rose beneath the railroad tracks. On March 19, 1881, the Golden Globe reported that as many as 40 men had been employed in the previous week to keep the track straight, but that it was still bulged considerably.

August 10, 1881. A cloudburst in Clear Creek Canyon 1½ miles east of Beaver Brook caused 22 "landslides" in 5 miles downstream. The railroad line was broken at several places, and debris as much as 5 feet deep was deposited on the track. [These 22 "landslides" may not have been true landslides and are not included in the count of landslides.]

June 10, 1882. Floods down Kinney Run [now called Kenneys Creek] and Tucker Gulch washed out the railroad beds.

July 3, 1882. Flood in Tucker Gulch caused moderate damage.

July 21, 1883. A landslide on the south side of North Table Mountain near the Valley Smelter caused damage to the Church Ditch and the railroad. Subsequent movement was reported on July 28 and August 4 of 1883.

August 11, 1883. Small flood on Tucker Gulch washed out roads.

July 14, 1887. A cloudburst caused floods in Tucker Gulch, Dry [now called Van Bibber], and Ralston Creeks. At Glencoe [now covered by waters of Ralston Reservoir] Ralston Creek was 150 feet wide and swept away the Post Office.

May 16, 1896. Another landslide occurred on the Gulf Railroad opposite the Carpenter place [on the south side of North Table Mountain].

July 25, 1896. Heavy rain the previous week washed out the Gulf Railroad tracks at Chimney Gulch [southwest of the campground, and across Clear Creek, at Golden].

July 24 and 25, 1896. Widespread floods on these dates were reported in the papers issued on August 1 and 8, 1896, and mentioned in the paper of May 21, 1898. Floods occurred in Mount Vernon Canyon, Cub Creek, Clear Creek, Tucker Gulch, Crismans [now called Cressmans] Gulch, and Ralston Creek. Great damage was sustained in Golden, and by the bridges and railroad tracks up Clear Creek Canyon. Six deaths resulted, three in Golden and three in Mount Vernon Canyon.

August 15, 1896. In Clear Creek Canyon two men, who were working on the railroad, were injured by a falling rock and three others were injured by being buried in a landslide.

August 22, 1896. A rockslide in Clear Creek Canyon 3 miles west of Golden near Guy Gulch delayed the train, and 100 feet of track was washed out near Beaver Brook.

September 5, 1896. Two men, while working on the railroad, were injured by dirt and rock caving on them. No location is given.

September 12, 1896. A small flood occurred on Tucker Gulch.

September 19, 1896. A man showed the editor a bottle of crude petroleum and water he had recovered from a crevice in some rocks near Golden Gate Canyon. [This started Golden's first oil boom and within a month a well was being drilled in the vicinity of the brickyard north of town—subsequent issues of the newspaper indicate that it was a dry hole.]

June 5, 1897. Another landslide on the Agricultural Ditch just west of Rees Easely's [South Table Mountain].

July 10, 1897. The railroad is building a 350-foot bridge at the slide 1½ miles below Golden.

August 7, 1897. A small flood occurred in Tucker Gulch.

April 8, 1899. A rockslide in Clear Creek Canyon derailed a Colorado and Southern locomotive.

July 22, 1899. A flood occurred on Ralston Creek.

August 12, 1899. A rockslide at the mouth of Golden Gate Canyon damaged the road.

May 5, 1900. The landslide below the old smelter moved again.

May 26, 1900. A great mass of rock broke off the face of Castle Rock with a report like a cannon.

November 8, 1902. The ground north of Clear Creek and below the smelter is moving the Colorado and Southern Railroad tracks.

November 29, 1902. A man almost stepped into a cave-in of an old coal cavern southwest of Golden.

March 14, 1903. A yawning chasm that should be fenced has formed at the little [new] White Ash Coal mine [called the New (Little) White Ash in the present report] north of Golden.

April 4, 1903. A flow of 40,000 gallons of water per day from an old coal mine was intercepted by the tunnel through the Laramie Formation for the Welch Ditch southwest of Golden.

September 16, 1907. A 12- by 12- by 12-foot boulder fell from the Tramway Quarry [SE¼ sec. 22, T. 3 S., R. 70 W.] on the south side of North Table Mountain and lodged in the Church Ditch just above a house.

April 20, 1907. A man was buried alive in a ditch being dug for a retaining wall on the landslide below the smelter.

May 4, 1907. Cracks opened in the ground below the Tramway Quarry [SE¼ sec. 22, T. 3 S., R. 70 W.] on the south side of North Table Mountain and the ground seemed to be moving. A huge mass of rock ploughed down the mountain below the quarry.

June 15, 1907. Ground near 14th and Ford Streets in Golden caved into Kinney Run [Kenneys Creek].

July 13, 1907. A flood on Clear Creek was caused by a cloudburst near Black Hawk. Water was as much as 5 feet deep on 11th Street and was running 2 feet over the top of the Ford Street bridge. The Washington Street bridge was moved off its abutments. There was much damage to the railroad west of Golden and flood debris was found 20 feet above the bed of Clear Creek. Damage amounted to about $50,000 [reported in the Oct. 20, 1907, issue]]

July 10, 1909. A cloudburst west of Golden caused Clear Creek to rise 5 feet in 20 minutes. Lawns and irrigation ditches were covered with sand and boulders.

July 31, 1909. A flood on Tucker Gulch washed out all bridges between Golden Gate Canyon and Clear Creek except the Colorado and Southern Railroad bridge which was completely covered with water. Flood waters reached to Washington Ave.

May 17, 1913. An immense boulder, accompanied by many small rocks, rolled from the top of North Table Mountain into the Church Ditch narrowly missing a rural mailman. It had rained heavily the preceding night.

August 16, 1913. A flood on Kinney Run [Kenneys Creek] was caused by a cloudburst [estimated 4 inches of rain in ½ hour]. About $10,000 damage was sustained by homes, businesses, and bridges on Ford Street.

September 6, 1913. Small floods occurred in several gulches in Golden. The railroad tracks west of Golden were covered by tons of rock and sand at Magpie Gulch [north side of Clear Creek, SW¼ sec. 28, T. 3 S., R. 70 W.]

March 14, 1914. A large deposit of bitumen-soaked sandstone was found near Turkey Creek south of Morrison.

April 4, 1914. A man was seriously injured at the rock quarry on North Table Mountain when pieces of basalt [latite] fell from the cliff without warning.

May 2, 1914. At 4:00 a.m. Tuesday morning a few thousand tons of rock slumped several yards and covered up the access road at the Tramway Quarry [SE¼ sec. 22. T. 3 S., R. 70 W.] on North Table Mountain. Heavy snow and rain have softened the "clay and ash." The ditch company and the railroad experienced much trouble in previous years when great sections of hillside moved slowly down toward Clear Creek.

July 18, 1914. On Saturday morning the biggest slide ever reported here took place just east of the Frank Owen's Ranch on South Table Mountain. Large crevices opened just below the Welch [Golden Canal] Ditch. A great mass of earth several hundred feet across moved several feet down the mountain. Some ground moved as a unit but some was badly cracked. The Agricultural Ditch was destroyed and the level ground at the base of the mountain was lifted into a ridge 15 feet high.

REFERENCES CITED

American Stratigraphic Co., 1956, S. D. Johnson Farmers Highline Canal and Reservoir Co., well no. 1: Well log no. 760, sec. 7, T. 3 S., R. 69 W., Jefferson County, Colo.

Argall, G. O., Jr., 1949, Industrial minerals of Colorado: Colorado School Mines Quart., v. 44, no. 2, 477 p.

Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., 1936, Correlation of the Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: U.S. Geol. Survey Prof. Paper 183, 66 p.

Berg, R. R., 1962, Subsurface interpretation of Golden fault at Soda Lakes, Jefferson County, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 5, p. 704–707.

Boos, C. M., and Boos, M. F., 1957, Tectonics of eastern flank and foothills of Front Range, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 12, p. 2603–2676.

Boos, M. F., and Boos, C. M., 1934, Granites of the Front Range—the Longs Peak-St. Vrain batholith: Geol. Soc. America Bull., v. 45, no. 2, p. 303–322.

Broin, T. L., 1958, Correlations of some Permian and Triassic strata of eastern Colorado and adjacent portions of Wyoming, Nebraska, and Kansas [abs.]: Geol. Soc. America Bull., v. 69, no. 12, pt. 2, p. 1540.

Brown, R. W., 1943, Cretaceous-Tertiary boundary in the Denver basin, Colorado: Geol. Soc. America Bull., v. 54, no. 1, p. 65–86.

———1962, Paleocene flora of the Rocky Mountains and Great Plains: U.S. Geol. Survey Prof. Paper 375, 119 p.

Bryant, Bruce, Miller, R. D., and Scott, G. R., 1973, Geologic map of the Indian Hills quadrangle, Jefferson County, Colorado: U.S. Geol. Survey Geol. Quad. Map GQ-1073 [1974].

Bush, A. L., 1964, Construction materials—Lightweight aggregates, *in* Mineral and water resources of Colorado: U.S. Cong., 88th, 2d sess., Comm. Print, p. 197–202.

Butters, R. M., 1913, Permian or "Permo-Carboniferous" of the eastern foothills of the Rocky Mountains in Colorado: Colorado Geol. Survey Bull. 5, pt. 2, p. 61–94.

Condra, G. E., Reed, E. C., [and Gordon, E. D.], 1950, Correlation of the Pleistocene deposits of Nebraska: Nebraska Geol. Survey Bull. 15A, 74 p., revised ed. of G. E. Condra, E. C. Reed, and E. D. Gordon, 1947.

Cross, C. W., 1889, The Denver Tertiary Formation: Colorado Sci. Soc. Proc., v. 3, pt. 1, p. 119–133.

Cross, C. W., and Hillebrand, W. F., 1882, On the minerals, mainly zeolites, occurring in the basalt of Table Mountain near Golden, Colorado: Am. Jour. Sci., 3d ser., v. 23, p. 452–458.

Dane, C. H., and Pierce, W. G., 1936, Dawson and Laramie formations in southeastern part of Denver basin, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 20, no. 10, p. 1308–1328.

Denny, C. S., 1965, Alluvial fans in the Death Valley region, California and Nevada: U.S. Geol. Survey Prof. Paper 466, 62 p.

Eldridge, G. H., 1889, On some stratigraphical and structural features of the country about Denver, Colorado: Colorado Sci. Soc. Proc., v. 3, pt. 1, p. 86–118.

Emmons, S. F., Cross, C. W., and Eldridge, G. H., 1896, Geology of the Denver basin in Colorado: U.S. Geol. Survey Mon. 27, 556 p.

Fenneman, N. M., 1905, Geology of the Boulder district, Colorado: U.S. Geol. Survey Bull. 265, 101 p.

Fieldner, A. C., Cooper, H. M., and Abernethy, R. F., 1937, Analyses of mine samples, *in* Analyses of Colorado coals: U.S. Bur. Mines Tech. Paper 574, p. 46-131.

Finlay, G. I., 1907, The Gleneyrie formation and its bearing on the age of the Fountain formation in the Manitou region, Colorado: Jour. Geology, v. 15, p. 586-589.

Gable, D. J., 1968, Geology of the crystalline rocks in the western part of the Morrison quadrangle, Jefferson County, Colorado: U.S. Geol. Survey Bull. 1251-E, 45 p.

Goddard, E. N., chm., and others, 1948, Rock-color chart: Natl. Research Council (repr. by Geol. Soc. America, 1951, 1970) 6 p.

Gude, A. J., III, 1950, Clay minerals of Laramie formation, Golden, Colorado, identified by X-ray diffraction: Am. Assoc. Petroleum Geologists Bull., v. 34, no. 8, p. 1699-1717.

Gude, A. J., III, and McKeown, F. A., 1952, Results of exploration at the old Leyden coal mine, Jefferson County, Colorado: U.S. Geol. Survey TEM Rept. 292, 14 p.

Harms, J. C., 1961, Laramide faults and stress distribution in Front Range, Colorado [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 3, p. 413-414.

Hayden, F. V., 1869, Preliminary field report [3d ann. rept.] of the U.S. Geological Survey of Colorado and New Mexico: Washington, U.S. Govt. Printing Office, 155 p.

———1874, [7th] Annual report of the U.S. Geological and Geographical Survey of the territories, embracing Colorado, being a report of progress of the exploration for the year 1873: Washington, U.S. Govt. Printing Office, 718 p.

———1877, Geological and geographical atlas of Colorado and portions of adjacent territory: U.S. Geol. and Geog. Surveys of the Territories.

Heaton, R. L., 1933, Ancestral Rockies and Mesozoic and late Paleozoic stratigraphy of Rocky Mountain region: Am. Assoc. Petroleum Geologists Bull., v. 17, no. 2, p. 109-168.

Henderson, C. W., 1926, Mining in Colorado; a history of discovery, development, and production: U.S. Geol. Survey Prof. Paper 138, 263 p.

Hickey, M. E., 1950, Investigations of local concrete aggregate and concrete mix studies—Cherry Creek Dam, U.S. Engineering Department: U.S. Bur. Reclamation, Br. Design and Construction, Research and Geology Div., Materials Lab. Rept. C-482, 20 p.

Holtz, W. G., and Gibbs, H. J., 1954, Engineering properties of expansive clays: Am. Soc. Civil Engineers Proc., v. 80, separate no. 516, p. 516-1 to 516-28.

Hubert, J. F., 1960, Petrology of the Fountain and Lyons Formations, Front Range, Colorado: Colorado School Mines Quart., v. 55, no. 1, p. 1-242.

Hunt, C. B., 1954, Pleistocene and Recent deposits in the Denver area, Colorado: U.S. Geol. Survey Bull. 996-C, p. 91-140.

Imlay, R. W., 1952, Correlation of the Jurassic formations of North America, exclusive of Canada: Geol. Soc. America Bull., v. 63, no. 9, p. 953-992.

Jahns, R. H., 1958, Residential ills in the Heartbreak Hills of southern California: Eng. and Sci., v. 22, no. 3, p. 13-20.

Johnson, J. H., 1925, The geology of the Golden area, Colorado: Colorado School Mines Quart., v. 20, no. 3, 25 p.

———1930a, Unconformity in Colorado Group in eastern Colorado: Am. Assoc. Petroleum Geologists Bull., v. 14, no. 6, p. 789-794.

———1930b, The geology of the Golden area, Colorado [2d ed., revised]: Colorado School Mines Quart., v. 25, no. 3, 33 p.

———1931, The paleontology of the Denver quadrangle, Colorado: Colorado Sci. Soc. Proc., v. 12, no. 11, p. 355-378.

Judd, W. R., Esmiol, E. E., Gould, J. P., Lowrie, C. R., Resler, Paul, Sherard, J. L., and Van Horn, Richard, compilers, 1954, Borehole data and engineering applications in the Denver area: Denver, Colo., Hotchkiss Mapping Co., Am. Soc. Civil Engineers, 62 p.

Keller, W. D., 1953, Clay minerals in the type section of the Morrison Formation: Jour. Sed. Petrology, v. 23, no. 2, p. 93-105.

Knowlton, F. H., 1922, The Laramie flora of the Denver basin, with a reveiw of the Laramie problem: U.S. Geol. Survey Prof. Paper 130, 175 p.

Lakes, Arthur, 1889, Geology of Colorado coal deposits: Colorado School Mines, Ann. Rept. Field Work, 264 p.

Lee, W. T., 1915, Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico: U.S. Geol. Survey Prof. Paper 95-C, p. 27-58.

———1927, Correlation of geologic formations between east-central Colorado, central Wyoming, and southern Montana: U.S. Geol. Survey Prof. Paper 149, 80 p.

LeRoy, L. W., 1946, Stratigraphy of the Golden-Morrison area, Jefferson County, Colorado: Colorado School Mines Quart., v. 41, no. 2, 115 p.

LeRoy, L. W., and Schieltz, N. C., 1958, Niobrara-Pierre boundary along Front Range, Colorado: Am. Assoc. Petroleum Geologists Bull, v. 42, no. 10, p. 2444-2464.

Lindvall, R. M., 1972, Geologic map of the Arvada quadrangle, Adams, Denver, and Jefferson Counties, Colorado: U.S. Geol. Survey Misc. Field Studies Map MF-348.

Lovering, T. S., Aurand, H. A., Lavington, C. S., and Wilson, J. H., 1932, Fox Hills Formation, northeastern Colorado: Am. Assoc. Petroleum Geologists Bull., v. 16, no. 7, p. 702-703.

Lovering, T. S., and Goddard, E. N., 1950, Geology and ore deposits of the Front Range, Colorado: U.S. Geol. Survey Prof. Paper 223, 319 p.

Maberry, J. O., and Lindvall, R. M., 1972, Geologic map of the Parker quadrangle, Arapahoe and Douglas Counties, Colorado: U.S. Geol. Survey Misc. Geol. Inv. Map I-770-A.

Maher, J. C., 1946, Correlation of the Paleozoic rocks across Las Animas arch in Baca, Las Animas, and Otero Counties, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 30, no. 10, p. 1756-1763.

Maher, J. C., and Collins, J. B., 1952, Correlation of Permian and Pennsylvanian rocks from western Kansas to the Front Range of Colorado: U.S. Geol. Survey Oil and Gas Inv. Chart OC-46.

Malde, H. E., 1955, Surficial geology of the Louisville quadrangle, Colorado: U.S. Geol. Survey Bull. 996-E, p. 217-259.

Malde, H. E., and Van Horn, Richard, 1965, Stratigraphy, soils, and geomorphology of the nonglacial Quaternary deposits between Boulder and Golden, Colorado, Trip 8 *in* Guidebook for one-day field conferences, Boulder area, Colorado—Internat. Assoc. Quaternary Research, 7th Cong., U.S.A., 1965: Lincoln, Nebr., Nebraska Acad. Sci., p. 40-47.

Maughan, E. K., and Wilson, R. F., 1960, Pennsylvanian and Permian strata in southern Wyoming and northern Colorado, *in* Rocky Mtn. Assoc. Geologists, Guide to the geology of Colorado: Denver, p. 34-42.

McKee, E. D., and others, 1956, Paleotectonic maps of the Jurassic System, *with a separate section on* Paleogeography, by R. W. Imlay: U.S. Geol. Survey Misc. Geol. Inv. Map I-175.

———1959, Paleotectonic maps of the Triassic System: U.S. Geol. Survey Misc. Geol. Inv. Map I-300, 33 p.

Mehl, M. G., 1931, Additions to the vertebrate record of the Dakota sandstone: Am. Jour. Sci., 5th ser., v. 21, no. 125, p. 441-452.

Mielenz, R. C., Greene, K. T., and Schieltz, N. C., 1951, Natural pozzolans for concrete: Econ. Geology, v. 46, no. 3, p. 311-328.

Miller, R. D., Van Horn, Richard, Dobrovolny, Ernest, and Buck, L. P., 1964, Geology of Franklin, Webster, and Nuckolls Counties, Nebraska: U.S. Geol. Survey Bull. 1165, 91 p.

Moody, J. D., 1947, Upper Montana group, Golden area, Jefferson County, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 8, p. 1454-1471.

Moore, D. G., and Scruton, P. C., 1957, Minor internal structures of some recent unconsolidated sediments [Gulf of Mexico]: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 12, p. 2723-2751.

Morrison, R. B., and Frye, J. C., 1965, Correlation of the middle and late Quaternary successions of the Lake Lahontan, Lake Bonneville, Rocky Mountain (Wasatch Range), southern Great Plains, and eastern Midwest areas: Nevada Bur. Mines Rept. 9, 45 p.

Mullineaux, D. R., and Crandell, D. R., 1962, Recent lahars from Mount St. Helens, Washington: Geol. Soc. America Bull., v. 73, no. 7, p. 855–869.

Munsell Color Co., 1954, Munsell soil color charts.

Nelson, C. E., 1969, Salvage archaeology on Van Bibber Creek, Site 5JF10: Southwestern Lore, v. 34, no. 4, p. 85–106.

Ogden, Lawrence, 1954, Rocky Mountain Jurassic time surface: Am. Assoc. Petroleum Geologists Bull., v. 38, no. 5, p. 914–916.

Oriel, S. S., and Craig, L. C., 1960, Lower Mesozoic rocks in Colorado, *in* Rocky Mtn. Assoc. Geologists, Guide to the geology of Colorado: Denver, p. 43–58.

Osterwald, F. W., 1961, Critical review of some tectonic problems in Cordilleran foreland: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 2, p. 219–237.

Patton, H. B., 1905, Faults in the Dakota formation at Golden, Colorado: Colorado School Mines Bull., v. 3, p. 26–32.

Peterson, W. L., 1964, Geology of the Platte Canyon quadrangle, Colorado: U.S. Geol. Survey Bull. 1181-C, 23 p.

Powers, H. A., 1961, Chlorine and fluorine in silicic volcanic glass, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424-B, p. B261–B263.

Powers, H. A., Young, E. J., and Barnett, P. R., 1958, Possible extension into Idaho, Nevada, and Utah of the Pearlette ash of Meade County, Kansas [abs.]: Geol. Soc. America Bull., v. 69, no. 12, p. 1631.

Prommel, H. C., and Hopkins, P. M., 1964, Metallic mineral resources—Placer gold, *in* Mineral and water resources of Colorado: U.S. Cong., 88th, 2d sess., Comm. Print, p. 85-93.

Reeside, J. B., Jr., 1957, Paleoecology of the Cretaceous seas of the Western Interior of the United States, Chap. 18 *of* Ladd, H. S. ed., Paleoecology: Geol. Soc. America Mem. 67, p. 505–541.

Reichert, S. O., 1954, Geology of the Golden-Green Mountain area, Jefferson County, Colorado: Colorado School Mines Quart., v. 49, no. 1, 96 p.

———1956, Post-Laramie stratigraphic correlations in the Denver basin, Colorado: Geol. Soc. America Bull., v. 67, no. 1, p. 107–111.

Richardson, G. B., 1912, Structure of the foothills of the Front Range, central Colorado [abs.]: Washington Acad. Sci. Jour., v. 2, p. 429–430.

Richmond, G. M., 1962, Quaternary stratigraphy of the La Sal Mountains, Utah: U.S. Geol. Survey Prof. Paper 324, 135 p.

Rubin, Meyer, and Alexander, Corrinne, 1960, U.S. Geological Survey radiocarbon dates,]Pt.] 5: Am. Jour. Sci. Radiocarbon Supp., v. 2, p. 129–185.

Schlocker, Julius, 1947, Clays of the montmorillonite-nontronite group in basaltic rocks near Golden, Colorado [abs.]: Geol. Soc. America Bull., v. 58, no. 12, pt. 2, p. 1225.

Scott, G. R., 1961, Preliminary geologic map of the Indian Hills quadrangle, Jefferson County, Colorado: U.S. Geol. Survey Misc. Geol. Inv. Map I-333.

———1962, Geology of the Littleton quadrangle, Jefferson, Douglas, and Arapahoe Counties, Colorado: U.S. Geol. Survey Bull. 1121-L, 53 p.

———1963a, Quaternary geology and geomorphic history of the Kassler quadrangle, Colorado: U.S. Geol. Survey Prof. Paper 421-A, p. 1–70.

———1963b, Bedrock geology of the Kassler quadrangle, Colorado: U.S. Geol. Survey Prof. Paper 421-B, p. 71–125.

———1970, Quaternary faulting and potential earthquakes in east-central Colorado, *in* Geological Survey research 1970: U.S. Geol. Survey Prof. Paper 700-C, p. C11–C18.

———1972, Geologic map of the Morrison quadrangle, Jefferson County, Colorado: U.S. Geol. Survey Misc. Geol. Inv. Map I-790-A.

Scott, G. R., and Cobban, W. A., 1959, So-called Hygiene group of northeastern Colorado [and Wyo.], *in* Rocky Mtn. Assoc. Geologists, Symposium on Cretaceous rocks of Colorado and adjacent areas: p. 124–131.

———1964, Stratigraphy of the Niobrara Formation at Pueblo, Colorado: U.S. Geol. Survey Prof. Paper 454-L, 30 p.

———1965, Geologic and biostratigraphic map of the Pierre Shale between Jarre Creek and Loveland, Colorado: U.S. Geol. Survey Misc. Geol. Inv. Map I-439, 4 p.

Shapiro, Leonard, and Brannock, W. W., 1956, Rapid analysis of silicate rocks: U.S. Geol. Survey Bull. 1036-C, p. 19–56.

Sheridan, D. M., Maxwell, C. H., and Albee, A. L., 1967, Geology and uranium deposits of the Ralston Buttes district, Jefferson County, Colorado, *with sections on* Paleozoic and younger sedimentary rocks, by Richard Van Horn: U.S. Geol. Survey Prof. Paper 520, 121 p.

Sheridan, D. M., Reed, J. C., Jr., and Bryant, Bruce, 1972, Geologic map of the Evergreen quadrangle, Jefferson County, Colorado: U.S. Geol. Survey Misc. Geol. Inv. Map I-786-A.

Schrock, R. R., 1948, Sequence in layered rocks, a study of features and structures useful for determining top and bottom or order of succession in bedded and tabular rock bodies: New York, McGraw-Hill, 507 p.

Smith, J. H., 1964, Geology of the sedimentary rocks of the Morrison quadrangle, Colorado: U.S. Geol. Survey Misc. Geol. Inv. Map I-428.

Spencer, F. D., 1961, Bedrock geology of the Louisville quadrangle, Colorado: U.S. Geol. Survey Geol. Quad. Map GQ-151.

Stewart, W. A., 1952, Structure and oil possibilities of the west flank of the Denver basin [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 36, no. 5, p. 966.

———1955, Structure of the foothills area west of Denver, Colorado, *in* Rocky Mtn. Assoc. Geologists, Field Conf. Guidebook 1955: p. 25–30.

Thompson, W. O., 1949, Lyons sandstone of Colorado Front Range: Am. Assoc. Petroleum Geologists Bull., v. 33, no. 1, p. 52–72.

Tieje, A. J., 1923, The red beds of the Front Range in Colorado; a study in sedimentation: Jour. Geology, v. 31, no. 3, p. 192–207.

Trask, P. D., 1932, Origin and environment of source sediments of petroleum: Houston, Tex., Am. Petroleum Inst. (printed by the Gulf Publishing Co.), 323 p.

U.S. Bureau of Reclamation, 1960, Earth manual: Washington, U.S. Govt. Printing Office, 751 p. (revised 1963).

U.S. Department of Agriculture, 1951, Soil Survey manual [revised ed.]: U.S. Dept. Agriculture Handb. 18, 503 p.

———1962, Identification and nomenclature of soil horizons: U.S. Dept. Agriculture, Supp. to Agriculture Handb. 18, p. 173–188.

Van Horn, Richard, 1954, Landslides near Golden, Colorado: Engineers' Bull., v. 38, no. 12, p. 6, 15.

———1957a, Ralston Creek formation, new name for Ralston formation of LeRoy (1946) [Colo.]: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 4, p. 755–756.

———1957b, Bedrock geology of the Golden quadrangle, Colorado: U.S. Geol. Survey Geol. Quad. Map GQ-103.

———1967, Soils on upper Quaternary deposits near Denver, Colorado, *in* Geological Survey research 1967: U.S. Geol. Survey Prof. Paper 575-D, p. D228-D232.

———1968a, Preliminary surficial geologic map and materials test data of the Golden quadrangle, Jefferson County, Colorado: U.S. Geol. Survey open-file report, 3 sheets.

———1968b, Physical property and construction use data sheet for surficial deposits: Assoc. Eng. Geologists Bull., v. 5, no. 1, p. 18–22.

———1972, Surficial and bedrock geologic map of the Golden quadrangle, Jefferson County, Colorado: U.S. Geol. Survey Misc. Geol. Inv. Map I-761-A.

Van Tuyl, F. M., and McLaren, R. L., 1932, Occurrences of oil in crystalline rocks in Colorado: Am. Assoc. Petroleum Geologists Bull., v. 16, no. 8, p. 769-776.

Waage, K. M., 1952, Clay deposits of the Denver-Golden area, Colorado: Colorado Sci. Soc. Proc., v. 15, no. 9, p. 373-390.

———1955, Dakota group in northern Front Range foothills, Colorado: U.S. Geol. Survey Prof. Paper 274-B, p. 15-51.

———1959, Stratigraphy of the Dakota group along the northern Front Range foothills, Colorado: U.S. Geol. Survey Oil and Gas Inv. Chart OC-60.

———1961, Stratigraphy and refractory clayrocks of the Dakota group along the northern Front Range, Colorado: U.S. Geol. Survey Bull. 1102, 154 p.

Wahlstrom, E. E., 1948, Pre-Fountain and recent weathering on Flagstaff Mountain near Boulder, Colorado: Geol. Soc. America Bull., v. 59, no. 12, pt. 1, p. 1173-1189.

Waldschmidt, W. A., 1939, The Table Mountain lavas and associated igneous rocks near Golden, Colorado: Colorado School Mines Quart., v. 34, no. 3, 62 p.

Wells, J. D., 1967, Geology of the Eldorado Springs quadrangle, Boulder and Jefferson Counties, Colorado: U.S. Geol. Survey Bull. 1221-D, 85 p.

Wells, J. D., Sheridan, D. M., and Albee, A. L., 1964, Relationship of Precambrian quartzite-schist sequence along Coal Creek to Idaho Springs Formation, Front Range, Colorado: U.S. Geol. Survey Prof. Paper 454-O, p. O1-O25.

Williams, Howel, Turner, F. J., and Gilbert, C. M., 1954, Petrography—An introduction to the study of rocks in thin sections: San Francisco, W. H. Freeman and Co., 406 p.

Yen, T. C., 1952, Molluscan fauna of the Morrison Formation, *with a section on* Summary of the stratigraphy of the Morrison formation, by J. B. Reeside, Jr.: U.S. Geol. Survey Prof. Paper 233-B, p. 21-51.

Ziegler, Victor, 1917, Foothills structure in northern Colorado: Colorado School Mines Quart., v. 12, no. 2, 39 p.

INDEX

[Page numbers of major references are in italics]

☆U.S. GOVERNMENT PRINTING OFFICE: 1976—677-340/64