Geology and Mineral Deposits of the Poncha Springs NE Quadrangle, Chaffee County, Colorado

By RALPH E. VAN ALSTINE

With a section on

Fluorspar Mines and Prospects

By RALPH E. VAN ALSTINE *and* DOAK C. COX

GEOLOGICAL SURVEY PROFESSIONAL PAPER 626

Prepared in cooperation with the
Colorado State Mining Industrial
Development Board

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1969

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. 70-602625

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

72 3656 309 97

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By Ralph E. Van Alstine

ABSTRACT

The Poncha Springs NE quadrangle, which contains a major fluorspar district, is in the Arkansas Valley between the Sawatch Range and the southward extension of the Park Range. Altitudes in the quadrangle lie between approximately 7,290 feet and 9,290 feet.

The geologic units mapped consist of Precambrian metamorphic and igneous rocks, Tertiary volcanic and sedimentary rocks, and unconsolidated Pleistocene and Holocene deposits. Precambrian hornblende gneiss and banded quartz-feldspar-biotite gneiss are intruded by a large mass of gneissic quartz monzonite. Quartzite and silicated marble are interlayered with the gneisses, which, together with other structural and mineralogic evidence, suggests that the metamorphic rocks were originally sediments. The gneissic quartz monzonite occupies about 25 square miles of the quadrangle and is cut by tabular bodies of granite, aplite, pegmatite, lamprophyre, dacite porphyry, and diabase, and by quartz veins that locally contain orthoclase, magnetite, specular hematite, pyrite, chalcopyrite, chlorite, and traces of purple fluorite.

The Tertiary volcanic and sedimentary rocks immediately overlie the Precambrian rocks. Volcanic rocks in the southern part of the quadrangle locally are more than 600 feet thick. The volcanic rocks consist chiefly of a lower unit of ash, mudflow deposit, and a rhyodacite porphyry flow of Eocene(?) age and an upper unit of ash-flow tuff that has black vitrophyre near the base and a grayish-pink to reddish-brown devitrified tuff above. The ash-flow tuff is early Oligocene in age, based upon potassium-argon dating of the black vitrophyre and upon pollen and spores found in tuff immediately underlying it.

A unit consisting of pyroclastic rocks, perlite, and a rhyolite flow that contains garnet and topaz, at the north edge of the quadrangle, is here named the Nathrop Volcanics. Dating by the potassium-argon method indicates that the perlite and rhyolite flow are late Oligocene in age.

Tuffaceous siltstone forms seven small masses resting directly on Precambrian rocks in the south-central part of the quadrangle. This unit, here called the Browns Canyon Formation, contains leaves and pollen comparable to the Creede flora and is Miocene in age.

Unconsolidated beds of clay, silt, sand, and gravel of the Dry Union Formation underlie most of the western part of the quadrangle. These sediments locally contain shards of volcanic glass, bentonite, and rhyolitic tuff layers. Vertebrate fossils indicate that the formation is Miocene and Pliocene in age.

Pleistocene deposits mantle much of the Dry Union Formation in the western part of the quadrangle; the deposits formed as outwash from multiple stages of mountain glaciation in the Sawatch Range to the west. In this quadrangle and the one immediately south, a sequence of nine gravel deposits was established, five of Wisconsinan Age and four older. A chevkinite-bearing rhyolitic volcanic ash in the third oldest gravel unit may be the equivalent of the Pearlette Ash Member of the Sappa Formation of late Kansan age in Kansas and Nebraska.

Holocene deposits consist of alluvium, colluvium, talus, landslide debris, and peat. The peat, determined to be less than 200 years old by radiocarbon dating, contains excellently preserved pollen, and bison and horse bones.

The quadrangle is on the east flank of the north-trending Sawatch anticline. The geologic structure is widely varied and ranges from complex folds in the Precambrian rocks to a linear fault trough of Tertiary age that parallels the Arkansas Valley. Steeply dipping foliation in the Precambrian metamorphic rocks generally strikes northeast or east. The foliation in the gneissic quartz monzonite mass commonly is parallel to that of the adjacent gneisses, although locally the mass is slightly discordant. The regional attitudes of several of the Tertiary units reflect downfaulting to the west, along the linear fault trough. A horst of Precambrian rocks overlain by patches of Miocene siltstone extends northwest as a salient into the fault trough. The normal fault bounding the horst on the southwest has localized major fluorspar deposits in the area.

The landscape is characterized by gently sloping surfaces at ten levels. The highest and earliest surface is a pediment of late Tertiary age. Three intermediate surfaces are pediments of early Pleistocene age, and six lower surfaces are on terraces of later Pleistocene age. Canyons or valleys have been cut at intervals since the late Tertiary pediment formed. The Arkansas River is superimposed from upper Tertiary sediments onto the hard rocks of the Browns Canyon area. The river flows for 9 miles through this canyon, a narrow gorge cut more than 500 feet deep in bedrock.

Epithermal deposits in the Browns Canyon district have yielded about $5 million worth of commercial fluorspar. Between 1927 and 1949 about 130,000 tons of fluorspar concentrates was recovered from about twice this quantity of ore. Deposits of copper, gold, gravel and sand, peat, pegmatite minerals, pumice and perlite, quartzite, and vermiculite also have been exploited in the quadrangle, but in 1967 only peat was being extracted.

The main normal fault zone forming the southwest boundary of a horst is mineralized with fluorspar almost continuously for nearly 3,000 feet. This fault zone, striking northwest between Precambrian rocks and Tertiary volcanic rocks, consists of two nearly parallel branches along much of its length; the east branch has yielded more fluorspar than the west branch.

Although the veins consist largely of fluorite and microcrystalline and chalcedonic quartz, some coarser grained quartz, opal, calcite, barite, pyrite, marcasite, black manganese oxides, iron oxides, and clay minerals also are present. The fluorite is mostly microgranular to fine grained and layered, and commonly has botryoidal, mammillary, and reniform surfaces and nodular structures. Pyrolusite, manganite, and psilomelane, identified by X-ray and spectrographic studies, were deposited earlier than, and contemporaneously with, the fluorite. Silicification and fluoritization were the major types of wallrock alteration.

Moderately alkaline fluoride waters, probably largely meteoric but with volcanic contributions, were found in fluorspar mine workings and nearby thermal springs. Chemical analyses indicated 13–15 parts per million fluoride, which is high for thermal springs closely associated with epithermal mineral deposits.

The late Tertiary fluorspar deposits formed under near-surface hot spring conditions from very dilute fluids; primary fluid inclusions in the fluorite are essentially fresh water. Study of the inclusions indicates that the temperature of deposition was about 119°–168°C. The heat and fluoride are regarded as volcanic contributions to the mineralizing fluid.

Estimated fluorspar resources of the Browns Canyon district total about two million short tons of crude material containing more than 15 percent CaF_2. Ore bodies mined were less than 10 feet to nearly 50 feet thick and ranged in grade from less than 25 percent to more than 75 percent CaF_2. Similar fluorspar resources may be found by exploring the known deposits further and by prospecting along certain other faults that are unexplored or inadequately tested. Geochemical prospecting, as a part of this project, revealed abnormal fluorine concentrations in residual soil and alluvium near a known vein.

INTRODUCTION

The Poncha Springs NE quadrangle is at the east edge of the Colorado mineral belt (Tweto and Sims, 1963, fig. 2) in the southern part of Chaffee County, central Colorado. The 7½-minute quadrangle, about 6 miles north of Salida and 100 miles southwest of Denver, covers nearly 60 square miles of T. 15 S., Rs. 77 and 78 W., Sixth Principal Meridian, and T. 51 N., Rs. 8 and 9 E., New Mexico Principal Meridian (fig. 1).

The quadrangle is in the Southern Rocky Mountains, near the junction of three major elongate ranges, and just east of the Continental Divide. It is north of the Sangre de Cristo Range, east of the Sawatch Range, which contains the highest peaks of Colorado, and west of the south termination of the Mosquito or Park Range. The area is traversed by the Arkansas River, which flows south for about 9 miles through Browns Canyon, a narrow gorge cut in bedrock. The area west of the Arkansas River is readily accessible from U.S. Highway 285, Colorado State Highway 291, and Chaffee County roads; east of the river, however, only the margins of the area are accessible by jeep. Elsewhere, service routes in San Isabel National Forest, east and west of the Arkansas Valley, provide access in the quadrangle.

This report describes the Precambrian, Tertiary, and Pleistocene geology and the mineral deposits that were investigated. Special attention is given to deposits of fluorspar, the most economically important mineral product of the area.

EARLIER REPORTS

Early geologic information, chiefly concerning the geomorphology and the unconsolidated materials of the upper Arkansas Valley, appears in various accounts of the Hayden surveys (Hayden, 1869, p. 76–78; 1874, p. 48–50; and 1876, p. 51–53). Cross (1886, 1893, 1895) presented some mineralogic, petrographic, and chemical data on the Precambrian and Tertiary rocks of the Salida area. Campbell (1922, p. 90–96 and sheet 3) described the geomorphology of the Denver & Rio Grande Western Railroad route along the Arkansas River in Browns Canyon. Powers (1935) discussed the physiographic history of the upper Arkansas Valley and described terraces that extend into the quadrangle. The geologic map of Colorado (Burbank and others, 1935) and Lovering and Goddard (1950, pl. 1) showed the rocks of this area as Precambrian hornblende gneiss and undivided Tertiary volcanic rocks.

Cox (1945, p. 270–277) and Van Alstine (1947, p. 460–463) briefly described some of the fluorspar deposits, and Bush (1951, p. 314, 326) gave information on pumice and perlite near Ruby Mountain at the north edge of the quadrangle. Honea (1955) also reported on the volcanic rocks of the Ruby Mountain area. Information on the geology and mineral deposits of areas next to this quadrangle is given in reports by Behre, Osborn, and Rainwater (1936), Bhutta (1954), Crawford (1913), De Voto (1961), Dings and Robinson (1957), Hanley, Heinrich, and Page (1950, p. 23–27), Lindgren (1908), Russell (1950), and Tweto (1960a, p. 1420–1422).

FIELD AND LABORATORY WORK

D. C. Cox, assisted at various times by J. O. Fisher, D. M. Henderson, and T. A. Steven, spent about 10 months from 1943 to 1945 investigating the fluorspar deposits and mapping the adjacent geology on enlarged aerial photographs. A preliminary geologic map, covering about 7 square miles of this quadrangle, was compiled on a planimetric base. The study was part of the U.S. Geological Survey's strategic minerals investigations and led to publications by Cox (1945) and Van Alstine (1947). Van Alstine spent about 2 months in the fluorspar district in 1953 gathering additional data on the fluorspar deposits and reviewing and modifying the earlier unpublished geologic maps. Later he studied more than 100 thin sections of rocks from the quadrangle, and in 1958 he began a more comprehensive investigation of the geology and mineral deposits and recorded the geology on a new topographic map. The present report combines data acquired by Van Alstine and by Cox and assistants, who did most of the detailed mapping of the fluorspar mines in 1943–45 when they were accessible and in operation.

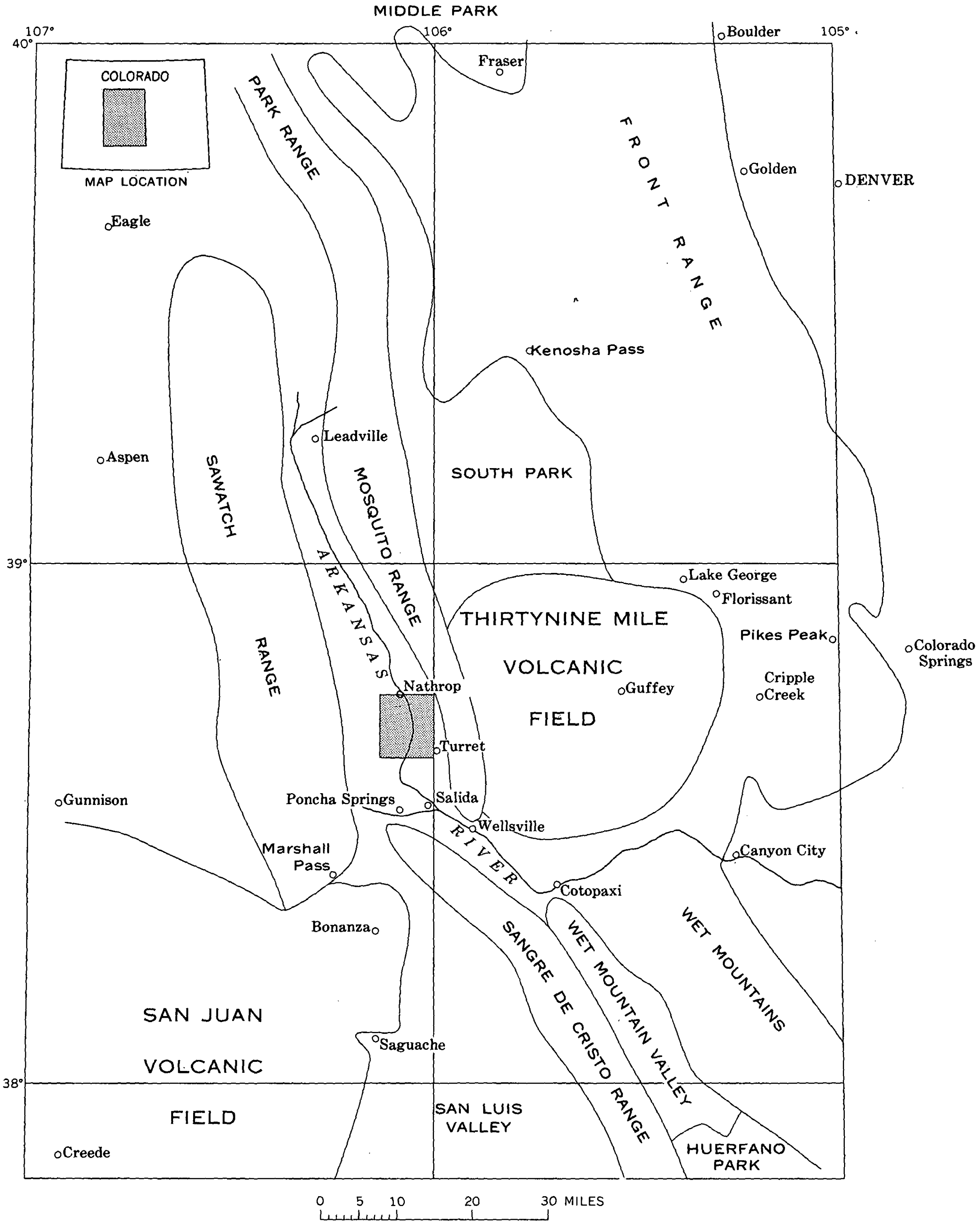


FIGURE 1.—Index map of south-central Colorado, showing location of Poncha Springs NE quadrangle.

Unless stated otherwise in the text, the rock-forming minerals were identified with a flat-stage petrographic microscope; index oils and compositional curves were employed.

ACKNOWLEDGMENTS

The Colorado State Mining Industrial Development Board, the Colorado State Geological Survey Board, and the Colorado State Metal Mining Fund participated in the financial support of the geologic work done intermittently in this quadrangle since 1943.

Among the people who facilitated the fieldwork are Everett Cole and H. B. Stroup, Colorado Fluorspar Corp.; S. F. Wickham, Colorado Fluorspar Mines, Inc.; S. H. Lloyd, American Fluorspar Corp.; R. H. Dickson and W. J. Trepp, General Chemical Division, Allied Chemical Corp.; P. L. Bancroft, U.S. Fluorspar & Manganese, Inc.; F. A. Mansheim, Commercial Minerals, Inc.; and R. W. Kramer, Kramer Mines, Inc.

I am indebted to many professional colleagues in the U.S. Geological Survey for field discussions of geologic problems, for chemical and spectrographic analyses, potassium-argon age determinations, for fluid inclusion investigations, and for X-ray identification of some minerals. Collaboration with M. G. Dings and C. T. Wrucke, U.S. Geological Survey, during their geologic investigations in the quadrangle bordering on the east, was especially helpful. Several U.S. Geological Survey geologists studied and identified the fossil collections, as follows: vertebrates, G. E. Lewis; plants, R. W. Brown and J. A. Wolfe; pollen, E. B. Leopold; and silicified wood, R. A. Scott. I am particularly grateful to Dwight R. Crandell, Gerald M. Richmond, and Glenn R. Scott, all of the U.S. Geological Survey, for advice, in the field, about the Pleistocene features. Mr. Richmond determined part of the glacial chronology in the quadrangle; his specific help and that of others are acknowledged at appropriate places in the text.

The suggestions of R. A. Sheppard and T. A. Steven, U.S. Geological Survey, who reviewed the manuscript, are sincerely appreciated.

SETTLEMENT AND CLIMATE

In 1779, Juan Bautista de Anza and a small armed force of Spaniards were the first white men to enter this area (Waters, 1958, p. 714). Zebulon M. Pike and his men, on an army expedition to the Arkansas Valley, South Park, and the San Luis Valley, spent Christmas of 1806 west of Salida. In 1860, placer gold was found nearby in Chaffee County, and irrigation and farming soon started. The Denver & Rio Grande Western Railroad in 1880 extended tracks from the Royal Gorge westward through Salida, which became the starting point for several narrow-gage branch lines.

The quadrangle is still sparsely inhabited, mainly by ranchers. Nathrop, situated along the Arkansas River and U.S. Highway 285 at the north edge of the area, contains about 10 homes. Salida, the seat of Chaffee County, is 6 miles southeast of this area and has about 5,000 inhabitants.

Temperatures at Salida since 1902 have ranged from 100°F to minus 35°F, with an annual mean of 45.7°F (Waters, 1958, p. 410–412). The mean annual precipitation is 11 inches at Salida and less than 10 inches in the arid intermontane basin between Salida and Buena Vista, 22 miles northwest. At Salida, about 1.5 inches of monthly precipitation falls in July and in August; about 1 inch per month in March, April, May, June, September, and October; and about 0.5 inch per month in January, February, November, and December. The average frost-free growing season is 111 days and extends from May 30 to September 18. The irrigated, fertile, broad benchlands west of the Arkansas River and south of Nathrop provide the basis for agricultural, dairy, and livestock products. As a result of the arid climate, vegetation elsewhere is meager, except along the valleys and north-facing slopes.

TERRAIN

Maximum relief is 2,000 feet; altitudes range from 7,290 feet, where the Arkansas River flows south from the area, to about 9,290 feet, at the northeast corner and east margin of the quadrangle. In most of the area west of the Arkansas River, surfaces on Pleistocene outwash and alluvial deposits rise gradually westward to an altitude of about 8,460 feet at the margin of the quadrangle. The Pleistocene deposits and older Tertiary unconsolidated deposits are dissected by Holocene and Pleistocene drainage. In the area east of the river, a highly dissected broad surface, developed chiefly upon Precambrian rocks, slopes gently westward toward Browns Canyon. This canyon is 400–600 feet deep throughout most of its length.

GEOLOGIC UNITS

Precambrian metamorphic and igneous rocks and Tertiary volcanic and sedimentary rocks form the bedrock exposed in the quadrangle (pl. 1). Locally, unconsolidated Pleistocene and Holocene deposits overlie these rocks. Paleozoic rocks crop out about 3,000 feet east of the quadrangle, and Mesozoic rocks have been mapped about 20 miles southwest and northeast of the quadrangle (Burbank and others, 1935).

PRECAMBRIAN ROCKS

METAMORPHIC ROCKS

Precambrian metamorphic rocks occupy about 4 square miles in the southeastern and south-central parts of the quadrangle and consist of banded quartz-feldspar-biotite gneiss and hornblende gneiss. The map units shown on plate 1 represent the predominant rock type at any given locality; the two rock types intergrade in places and commonly are so thinly interlayered that they could not be differentiated at the present map scale. The original thickness of the metamorphic rocks has not been determined but seems to have been several thousands of feet.

BANDED GNEISS

The banded gneiss is a fine- to medium-grained foliated rock that consists chiefly of quartz, plagioclase, microcline, and biotite. The color ranges from nearly white to almost black, depending upon the relative amounts of light and dark minerals. Layers of a leucocratic or felsic quartz-rich variety are especially resistant to erosion; locally, this variety is clearly a quartzite.

Thin sections of banded gneiss have characteristic ranges of mineral composition as follows: Approximately 30 to more than 90 percent quartz, a few percent to 40 percent plagioclase, 5–25 percent microcline, and 0–15 percent biotite; hornblende, muscovite, and garnet constitute a few percent of some specimens. Magnetite apatite, and sphene are the common accessory minerals, and zircon is rare. Quartz occurs chiefly as rounded and irregular grains that have wavy extinction; some are rimmed by chlorite, and others have sutured margins. The plagioclase is chiefly andesine. A dark, mafic variety of banded gneiss contains a small quantity of labradorite and hornblende; in the leucocratic variety, oligoclase and albite are the chief plagioclase minerals. Some of the feldspar grains have wavy extinction and granulated margins.

The foliation is especially well shown by the arrangement of flakes, clusters, lenses, wispy layers, and larger bands of the micaceous minerals. In places, lenses and clots of biotite and muscovite poikilitically enclose quartz and plagioclase. Lineation locally is evidenced by the elongation of quartz or hornblende within the plane of foliation. Some of the strongly foliated banded gneiss contains ptygmatic folds and highly crenulated veinlets of quartz, plagioclase, and biotite, especially near a large intrusive body. The grains are equidimensional in some layers of banded gneiss, and the rock is a granulite.

The plagioclase in some banded gneiss is partly altered to sericite and clinozoisite, but adjacent microcline is unaltered. Biotite is partly altered to chlorite; hornblende to chlorite, epidote, clinozoisite, and magnetite; and magnetite to hematite. Some specimens of gneiss contain a few grains of pyrite and microscopic veinlets of calcite.

Gray fine-grained banded marble forms thin concordant layers in banded gneiss in a railroad cut along the Arkansas River in SE¼SW¼ sec. 14, T. 51 N., R. 8 E. The marble layers are 2–8 inches thick and are traceable along strike for only a few feet. The marble is composed of calcite, garnet, scapolite (mizzonite), diopside, epidote, clinozoisite, and a few grains of microcline, perthite, quartz, biotite, and sphene. The silicate minerals occur as grains and clusters within and between calcite grains. Most of the interlocking calcite grains have twin lamellae that are locally bent. Calcite also occurs as very fine grained aggregates and as late-formed veinlets transecting the silicate minerals.

Skarn, in pendants in a gneissic quartz monzonite body, probably formed from similar calcareous layers. At a locality about 2 miles south of the marble layers in the railroad cut described above, the skarn is composed mainly of garnet, epidote, quartz, and calcite; that at another locality, about three quarters of a mile north of the cut, is associated with pegmatite and is composed of garnet, epidote, quartz, calcite, scapolite (mizzonite), green fibrous amphibole, and sphene.

HORNBLENDE GNEISS

The hornblende gneiss is a dark, foliated, and fine- to medium-grained rock containing 35–65 percent hornblende, 25–35 percent plagioclase, as much as 10 percent each of biotite and strained quartz, and rare microcline, orthoclase, diopside, and andalusite; magnetite, apatite, and sphene are the abundant accessory minerals. Cordierite is a fairly common but easily overlooked constituent in some specimens of the hornblende gneiss; it is locally twinned, crowded with inclusions, and partly altered to pinite. Oriented flakes and small clusters of biotite define the foliation of the gneiss. In places, lineation is expressed by the parallel orientation of hornblende. The plagioclase commonly is andesine, but locally it is as calcic as bytownite. Some of the hornblende and biotite is altered to chlorite, and the plagioclase is commonly sericitized or saussuritized to aggregates of sericite, clinozoisite, epidote, and a little calcite. Veinlets of epidote and chlorite are conspicuous in many outcrops of hornblende gneiss. At the Ace High and Jack Pot copper prospects, the gneiss has been reorganized into a magnesian skarnlike aggregate of silicate minerals.

ORIGIN

The banded gneiss probably formed by moderate- to high-grade dynamothermal metamorphism of sedimentary rocks. Although nearly all sedimentary textures and structures were destroyed during recrystallization, the concordance of the thin marble layers with the gneiss is regarded as relict from the original sedimentary rocks. The local preponderance of quartz over other minerals, differences in thickness of adjacent layers, and persistence of thin layers along strike for hundreds of feet similarly suggest a sedimentary origin.

The hornblende gneiss was probably also a sedimentary rock, but original textures and structures were obliterated by metamorphism to the amphibolite facies. Layers commonly are structurally conformable with layering in the banded gneiss; although some layers are thick and persistent, others are less than 6 inches thick and lenticular.

IGNEOUS ROCKS

GNEISSIC QUARTZ MONZONITE

Gneissic quartz monzonite occupies about 25 square miles of the quadrangle and forms the southern part of a large granitic mass that extends about 30 miles northward along the Arkansas Valley, nearly to Leadville (Tweto and Sims, 1963, pl. 1). The gneissic quartz monzonite is typically coarse grained, gray to pink, foliated, and porphyroblastic. Crystals of potassium feldspar as much as 2 inches long are abundant; in a few places these porphyroblasts are rounded and lenticular and form augen. Commonly, the gneissic quartz monzonite weathers into topographic domes and large spheroidal boulders.

Thin sections indicate that the rock is hypidiomorphic granular, seriate, and porphyroblastic and that it is composed of quartz (15–47 percent), microcline (10–40 percent), orthoclase (0–15 percent), plagioclase (10–35 percent), biotite (0–8 percent), hornblende (0–5 percent), and the accessory minerals (2–4 percent) magnetite, ilmenite, sphene, apatite, zircon, pyrite, and fluorite. Quartz grains have wavy extinction and some sutured margins; quartz also occurs as blebs in feldspars and as rims around them. Much of the orthoclase is perthitic, and some is intergrown with quartz, forming micropegmatite. Microcline poikilitically encloses quartz, micropegmatite, and plagioclase. Plagioclase, which is partly sericitized and kaolinized, ranges from albite to andesine; oligoclase and andesine are most common. Biotite is greenish brown, and hornblende is bluish green. Colorless garnet and muscovite were observed in several thin sections. Alteration minerals include sericite, kaolinite, penninite chlorite, epidote, calcite, hematite, and limonite.

A chemical analysis (table 1) of the gneissic quartz monzonite represents fresh rock from the Puzzle fluorspar mine along the east side of Chaffee County Road 60, in NW1/4 sec. 27, T. 51 N., R. 8 E. Table 2 gives the norm calculated from the chemical analysis and the mode averaged from three thin sections. As the amounts of quartz, potassium feldspar, and plagioclase are nearly equal, the rock is a quartz monzonite. The chemical analysis and mode are strikingly similar to those of the Browns Pass Quartz Monzonite (Barker and Brock, 1965, especially sample Bf–20 of table 1), which forms syntectonic stocks on the Continental Divide about 12 miles northwest of, and several thousand feet above, the Poncha Springs NE quadrangle.

TABLE 1.—*Chemical composition, in weight percent, of gneissic quartz monzonite, Poncha Springs NE quadrangle*

[Rapid rock analysis by Paul Elmore, Samuel Botts, and Gillison Chloe, employing methods similar to those described by Shapiro and Brannock (1962). BeO and F analyzed by Jesse Warr, Jr. Minor elements determined by semiquantitative spectrographic analysis, Ivan Barlow, analyst. Lab. No. 159507]

Major oxides					
SiO_2	69.9	Na_2O	2.6	P_2O_5	0.24
Al_2O_3	14.5	K_2O	4.9	MnO	.06
Fe_2O_3	1.0	H_2O-	.31	CO_2	.17
FeO	1.8	H_2O+	.83	F	.07
MgO	.53	TiO_2	.62		
CaO	2.3			Total	99.83

Minor elements[1]					
Ag	<0.00007	Dy	<0.003	Sn	0.0003
Ba	.1	Ga	.0015	Sr	.02
Be	.00015	La	.007	V	.005
Ce	.02	Nb	.001	Y	.007
Co	.0005	Ni	.003	Yb	.0007
Cr	.001	Pb	.007	Zr	.1
Cu	.003	Sc	.001		

[1] Elements looked for but not detected: As, Au, B, Bi, Cd, Er, Eu, Gd, Ge, Hf, Hg, Ho, In, Li, Lu, Mo, Nd, Pd, Pr, Pt, Re, Sb, Sm, Ta, Tb, Te, Th, Tl, Tm, U, W, Zn.

NOTE: Powder density by air pycnometer is 2.68.

TABLE 2.—*Norm and mode of gneissic quartz monzonite, Poncha Springs NE quadrangle*[1]

Norm (weight percent)			
Quartz	29.8	Hypersthene	2.8
Orthoclase	28.9	Magnetite	1.4
Albite	22.0	Ilmenite	1.2
Anorthite	11.1	Fluorite	.1
Corundum	.8		
		Total	98.1

Mode (volume percent)			
Quartz	35	Biotite	5
Microcline-perthite	30	Magnetite-ilmenite	1
Andesine (An_{35-40})	29		

[1] Calculated calcite molecule (0.4 percent) regarded as not forming part of the norm, as thin sections indicate calcite is a minor alteration product. All CaO was used to calculate normative anorthite and fluorite.

Radiometric ages have been published for the gneissic quartz monzonite mass in localities northeast and north of the Poncha Springs NE quadrangle. As reported by Grose and Hutchinson (1960, p. 157), biotite from this mass, about 6 miles north of the Poncha Springs NE quadrangle, near Trout Creek Pass along U.S. Highways 24 and 285, was dated by the potassium-argon method as being about 1.43 billion years old (Giffin and Kulp, 1960, p. 220–221). A determination by the rubidium-strontium method, however, gave the age of the same intrusive rock as 1.70 billion years (Hutchinson and Hedge, 1967). Similarly, a rubidium-strontium age determination reported for a whole-rock sample collected in the Arkansas Valley, from a roadcut 0.7 mile north of the intersection of U.S. Highway 24 and Colorado Highway 82, near the north end of the quartz monzonite mass suggests that it was emplaced about 1.65 billion years ago, a time of widespread granitic intrusion in the Sawatch Range (Wetherill and Bickford, 1965). Comparison with granitic masses to the northeast, in or near the Front Range, indicates that these ages are greater than those of the Pikes Peak Granite, which is about 1 billion years old (Aldrich and others, 1958, p. 1129–1130; Hutchinson, 1960, p. 180), and of both the Silver Plume Granite and the granite near Kenosha Pass, which are 1.3 billion years old (Aldrich and others, 1958, p. 1130; Hutchinson, 1960, p. 180). The rubidium-strontium determinations on the gneissic quartz monzonite agree closely with the 1.73 billion-year age of the Boulder Creek Granite, which was determined on zircon by T. W. Stern (U.S. Geological Survey, 1964, p. A95). The gneissic quartz monzonite may represent the widespread crystallization of granitic rocks in middle Precambrian time in Wyoming, Colorado, New Mexico, and Arizona (Aldrich and others, 1957).

The gneissic quartz monzonite is regarded as a synkinematic mass that was emplaced during the period of deformation when the adjacent rocks were folded and metamorphosed. The contacts and foliation of the quartz monzonite mass commonly are parallel to the banded structure and foliation of the adjacent gneisses, although locally the mass is slightly discordant. The south contact and foliation of the gneissic quartz monzonite at the north edge of Stafford Gulch, near the east side of the quadrangle, are parallel to the banding of the adjacent gneiss, which dips about 45° N. Near the south edge of the quadrangle and northwest of the Arkansas River, the foliation dips synformally in gneissic quartz monzonite and in adjacent septa of metamorphic rocks. Locally the igneous rock is gradational into the metamorphic rocks through a zone of migmatite or injected gneiss as much as 10 feet thick. Near its margin, the grain size of the gneissic quartz monzonite commonly is finer and more uniform, biotite content increases, and the foliation is more obvious.

The gneissic quartz monzonite is transected by many breccia zones veined by quartz or chalcedony containing small quantities of orthoclase, magnetite, specular hematite, martite, pyrite, chalcopyrite, chlorite, and traces of purple fluorite. These veins are especially abundant in sec. 27 and the north half of sec. 34, T. 51 N., R. 8 E., where they generally trend northwest in the gneissic quartz monzonite and adjacent metamorphic rocks.

The gneissic quartz monzonite contains many large and small xenoliths of metasedimentary rocks elongated and foliated parallel to the foliation in the igneous rock. Some large pendants of banded gneiss are more resistant to erosion than the gneissic quartz monzonite and stand out as knobs; two quartzite deposits in such pendants are described later. Inclusions of black biotite-magnetite rock form knobs in SW¼ sec. 20 and SE¼ sec. 19, T. 51 N., R. 9 E. Thin-section studies indicate this rock contains about 85 percent biotite, 10 percent magnetite, and about 5 percent quartz, sphene, apatite, and limonite. At a prospect in SW¼ sec. 29, T. 15 S., R. 77 W., biotite in an inclusion of hornblende gneiss is altered to vermiculite.

Dikes and sills of granite, aplite, pegmatite, lamprophyre, dacite porphyry, and diabase, which are described separately below, cut the gneissic quartz monzonite. These tabular intrusive rocks are considered to be Precambrian; they do not extend into the Paleozoic rocks exposed less than a mile beyond the east edge of this quadrangle (C. T. Wrucke, oral commun., Aug. 1965).

TABULAR INTRUSIVE ROCKS

Granite.—Several small dikes of granite cut the gneissic quartz monzonite and in turn are cut by aplite dikes. The granite dikes are exposed at the east edge of the quadrangle, between Sawmill Gulch and Spring Gulch. They generally trend east-northeast, dip steeply, and are foliated approximately parallel to the contacts. The dikes are apophyses of a larger body that crops out a few hundred feet east of the quadrangle edge (C. T. Wrucke, oral commun., Aug. 1965).

The granite is medium grained, except for some coarse potassium feldspar crystals and quartz aggregates, and consists chiefly of microcline, quartz, and plagioclase, and minor biotite, apatite, and magnetite. The microcline is clear and poikilitically encloses quartz blebs, plagioclase, and smaller microcline crystals. Strained quartz occurs as blebs, irregular patches, and aggregates of grains with sutured edges. The plagioclase is andesine, approximately An_{35}; most is clouded by wisps of sericite and stained with hematite. Greenish biotite is partly altered to chlorite; and magnetite, to hematite. The rock is strongly foliated; large microcline crystals, biotite flakes, and plagioclase-rich layers especially show the parallel alinement. Because plagioclase is much less abundant than microcline, the rock is granite rather than quartz monzonite.

Aplite.—Steeply dipping dikes and sills of fine- to medium-grained pink aplite cut the gneissic quartz monzonite and generally crop out as more resistant topographic features. The aplites are as much as 20 feet thick, are cut by thin pegmatite dikes and quartz veins, and are vaguely foliated parallel to their contacts.

Thin-section studies indicate that the aplite is composed chiefly of strained quartz (15–60 percent), microcline (15–55 percent), sericitized plagioclase (5–20 percent), biotite (1–5 percent) partly altered to penninite chlorite, and muscovite (1–2 percent). The plagioclase is albite-oligoclase, a more sodic feldspar than that generally found in the adjacent gneissic quartz monzonite. Minor minerals are epidote, green hornblende, brown garnet, magnetite, apatite, sphene, zircon, rutile, calcite, hematite, and limonite.

Pegmatite.—Steeply dipping dikes and sills of coarse-grained granitic pegmatite cut the gneissic quartz monzonite and adjacent gneisses. The pegmatites are commonly parallel to the foliation in the adjacent rocks or transect it at small angles. Pegmatites are abundant in the areas of Precambrian rocks, and only the larger bodies are shown on the map. The pegmatites range in size from stringers to several bodies more than 50 feet thick north of Cat Gulch at the east edge of the quadrangle. Pegmatites locally cut aplite dikes and are cut by quartz veins.

The pegmatites generally are simple and unzoned; a few have cores of quartz and outer zones containing small clusters of muscovite. Quartz and pink microcline constitute about 90 percent of most pegmatites; graphic texture is locally present. Additional minerals are albite, oligoclase, muscovite, biotite, magnetite, red-brown garnet, black tourmaline, epidote, and very rare green beryl. Much of the magnetite is altered to hematite; a few unaltered octahedrons of magnetite are as much as 1.5 inches across. Many of the pegmatites in the northern part of the quadrangle, between Cottonwood and Middle Cottonwood Creeks, contain pale-rose quartz and black tourmaline, especially in the core zones. Some striated tourmaline crystals are 1 inch in diameter and 4 inches long; many are fractured and cemented by quartz.

North of Cat Gulch, in the west-central part of sec. 29, T. 51 N., R. 9 E., an east-trending pegmatite cuts banded gneiss near the crest of a divide. North of the pegmatite large red-brown garnets occur in a gneissic matrix of cummingtonite, labradorite (approximately An_{50}), biotite, quartz, and minor magnetite, epidote, chlorite, and apatite. The cummingtonite is optically positive with a large optic angle and indices of refraction between 1.66 and 1.68; Z is greenish brown, and X and Y are pale brown. The garnets weather out of the gneiss and accumulate locally at the surface along the north-facing slope. Crystals that have well-formed dodecahedral and trapezohedral faces are as much as 5 inches in diameter and resemble garnets found in metamorphic rocks next to pegmatites at two localities 2.75 and 3.75 miles south in the adjacent Poncha Springs SE quadrangle. Garnet from the southernmost locality, at the old Sedalia copper mine, has been chemically analyzed and found to be almandite with a specific gravity of 4.163 (Penfield and Sperry, 1886, p. 310–311).

Lamprophyre.—Many dikes of dark-gray to greenish-gray lamprophyre transect the gneissic quartz monzonite; one dike cuts the older banded gneiss unit about 800 feet from the mass of gneissic quartz monzonite. Several dikes have chilled borders, and none show marked effects upon the wallrocks. They commonly are less than 10 feet thick, but some are as much as 20 feet thick; several dikes are more than 2 miles long. The dikes generally strike east or northeast, roughly parallel to the trend of foliation in the wallrock, but commonly dip more steeply than the foliation.

The lamprophyres are classed as vogesites or spessartites, as the main constituents are green hornblende and orthoclase or plagioclase, respectively. Porphyritic and panidiomorphic textures are conspicuous; medium-grained to fine-grained phenocrysts are set in a fine-grained to microcrystalline groundmass consisting largely of the same minerals. In most thin sections of vogesite, minor plagioclase (albite to andesine) is zoned. The zoned plagioclase in the spessartite is andesine. Biotite and quartz rarely occur as phenocrysts but commonly are present in the groundmass. Apatite, sphene, and magnetite are abundant accessory minerals. Calcite is found as veinlets, irregular patches, grains, and rims around quartz inclusions; it is an alteration product of hornblende and plagioclase. Other alteration products are kaolinite and sericite formed from orthoclase; sericite, epidote, and clinozoisite, from plagioclase; chlorite, epidote, clinozoisite, and magnetite, from hornblende; chlorite, from biotite; and hematite, from magnetite.

Inclusions in several lamprophyre dikes consist of rounded quartz derived from the older Precambrian rocks; some are nearly 2 cm in diameter. The inclusions consist of grains and aggregates of strained quartz that have embayed and corroded borders. Some of the quartz grains are surrounded by quartz rims that have the same optic orientation as the grains; other grains are rimmed with calcite. In one thin section, a fractured pink garnet inclusion is embayed by the groundmass; rimmed with chlorite (penninite), calcite, and epidote; and cut by veinlets of chlorite and sericite.

Dacite porphyry.—At the east edge of the quadrangle, SE¼ sec. 19, and SW¼ sec. 20, T. 51 N., R. 9 E., a vertical dike of gray dacite porphyry trends eastward in gneissic quartz monzonite. The dike is about 15 feet thick and was traced for approximately 1 mile. The age of the dacite porphyry relative to other dikes in the Precambrian terrane is not known; it is considered Precambrian, but in mineral composition it resembles the granodiorite or quartz monzonite of a Tertiary stock exposed about 2 miles east of the quadrangle (Bhutta, 1954).

The rock consists of medium-grained phenocrysts of zoned plagioclase, greenish-brown biotite, green hornblende, quartz, and rare brownish-green augite in a fine-grained groundmass of these minerals, orthoclase, apatite, and magnetite. The plagioclase is oligoclase-andesine (approximately An_{25-40}), as determined by measuring extinction angles, and is slightly sericitized. Although the hornblende is almost completely altered to aggregates of chlorite, biotite, magnetite, and calcite, the euhedral shapes of original crystals are commonly retained. Other alteration products are epidote and hematite. The quartz grains are rounded and partly resorbed and generally lack undulatory extinction.

Diabase.—Within the gneissic quartz monzonite NW¼ sec. 29, T. 51 N., R. 9 E., at the east edge of the quadrangle, a vertical black diabase dike trends N. 20° E. The dike is about 20 feet thick and was traced for about 500 feet. Its age is not definitely known; because it is not markedly foliated and contains relatively unaltered augite and plagioclase compared with the other types of dikes, the diabase is regarded as one of the youngest dike rocks in the quadrangle.

Microscopic study indicates that the diabase is subophitic and fine grained, except for some plagioclase crystals more than 1 mm long. The plagioclase is andesine (approximately An_{40}), as determined by measuring extinction angles. Augite is pinkish brown and not distinctly pleochroic; some grains are partly altered to chlorite, biotite, and calcite. Magnetite occurs as euhedral crystals and smaller skeleton crystals within plagioclase and augite; it is accompanied locally by irregular patches of pyrite. Apatite needles are common, and grains of epidote occur sparingly.

TERTIARY ROCKS

Tertiary volcanic and sedimentary rocks immediately overlie the Precambrian rocks in the Poncha Springs NE quadrangle, although Paleozoic and Mesozoic rocks exposed in adjacent areas probably once covered this quadrangle. An older sequence of Tertiary volcanic rocks crops out in secs. 22 and 23, T. 51 N., R. 8 E., in the south-central part of the quadrangle. The sequence includes, from base to top: Rhyodacitic ash; volcanic mudflow deposit; rhyodacite porphyry flow; and an ash-flow tuff consisting of minor nonwelded tuff at the base overlain in turn by a black obsidianlike vitrophyre and red-brown and pink t ogray devitrified rhyolitic welded tuff. The rhyodacitic rocks are considered to be Eocene (?), and the rhyolitic tuffs are Oligocene.

A younger sequence of volcanic rocks exposed in the north-central part of the quadrangle, here named the Nathrop Volcanics, consists of pumiceous tuff and breccia, perlite, and a rhyolite flow. The perlite and flow are late Oligocene.

Sedimentary rocks, dominantly tuffaceous siltstone, rest directly on Precambrian rocks in several small areas near the south-central part of the quadrangle. These rocks, here named the Browns Canyon Formation, are regarded as Miocene.

The southwestern part of the quadrangle is covered by essentially unconsolidated beds of clay, silt, sand, and gravel of the Dry Union Formation (Miocene and Pliocene). These sediments locally contain bentonite, shards of volcanic glass, and rhyolitic tuff layers.

RHYODACITIC ASH, VOLCANIC MUDFLOW DEPOSIT, AND FLOW

Poorly consolidated rhyodacitic ash that typically is unstratified and weathers to a greenish-gray soil covers about half a square mile in three separate areas of outcrop in the south-central part of the quadrangle, west of the Arkansas River. The ash rests unconformably on Precambrian rocks and almost everywhere is overlain directly by a rhyodacite porphyry flow. Locally, rhyolitic tuff overlies the ash, or upper Tertiary sediments rest unconformably upon it. The ash is about 10 feet thick west of Chaffee County Road 60 in sec. 27, T. 51 N., R. 8 E., and is estimated to be more than 100 feet thick to the north, in secs. 14, 22, and 23, T. 51 N., R. 8 E.

About 12 feet of distinctly bedded white compact pumiceous argillized tuff dips 20° SW. in an outcrop northwest of the intersection of U.S. Highway 285 and Fourmile Creek, sec. 33, T. 51 N., R. 8 E. This bedded tuff, a local deposit within the rhyodacitic ash, immediately underlies ashy material, lithic tuff containing fragments of rhyodacite porphyry and devitrified perlitic rhyodacite virtrophyre, and a younger rhyodacite porphyry flow. The bedded white tuff is cut by veinlets of chalcedonic silica, calcite, and gypsum.

Some of the rhyodacitic ash is altered to a waxy, conchoidally fracturing bentonitic clay that disaggregates and swells rapidly in water. The predominant clay mineral has indices of refraction of 1.51–1.52 and probably is montmorillonite. Locally the less altered ash contains fragments of greenish glass that has an index of refraction of 1.52 to 1.53, fresh plates of brown and green biotite, zoned oligoclase-andesine, and rare euhedral quartz. The ash commonly is impregnated with calcite, aragonite, and yellow- to red-weathering ankerite.

A local volcanic mudflow deposit, mapped as part of the rhyodacitic ash unit, is 15–20 feet thick, consists chiefly of pebbles and cobbles of rhyodacite porphyry embedded in greenish ash, and lies beneath large boulders of gneissic quartz monzonite embedded in a brownish matrix in the NE¼SE¼ sec. 22, T. 51 N., R. 8 E. Fragments of silicified wood collected at this locality by D. C. Cox were identified by R. W. Brown (written commun., Sept. 22, 1954) as coniferous wood, probably *Abies* sp. Silicified wood, collected from the ash at five other localities by the writer, also was examined by R. W. Brown and R. A. Scott (written commun., Oct. 22, 1963), but provided no additional information. A sample of ash was submitted to Estella B. Leopold, who reported (written commun., Apr. 27, 1964) that it contained no pollen or spores; similarly, G. W. Andrews (oral commun., Mar. 9, 1965) found no diatoms in samples of the ash.

The ash probably has a chemical composition similar to that of the rhyodacite porphyry flow that overlies it in many places; the ash contains abundant pieces of rhyodacite porphyry, and the minerals and indices of refraction of glass in the two units are similar. Evidently the ash is chiefly an early pyroclastic phase of the rhyodacite outburst.

A rhyodacite porphyry flow, as much as 50 feet thick, is well exposed in the E½ sec. 33 and W½ sec. 23, T. 51 N., R. 8 E., in the south-central part of the quadrangle. The rock generally is gray brown when fresh and weathers purplish gray. Plagioclase phenocrysts are partly resorbed conspicuously zoned andesine to labradorite (approximately An_{35}–An_{65}) and are altered locally to sericite and a clay mineral. Euhedral brown and green biotite is slightly altered to chlorite and magnetite. Phenocrysts of augite and pleochroic pink to green hypersthene are rare. Apatite, zircon, and hematite-rimmed magnetite-ilmenite are the accessory minerals. Fluorite, tridymite, calcite, chlorite, a clay mineral, and a zeolite-like mineral occupy some of the round and elliptical vesicles. The conspicuously flow-banded groundmass is commonly cloudy gray to brown and microcrystalline or glassy. The microcrystalline groundmass contains abundant microlites and oriented laths of feldspar. Many specimens have black, reddish-brown, or green glass as the main constituent.

Near the west edge of sec. 27, T. 51 N., R. 8 E., the rhyodacite flow consists of about 5 feet of green perlitic glass having an index of refraction of approximately 1.52. The phenocrysts are biotite, zoned andesine containing glass blebs, and pleochroic hypersthene that is partly altered to chlorite and calcite. The accessory minerals are magnetite, apatite, and zircon. Reddish and black vitrophyre was found in the rhyodacitic volcanic rocks nearby, to the northeast in secs. 22 and 23.

Field and thin-section studies first suggested the rhyodacite flow is an andesite, but chemical analysis indicated it is more appropriately a rhyodacite (table 3). The analyzed sample was collected in NE¼SE¼ sec. 22, T. 51 N., R 8 E. Thin-section study of this analyzed rock shows that the mode is approximately 60 percent cryptocrystalline groundmass, 2 percent vesicles, 30 percent labradorite (An_{55-65}), 5 percent biotite, and 3 percent hypersthene and accessory minerals.

TABLE 3.—*Chemical composition and norm, in weight percent, of rhyodacite porphyry, Poncha Springs NE quadrangle*

[Rapid rock analysis by Paul Elmore, Samuel Botts, and Gillison Chloe, employing methods similar to those described by Shapiro and Brannock (1962). BeO and F analyzed by Jesse Warr, Jr. Minor elements, determined by semiquantitative spectrographic analysis, Ivan Barlow, analyst. Lab. No. 159508]

Major oxides					
SiO_2	60.5	Na_2O	3.6	P_2O_5	0.34
Al_2O_3	18.9	K_2O	3.6	MnO	.06
Fe_2O_3	4.7	H_2O-	1.2	CO_2	<.05
FeO	.37	H_2O+	.95	F	.11
MgO	.86	TiO_2	.79		
CaO	4.4			Total	100.38
Norm					
Quartz	16.1	Corundum	1.8	Ilmenite	0.8
Orthoclase	21.1	Enstatite	2.2	Hematite	4.6
Albite	30.4	Apatite	.7	Rutile	.4
Anorthite	19.7	Fluorite	.1		
				Total	97.9
Minor elements [1]					
Ag	<0.00007	Ga	0.002	Sn	.002
Ba	.2	La	.015	Sr	.2
Be	.0001	Mo	.0003	V	.015
Ce	.03	Nb	.0007	Y	.003
Co	.0015	Ni	.003	Yb	.0003
Cr	.0015	Pb	.03	Zr	.07
Cu	.002	Sc	.0015		

[1] Elements looked for but not detected: As, Au, B, Bi, Cd, Dy, Er, Eu, Gd, Ge, Hf, Hg, Ho, In, Li, Lu, Nd, Pd, Pr, Pt, Re, Sb, Sm, Ta, Tb, Te, Th, Tl Tm, U, W, Zn.

NOTE: Powder density by air pycnometer is 2.63.

The source and age of the rhyodacitic volcanic rocks are problematical. The nearest reported sources of somewhat similar intermediate volcanic rocks are the Buffalo Peaks volcanic center (Stark and others, 1949, p. 105), about 17 miles north, and the caldera of the Thirtynine Mile volcanic field near Guffey, about 25 miles east of the quadrangle (Chapin and Epis, 1964, p. 147–148). Cross and Emmons (1883, p. 14) first reported a sequence of andesitic tuff and flows containing pleochroic hypersthene and hornblende at Buffalo Peaks. At a locality south of Trout Creek and about 5 miles north of the Poncha Springs NE quadrangle, andesitic vitric crystal tuff more than 800 feet thick may correlate with the tuff at Buffalo Peaks (De Voto, 1961). This tuff locally underlies devitrified rhyolitic ash-flow tuff that has a black glass at the base—a sequence like that in the adjacent Poncha Springs NE quadrangle. Andesitic laharic breccias, flow breccias, tuffs, and flows as much as 800 feet thick near the base of the sequence in the Thirtynine Mile volcanic field (Chapin and Epis, 1964, p. 149, 155) underlie tuffaceous sediments of the Antero Formation of Stark and others (1949), which is early Oligocene (Chadronian) in age and was dated primarily by vertebrate fossils (Stark and others, 1949, p. 66; De Voto, 1964, p. 121). A potassium-argon age for a flow in this andesitic unit is 34.1 ± 1.1 million years (Epis and Chapin, 1968, p. 65). The Tertiary rhyodacitic volcanic rocks of the Poncha Springs NE quadrangle may be Eocene, however, for commonly they were strongly weathered or removed by erosion before the overlying lower Oligocene rhyolitic tuffs were deposited.

RHYOLITIC ASH-FLOW TUFF

Rhyolitic ash-flow tuff covers about 2 square miles of the southeastern and south-central parts of the quadrangle (pl. 1). It is locally more than 500 feet thick where it accumulated north of Railroad Gulch, next to east-trending faults. The tuff has patchy distribution and unconformably overlies a weathered and eroded rhyodacite porphyry flow, rhyodacitic ash, and Precambrian rocks. Additional remnants lie immediately east of the quadrangle.

The rhyolitic ash-flow tuff commonly has very pronounced zoning from gray argillized tuff and local yellow opalized tuff at the base, through black vitrophyric densely welded tuff, to gray, reddish-brown, and pink devitrified welded tuff that comprises most of the unit. The black glassy rock near the base forms a very conspicuous and persistent zone.

The lowest rocks in the ash-flow tuff unit in secs. 22 and 23, T. 51 N., R. 8 E., are fossiliferous yellowish- to purplish-gray argillized tuff and local yellow opalized tuff that range in thickness from less than a foot to nearly 20 feet. These altered tuffs are best exposed along the southwest side of Chaffee County Road 60 in SW¼ sec. 23, where three layers of opalized tuff, totaling 3.5 feet in thickness, alternate with argillized tuff through a section about 12 feet thick. This material forms the altered nonwelded and partly welded zones that commonly occur near the base of an ash flow (Smith, 1960, p. 154). The poorly consolidated argillized tuff is composed of angular grains of sanidine, plagioclase, and biotite in a matrix of clay and some limonite. It is poorly exposed in contrast with the interlayered, hard, opalized material.

The yellow opalized tuff consists mainly of conchoidally facturing opal that has a waxy luster. Small cavities are lined with chalcedony and layers of yellow botryoidal opal. The opal contains inclusions, as much as 1 inch in diameter, of rhyodacite porphyry and silicified tuff. Phenocrysts in the layered isotropic opal consist of zoned sanidine, zoned oligoclase-andesine (approximately An_{25-45}), biotite, magnetite, apatite, and zircon. Sanidine and plagioclase occur in approximately equal amounts. The feldspars and biotite are partly opalized along their margins, and a few zoned plagioclase grains have opalized centers. Chalcedony forms irregular patches, veinlets, and spherulitic aggregates within the opal. The opal has an index of refraction of 1.445–1.450; circular, radial, and irregular shrinkage cracks; and relict structures that suggest curved fragments of crushed pumice. Mineral grains form as much as 75 percent of the rock and locally give it a granitoid appearance. Angular feldspar grains commonly are broken and jammed together and have highly disjointed albite twinning; biotite grains are bent against them. These features suggest that some of the opalized material may have been partly welded before being silicified.

The argillized and opalized tuff contains many pieces of fossil wood, some as much as 1 foot in diameter. Most wood is replaced by chalcedony, but some is carbonized. The silicified wood is red, brown, gray, tan, or pale green; yellow opal containing biotite and feldspars locally fills cracks in it.

The black vitrophyre, a very conspicuous cliff-forming glassy unit near the base of the ash-flow tuff, provides an excellent marker for mapping. This glassy unit is best exposed along Chaffee County Road 60, where samples were collected for chemical analysis and for potassium-argon age determination. At a sharp turn in the road, this conchoidally fracturing glassy rock has well-formed columnar structure (fig. 2); some six-faced columns are more than a foot in diameter. North across the gulch from this locality, the black vitrophyre is about 60 feet thick, the maximum thickness of the unit found in the quadrangle.

Brown isotropic glass forms 60–70 percent of the black vitrophyre. Fluidal layering, perlitic structure, and shard structure are very conspicuous. The glass, which has an index of refraction slightly less than 1.51, contains abundant crystal fragments of zoned sanidine, zoned oligoclase-andesine (approximately An_{25-40}), biotite, magnetite, apatite, zircon, and very rare augite. The ratio of sanidine to plagioclase ranges approximately from 1:1 to 2:1. Angular grains of fresh feldspar are as much as 6 mm in diameter; biotite and augite, some slightly altered to chlorite, commonly are

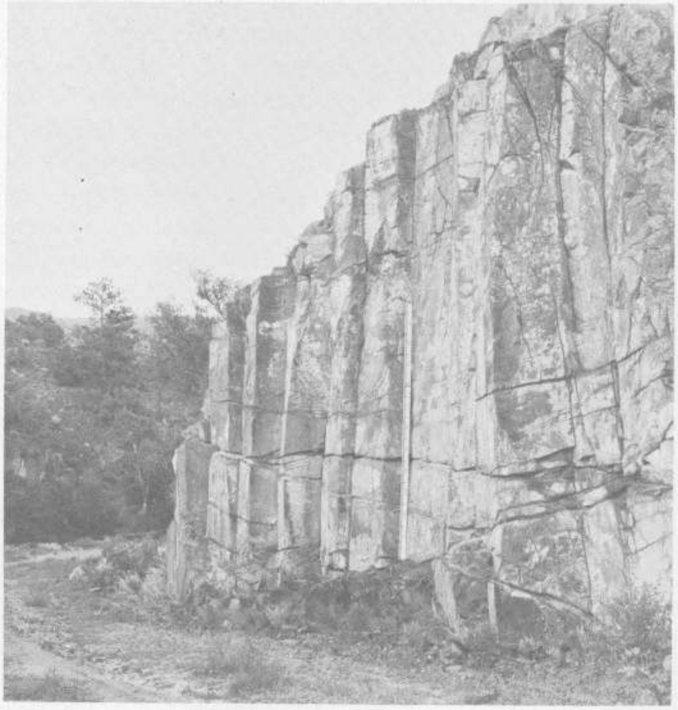


FIGURE 2.—Columnar jointing in black vitrophyric welded tuff, NE¼SE¼ sec. 22, T. 51 N., R. 8 E. Scale indicated by 12-foot rod. Photograph by D. C. Cox.

less than 1 mm in diameter. Locally, veinlets and small, irregular shaped cavities contain calcite, chalcedony, heulandite, and limonitic clay. Inclusions in the black vitrophyre consist of rhyodacite porphyry, silicified crystal tuff, and crushed pumice with glass shards elongated and squeezed between feldspar grains. The inclusions are less than 1 inch in diameter; some have rims of fibrous chalcedony.

Mineralogical, textural, and chemical differences between the ash-flow tuffs from the two areas of volcanic rocks that are separated by about 1 mile of upfaulted Precambrian rocks (pl. 1) near the south edge of the quadrangle suggest that these ash flows may be different units. The ash-flow tuff in the area southwest of the fluorspar district lacks the persistent basal black vitrophyre of the ash-flow tuff to the northeast. An altered and largely devitrified purple porphyritic welded tuff, near the base of a 350-foot section of the southwestern rhyolitic welded tuff and faulted against Precambrian rocks on the 100-foot level of the Colorado-American fluorspar mine, contains unzoned sanidine and albite; the black vitrophyre to the northeast contains zoned sanidine and oligoclase-andesine. The feldspars in the purple welded tuff at the fluorspar deposit are partly replaced by quartz and calcite, which also form many veinlets in the rock.

Northeast of the fluorspar district, pinkish-gray to reddish-brown devitrified welded tuff overlies the black vitrophyre and commonly weathers to pinnacles. This is the thickest and most widespread part of the ash-flow tuff unit; the top is not exposed in the quadrangle, and an unknown thickness has been removed by erosion. Less than 100 feet of devitrified welded tuff remains west of the Arkansas River in SW¼ sec. 23, T. 51 N., R. 8 E., but east of the Arkansas River in secs. 25 and 26, the devitrified tuff is more than 500 feet thick.

Eutaxitic structure within the devitrified welded tuff is generally obvious in outcrops, except where the rock has been strongly silicified or otherwise altered. This streaky foliate structure, produced by the flattening of pumice fragments, is emphasized by alternating pinkish-gray and reddish-brown lenses of materials that have different degrees of porosity or devitrification. Some lenses are more than 2 inches thick and about 1 foot long. Thin sections show that some lenticular and irregular cavities are lined with vapor-phase minerals and alteration products consisting of sanidine, tridymite plates, quartz that contains chlorite plates, limonite-stained chalcedony, and a central filling of euhedral fluorite, barite, and a montmorillonite-type clay mineral.

Layering resembling flow banding of lava is found in a light-pink variety of welded tuff east of the Arkansas River, near the top of the thick section exposed on the divide north of Railroad Gulch. The layering is most pronounced (fig. 3) about 50 feet above and 400–500 feet southwest of an area where a small inlier of Precambrian gneissic quartz monzonite is completely rimmed by outward-dipping black vitrophyric welded tuff (pl. 1). This layering may have been caused

FIGURE 3.—Pronounced layering in devitrified rhyolitic welded tuff, possibly the result of mass flowage during welding. NW¼SW¼ sec. 25, T. 51 N., R. 8 E.

by mass flowage during welding of the ash flow (Smith, 1960, p. 151), which possibly occurred on a steep slope of the buried topography or as a result of movement along the faults about 2,000 feet to the south and southwest.

The devitrified welded tuff is composed chiefly of sanidine, biotite, cristobalite, tridymite, magnetite, apatite, zircon, sphene, fluorite, and topaz in a microcrystalline and locally glassy groundmass that is white, gray, yellow, red, or brown in reflected light. Shard outlines are barely recognizable in much of the devitrified groundmass. Sanidine crystals, some zoned, are as much as 8 mm long; some crystals are partly replaced by quartz, sericite, chlorite, fluorite, calcite, hematite, and a clay mineral. Locally near the base of the devitrified welded tuff, a small quantity of oligoclase-andesine accompanies the sanidine. Biotite is pale brown, reddish brown, and blackish brown and locally contains quartz along the cleavage or is partly replaced by quartz, chlorite, magnetite, or hematite. Inclusions of gray silicified tuff, rhyodacite, and Precambrian rocks generally are less than an inch in diameter. The devitrified welded tuff commonly is silicified; near faults or veins, it may also be argillized, sericitized, chloritized, carbonatized, pyritized, or fluoritized.

The devitrified welded tuff and black vitrophyre are considered different zones of a single genetic unit: both rocks have similar plagioclase and chemical compositions (table 4); plagioclase content decreases progressively upward within the devitrified rock; and the thin, black vitrophyre beneath the devitrified rock is remarkedly persistent in areas both topographically high and low at the time of emplacement. In SW¼ sec. 23, T. 51 N., R. 8 E., the devitrified welded tuff is grayer near the contact with the underlying black vitrophyric welded tuff; here it contains oligoclase-andesine (approximately AN_{25-45}), which is essentially the same composition as that of plagioclase in the underlying vitrophyre. Within the devitrified welded tuff, the ratio of sanidine to plagioclase is approximately 3:1 to 5:1, whereas in the immediately underlying black vitrophyre it is approximately 1:1 to 2:1.

The analyzed black vitrophyre collected from the center of a column (fig. 2) is about 66 percent glass, 17 percent sanidine, 14 percent andesine (about An_{40}), 2 percent biotite, and 1 percent reddish-black iron oxide.

The devitrified welded tuff above the black vitrophyre is widespread in the Cameron Mountain quadrangle east of the Poncha Springs NE quadrangle. A sample of this rock from Herring Park, Park County (SE¼ sec. 26, T. 15 S., R. 76 W.), about 6 miles east of the Poncha Springs NE quadrangle was analyzed for major oxides and minor elements (written communs., M. G. Dings, Apr. 8, 1963, and C. T. Wrucke, Feb. 6, 1967). The analysis (table 4) is remarkably similar to that of the black vitrophyre of the Poncha Springs NE quadrangle, especially if the analysis of the vitrophyre is recalculated on a water-free basis.

A chemical analysis (table 4) of a sample of devitrified welded tuff from the Poncha Springs NE quadrangle (SW¼SW¼ sec. 27, T. 51 N., R. 8 E.) indicates that it is calc-alkalic rhyolite. This analyzed rock is about 62 percent microcrystalline groundmass, 21 percent quartz, 15 percent sanidine, 1 percent biotite, and 1 percent iron-oxide minerals. The rock is somewhat altered in the fluorspar district, as shown by the presence of quartz in veinlets and in aggregates replacing some of the sanidine phenocrysts and by the unusually high $K_2O:Na_2O$ ratio.

TABLE 4.—*Chemical compositions and norms of black vitrophyric welded tuff and devitrified welded tuffs, Chaffee and Park Counties*

[Weight percent]

Sample	Black vitrophyric welded tuff	Devitrified welded tuff	
Lab. No	159509	14166	159510
Chemical analyses			
SiO_2	66.3	69.35	72.7
Al_2O_3	15.9	15.16	13.6
Fe_2O_3	1.2	2.06	1.2
FeO	.57	.16	.28
MgO	.40	.43	.32
CaO	1.3	1.18	.25
Na_2O	3.4	3.51	2.0
K_2O	6.1	6.14	8.0
H_2O^-	.41	.46	.48
H_2O^+	2.9	.54	.72
TiO_2	.52	.46	.46
P_2O_5	.08	.10	.08
MnO	.06	.07	.02
CO_2	<.05	.01	<.05
F	.08	.10	.04
Cl		.03	----------
Subtotal		99.76	----------
Less O		.05	----------
Total	99.22	99.71	100.15
Density [1]	2.49	----------	2.62
Semiquantitative spectrographic analyses			
Ag	<0.00007	[2] 0	<0.00007
Ba	.3	.2	.3
Be	.0003	.0003	.00015
Ce	.03	.02	.03
Cr	[2] 0	.0005	[2] 0
Cu	.0002	.0007	.00015
Ga	.0015	.003	.001
La	.02	.015	.015
Mo	.0005	.0007	[2] 0
Nb	.001	.002	.0015

See footnotes at end of table.

TABLE 4.—*Chemical compositions and norms of black vitrophyric welded tuff and devitrified welded tuffs, Chaffee and Park Counties*—Continued

[Weight percent]

Sample	Black vitrophyric welded tuff	Devitrified welded tuff	
Lab. No	159509	14166	159510
Semiquantitative spectrographic analyses			
Nd	[2] 0	.015	.01
Ni	[2] 0	[2] 0	.01
Pb	.002	.005	.001
Sc	.0007	.0007	.0005
Sr	.1	.07	.05
V	.002	.003	.0015
Y	.003	.005	.002
Yb	.0003	.0005	.0002
Zr	.1	.03	.2
Norms			
Quartz	21.0	22.8	29.5
Orthoclase	37.8	36.1	47.3
Albite	29.3	29.3	16.8
Anorthite	6.7	5.6	1.4
Corundum	1.5	.8	1.1
Enstatite	1.1	1.0	.8
Ilmenite	.9	.5	.6
Magnetite	.5	----------	----------
Hematite	1.0	2.1	1.3
Rutile	----------	.2	.2
Fluorite	.2	.2	----------
Total	100.0	98.6	99.0

[1] Powder density by air pycnometer.

[2] Element was looked for but not detected. Other elements looked for but not detected in all three rocks: As, Au, B, Bi, Cd, Co, Eu, Ge, Hf, Hg, In, Li, Pd, Pr, Pt, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, U, W, Zn. Also looked for but not detected in 159509 and 159510; Dy, Er, Gd, Ho, Lu, Tb, Tm.

159509. Black vitrophyric welded tuff; Poncha Springs NE quadrangle, Chaffee County; rapid rock analysis by Paul Elmore, Samuel Botts, and Gillison Chloe; F analysis by Jesse Warr, Jr.; semiquantitative spectrographic analysis by Ivan Barlow.

14166. Devitrified welded tuff; Cameron Mountain quadrangle, Park County; standard rock analysis by Ellen Daniels; semiquantitative spectrographic analysis by J. C. Hamilton.

159510. Devitrified welded tuff; Poncha Springs NE quadrangle, Chaffee County; rapid rock analysis by Paul Elmore, Samuel Botts, and Gillison Chloe; F analysis by Jesse Warr, Jr.; semiquantitative spectrographic analysis by Ivan Barlow.

Comparison of the minor elements in the rhyodacite porphyry flow (table 3) and in ash-flow tuff (table 4) from the Poncha Springs NE quadrangle vicinity with those in similar silicic volcanic rocks elsewhere (Coats, 1956, p. 76; Rankama and Sahama, 1950; Lipman and others, 1966, p. 32–33) indicates that all these local rocks are high in barium, cerium, lanthanum, strontium, and zirconium; and the rhyodacitic flow is unusually high in lead. The local rocks are low in beryllium, boron, and lithium; their fluorine content is either below the mean (820 ppm) for 167 samples of silicic volcanic rocks of Cenozoic age in the Western United States (Coats and others, 1963), or only slightly greater than this value. The maximum fluorine value is 1,100 ppm for the sample of rhyodacite porphyry.

The ash-flow tuff, including the basal black vitrophyre, is early Oligocene, based on paleobotanical evidence and potassium-argon dating. More than 100 specimens of dark- and light-colored silicified wood were collected from unwelded tuff beneath the black vitrophyre at various localities in the quadrangle vicinity. Some of the first-collected silicified wood specimens were identified as coniferous, probably *Abies* sp., by R. W. Brown (written commun., Sept. 22, 1954). R. A. Scott examined the remainder of the specimens and reported (written communs., May 18, 1960 and Oct. 22, 1963) that they consist of coniferous wood, poorly preserved owing to primary degradation and alteration accompanying silicification. Scott cut sections of the better preserved specimens and tentatively identified one collected near the west edge of sec. 22, T. 15 S., R. 77 W., just east of the quadrangle. He stated in his 1960 communication:

> The observable features of this wood are those of the Podocarpaceae, a family of conifers now chiefly found in the Southern Hemisphere. The wood is tentatively identified as cf. *Podocarpoxylon*. Wood of this type is known only from lower Tertiary rocks in this country. The tentative identification suggests but does not confirm an early Tertiary age for the source beds.

Carbonized fossil plant material also was found in the unwelded tuff at the base of this ash-flow tuff unit. A specimen collected at USGS paleobotany locality D3301, in the SW¼SW¼ sec. 23, T. 51 N., R. 8 E., along the southwest edge of Chaffee County Road 60, contains the following pollen and spores (Estella B. Leopold, written commun., Feb. 1, 1966):

Selaginella cf. *S. densa*
Lycopodium cf. *L. complanatum*
    cf. *L. cernum*
    cf. *L. selago*
Pinus
Picea
Ephedra cf. *E. nevadensis*
    cf. *E. torreyana*
Abies cf. *A. lasiocarpa*
cf. *Juniperus*
Sequoia-Metasequoia group
Zelkova-Ulmus
Quercus
Betula
Ostrya-Carpinus
Alnus cf. *A. japonica*
Juglans
Pterocarya
Carya
cf. *Engelhardtia*
cf. *Conzattia*
Eucommia

According to Miss Leopold, the *Sequoia-Metasequoia* group and about 36 percent of the identified vascular groups are now exotic to the Rocky Mountain region;

these include *Zelkova-Ulmus* of the elm family, *Juglans*, *Pterocarya*, and *Carya* of the walnut family, and *Eucommia* (Eucommiaceae). She stated that in comparison with the Creede flora, which has only 9 percent of its identified genera now exotic to the region (Steven and Ratté, 1965, p. 47), this flora seems older. Recent potassium-argon data (T. A. Steven, written commun., Feb. 1, 1966) suggest a late Oligocene or early Miocene age for the Creede Formation. On the other hand, the flora of the Florissant Formation, which MacGinitie (1953, p. 75) considered early Oligocene, is distinctly older than the flora from the Poncha Springs NE quadrangle (E. B. Leopold, written commun., Feb. 1, 1966). According to Miss Leopold, these comparisons support an Oligocene age for this plant-bearing tuff in the Poncha Springs NE quadrangle.

Potassium-argon age determinations on sanidine and biotite concentrates from the basal black vitrophyric welded tuff gave ages of about 35 million and 37 million years, respectively. The radiometric data for this chemically analyzed rock (table 4 and fig. 2) are given in table 5. Because of recent refinements in analytical techniques used in potassium-argon age determinations, these ages replace the 34±3 million-year age previously published for this rock (Van Alstine, 1965, p. D60). The radiometric ages indicate that the vitrophyre formed during early Oligocene according to the time scales of Kulp (1961) and Holmes (1960), or during the Chadronian "Land-Mammal Age" (32–37 million years ago), as proposed by Evernden, Savage, Curtis, and James (1964, p. 165, 167).

TABLE 5.—*Sample data for potassium-argon age determinations, black vitrophyric welded tuff, Chaffee County*

Mineral	K_2O (weight percent)	Radiogenic Ar^{40} / K^{40}	Radiogenic Ar^{40} / Total Ar^{40}	Age (millions of years)
Sanidine	[1] 10.14	0.00208	0.92	35.4±1.1
Biotite	7.94	.00220	.87	37.3±1.9

[1] Average of 10.11 and 10.16.

Decay constants for K^{40}: $\lambda_\epsilon = 0.585 \times 10^{-10}$ yr^{-1}; $\lambda_\beta = 4.72 \times 10^{-10}$ yr^{-1}.
Atomic abundance of $K^{40} = 1.19 \times 10^{-4}$.
Analysts: R. F. Marvin, H. H. Mehnert, Violet Merritt, Paul Elmore, and H. Smith. U.S. Geol. Survey.
Collection site: NE¼SE¼ sec. 22, T. 51 N., R. 8 E.

The radiometrically dated ash-flow tuff is apparently the same unit as the Agate Creek Formation of De Voto (1964, p. 119–121), which Chapin and Epis (1964, p. 148–151) and Dings (U.S. Geological Survey, 1964, p. A97) indicated is older than the Antero Formation of Stark and others (1949, p. 63–68), dated by vertebrate fossils as early Oligocene. De Voto (1964, fig. 3) mapped his Agate Creek Formation, also chiefly reddish devitrified welded tuff containing black glassy porphyritic welded tuff near the base, intermittently from his type locality to a point in the Antero quadrangle about 1 mile from the northeast corner of the Poncha Springs NE quadrangle. This site is just upslope from the place where the writer collected the silicified wood (p. 14) that appeared to be of early Tertiary age.

The source of this ash-flow tuff is possibly close to the Poncha Springs NE quadrangle, where the basal vitrophyre and overlying devitrified welded tuff are thickest. Chapin and Epis (1964, pl. 1, p. 146) regarded this tuff, their ash flow 4, as having come from the Thirtynine Mile caldera, about 25 miles east of the Poncha Springs NE quadrangle.

NATHROP VOLCANICS

Pumiceous tuff and breccia, perlite that contains black obsidian pellets, and a rhyolite flow that contains small crystals of gem-quality garnet and topaz (Pearl, 1958, p. 70–73) comprise a volcanic sequence more than 500 feet thick along the Arkansas River near Ruby Mountain at the north edge of the quadrangle. This lithologic unit is sufficiently distinct to warrant a separate rock-stratigraphic designation and is here called the Nathrop Volcanics after the small community about half a mile to the west. The volcanic rocks rest directly on Precambrian gneissic quartz monzonite and are of late Oligocene age. They are exposed chiefly in a small readily accessible area, about one-quarter of a mile wide and 1.25 miles long, in the Poncha Springs NE quadrangle and the Buena Vista quadrangle to the north. The type locality is in secs. 11–13, T. 15 S., R. 78 W.

These volcanic rocks formerly had a wider distribution but were partly removed by erosion; a much thinner sequence of the same rocks is exposed in a narrow graben in Precambrian gneissic quartz monzonite in NW¼ NW¼ sec. 29, T. 15 S., R. 77 W., about 2.75 miles southeast of Ruby Mountain. In addition, similar rocks occur on Bald Mountain about 1.5 miles northeast of Ruby Mountain in the Buena Vista quadrangle (Honea, 1955).

The pumiceous tuff is a white to tan, consolidated, generally indistinctly bedded rock containing angular to subrounded unsorted fragments of tuff, glass, and, in some places, Precambrian rocks embedded in a matrix of pumice and shards. Some of the glass fragments are perlitic spherules and have an index of refraction of about 1.50; others are not perlitic and have an index of about 1.49. Thin-section studies indicate that some glass fragments are partly devitrified to feldspar and cristobalite and altered to a clay mineral. Fragments of sanidine, oligoclase, and quartz occur in small amounts; other minerals are magnetite, altered partly to hematite, and a soft black manganese-oxide mineral. The pumice which has an index of refraction of about 1.50, is partly altered to feldspar and cristobalite, but cellular and filamentous structures are still recognizable. In some specimens the vesicles contain chlorite, calcite, or opal. Breccia is present locally within the pumiceous tuff and is especially conspicuous near the top, where angular blocks of pumice as much as 4 feet across are enclosed in pink hematite-stained, partly argillized material; most of the pumice fragments, however, are less than 2 inches in diameter. Pumiceous breccia is about 20 feet thick at the east side of Ruby Mountain and overlies about 70 feet of light-colored pumiceous tuff.

About 110 feet of west-dipping perlite lies above the pumiceous tuff and breccia along the east-facing slope of Ruby Mountain. The perlite is a light-gray, brownish-gray, dark-gray, and black isotropic glass that has shelly perlitic structure and rare spherulitic structure. Thin-section studies indicate that some of the perlite contains clay and hematite along the perlitic structure and locally has chlorite in vesicles. A few phenocrysts of quartz, sanidine, and oligoclase were found; the margins of the feldspars bear evidence of partial resorption. Much of the perlite is light gray and contains abundant hard shiny pellets of black glass. These obsidian pellets are 1–12 mm in diameter and have an index of refraction of about 1.49, in contrast with the 1.50 index of the surrounding perlite. The black glass contains microlites of feldspar, very rare biotite, and sufficient magnetite dust to make the pellets slightly magnetic. Such obsidian pellets, known to collectors as "Apache Tears," are more appropriately called marekanites. Ross and Smith (1955) studied marekanites from several other localities and found that the obsidian cores surrounded by concentrically cracked perlite contain less than 1 percent water, that the perlite contains 2–5 percent water, and that the obsidian consistently has a lower index of refraction than the corresponding perlite. They concluded that the entire mass was originally obsidian and that the perlite formed by hydration after emplacement of the original glass.

Chemical analyses of obsidian pellets and perlite, collected at the north end of Ruby Mountain by R. L. Smith and the writer, are given in table 6. Comparisons of the chemical analyses with the norms show that the change from obsidian to perlite results chiefly in increases in water and K_2O, decreases in Na_2O and CaO, and a change from magnetite to hematite; similar chemical changes in other hydrated silicic glasses were reported by Lipman (1965) and Truesdell (1966). The fluorine and normative fluorite values for the obsidian pellets and perlite are about twice the maximums of corresponding values for analyzed samples from the older Tertiary volcanic rocks (tables 3 and 4).

TABLE 6.—*Chemical compositions and norms of obsidian pellets and perlite from Ruby Mountain, Chaffee County* [1]

[Weight percent]

Sample	Obsidian	Perlite
Lab. No.	100414	100415
Chemical analyses [Standard rock analyses by E. L. Munson]		
SiO_2	76. 57	74. 34
Al_2O_3	12. 78	12. 55
Fe_2O_3	. 35	. 44
FeO	. 33	. 13
MgO	. 05	. 05
CaO	. 45	. 40
Na_2O	4. 31	3. 97
K_2O	4. 54	4. 72
H_2O+	. 22	2. 83
H_2O-	. 05	. 13
TiO_2	. 08	. 07
P_2O_5	. 00	. 00
MnO	. 01	. 01
Cl	. 07	. 05
F	. 18	. 23
Subtotal	100. 08	100. 01
Less O	. 10	. 11
Total	99. 98	99. 90
Semiquantitative spectrographic analyses [Analyst: Harriet Neiman]		
Ba	0. 1	0. 15
Be	. 0001	[2] 0
Co	. 0005	. 0015
Cr	. 0003	. 0005
Cu	. 0005	. 003
Ga	. 0015	. 0015
Nb	[2] 0	. 001
Ni	. 0003	. 0007
Pb	. 002	. 001
Sc	[2] 0	. 001
Sr	. 05	. 07
V	. 005	. 015
Y	[2] 0	. 002
Yb	[2] 0	. 0002
Zr	. 007	. 007
Norms		
Quartz	33. 5	33. 6
Orthoclase	27. 2	28. 9
Albite	36. 2	34. 6
Anorthite	1. 5	1. 1
Corundum	. 2	. 4
Ferrosilite	. 1	----------
Magnetite	. 7	----------
Hematite	----------	. 5
Fluorite	. 4	. 5
Total	99. 8	99. 6

[1] Locality: Poncha Springs NE quadrangle, north end of Ruby Mountain, NE¼NW¼ sec. 13, T. 15 S., R. 78 W.

[2] Element was looked for but not detected. Other elements looked for but not detected are Ag, As, Au, B, Bi, Cd, Ce, Ge, Hf, Hg, In, La, Li, Mo, Pd, Pt, Re, Sb, Sn, Ta, Te, Th, Tl, U, W, Zn.

A steeply west-dipping flow of gray rhyolite forms the upper part and west face of Ruby Mountain, which rises about 400 feet above the Arkansas River. The rhyolite overlies the perlite and is about 300 feet thick. The rock is pinkish when wet and locally is stained with manganese oxide; generally it has very conspicuous flow layering and a parallel platy structure. Commonly, the rhyolite is spherulitic, lithophysal, or vesicular. The spherulites range from less than 0.1 inch to 3 inches in diameter; the largest, near the top of Ruby Mountain, consist chiefly of quartz and feldspar. Lithophysae, as much as 2 inches in diameter, are composed mainly of sanidine shells coated with quartz. Elliptical and irregular vesicles generally are less than 1 inch in longest dimension.

Minerals in the vesicles and lithophysae of the rhyolite include garnet, topaz, sanidine, quartz, tridymite, opal, calcite, magnetite, and hematite. The presence of garnet and topaz was first reported by Smith (1883, p. 32). The garnet occurs as transparent, glassy, red-brown to cinnamon-brown crystals, generally less than 0.25 inch in diameter, and it evidently was mistaken for the ruby variety of corundum when Ruby Mountain was first named. Accordingly to Sinkankas (1959, p. 284), some of the garnets at the Ruby Mountain locality are as much as half an inch in diameter and are large enough to cut as gem stones. A few crystals are simple trapezohedrons, but most are trapezohedrons modified by dodecahedrons. The garnet has a specific gravity of 4.23 at 18°C (Cross, 1886, p. 435) and an index of refraction of 1.820 (Jaffe, 1951, p. 136). The following published chemical analysis (table 7) of the garnet indicates that it is the spessartite variety. Spectrographic analysis (Jaffe, 1951, p. 134) of garnet from this locality indicates Si, Mn, Al, and Fe as major constituents; Ca as a minor constituent; traces of Mg, Zn, Ti, Na, Y, Sc, and Ga; and the absence of F, Li, Sr, Nb, Cr, and V. Large dodecahedral almandite garnets found near Salida at the inactive Sedalia copper mine have been incorrectly attributed to this Ruby Mountain locality (Ford, 1932, p. 596).

TABLE 7.—*Chemical analysis of spessartite garnet from Ruby Mountain, Chaffee County*

[From Cross (1886, p. 435)]

Constituent	*Weight percent*	*Constituent*	*Weight percent*
SiO_2	35.66	CaO	1.15
Al_2O_3	18.55	K_2O	.27
Fe_2O_3	.32	Na_2O	.21
FeO	14.25	H_2O	.44
MnO	29.48		
		Total	100.33

Clear, transparent, yellowish to colorless, prismatic crystals of topaz one-quarter of an inch or less in diameter are much less abundant than garnet. Crystal forms recognized are prisms, pyramids, basal pinacoids, macrodomes, and brachydomes. Sinkankas (1959, p. 102) stated that this topaz has a specific gravity of 3.567 and that some of the largest crystals can be cut into small brilliant gems.

Very small crystals of glassy sanidine are especially abundant in the lithophysal cavities. The *Y* index of refraction is about 1.525, which is that of a soda sanidine containing about 30 percent Ab (Tröger, 1952, p. 96).

Silica minerals, magnetite, and hematite also are common in the cavities of the rhyolite. Quartz forms slender prisms, both singly and doubly terminated, that rest on garnet or are intergrown with it. According to Rogers and Cahn (1937), minute prismatic quartz crystals from Ruby Mountain have prominent pinacoidal faces, one of the very few authentic occurrences of the pinacoid on quartz. Other silica minerals found in the rhyolite are platy tridymite; hard, bluish, isotropic opal; and fibrous chalcedony. Magnetite occurs as tiny octahedrons, and hematite as six-sided flat rhombs.

The rhyolite flow consists of sparse phenocrysts of quartz, euhedral and partly resorbed feldspar tablets, and very rare tiny crystals of brown biotite, in a dense microcrystalline groundmass. A modal analysis of this rock gives a composition of 85.9 percent crystalline groundmass, 6.6 percent sanidine, 3.1 percent plagioclase, 4.4 percent quartz, and a trace of iron oxides (Carmichael, 1963, p. 105). Some of the quartz crystals are doubly terminated, and most are smoky, especially in the central part of the crystals. In reflected light many of the feldspar crystals are chatoyant. MacKenzie and Smith (1956, p. 411, 413, 418) found that the sanidine phenocrysts have an optic axial angle of about 31° and are cryptoperthitic with pericline twinning of the sodium feldspar phase; chemical analysis gave their composition as $Or_{60.4}Ab_{37.5}An_{2.1}$. The plagioclase was determined optically by the writer to be oligoclase, about An_{15}. Partial chemical analysis indicates that the plagioclase phenocrysts are $Or_{7.8}Ab_{81.2}An_{11}$ (MacKenzie and Smith, 1956, p. 426). The groundmass, where not silicified or partly altered to clay, consists of quartz, feldspar (apparently untwinned and largely sanidine), tridymite, chlorite, topaz, magnetite, and very rare fluorite. Locally, quartz and feldspar are intergrown, and quartz poikilitically encloses feldspar crystals; alternating layers of these two minerals emphasize the flow layering in the rhyolite. Tridymite occurs in characteristic pseudohexagonal plates with wedge twinning. Crystals and clusters of topaz are fairly common in the groundmass. Cubes of fluorite were found in one thin section.

A chemical analysis of the groundmass of the rhyolite and a spectrographic analysis of the whole rock are given in table 8. Comparisons of these analyses with an early whole-rock analysis (Cross, 1886, p. 438) of this flow and with the analyses (table 6) of the immediately underlying obsidian and perlite, suggest that the 69.89 percent SiO_2 in the analysis reported by Cross is too low and that the 17.94 percent Al_2O_3 reported by Cross is too high.

TABLE 8.—*Chemical and semiquantitative spectrographic analyses in weight percent, gray rhyolite flow, Ruby Mountain, Chaffee County*

Chemical analyses from Carmichael (1963, p. 109). Spectrographic analyses from D. R. Shawe (written commun., May 10, 1963); analyst, J. C. Hamilton; lot 5060]

Chemical analysis of groundmass

SiO_2	77.1	MnO	0.07	P_2O_5	Nil
TiO_2	.07	MgO	.04	H_2O+	0.44
Al_2O_3	12.4	CaO	.43	H_2O-	.09
Fe_2O_3	.35	Na_2O	4.5		
FeO	.25	K_2O	4.4	Total	100.2

Spectrographic analysis of whole rock [1]

Si-Major constituent		K	5	Ga	0.003
Al	7	Ti	.05	Nb	.005
Fe	.3	Mn	.05	Pb	.005
Mg	.05	Ba	.002	Yb	.00015
Ca	.2	Be	.0005	Zr	.005
Na	3	Cu	.0005		

[1] Elements looked for but not found: Ag, As, Au, B, Bi, Cd, Ce, Co, Cr, Ge, Hf, Hg, In, La, Li, Mo, Ni, P, Pd, Pt, Re, Sb, Sc, Sn, Sr, Ta, Te, Th, Tl, U, V, W, Y, Zn.

Two possible sources of the Nathrop Volcanics are in the Buena Vista quadrangle immediately to the north. Near the north end of Sugarloaf Mountain, less than a mile north of Ruby Mountain, the rhyolite is separated from Precambrian gneissic quartz monzonite by a narrow gulch containing talus of the two rocks but no evidence of faults. Flow layering of the rhyolite dips very steeply here and is highly contorted, whereas near the south end of Sugarloaf Mountain the layering dips less than 40° SW. The steep gulch trends southeast, and the trend was followed about 1,000 feet southeast to a lamprophyre dike, striking N. 55°–80° W. and dipping 65°–75° N., in gneissic quartz monzonite. The dike extends southeast for a total length of 4.25 miles and into the Poncha Springs NE quadrangle, where it was mapped for 2.5 miles. Possibly, the structure in the Precambrian rocks that localized the lamprophyre dike was reactivated in Tertiary time and at Sugarloaf Mountain became the outlet for an eruption of rhyolite. The second possible source of these volcanic rocks is Bald Mountain, about 1.5 miles northeast of Ruby Mountain, which Hayden (1869, p. 78) regarded as an old volcano. According to Honea (1955), it is a composite cone that has an upper alkalic rhyolite flow, a basal quartz latite flow, and intervening pyroclastic rocks dipping away from a central conduit on all sides.

The Nathrop Volcanics are older than the Dry Union Formation of Miocene and Pliocene age; cobbles of the distinctive rhyolite from the Nathrop occur within the Dry Union along U.S. Highway 285 near the intersection with Chaffee County Road 60. The most common volcanic rocks forming these cobbles are a silicified spherulitic rhyolite that contains phenocrysts of argillized feldspar and smoky quartz, and a purplish-gray rhyolite that has flow layering and lithophysae containing brown garnet crystals and clay.

Potassium-argon age determinations indicate that the Nathrop Volcanics were erupted in late Oligocene time, about 28 million to 29 million years ago. The determinations were made on obsidian pellets from perlite that underlies the rhyolite flow near the north end of Ruby Mountain and on sanidine concentrated from samples of a phenocryst-rich part of the rhyolite flow, collected about 0.67 mile northwest of Ruby Mountain in the Buena Vista quadrangle. Table 9 gives additional information about the samples (R. F. Marvin, written commun., July 29, 1966).

TABLE 9.—*Sample data for potassium-argon age determinations, Nathrop Volcanics, Chaffee County*

Material	K_2O (weight percent)	Radiogenic Ar^{40}	Radiogenic Ar^{40}	Age (millions of years)
		K^{40}	Total Ar^{40}	
Obsidian [1]	4.56	0.00172	0.91	29.3±1.5
Sanidine [2]	[4] 10.25	.00171	.98	29.1± .9
Sanidine [3]	[5] 9.90	.00165	.98	28.0± .8

[1] Pellets from perlite collected by R. E. Van Alstine, Ruby Mountain, NE¼NW¼ sec. 13, T. 15 S., R. 78 W., Poncha Springs NE quadrangle; pellets treated with HF to remove perlite coating.

[2] Concentrated from porphyritic rhyolite collected by R. F. Marvin, near northwest end of Sugarloaf Mountain, SE¼NE¼ sec. 11, T. 15 S., R. 78 W., Buena Vista quadrangle.

[3] Concentrated from porphyritic rhyolite collected by R. F. Marvin, from small quarry on west side of Arkansas River, SW¼SE¼ sec. 11, T. 15 S., R. 78 W., Buena Vista quadrangle.

[4] Average of 10.26 and 10.24.

[5] Average of 9.88 and 9.93.

Decay constants for K^{40}: $\lambda_\epsilon=0.585\times10^{-10}$ yr^{-1}; $\lambda_\beta=4.72\times10^{-10}$ yr^{-1}.
Atomic abundance of $K^{40}=1.19\times10^{-4}$.
Analysts: R. F. Marvin, H. H. Mehnert, Wayne Mountjoy, and Violet Merritt.

BROWNS CANYON FORMATION

Seven small residual masses of Miocene rocks, containing a flora similar to that at Creede, Colo. (about 70 miles southwest of the Poncha Springs NE quadrangle), and consisting predominantly of thin-bedded tuffaceous siltstone, rest unconformably on Precambrian gneissic quartz monzonite at altitudes ranging from 7,700 to 7,860 feet in the south-central part of the quadrangle. The unit is not definitely correlated with named formations, for it cannot be continuously traced into any type area of Tertiary rocks. As it is mappable and forms a significant part of the Tertiary record, the unit is here named the Browns Canyon Formation, after the nearby feature to the east in the Poncha Springs NE quadrangle. No type section of this thin unit is described, as it has patchy distribution because of faulting and erosion, and the lithology varies considerably from remnant to remnant. The type locality is in secs. 22, 27, and 28, T. 51 N., R. 8 E.

The thickness of the formation ranges from a few feet to about 50 feet. The thickest section caps a hill east of the Puzzle fluorspar deposit in sec. 27, T. 51 N., R. 8 E., where the beds are faulted, folded, and cut by fluorite veinlets.

The formation consists of gray and brown to yellow-brown tuffaceous siltstone, locally finely ripple marked and interbedded with calcareous siltstone, sandy siltstone, ferruginous claystone, and lithic and crystal tuff. The rocks generally are moderately well consolidated; locally they are dense and flinty and have a conchoidal fracture. A basal conglomeratic arkose contains angular to subrounded fragments mainly of the underlying quartz monzonite. The tuffaceous siltstone is composed chiefly of angular quartz and feldspar grains in a locally silicified silty matrix in which shard structure and pumice fragments are evident. Many of the quartz grains are strained, and the feldspars are orthoclase, microcline, perthite, sanidine, and andesine. Other constituents of the tuffaceous siltstone are frayed and euhedral biotite, magnetite, zircon, pink garnet, and rarer grains of apatite, epidote, sillimanite, and muscovite. Silt particles of some of these minerals and chlorite, limonite, sericite, chalcedonic quartz, and a clay mineral, probably kaolinite, locally form 50–90 percent of the rock. The ferruginous claystone is made up chiefly of very fine grained kaolinite, limonite, and hematite. Interbedded lithic tuff near the Manganese Hill fluorspar deposit (No. 6 on pl. 1) contains fragments of pyroclastic rocks, volcanic glass, some of which is perlitic, and flow-layered, spherulitic, vesicular rhyolite like that of the Nathrop Volcanics.

The sediments, derived chiefly from Precambrian rocks and Tertiary volcanic rocks, evidently were deposited under lacustrine or flood-plain conditions in rather quiet and shallow water. The basin of deposition is now localized on a horst structure, which is still topographically as well as structurally high. Oligocene rhyolitic welded tuff and younger Tertiary strata are nearby, both to the northeast and southwest (pl. 1); to the southeast, a high ridge of Precambrian metamorphic rocks rises 400–500 feet above the siltstone remnants. Tuffaceous siltstone may underlie upper Tertiary sediments in a trough between here and the Sawatch Range to the west.

The Browns Canyon Formation is mapped as an older unit and separate from the Dry Union Formation for the following reasons: (1) The siltstone is more consolidated, indurated, folded, and faulted than the Dry Union sediments, which are unconsolidated in the quadrangle except where a few beds are cemented with calcite; (2) the siltstone has a different lithology and locally is mineralized with fluorite, and nearby Dry Union strata are not; (3) in its northeasternmost exposure, the tuffaceous siltstone dips steeply on the upthrown side of a normal fault, and nearly horizontal Dry Union gravels form the hanging wall; (4) the fossils of the two formations are quite different, for fissile beds of the tuffaceous siltstone contain plant fossils regarded as Miocene, in contrast to Pliocene vertebrate fossils of the nearby unconsolidated strata (Van Alstine and Lewis, 1960). Diatoms, sometimes helpful in dating Tertiary deposits, were searched for in both the tuffaceous siltstone and Dry Union Formation but none were found (G. W. Andrews, written commun., Mar. 14, 1962, and oral commun., Feb. 25, 1965).

Plant fossils collected from fissile tuffaceous siltstone at two localities along Chaffee County Road 60 were studied by R. W. Brown and J. A. Wolfe of the U.S Geological Survey. Specimens from USGS paleobotany locality D4265 (SE¼NW¼ sec. 27, T. 51 N., R. 8 E.) contain *Abies rigida* Knowlton and *Pinus crossii* Knowlton (Wolfe, written commun., Mar. 10, 1962). From USGS paleobotany locality 9497, about 150 feet northwest of Chaffee County Road 60 in SW¼ SE¼ sec. 22, T. 51 N., R. 8 E., Brown reported *Pinus* sp., *Sequoia* sp., ?*Sorbus* sp., *Abies* sp., *Chamaecyparis* sp., and *Alnus* sp. (written communs., Oct. 1, 1954, June 4, 1957, and Nov. 19, 1958). According to Brown the leaf called ?*Sorbus* sp. is probably the same species as that found in Tertiary strata at Creede, Colo., and the presence of pine, sequoia, and fir also points toward comparison with the Creede flora described by Knowlton (1923). Wolfe found *Pinus crossii* Knowlton and *Abies* (probably *Abies rigida*) in the writer's specimens from USGS paleobotany locality 9497 and gave the age as probably late Tertiary, Miocene at the oldest (written communs., Mar. 10, 1962 and Sept. 27, 1963). More recently, Wolfe (oral commun., Mar. 18, 1965) stated that cumulative evidence indicates this flora in the Poncha Springs NE quadrangle, and in the Marshall Pass area to the southwest, is Miocene. This Miocene age assignment, based upon the fossil plants, is supported by a pollen study and by the previously mentioned lithologic and structural evidence that indicate the Browns Canyon Formation is older than the Dry Union Formation (Miocene and Pliocene); both formations contain clasts of the distinctive rhyolite flow (the youngest unit of the upper Oligocene Nathrop Volcanics).

A processed sample of weakly calcareous but well indurated tuffaceous siltstone, bearing fossil fir and pine at USGS paleobotany locality D4265, contains about

100 rather well preserved pollen grains (E. B. Leopold, written communs., Feb. 25 and Mar. 7, 1969):

Pinus (primarily non-white pines)	84
Picea	4
Chenopodiaceae	1
Monocot. undet	1
Compositae, *Ambrosia* type	1
Compositae, long-spined type	1
Quercus?	1
Undet. non-tree pollen	3

Miss Leopold reported:

> The sample was scrubbed with wire brush, soap, and water before preparation. * * * Both a large pollen (similar to ponderosa) and a very small pollen (similar to closed cone pines such as pinyon) of Diploxylon pine forms are present, but mostly the latter. The assemblage is extremely simple and, from pollen alone, contains no Tertiary relict genera. * * * We can suppose from the presence of long-spined and also *Ambrosia*-type Compositae that the sample is of Miocene or younger age.

Similar tuffaceous siltstones, interbedded with limy siltstone and ash and containing a flora like that of the Browns Canyon and Creede Formations, are at the north edge of a Tertiary volcanic field, adjacent to Precambrian and Paleozoic rocks, about 22 miles southwest of the plant fossil localities in the Poncha Springs NE quadrangle, between this quadrangle and Creede, Colo. The flora was collected 1–3 miles west of Marshall Pass at the west edge of the adjacent Bonanza quadrangle; there, the writer found six siltstone exposures along the road that follows the abandoned railroad route over Marshall Pass. The two best fossil localities are south of the former Shavano siding (Knowlton, 1923, p. 184; "Loc. Cross. 1914, No. 516 [6889]"), in the NE¼ sec. 26, and the NW¼ sec. 34, T. 48 N., R. 6 E., where the writer collected plants that Wolfe (written communs., Dec. 22, 1959, and Mar. 10, 1962) identified as *Abies rigida* Knowlton, *Pinus crossii* Knowlton, *Mahonia marginata* (Lesquereux) Arnold, and *Cercocarpus holmesi* Axelrod. According to the written communications from Wolfe, this assemblage is characteristic of the Creede flora (Knowlton, 1923, p. 184; Wolfe, 1964, p. N25).

The presence of a distinctive flora in tuffaceous siltstones in these areas and in the Creede Formation suggests that the rocks may be about the same age, though deposited in separate basins. The Creede Formation was deposited in a structural trough, about 15 miles in diameter, around the domed core of a caldera in the central San Juan Mountains (Steven and Ratté, 1964, p. D62). Although a recently published estimate of its age ranges from late Miocene through middle Pliocene (Steven and Ratté, 1965, p. 47), later potassium-argon data suggest that a late Oligocene or early Miocene age is more probable (T. A. Steven, written commun., Feb. 1, 1966).

Similar tuffaceous fine clastics in a continental sedimentary sequence are reported from South Park, about 13 miles northeast of the Poncha Springs NE quadrangle. A thick section of conglomerate, arkosic sandstone, and mudstone, which are locally tuffaceous and dip as much as 28°, rests with angular unconformity on the Antero Formation of Stark and others (1949, p. 63–68), dated as Oligocene by vertebrate fossils (De Voto, 1964, p. 123–124); De Voto considers these South Park clastic rocks as Oligocene-Miocene, although fossils were not found.

DRY UNION FORMATION

Poorly consolidated sediments of the Dry Union Formation of Miocene and Pliocene age unconformably overlie deformed and eroded earlier Tertiary volcanic rocks and Precambrian rocks, and in turn are unconformably overlain by Pleistocene pediment gravels and glacial outwash. The type locality of the Dry Union Formation is in the Leadville area, about 30 miles north of the Poncha Springs NE quadrangle (Tweto, 1961). Tweto and the writer together examined exposures of the formation in the intervening area in the Arkansas Valley to ensure that this name is justified for the beds in the Poncha Springs NE quadrangle. The beds in the Poncha Springs area were first regarded as Pliocene lake deposits by Hayden (1869, p. 77; 1874, p. 48), who called them the Arkansas marl.

The Dry Union Formation occupies much of the western part of the quadrangle and consists chiefly of interlayered white, gray, and tan clays, silts, sands, and gravels. Areas underlain by this formation commonly have a badland topography and are covered with pebbles and cobbles that concentrated at the surface as the finer materials were washed away. Individual beds generally are more than 10 feet thick and have little sorting and internal stratification. Some of the sands and gravels are finely bedded, however, and locally are crossbedded; bedding dips gently in various directions. These detrital sediments are poorly consolidated except where cemented by porous caliche or coarse calcite. The finer sediments are slightly calcareous. Sands and silts locally contain nodules of calcite and black manganese oxide and tubular concretions of calcite and chlorite.

Some of the clays and silts are bentonites, formed by alteration of volcanic ash. A sample of silty bentonite, collected in the roadcut of U.S. Highway 285 at the south edge of the quadrangle and studied by X-ray methods, consists of montmorillonite, quartz, sanidine, and muscovite; the overlying bentonitic clay is about 99 percent montmorillonite (Helen Mark, U.S. Geol. Survey, written commun., Jan. 31, 1962). A sample of clay from USGS vertebrate fossil locality D298 (SE¼ sec. 16, T 51 N., R. 8 E.), about 1,200 feet east of the highway, is composed of these minerals and illite; the clay fraction is about equally divided between montmorillonite and illite. The clays at both localities feel greasy and readily swell and disaggregate when immersed in water.

The sands are locally tuffaceous and contain shards in addition to quartz, sanidine, orthoclase, microcline, plagioclase, biotite, muscovite, blue-green hornblende, magnetite, epidote, sphene, zircon, and garnet. The shards are isotropic and have an index of refraction of about 1.50.

The gravels contain angular and subrounded pebbles and cobbles of predominantly Precambrian rocks and Tertiary volcanic rocks like those exposed in the east half of the quadrangle. The following also are abundant as clasts within these gravels: The Mount Princeton Quartz Monzonite (Tertiary), exposed in the Sawatch Range to the west; tan chert, purplish quartzite, greenish siltstone, and gray limestone from Paleozoic beds; and various quartz-feldspar-biotite porphyries, probably of Tertiary age.

Coarse gravel of the Dry Union Formation, exposed in sec. 35, T. 51 N., R. 8 E., near the south edge of the quadrangle, rests on a widespread pediment that slopes 2°–4° westward across chiefly Precambrian rocks and volcanic rocks of Oligocene age. (See pl. 1.) The gravel locally is more than 100 feet thick and contains subrounded and rounded boulders and cobbles of these nearby Precambrian and Tertiary rocks, and fragments of chert, quartzite, and other Paleozoic rocks that crop out about 5 miles to the east. The gravel is exposed east of and about 750 feet above the Arkansas River and about 400 feet above a deposit of early Pleistocene gravel. Approximately 2 miles southeast of and just beyond the quadrangle, this coarse gravel is cut by faults and displaced about 200 feet vertically.

The Dry Union Formation consists chiefly of floodplain and alluvial-fan deposits. Some of the Dry Union sediments were derived from the north; gravels near the south edge of the quadrangle contain fragments of spherulitic rhyolite and garnet-bearing lithophysal rhyolite found in the Nathrop Volcanics at Ruby Mountain at the north edge of the quadrangle. Additional support for deposition of the Dry Union Formation in part from a through-flowing stream from the north is the recognition (Ogden Tweto, oral commun., July 1963) along Chaffee County Road 60 of pebbles of the distinctive Pando Porphyry of early Tertiary age (Pearson and others, 1962). This porphyry is a dense white quartz latite that forms plugs and sills along the Arkansas River drainage in the Leadville area (Tweto, 1960b, p. 73).

Lack of a continuous section or of widespread horizon markers, variable direction of dip, and local faulting of unknown displacement prevent determination of the thickness of the Dry Union Formation; furthermore, the top of the formation is eroded. About 500 feet of the formation is exposed in the Poncha Springs SE quadrangle, along U.S. Highway 285 and west of the Arkansas River, where the beds extend to an unknown depth in a fault trough.

The Miocene and Pliocene age of the Dry Union Formation is based upon vertebrate fossils. A molar found in the Poncha Springs SE quadrangle at a locality south of Salida was identified by A. S. Romer as that of the Pliocene equid *Pliohippus leidyanus* Osborn (Powers, 1935, p. 189); correspondence with W. E. Powers (Jan. 27, 1960) suggests that this fossil locality is in the SW¼ sec. 7, T. 49 N., R. 9 E. Van Alstine and Lewis (1960) reported that Pliocene vertebrate fossils from localities in the Poncha Springs SE quadrangle are comparable to the fauna of the Ogallala Formation of Nebraska. G. E. Lewis reexamined all specimens of Tertiary vertebrate fossils that the writer collected since 1958 from the two localities (Pl. 1) in the Poncha Springs NE quadrangle and reported as follows (written commun., Feb. 27, 1969):

USGS fossil vertebrate locality D296 (SW¼ sec. 34, T. 51 N., R. 8 E.).
- mastodont, genus and species indeterminate, enamel fragments of cheek tooth.
- ?*Neohipparion* sp., proximal phalanx from lateral toe of 3-toed horse.
- camelid, genus and species indeterminate, fragments of distal end of metapodial.
- merycodont, genus and species indeterminate, proximal articular fragment of radius.

USGS fossil vertebrate locality D298 (center of the S½ sec. 16, T. 51 N., R. 8 E.).
- *Neohipparion* sp., cheek teeth and fragments thereof, upper and lower, deciduous and permanent; distal fragments of metapodials, one proximal phalanx and two medial phalanges of digit 3.
- very large camelid, genus and species indeterminate, two distal fragments of metapodial.
- merycodont, genus and species indeterminate, astragalus.

Lewis stated:

> The specimens identified from these two localities are of Pliocene age, but of themselves they are not diagnostic of any particular subdivision of the Pliocene. We do know, however, that I have identified upper Miocene and upper Pliocene vertebrates from the Dry Union Formation in the adjoining southern half of the Poncha Springs quadrangle. There, *Merychippus* cf. *M. calamarius* (Cope) occurs, and ?*Megatylopus* sp. and ?*Yumaceras figginsi* Frick occur together with *Neohipparion*.

It may be assumed, therefore, that the age of the Dry Union Formation in the northeast quarter of the Poncha Springs quadrangle is not restricted to only a short part of Pliocene time.

Earlier, Lewis (written commun., Dec. 17, 1968) had suggested that the Miocene and Pliocene formations of the Santa Fe Group (Spiegel and Baldwin, 1963, p. 38–63) to the south in the Rio Grande trough possibly once extended continuously northward into the upper Arkansas Valley. Van Alstine (1968) has shown that the Arkansas Valley and San Luis Valley, the northward continuation of the Rio Grande trough, are connected by a structural trough that contains upper Tertiary sediments, rather than being separated by a barrier of Precambrian rocks as previously believed.

Evidence of plant life from the Dry Union Formation in the quadrangle consists of fragments of unidentifiable silicified wood (R. A. Scott, written commun., Oct. 22, 1963) and pollen of chenopods, pine, *Artemisia*, and the family Compositae (E. B. Leopold, written commun., July 23, 1959), from SE¼SE¼ sec. 28, T. 51 N., R. 8 E. Samples of clay and silt collected from this formation at two localities were disaggregated, concentrated, and searched for diatoms without success (G. W. Andrews, oral commun., Feb. 25, 1965).

The Dry Union Formation in the quadrangle may be partly equivalent to the lithologically similar Wagontongue Formation of Stark and others (1949, p. 68–69) to the northeast, in South Park. C. L. Gazin, U.S. National Museum, identified a tooth-bearing jaw from this formation as that of a fossil horse of late Miocene or early Pliocene age. According to Lewis (Van Alstine and Lewis, 1960), the *Neohipparion* from the Poncha Springs NE quadrangle possibly is comparable in age to this horse from the Wagontongue Formation.

QUATERNARY DEPOSITS

PLEISTOCENE DEPOSITS

A sequence of Pleistocene deposits, which is remarkably complete when compared with sequences established elsewhere in the Rocky Mountains (Richmond, 1965), locally mantles the easily eroded Dry Union sediments in the western part of the quadrangle (fig. 4). These deposits formed in multiple stages, chiefly as outwash from mountain glaciers in the Sawatch Range to the west. In this quadrangle and the one immediately south, a sequence of nine gravel deposits was established, five of Wisconsinan Age and four older.

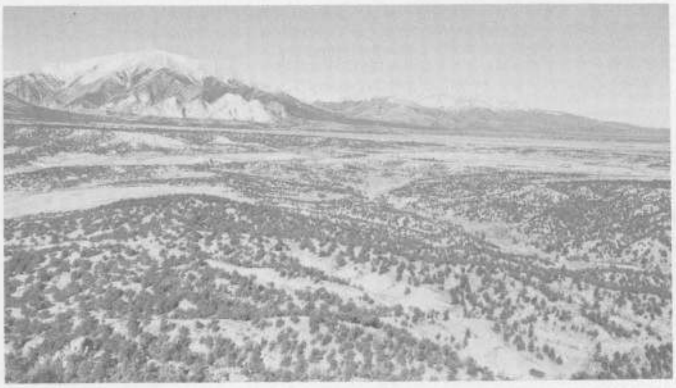


FIGURE 4.—View northwest toward Mount Princeton, showing Pleistocene gravel-covered surfaces on Dry Union Formation of Miocene and Pliocene age. From NE¼ sec. 27, T. 51 N., R. 8 E. Photograph by D. C. Cox.

The Pleistocene deposits in this part of the Arkansas Valley have been interpreted several ways in the geologic literature. Successive levels of deposits were first mentioned by Hayden (1869, p. 77; 1874, p. 48), who believed they formed in a glacial lake basin. Powers (1935, p. 188) recorded seven boulder-capped alluvial terraces along the Arkansas Valley and regarded the two highest terraces as older than any glacial stages of the region. In his figure 10, Powers showed three moraines along Chalk Creek, beyond the northwest corner of the Poncha Springs NE quadrangle. The youngest moraine was cited as being Wisconsinan in age and was correlated (1935, p. 197) with his second terrace; the first pre-Wisconsinan moraine was correlated with his third terrace; and the earliest moraine was correlated with his fifth terrace. Ray (1940, p. 1902–1903) believed that all three moraines shown by Powers should be assigned to the Wisconsin Glaciation.

The present interpretation of the Pleistocene deposits, summarized in table 10, is based chiefly upon: (1) the topographic positions of three older units on high-level erosion surfaces regarded as pediments, and of six units in outwash plains and terraces graded to former levels of the Arkansas River; (2) the tracing of all but the second earliest unit upslope into terminal moraines of former glaciers that descended to altitudes as low as 8,200 feet and ended less than 3 miles west of the Poncha Springs NE and SE quadrangles; (3) the field determination of the youngest outwash gravels as deposits of various stades of the Wisconsin Glaciation (G. M. Richmond, written commun., Mar. 25, 1964); (4) the discovery of a chevkinite-bearing rhyolitic volcanic ash within the third oldest gravel unit, which may be the equivalent of the Pearlette Ash Member of the Sappa Formation of late Kansan age in Kansas and Nebraska; and (5) the presence of more strongly developed soils on the older gravels, which also commonly contain more highly weathered rock fragments. The writer determined the heights (table 10) and distribution of the various Pleistocene deposits in the Poncha Springs NE and SE quadrangles from measurements in the field, from aerial photographs, and from special topographic maps of the Arkansas River, Colo. (U.S. Geological

Survey, 1955). Heights at which the east-sloping gravels lie above the present drainage system are not given in table 10, for the heights vary with horizontal distance from the Arkansas River.

TABLE 10.—*Pleistocene deposits, Poncha Springs NE quadrangle, Chaffee County*

Gravel unit	*Height*[1] *(feet)*	*Probable age*
		Wisconsinan:
9	<10	Pinedale III
8	30	Pinedale II
7	20	Pinedale I
6	50	Bull Lake II
5	40	Bull Lake I
4	70	Illinoian
3	80	Kansan
2	70	Nebraskan
1	100	Nebraskan

[1] Approximate height of upper surface of gravel above surface on next younger gravel.

Some idea of the thickness of the various Pleistocene gravels exposed in the Poncha Springs NE and SE quadrangles can be obtained from table 10. The thickest and most widespread is gravel 1, which is more than 100 feet thick about 1.5 miles west of the northwest corner of the quadrangle; the deposit consists of outwash gravel overlain by alluvial-fan gravel, in which G. M. Richmond (written commun., Mar. 25, 1964) recognized buried soils in a roadcut in NW¼ sec. 19, T. 15 S., R. 78 W.

Gravels 1, 2, and 3 are typically exposed on high benches west of the Arkansas River, and they cap divides between tributary streams that flow eastward from the Sawatch Range. In the Poncha Springs NE quadrangle and the one immediately south, the gravels rest with angular unconformity upon faulted, tilted, and bevelled Dry Union sediments; angular differences are as much as 12° between the Dry Union beds and the overlying eastward-sloping pediment veneers. Locally, springs mark the unconformities below the gravels. The unconformity beneath gravel 2, where cut by U.S. Highway 285 between secs. 34 and 35, T. 15 S., R. 78 W., was so saturated with water that perforated pipe was installed to drain the roadbed.

The four pre-Wisconsinan gravels consist chiefly of outwash gravel that contains tightly packed, rounded cobbles and boulders—some of them striated—and alluvial fan gravel that contains more angular rock fragments. Most of the clasts are various Precambrian intrusive and metamorphic rocks and Tertiary granitic and porphyritic intrusive rocks that crop out in the Sawatch Range (Dings and Robinson, 1957). A boulder of Mount Antero Granite from gravel 1, found in SE¼SE¼ sec. 17, T. 51 N., R. 8 E., contains aquamarine. This boulder undoubtedly was derived from the Mount Antero region, about 7 miles due west; Adams (1953) described the aquamarine-bearing beryllium deposits that occur there. Many pieces of rotten rock, especially coarse-grained granitic types, were thoroughly weathered in place; fragments of boulders can be broken off and crumbled in the hands. Commonly, the clasts and sandy and silty matrix are stained red-brown with iron oxides. The gravels are moderately well to poorly sorted and locally stratified. In some outcrops, a few feet of locally crossbedded sandy and silty alluvium occurs at the top of the gravel units.

Soils on the surfaces of the four pre-Wisconsinan gravels locally are relict and have been forming since deposition of the gravels. In general, these soils are much thicker and more strongly developed than those on the younger Pleistocene gravels; they also are greatly enriched in calcium carbonate, possibly the result of a long period of development under arid to semiarid conditions. The dark-brown B-horizons, locally calcareous, are 1–2 feet thick and in some places are underlain by as much as 19 feet of oxidized, iron-stained material. The thickest Cca-horizon (lime-enriched material) that was observed beneath the B-horizon is in the quadrangle to the south, in a roadcut along U.S. Highway 285 about 2 miles north of Poncha Springs; there it forms 25 feet of a 28-foot thickness of gravel 3. In the four pre-Wisconsinan gravel units, calcite forms caliche crusts several inches thick on the undersides of boulders; the crusts commonly are thickest in the oldest units.

A narrow east-trending deposit of gray gravel that may be a channel fill in gravel 2 was mapped as part of that unit. This coarse gray gravel, which contains well-rounded boulders and cobbles, is best exposed in a recent roadcut of U.S. Highway 285, in secs. 34 and 35, T. 15 S., R. 78 W., and in the gravel pit to the east; it extends eastward to a hill of gravel 1 and westward to a Holocene deposit of peat.

In gravel 2, tan silty volcanic ash occurs as a white-weathering layer about 1 foot thick on the west side of a roadcut along U.S. Highway 285 in SW¼SW¼ sec. 9, T. 51 N., R. 8 E., where it is overlain by about 6 feet of silt. Panned samples of the ash contained magnetite, brown biotite, blue-green hornblende, sanidine, epidote, pink garnet, and small rounded fragments of intrusive rocks; probably most of these constituents are of detrital origin. R. E. Wilcox (written commun., May 17, 1966) determined the predominant index of refraction of glass shards within the ash to be 1.496–1.497. During a preliminary study of the heavy fraction of a sample of this ash, Wilcox did not find chevkinite or other types of glass-bearing phenocrysts that are present in volcanic ash in the younger gravel 3; he concluded that the sample probably represents a different ash fall. Similarly, volcanic ash has been reported from the La Sal Mountains, Utah, in Nebraskan alluvial sand and gravel that unconformably underlies Kansan alluvium and colluvium that contains chevkinite-bearing ash (Richmond, 1962, p. 34, 35, 94).

Two pre-Kansan Pleistocene alluvial deposits are known from other localities in Colorado. East of the Front Range, between Pueblo and Plainview (north of Golden), two fluviatile deposits, which rest on pediments about 100 feet apart vertically, have been regarded as Nebraskan or earliest Pleistocene (Scott, 1963a, p. C52–C53; Scott, 1963b).

Gravel 3, probably of Kansan age, contains 3 inches to 1 foot of white-weathering volcanic ash in colluvium above alluvium along the west side of a roadcut of U.S. Highway 285, on the boundary between secs. 34 and 35, T. 15 S., R. 78 W.; unidentifiable bone fragments and half a lower cheek tooth of fossil *Equus* sp. (horse) of Pleistocene age (G. E. Lewis, written commun., Nov. 2, 1967) were found in the colluvium. Magnetite, brown biotite, blue-green hornblende, sanidine, and epidote are the chief mineral constituents of panned concentrates of the ash. According to a preliminary study (R. E. Wilcox, written commun., May 17, 1966), glass-bearing phenocrysts in the heavy fraction of an ash sample include clinopyroxene (*nX* 1.728–1.730), chevkinite, magnetite, colorless zircon, and ilmenite(?); frosted and slightly milky shards that have a predominant index of refraction of 1.499–1.502 are also present.

Similar ash was found in gravel 3 in the Poncha Springs SE quadrangle in the SE¼NE¼ sec. 17, T. 50 N., R. 8 E. It is as much as 3 feet thick and is exposed in an east-facing cliff at an altitude of about 7,820 feet. The ash dips gently northeast within silt that underlies about 20 feet of gravel and overlies about 8 feet of gravel resting unconformably on the Dry Union Formation (Miocene and Pliocene). A preliminary study of this ash (R. E. Wilcox, written commun., May 17, 1966) indicates that the predominant index of refraction of the glass shards is 1.499–1.501, and that the glass-bearing phenocrysts in the heavy fraction include clinopyroxene (*nX* 1.727–1.731), chevkinite, magnetite, colorless zircon, and ilmenite(?). Chevkinite, a titanosilicate of cerium earths characterized by extreme pleochroism and high indices of refraction, occurs in rhyolitic volcanic ash of Pleistocene age in several midcontinental and western States (Swineford, 1963; Young and Powers, 1960). Chevkinite-bearing ash, petrographically similar to the Pearlette Ash Member of the Sappa Formation of late Kansan age in Kansas and Nebraska, has been found elsewhere in Colorado in deposits regarded as Kansan in age; these deposits are at various localities in the Denver area, 65–100 miles northeast of the Poncha Springs quadrangle (Scott, 1963a, p. 16–18), and near the Gunnison River, about 75 miles west (Dickinson, 1964) of the quadrangle. This ash type is also present in the La Sal Mountains, Utah, in Kansan alluvium and colluvium (Richmond, 1962, p. 34, 35, 95).

The above data do not provide conclusive evidence that the ash from gravel 3 at the two localities in the Poncha Springs quadrangles is the Pearlette Ash Member of the Sappa Formation, although Wilcox (written commun., May 17, 1966) pointed out their similarities in mineral content and index of refraction of the shards. The distribution of the Pearlette and Pearlette-like ash localities and problems concerning sources and correlation of the ash beds are considered in a publication by Wilcox (1965, p. 811–812).

Gravel 4, probably of Illinoian age, forms a terrace above gravel 5, north of and below the volcanic ash-bearing gravel 3 locality along U.S. Highway 285 in the northwestern part of the quadrangle. The clasts in the well-developed Cca-soil horizon are thickly coated with caliche where the gravel is exposed in an irrigation ditch north of Gas Creek in NW¼NE¼ sec. 34, T. 15 S., R. 78 W. The thickness of this soil horizon could not be measured in the mapped area; but in the Poncha Springs SE quadrangle where deposits of gravel 4 are more extensive, the Cca-horizon is approximately 14 feet thick in a roadcut along U.S. Highway 285, about a mile north of Poncha Springs.

Deposits of gravel 5 are found in both the Poncha Springs NE and SE quadrangles, although they were largely eroded from the area when younger deposits formed. Some deposits of gravel 5 are traceable westward as outwash from early Bull Lake moraines. Typically, the gravels occur in channels cut chiefly in older Pleistocene deposits, or they form a terrace below pre-Wisconsinan gravel and above a sequence of terraces of other Bull Lake deposits and Pinedale deposits. The soil on gravel 5 is thinner and less well developed than the soils on the older and higher gravel deposits. It consists of about 1 foot of a brown-clay B-horizon and nearly 9 feet of Cca-horizon, in which caliche crusts are about 1 inch thick on the undersides of boulders.

Gravel 6 was examined in the field by G. M. Richmond, who interpreted it (written commun., Mar. 25, 1964) as outwash from the upper Bull Lake Glaciation. This deposit forms an extensive outwash plain, sloping east at about 140 feet per mile, south of Chalk Creek in the northwestern part of the quadrangle. The gravel is of unknown thickness and extends upslope 1.5–2.5 miles west of the quadrangle into terminal moraines in the valleys of Chalk Creek and Browns Creek. The unit consists chiefly of gravel with sandy lenses; the rock fragments are like those found in the older Pleistocene gravels, but thoroughly weathered boulders are not so common. The Cca-horizon of the soil developed on gravel 6 is as much as 7 feet thick and contains boulders with caliche crusts less than half an inch thick on the undersides.

Gravels 7, 8, and 9 are coarse outwash gravels representing three stades of the Pinedale Glaciation (G. M. Richmond, written commun., Mar. 25, 1964). These deposits locally occupy terraces at successively lower levels along Chalk Creek and the Arkansas River. (See table 10.) Gravel 7 is the most extensive and forms a prominent terrace. In Browns Canyon, only terraces containing gravel 7 are shown on the geologic map; local remnants of the two younger terraces, too small to be mapped, were found at the south edge of sec. 23, T. 51 N., R 8 E. Similarly, only a few remnants of the terrace and gravel 8 along Chalk Creek are large enough to map. Deposits of gravel 9 are small and are not shown as features on the topographic map; these are included with Holocene flood-plain gravels on the geologic map (pl. 1).

In the valley of Chalk Creek, outwash-gravel units 7, 8, and 9 extend 1.5–2.75 miles west of the quadrangle into corresponding terminal moraines, according to Richmond. Similarly, gravel 7 along Browns Creek, about 4 miles south, ends upstream at a terminal moraine about 2 miles beyond the west edge of the quadrangle. Rock fragments in the three Pinedale gravels are like those in the older gravels at higher levels but generally are less weathered. The surface of gravel 7 slopes about 100 feet per mile throughout much of its extent along Chalk Creek and steepens to approximately 140 feet per mile near the moraine.

Soils formed on gravels 7, 8, and 9 are poorly developed and are thinner and grayer than those on the older gravels. The slightly oxidized B horizon, composed of several inches of clay, does not effervesce with dilute hydrochloric acid. Similarly, the underlying C horizon is not calcareous, except for a thin layer of caliche on the underside of some boulders.

HOLOCENE DEPOSITS

Only a few Holocene deposits are extensive or thick enough to be shown on the geologic map; these consist chiefly of silt, sand, and gravel comprising the alluvium and colluvium of the Arkansas River valley and tributaries. Most mountainous slopes in the eastern part of the area are covered with coarse talus or finer colluvium. Two landslides are shown near the south-central edge of the quadrangle. The landslide on the west side of Arkansas River consists of blocks of Precambrian igneous and metamorphic rocks; it may be partly late Pleistocene in age, for huge angular blocks of the Precambrian rocks are abundant downstream in gravel 7, south of the mouth of Browns Canyon. The second landslide is across the river and about a mile southeast; it is composed largely of blocks of Tertiary welded tuff that came from the east from a cliff above nonwelded tuff.

A Holocene deposit of peat, about 3 miles long, 100–1,500 feet wide, and 1–10 feet thick, follows the course of Gas Creek in the northwestern part of the quadrangle (pl. 1). The peat is being excavated for market about 1 mile east of U.S. Highway 285, along the drainage near the south edge of the outwash plain of gravel 6; here the peat rests chiefly on sandy material of this Pleistocene unit. Much of the area underlain by the peat is swampy and covered with hummocks of grass.

Vertebrate remains, pollen, and a sample for a radiocarbon age determination were collected from the peat (USGS paleobotany loc. D1373) near the southeast corner of sec. 27, T. 15 S., R. 78 W., where the Colorado State Highway Department cut about 10 feet of peat along Gas Creek in constructing a new section of U.S. Highway 285 in 1958. The writer examined many cubic yards of this peat when it was spread upon a field about 2,000 feet southward and above the east edge of the highway cut, and found the proximal end of a tibia from *Equus* sp. indet., of late Pleistocene or Holocene age, and a metatarsal from *Bison* sp. indet., probably *Bison bison* Linnaeus of Holocene age, according to G. E. Lewis, U.S. Geological Survey, and C. B. Schultz and L. G. Tanner, University of Nebraska State Museum and Geology Department (G. E. Lewis, written commun., June 1, 1959). The mud matrix associated with the vertebrate collections was examined by E. B. Leopold, who reported (written commun., Jan. 26, 1959) many excellently preserved pollen grains of pine, spruce, oak, *Juncus*, grass, Cyperaceae, *Eriogonum*, *Artemisia*, Compositae, Chenopodiaceae, and undet. monocots, dicots, and spores. She concluded that the pollen could be Pleistocene or Holocene. A sample (USGS lab. No. W–989) of fire-charred wood from the peat at this locality, however, was determined to be less than 200 years old (Meyer Rubin, written commun., July 18, 1961).

STRUCTURAL GEOLOGY

The complex geologic structures within the quadrangle are dominated by folds in the Precambrian rocks and by northwest-trending and north-trending faults, chiefly of Tertiary age, that are apparently related to a structural trough along the Arkansas Valley. Deformations that produced the structural features probably occurred during Precambrian, Laramide, and late Tertiary times.

The earliest recorded structural event was the Precambrian folding that accompanied metamorphism and emplacement of the syntectonic body of gneissic quartz monzonite. In the large pendant of gneisses in the south-central part of the quadrangle, the foliation and lithologic layering strike northeast and dip steeply northwest and southeast, parallel to the foliation of the adjacent gneissic quartz monzonite. These relationships suggest that the metamorphic rocks here lie in large isoclinal folds with steep axial planes. The plunges of a few small drag folds and of the lineation of hornblende crystals in hornblende gneiss range from about 25° to 60° NE. In the metamorphic rocks south of the igneous body near the southeast corner of the quadrangle, the foliation and lithologic layering were folded into northwest-trending synform and antiform structures. The gneisses here, as those elsewhere in the quadrangle, were completely recrystallized, and original textures and structures of the metasedimentary rocks were obliterated. For these reasons and because of a lack of stratigraphic markers, additional complexities of folding in the gneisses were not determined.

Foliation in the main body of gneissic quartz monzonite chiefly trends northeast to east and dips steeply north or south. In the central part of the quadrangle, however, the foliation dips gently north, and in other places the attitude of the foliation is highly variable. A less conspicuous foliation in most of the dike rocks cutting the gneissic quartz monzonite is similar to that of the host rock, and it indicates that these dikes were intruded before the close of the regional metamorphism that affected the intrusive body and adjacent rocks.

No faults of unquestioned Precambrian age were observed in the quadrangle. The persistent east-trending lamprophyre dikes and some of the other Precambrian dikes, however, may have been intruded along faults, but evidence for movement along such predike structures was not found in the intrusive rock that they transect. Probably some of the faults shown on the geologic map (pl. 1) formed originally in Precambrian time and were reactivated much later, for nearly all displace Oligocene volcanic rocks or younger Tertiary sediments. The quartz veins that contain magnetite, specularite, pyrite, chalcopyrite, chlorite, and traces of purple fluorite may be of Precambrian age. Many of these quartz veins trend northwest along faults and joints, across the grain of the Precambrian host rocks and roughly parallel to normal faults along the margins of a horst in the south-central part of the quadrangle.

The regional geology indicates the rocks of the quadrangle also were deformed during the Laramide orogeny of Late Cretaceous to early Tertiary age. The quadrangle lies on the east flank of the north-trending Sawatch anticline. Thousands of feet of once-overlying Paleozoic and Mesozoic sedimentary rocks have been eroded, and the core of Precambrian crystalline rocks is exposed high in the Sawatch Range to the southwest (Dings and Robinson, 1957, pl. 1). East-dipping lower Paleozoic rocks crop out about 3,000 feet east of the northeast edge of the quadrangle. During the Laramide orogeny in early Tertiary time, a batholith and several stocks were emplaced in the Sawatch Range beyond the west edge of the quadrangle (Dings and Robinson, 1957, p. 33–34). About 2 miles east of the quandrange, a Laramide stock invaded the Paleozoic rocks and was eroded and partly covered by Tertiary volcanic rocks (Behre and others, 1936). The quadrangle lies between these two centers of Laramide intrusion and probably was involved in similar processes.

The attitudes of many of the Tertiary units in the Poncha Springs NE quadrangle reflect downfaulting to the west, associated with a trough along the Arkansas Valley. West of the river the rhyodacitic volcanics of early Tertiary age dip westward beneath Dry Union sediments. Although moderate dips, generally less than 45°, in Oligocene ash-flow tuff are largely the result of folding near faults, the ash-flow tuff in the southeastern part of the quadrangle slopes gently west toward the trough. The Nathrop Volcanics of later Oligocene age also dip west, at moderate to steep angles, into the adjacent trough. The tuffaceous siltstones of the Browns Canyon Formation of Miocene age generally have low dips; near faults, however, they dip as much as 55° and are thrown into small folds. Directions of dip in the younger Dry Union Formation are highly variable and are believed to reflect initial dips, as well as tilting of the beds near faults.

In the southwestern part of the quadrangle, several north-trending faults cut Dry Union beds but not the overlying Pleistocene gravels. Their position on plate 1 is based chiefly upon lineaments on aerial photographs. The faults extend southward through the Poncha Springs SE quadrangle, where they cut late Tertiary sediments and Precambrian bedrock near the south margin of the Arkansas Valley.

Many of the faults shown on the geologic map apparently are related to the east side of the basin and range type structural depression that parallels the north-trending Arkansas Valley. This rift or graben structure (Gabelman, 1952, p. 1608–1609) has been referred to (Tweto, 1964, p. 19–20; Karig, 1965) as a northward extension of the Rio Grande trough, a long narrow depression broken by many en echelon horsts and grabens that trends south through the San Luis Valley into New Mexico and Mexico (Burbank and Goddard, 1937, p. 933; Kelley, 1952, 1956; Joesting and others, 1961). The total thickness and nature of the rocks beneath the Dry Union sediments in the trough in this quadrangle are unknown; on the horst (sec. 27, T. 51 N., R. 8 E.) which extends northwest into the depression, the Precambrian rocks are overlain by lower Tertiary volcanic rocks, Miocene tuffaceous siltstones, and Dry Union sediments.

The main fault near the east margin of the trough along the Arkansas Valley is probably buried beneath Dry Union sediments. According to James E. Case (written commun., Apr. 23, 1965), preliminary results of a geophysical survey indicate a steep gravity gradient, suggestive of a steep fault downthrown on the west side, along a trend extending south from sec. 14, T. 15 S., R. 78 W., between the Arkansas River and U.S. Highway 285. In the Buena Vista quadrangle, approximately a third of a mile north along this trend, the axes of small folds—possibly drag folds near a concealed fault—in the Nathrop Volcanics similarly strike N. 10° W. at the west edge of the Arkansas River. This hypothetical fault, not shown on plate 1, is parallel to the north-south axis of the Sawatch anticline.

Several other north-trending faults, west and east of the Arkansas River, are east of the buried fault and probably are related to it. Displacement of Precambrian aplite and lamprophyre dikes and Oligocene volcanic rocks in the quadrangle and to the south, indicates that the west sides are dropped down—possibly as much as 1,000 feet—along the steeply west-dipping to vertical normal faults. At the Ace High and Jack Pot claims, in the southeast corner of the quadrangle, a quartz-chalcopyrite vein that dips 75° W. and a vertical pegmatite dike along a north-trending fault zone may indicate that movement along some of the faults of this system started as early as Precambrian time. Extensive erosion of Paleozoic and Mesozoic rocks and earlier movements along the north-trending faults took place before the Oligocene welded tuffs were emplaced upon the Precambrian rocks. Movement along some of these north-trending faults evidently stopped before late Tertiary time because the Dry Union Formation conceals the fault in W½, sec. 11, T. 51 N., R. 8 E., and the erosion surface on which this formation was deposited truncates a north-trending fault farther east. (See pl. 1.)

Locally, the north-trending faults are marked by zones of schistose, slickensided, brecciated, or altered rock containing vienlets of epidote, chlorite, and quartz and grains of chalcopyrite; furthermore, in some of the fault zones the feldspar porphyroblasts and gneissic quartz monzonite are reduced to lenticular augen in a schistose matrix. Elsewhere, these faults are obscured by soil, alluvium, or colluvium and are difficult to locate in the field. Photogeologic interpretation was helpful because many of the fault traces are recognized on aerial photographs as lineaments that follow strike valleys, alined saddles or sags, and scarps or other topographic breaks. Ground checks failed to confirm faulting along several linear features that were noted on the aerial photographs near, and parallel to, the mapped north-trending faults near the east edge of the quadrangle. These features may be the result of soil, vegetation, or topographic differences not necessarily related to underlying faults.

A horst of Precambrian rocks with patches of overlying lower Tertiary volcanic rocks and Miocene siltstone forms a salient extending northwest from the east side of the Arkansas Valley at the south-central edge of of the quadrangle. The horst is bounded on the northeast and southwest by normal faults that bring Precambrian rocks abruptly in contact with Oligocene volcanic rocks that dip gently away from the structure. The fault that bounds the horst on the southwest localized major fluorspar deposits of the Browns Canyon district; this fault is described in detail in the section on fluorspar deposits. A graben and a narrower horst with volcanic rocks lie immediately southwest of the fault. The fault bounding the major horst on the northeast dips 65°–75° NE., and places Oligocene volcanic rocks on the northeast down against Precambrian rocks. The Miocene and Pliocene Dry Union Formation similarly is dropped down against a small patch of Miocene tuffaceous siltstones resting on Precambrian gneissic quartz monzonite in the SW¼SE¼ sec. 22, T. 51 N., R. 8 E. To the southeast this fault has offset, for several hundred feet, the pediment on which the Dry Union sediments were deposited (pl. 1); the northeast side moved down. Faults and joints containing northeast- and northwest-trending fluorspar veins and northwest-trending quartz-specularite veins transect the horst. This horst may extend northwest across the Arkansas Valley trough for about 5 miles from the contact of these late Tertiary and Precambrian rocks in the SE¼ sec. 21, T. 51 N., R. 8 E., because a preliminary geophysical survey indicates the axis of a transverse gravity high lies along this trend (James E. Case, written commun., Apr. 23, 1965). Similarly, faults related to the horst may extend about 6 miles southeast of Salida to Wellsville, where northwest-trending faults could not be dated more closely than post-Permian and pre-Pleistocene (Litsey, 1958, pl. 1, p. 1164, 1171).

Near the east edge of the quadrangle and south of Green Gulch, a steep east-trending fault cuts the gneissic quartz monzonite. The fault surface and the intersection of the fault with the long north-south fault were not observed, but the trace of the east-trending fault is marked by abundant chlorite, epidote, and quartz. To the west, the fault has displaced an aplite dike downward on the south side; similarly, east of the quadrangle this fault has dropped Paleozoic rocks downward on the south side (C. T. Wrucke, oral commun., Aug. 1964). This fault may belong to a system of late Tertiary east-trending faults that have preserved the Nathrop Volcanics in a narrow graben structure to the north (NW¼NW¼ sec. 29, T. 15 S., R. 77 W.) and that displace Dry Union sediments just beyond the south edge of the quadrangle.

Several small normal faults that cut the Dry Union Formation in W½ sec. 21 and near the center of sec. 22, T. 51 N., R. 8 E., may have resulted from renewed movement along major concealed faults. At the first of these localities, a roadcut along an older section of U.S. Highway 285, four faults occur within a distance of 15 feet; the faults strike within 30° of N. 80° E., dip 50°–75° S., and apparently have very small displacement. This exposure is approximately at the intersection of projected northwest trends of several faults that are related to the major horst structure. An east-trending fault at the locality in section 22 dips 75° N., has a displacement of at least 15 feet, and may be related to movement along the buried north-south fault that marks the east margin of the trough along the Arkansas Valley.

GEOMORPHOLOGY

The landscape of this part of the Arkansas Valley is characterized by gently sloping surfaces at 10 levels. The earliest and highest late Tertiary pediment slopes west-southwest and was cut on Precambrian rocks and Oligocene volcanic rocks, mainly east of the Arkansas River. Three intermediate pediments of early Pleistocene age slope east and were cut chiefly on Dry Union sediments between the Arkansas River and the Sawatch Range. Six lower, later Pleistocene terraces locally border the Arkansas River or its main tributary streams.

An older Tertiary surface, buried beneath the remnants of Oligocene volcanic rocks, was too extensively faulted and folded for its origin to be determined. In places, however, the basal nonwelded tuff and overlying black vitrophyre of the ash-flow tuff unit were deposited upon a gently sloping or rolling surface. The most extensive remnant is exposed for nearly a mile along the feature named "The Reef" in sec. 30, T. 51 N., R. 9 E., and in the adjoining section to the west, where its calculated slope is about 7° WSW. Possibly, later erosion that formed the late Tertiary pediment surface partly exhumed this segment of the older surface.

A younger and better exposed pediment of late Tertiary age, east of the Arkansas River, slopes west-southwest across the present course of the river and disappears beneath the Dry Union Formation. (See pl. 1.) Remnants of Dry Union alluvial gravel deposited upon this surface were mapped near the south-central edge of the quadrangle and in the adjoining quadrangle to the south. The pediment is regarded as the erosion surface from which the Dry Union sediments were partly derived and across which they were transported southward and westward to a structural trough east of the Sawatch Range. In the quadrangle this surface slopes 2–4° west, from an altitude of about 8,800 feet to about 7,700 feet. Although the pediment slopes less than 1° from north to south, it has more than twice the present gradient of 33 feet per mile for the Arkansas River from Chalk Creek to the mouth of Browns Canyon, about 9 miles south. This erosion surface is faulted near the south edge of Railroad Gulch (pl. 1) and also in Longs Gulch, about a mile south of the quadrangle. At both localities the surface is covered with Dry Union gravel along the south sides of these east-trending faults.

Some areas of resistant Precambrian rocks rise several hundred feet above this late Tertiary pediment and form remnants east and west of the Arkansas River. Canyons cut the pediment surface to depths greater than 600 feet; the deepest is Browns Canyon along the Arkansas River. Probably the course of the river was entrenched in the hard rocks of Browns Canyon after superimposition from the Dry Union Formation (Miocene and Pliocene), which rests on the pediment.

West of the Arkansas River, three east-sloping pediments covered with outwash and alluvium of gravels 1, 2, and 3 of early Pleistocene age (table 10) lie at successively lower elevations and are graded to former levels of the south-flowing river. The pediment beneath gravel 1 is the most widespread and extends for miles along the mountain front; it slopes eastward about 35 feet per mile near the river and steepens to about 300 feet per mile near the front of the Sawatch Range. The difference in height between the pediments beneath gravels 1 and 2 is about 100 feet, measured approximately 3 miles south of Nathrop and near the Arkansas River. A similar difference exists between two Pleistocene pediments, also of pre-Kansan age (Scott, 1963a, p. 18, 52, 53), at various localities along the east flank of the Front Range, which is about 65 miles east of the Poncha Springs NE quadrangle.

The three pediments, which bevel faulted and tilted Dry Union beds, probably formed when streams overloaded with glacial outwash and alluvial-fan material eroded laterally. The changes in base level of the major drainage that produced pediments and associated deposits at the various levels are attributed largely to Pleistocene climatic changes.

Canyons or valleys have been cut at intervals by the Arkansas River and many of its tributaries since the late Tertiary pediment formed. The accelerated erosion may be partly attributed to widespread uplift of the Rocky Mountain region. Abandoned canyons cut in Precambrian rocks at different Pleistocene levels are found in several places along the Arkansas River through Browns Canyon. A canyon, now abandoned, also was cut in Oligocene volcanic rocks in SW¼SW¼ sec. 27, T. 51 N., R. 8 E., probably in Wisconsinan time when Threemile Creek was at levels below a deposit of gravel 4 about a mile downstream, to the southeast just beyond the quadrangle. Evidence for repeated valley formation consists of abandoned valleys, valleys that contain misfit drainage in the earlier Pleistocene pediments and deposits, and the succession of terraces south of Chalk Creek.

The landforms and drainage that developed on the hard rocks east of the Arkansas River contrast strongly with those on the soft sediments in the western part of the quadrangle. Erosion east of the river produced a west-sloping pediment of late Tertiary age, narrow canyons and fault-controlled valleys, domes of granitic rock, and spires and cliffs of welded tuff. Streams east of the river are intermittent, commonly enter the river from valleys with greatly increased gradients near the river, and evidently never were fed by glacial melt waters. West of the river, the terrain is characterized by: Badland topography developed on the Dry Union Formation; three east-sloping pediments beneath Pleistocene gravels; rather broad, straight, east-trending valleys with gravel-capped interfluves; and terraces. The higher levels provide grazing land in much of the area, and the lower terraces yield most of the crops. Several evenly graded perennial streams rise high in the Sawatch Range west of terminal moraines. Apparently they have been well supplied with water since Pleistocene time and now furnish water for irrigation ditches.

SUMMARY OF GEOLOGIC HISTORY

The local geologic record began in Precambrian time with deposition from marine or continental waters of thick arkosic quartz-rich sands, a few thin lenses of limestone, and thicker layers that possibly were dolomitic or argillaceous sediments. These units were indurated and later folded, recrystallized, and foliated to form banded gneiss, marble, and hornblende gneiss, probably during a period of metamorphism accompanying emplacement of a body of gneissic quartz monzonite about 1.7 billion years ago. The gneissic quartz monzonite was cut by dikes of granite, aplite, pegmatite, lamprophyre, dacite porphyry, and diabase, and by quartz veins locally containing magnetite, specularite, pyrite, chalcopyrite, chlorite, and traces of purple fluorite.

Records of Paleozoic and Mesozoic history are missing; any rocks of these eras that remain in the quadrangle are buried in the Arkansas Valley trough. Evidence from adjacent quadrangles indicates that Precambrian rocks were eroded extensively to a surface of very low relief before the area received about 1,000 feet of sediments from shallow Paleozoic seas; deposition was interrupted by several periods of uplift and erosion. A thickness of 3,000–5,000 feet of nonmarine and marine sediments was laid down later in the Paleozoic era (Gabelman, 1952, p. 1582, fig. 3), and an additional 5,000 feet or so of Mesozoic marine and nonmarine sediments probably covered the area (Stark and others, 1949, p. 34–45; Tweto, 1964, p. 15–16). Late Mesozoic time was marked by withdrawal of the Cretaceous sea, the last sea that invaded Colorado, and also by the start of the Laramide orogeny, a major mountain-building event and period of igneous activity here and elsewhere in the Rocky Mountains. During this orogeny, which continued well into the Tertiary period, the Sawatch and Park Ranges (near the west and east edges of the quadrangle, respectively) were uplifted, folded, and faulted. The quadrangle is on the east flank of the faulted Sawatch anticline that also formed at this time.

After an extensive period of erosion, the emplacement of the volcanic rocks was initiated by extrusion of rhyodacitic ash and lava upon the Precambrian rocks in early Tertiary time. An unconformity developed, inasmuch as these volcanics locally were entirely eroded before the extrusion of ash flows that for the most part formed the rhyolitic welded tuffs in Oligocene time, about 35 million years ago. Faulting and small-scale folding evidently accompanied and followed the emplacement of ash-flow tuff. North-trending block faults that formed the framework for the Arkansas Valley trough may have been active at this time and during late Oligocene time, when pumiceous tuff, breccia, perlite, and a rhyolite flow of the Nathrop Volcanics were emplaced. After a period of erosion, the basal conglomerate and tuffaceous siltstones of the Browns Canyon Formation (Miocene) were laid down, chiefly as local flood-plain or lake deposits. These Miocene rocks were then faulted and folded. Fluorspar mineralization followed.

In later Miocene and Pliocene time thick clays, silts, sands, gravels, and bentonitic ash formed the Dry Union Formation. Deposition was accompanied by recurrent faulting and deepening of the Arkansas Valley trough, in which most of these sediments accumulated. Detritus for the Dry Union Formation was transported westward and southward across an erosion surface, well-formed in the eastern part of the quadrangle. The last clearly dated tectonic activity in the quadrangle occurred next; the Dry Union Formation was faulted and tilted in various directions, and the raising of a horst extending northwest into the Arkansas Valley trough was completed. The Rocky Mountain region was uplifted in later Pliocene or early Quaternary time, and the ancestral Arkansas River was superimposed from the Dry Union Formation and cut downward into the hard rocks of the Browns Canyon area. Erosion and canyon cutting were dominant thereafter in the eastern part of the quadrangle.

During Pleistocene time the Sawatch Range, beyond the west edge of the quadrangle, was glaciated extensively; terminal moraines ended less than 3 miles from the Poncha Springs NE and SE quadrangles. Outwash and alluvial-fan gravels, representing at least eight stages of glaciation, were deposited on a series of three pediments and six lower terraces that developed on the Dry Union Formation. The deposits at various heights are related to former levels of the Arkansas River and probably to Pleistocene climatic changes.

The quadrangle is currently being dissected by the Arkansas River and its tributaries. Holocene deposits consist of silt, sand, and gravel that form the alluvium and colluvium of the present drainage system, several landslide accumulations, talus debris, and a peat deposit that is probably less than 200 years old.

ECONOMIC GEOLOGY

Mines that still contain large fluorspar resources in the Poncha Springs NE quadrangle have yielded about $5 million worth of commercial concentrates. Deposits of copper, gold, gravel and sand, peat, pegmatite minerals, pumice and perlite, quartzite, and vermiculite also have been exploited, but in 1967 only peat was being extracted.

FLUORSPAR DEPOSITS

HISTORY OF PRODUCTION AND OWNERSHIP

The Browns Canyon district is one of the major fluorspar districts of the United States because of its substantial production and resources. Fluorspar was discovered in the district about 1923, and the earliest recorded shipments were made in 1927. An analysis of shipment figures furnished by some of the mine and mill operators and of those recorded by the U.S. Bureau of Mines indicates that approximately 130,000 tons of fluorspar concentrates was recovered from about twice that quantity of ore from the district. Concentrates were shipped until 1949, about 80 percent of them in the last 8 years of operation. Approximately 59 percent of the concentrates was metallurgical grade, containing about 85 percent CaF_2; 39 percent was ceramic grade, containing about 92–97 percent CaF_2; and 2 percent was acid grade, containing about 98 percent CaF_2. Production of acid-grade fluorspar by flotation and metallurgical-grade fluorspar by jigging was difficult because the ore commonly consists of intimate intergrowths of very fine grained fluorite and silica minerals. Much of the metallurgical-grade and some of the ceramic-grade products resulted from handpicking of selectively mined ore.

Most of the production has come from claims formerly held by Colorado Fluorspar Mines, Inc. (successor to Colorado Fluorspar Corp. in 1945), and American Fluorspar Corp. Allied Chemical Corp., General Chemical Division, acquired the holdings of both organizations, the former in 1948 and the latter in 1946. Other mining centered on claims of United States Fluorspar & Manganese, Inc. (formerly United States Fluorspar, Inc., successor to Chaffee County Fluorspar Corp.) and Commercial Minerals, Inc. (formerly Universal Mines, successor to Mansheim-Salida Fluorspar Co.); some of the claims of Commercial Minerals, Inc., were leased to Kramer Mines, Inc., which produced fluorspar during 1942–1944.

Four flotation mills, each with a daily capacity of about 100 tons of mill heads, operated in the district. The mill of Colorado Fluorspar Corp. and its successors was active between 1939 and 1948. The mills of Kramer Mines, Inc., and Fluorspar Processing Co., associated with American Fluorspar Corp., were put into operation in 1942. The Kramer mill was destroyed by fire in 1944, and the Fluorspar Processing Corp. mill was dismantled after Allied Chemical Corp. acquired the American Fluorspar Corp. holdings in 1946. The mill of United States Fluorspar & Manganese, Inc., built in 1945, operated sporadically on ore from the district in 1945 and 1946; this mill and that of the former Colorado Fluorspar Corp. are still in the district but are not in operable condition.

LOCALIZATION AND STRUCTURE

Most of the fluorspar production has come from a normal fault zone that strikes N. 30°–50° W. and dips 65°–85° SW.; several other mineralized faults shown on plate 1 have yielded ore. The main fault zone (fig. 5),

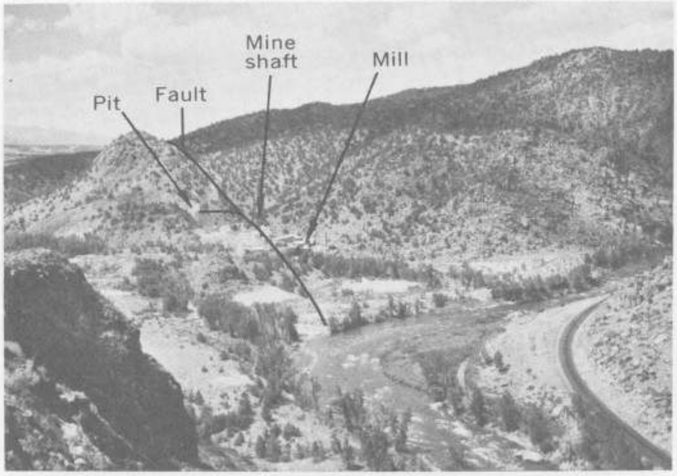


FIGURE 5.—View northwest from Arkansas River, showing the main fault zone between hills of Tertiary rhyolitic welded tuff (left) and Precambrian rocks (right) and the Colorado-American fluorspar mine.

which forms the southwest boundary of the horst described previously, is mineralized with fluorspar almost continuously for nearly 3,000 feet in secs. 34 and 27, T. 51 N., R. 8 E. Along much of its length this fault zone consists of two nearly parallel branches, best exposed in the Colorado-American deposit. The west wall of the west branch is composed of approximately 350 feet of welded ash-flow tuff of Oligocene age overlying Precambrian rocks; Precambrian rocks form the east wall or footwall. The more productive east branch has Precambrian rocks on both walls. Various Precambrian units here are offset by left-lateral as well as vertical displacement. Some of the strike-slip movement took place after the fluorspar mineralization because slickensided fault surfaces, bearing gently raking striae and grooves, cut the fluorspar and microcrystalline quartz that were deposited toward the close of the period of mineralization.

Many of the veins nearly fill single fissures between highly slickensided abrupt walls. Vugs and water courses, some containing wad and clay, are as much as 4 by 8 feet in horizontal cross section and 30 feet high (Cox, 1945, p. 273). The walls of the deposit are indefinite in other places where the mineralized fault zone is more complex, consisting of replaced breccia fragments and parallel and en echelon lenses. The footwall generally is better defined than the hanging wall.

Precambrian gneissic quartz monzonite and Tertiary rhyolitic welded tuff were the most competent rocks during faulting and maintained openings suitable for the movement of ore-forming solutions. Throughout the district, the walls of oreshoots generally are one or both of these rock types.

MINERALOGY

The veins consist almost entirely of fluorite and microcrystalline and chalcedonic quartz. Minor quantities of coarser grained quartz, opal, calcite, barite, pyrite, marcasite, black manganese oxides, iron oxides, and clay minerals also occur.

The fluorite ranges from microgranular to coarse grained; most is microgranular to fine grained. Locally, crystals of medium-grained fluorite loosely interlock and form the so-called "sugar spar." Coarsely crystalline fluorite generally is glassy and has radial-fibrous or columnar structure; a piece is very rarely cleavable into large fragments. Much of the fluorite is botryoidal, mammillary, or reniform. The surface of some fine-grained fluorite is rippled in a manner that suggests slight downward flow of gelatinous material. Chocolate-brown, purple, red, pink, green, yellow, gray, white, and colorless varieties of fluorite have been observed; the colors fade upon weathering of the fluorite. All varieties were tested with an ultraviolet lamp, and none fluoresces.

The fluorite is commonly made up of layers (fig. 6) ranging in thickness from less than 1 mm to more than 2 feet. Material consisting of layers of fluorite of different colors and grain sizes is known locally as "ribbon spar" or "bacon spar." Some of the layered fluorite forms nodular ore (fig. 7) composed of nearly concentric layers of fluorite around breccia fragments of country rock, fluorite, or chalcedony. An origin for the formation of such nodular fluorspar ore by alternate rotation of breccia fragments and deposition of fluorite has been suggested (Van Alstine, 1944, p. 122–123).

Well-formed crystals of fluorite are not very common and are generally less than a millimeter on edge. Hand-lens and microscopic examination of specimens, however, revealed the following crystal habits: cube; octahedron; dodecahedron; octahedron modified by cube, dodecahedron, trapezohedron, trisoctahedron, tetrahexahedron, and hexoctahedron; dodecahedron modified by cube; and trapezohedron modified by cube and octahedron. Cubes are most abundant, especially as a coating of the botryoidal, mammillary, and reniform surfaces. Some octahedra are built of smaller octahedra in parallel growth.

Although octahedral and dodecahedral fluorite have been considered higher temperature or earlier forms than cubic fluorite (Kalb and Koch, 1929; Drugman, 1932; Ingerson, 1955, p. 394), in specimens from the Browns Canyon district these three forms were found together and evidently were deposited simultaneously. Cubes and dodecahedra occur together in one specimen, and dodecahedra and octahedra modified by cubes in an-

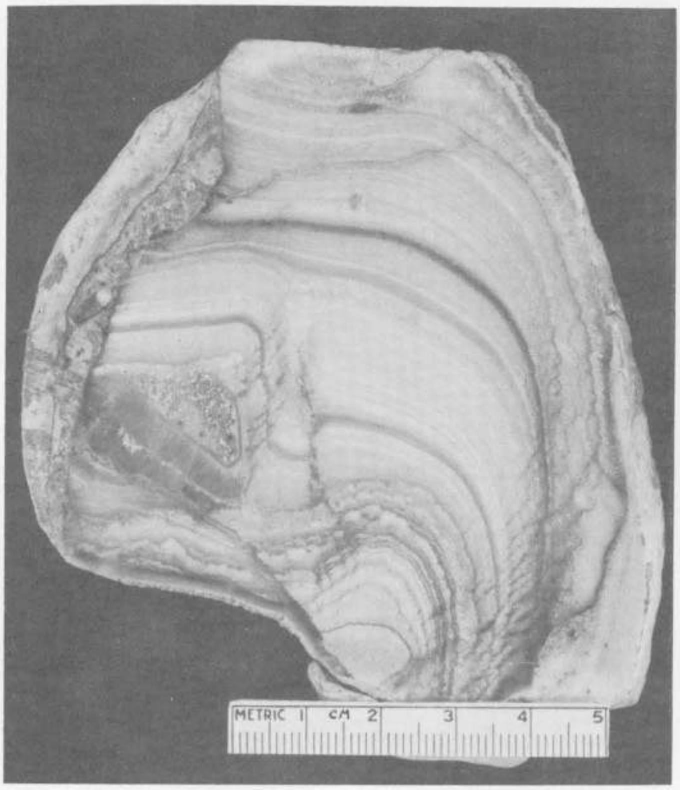


FIGURE 6.—Fine-grained layered fluorite, Last Chance fluorspar deposit. Scale shown in centimeters. Photograph by J. A. Denson.

other. In a specimen from the lower level of the Chimney Hill deposit, fluorite crystals less than 0.04 mm in diameter, extracted from a crack at the contact of layers of fluorite and microcrystalline quartz, have the following four habits, listed in decreasing order of abundance: cube and dodecahedron, cube, octahedron and cube, and dodecahedron.

Microcrystalline to chalcedonic quartz is the other major constituent of the fluorspar deposits; it is white, gray, or pinkish and is commonly interlayered and intergrown with fine-grained and microgranular fluorite. Intergrowths of fluorite and silica minerals range from soft, nearly pure fluorite to hard, nearly pure siliceous material. Chalcedony with typical fibrous or aggregate structure is not nearly so abundant as microcrystalline quartz. The microcrystalline quartz occurs as tiny wedge-shaped crystals, some twinned, in fluorite; as microscopic films along the cleavage of fluorite; as rims around fluorite grains and linings of vugs in fine-grained fluorite; and as mosaics within and between layers of fluorite. The grain size of much of the quartz in fluorite is less than 0.01 mm. Quartz also forms veins and replaces fault gouge and breccia fragments. In the Colorado-American fluorspar deposit a vein of microcrystalline quartz against part of the hanging wall is as much as 14 inches thick; the quartz replaced the wallrock slightly, but it has a slickensided and polished contact with the fluorite. Locally it contains grains of pyrite and is cut by veinlets of fluorite and pyrite.

FIGURE 7.—Nodular fluorite consisting of brecciated, silicified rhyolitic welded tuff, chalcedony, and early fluorite surrounded by thin layers of gray and white fluorite; Colorado-American deposit. Scale shown in centimeters. Photograph by J. A. Denson.

Minor quantities of more coarsely crystalline quartz are present in microcrystalline quartz and fine-grained fluorite. Colorless and pinkish doubly terminated quartz crystals locally line vugs in fluorite and, in turn, are coated with botryoidal fluorite.

Opal with ring structures is interlayered with fluorite, microcrystalline and chalcedonic quartz, montmorillonite, and iron oxides. Opaline silica, coating botryoidal fluorite at the Alderman deposit and lining a cavity in the fluorspar vein at the Colorado-American deposit, represents the latest phase of mineralization in these places. X-ray examination of this opaline material by J. C. Hathaway (written commun., Jan. 28, 1958) and J. W. Hosterman (written commun., June 10, 1965) revealed approximately 50 percent low-temperature cristobalite, 25 percent flfluorite, 15 percent montmorillonite, and 10 percent quartz.

Calcite occurs chiefly as veinlets in greenish fluorite, as tiny grains in soft red fluorite with iron oxides and clay, and as brecciated fragments with fine gray fluorite in microcrystalline quartz. More calcite was seen on the lower level of the Chimney Hill deposit than elsewhere in the district; some of the calcite there is lameller and is partly replaced by quartz.

Barite chiefly forms irregular grains in fine-grained fluorite; one specimen of layered fluorspar contains nearly 20 percent barite. Tiny barite crystals locally coat botryoidal fluorite in vugs in the veins.

Pyrite is rare in the fluorspar deposits but does occur in some small patches and veins of microcrystalline quartz, in fluoritized breccia fragments, and in a few specimens of layered fluorite with marcasite, hematite, and limonite. A polished section of the sulfide minerals shows that marcasite fills cracks in pyrite and is partly replaced by fluorite.

Manganese-oxide minerals were observed in all the productive fluorspar deposits, chiefly as layers and veinlets formed before and during the deposition of the fluorite. Postfluorite manganese oxide, associated with barite and montmorillonite, coats fluorite and quartz crystals in a few vugs in the Colorado-American fluorspar deposit. Material from small pockets in the Manganese Hill fluorspar deposit contains about 20 percent manganese. No sizable bodies of minable manganese ore, however, have been found in the Browns Canyon district.

Three manganese-oxide minerals—pyrolusite, manganite, and psilomelane—are constituents of fluorspar veins in or near the Browns Canyon district. X-ray study of these minerals was made by Edward Chao (written commun., June 13, 1958). Pyrolusite, a soft radiating acicular black metallic mineral with black streak, occurs along a fault between rhyolitic welded tuff of Oligocene age and Precambrian rocks east of the Arkansas River (SE¼ sec. 2, T. 50 N., R. 8 E.), just beyond the south edge of the quadrangle. The pyrolusite is associated with chalcedony, pinkish fluorite, and barite, and is clearly earlier than the fluorite. Manganite occurs as a moderately hard massive brown mineral with brown streak, in the Manganese Hill fluorspar mine of U.S. Fluorspar & Manganese, Inc., NE¼ sec. 28, T. 51 N., R. 8 E. The manganite is accompanied by quartz, pyrite, fluorite, and barite, in a deposit that occupies a fault in Precambrian gneissic quartz monzonite and tuffaceous siltstone of the Browns Canyon Formation. The manganite formed earlier than, and contemporaneously with, the fluorite. Tungsten-bearing (table 11) psilomelane, a hard grayish-black metallic mineral with black streak, coats fragments of silicified and brecciated rhyolitic welded tuff at the Alderman fluorspar deposit (SE¼ sec. 34, T. 51 N., R. 8 E.), where it preceded (fig. 8), and is interlayered with, botryoidal yellowish and colorless fluorite. A thin section of a fault-breccia fragment of the volcanic rock and its outer layers of minerals was examined by E. S. Larsen, 3d, and S. K. Neuschel, who noted (written commun., Aug. 25, 1958) that the manganese mineral forms a uniform coating over the breccia fragment and presents a microcolloform surface to the fluorite. The fluorite was deposited in the open space around the manganese mineral and in shrinkage cracks within the layer of manganese oxide. In other specimens the sequence is fluorite, psilomelane, fluorite, and psilomelane (Hewett, 1964, p. 1452). Manganese-oxide minerals are found also in the Last Chance and Snowflake fluorspar deposits, as described later. Epithermal veins of fluorite and manganese-oxide minerals that contain almost 1 percent tungsten, here and elsewhere in southwestern United States, have been placed in a single late Tertiary metallogenetic epoch of short duration (Hewett and Fleischer, 1960; Hewett and others, 1963; Hewett, 1964).

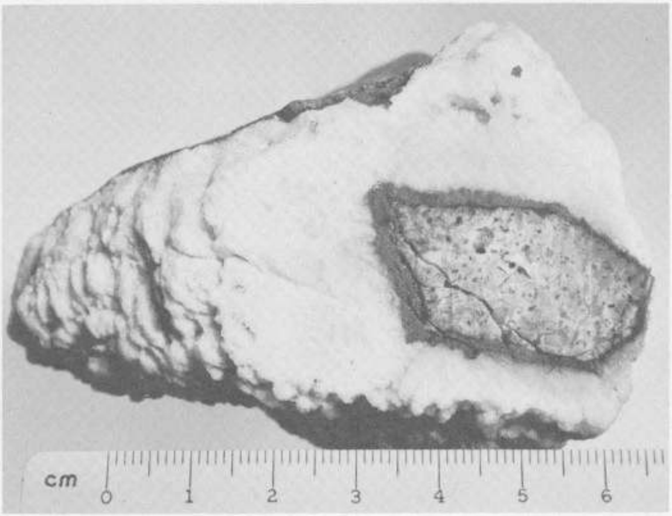


FIGURE 8.—Breccia fragment of rhyolitic welded tuff coated by psilomelane (dark layer) and fluorite; specimen from dump at Alderman fluorspar deposit. Photograph by J. A. Denson.

TABLE 11.—*Semiquantitative spectrographic analysis, in weight percent, of manganese oxide, Alderman fluorspar deposit, Browns Canyon district, Chaffee County*

[From Hewett (1964, p. 1444); lab. No. 302037]

Si	Major	Mn	Major	Nb	0. 003
Al	1. 5	Ba	3. 0	Pb	. 007
Fe	. 15	Be	. 003	Sr	. 07
Mg	. 3	Cr	. 0007	V	. 003
Ca	3. 0	Cu	. 007	W	. 7
Na	. 07	Ga	. 007	Zr	. 015
Ti	. 003				

NOTE: Elements looked for but not detected: Ag, As, B, Co, Ge, K, La, Mo, Nd, Ni, P, Sb, Sc, Tl, Y, Zn.

Small quantities of iron oxides occur as rims of limonite and hematite around fluorite grains; as blebs, patches, and veinlets within fluorite; as films between layers of fluorite; with mircrocrystalline quartz in breccia fragments cemented by fluorite; as coatings on fluorite crystals in vugs; and with montmorillonite cementing breccia fragments of fluorite. Some of the yellowish-brown iron oxide probably is goethite, as it is visibly crystalline, translucent, and anisotropic under the mircroscope. Analyses indicate that the iron-oxide content of fluorspar from the Browns Canyon district generally is less than 1 percent. A thin section of fluorspar from a vein east of the Puzzle deposit (NW¼ sec. 27, T. 51 N., R. 8 E.), however, is estimated to contain nearly 10 percent iron oxides, and red fluorspar ore from the Last Chance deposit to the northeast has 24.6 percent Fe_2O_3 (Norman Davidson, analyst, Feb. 3, 1943).

Clay minerals in the fluorspar deposits are montmorillonite, a montmorillonitelike mineral, and kaolinite. Montmorillonite, identified by X-ray method (Helen Mark, written commun., Jan. 31, 1962), occurs at the Colorado-American deposit as thin films between early quartz and fluorite and as white to brownish-gray patches and grains in and upon fluorite, accompanied locally by microcrystalline quartz and opal. Mary E. Mrose found by X-ray study that another clay mineral (Lab. No. 152688) which coats fluorite octahedra from this deposit is similar to montmorillonite. Visual spectrographic examination of this montmorillonitelike mineral by N. F. Sheffey showed the presence of calcium, magnesium, and aluminum, but not potassium (M. E. Mrose, written commun., May 6, 1958). A white clay from the fluorspar vein at the Manganese Hill deposit, tested chemically and optically, was identified as kaolinite (J. J. Glass, written commun., Aug. 24, 1944).

PARAGENESIS

Studies of exposures, hand specimens, thin sections, and polished sections indicate that fluorite, quartz, calcite, manganese-oxide minerals, and clay minerals were deposited in many stages throughout the period of mineralization. The sequence of deposition upon many wallrock breccia fragments began with fine quartz and montmorillonite, followed by purplish and gray fluorite. Elsewhere, coarse green octahedral fluorite commonly was the first mineral deposited. Most of the later fluorite is layered, coarse or fine grained, and botryoidal; locally a crust of fine-grained white fluorite is latest. Fluorite and quartz were contemporaneous with, and in part later than, rare pyrite; pyrite formed before marcasite. Barite, opal, and iron-oxide minerals were deposited along with the fluorite, or later.

WALLROCK ALTERATION

Alteration products in the exposed wallrocks of the fluorspar veins are not very conspicuous and generally extend no more than several inches on either side of the vein. Silicification and fluoritization were the major types of alteration, and in places clay minerals, chlorite, and a zeolite formed in the wallrocks.

The alteration effects appear in thin section chiefly as partial replacements of feldspars and biotite and as veinlets of fluorite and quartz with small quantities of chlorite. Phenocrysts of sanidine and biotite in the rhyolitic volcanic rocks were especially susceptible to alteration. Some sanidine crystals are partly replaced by quartz, fluorite, chlorite, sericite, and clay minerals; biotite crystals are partly altered to chlorite and quartz. Locally the wallrocks contain a few patches of sericite, clay minerals, and grains of calcite, barite, and pyrite. Tiny crystals of quartz, barite, and stilbite (X-ray identification by B. M. Madsen, May 8, 1967) coat fractures in rhyolitic welded tuff adjacent to the Chimney Hill fluorspar deposit. The zeolite is optically negative, and the index of refraction of Y is 1.4925±0.0005, indicating a high-silica stilbite according to Miss Madsen. Zeolites evidently have not been recorded previously as wallrock alteration or vein minerals in published descriptions of commercial fluorspar deposits of the United States; however, stilbite, heulandite, laumontite, phillipsite, and chabazite coat fluorite crystals in cavities next to a fluorite vein in Connecticut (Myer, 1962).

Although it was suggested that adularia is the potassic feldspar in the rhyolitic wallrock at the Alderman fluorspar deposit (Hewett, 1964, p. 1454), the presence of adularia was not confirmed by X-ray determination, using the method of Wright (1968). This X-ray investigation indicated that the potassic feldspar is monoclinic low sanidine and that sodic feldspar is lacking. Sanidine is a common mineral in the welded tuffs of the quadrangle, where it occurs as phenocrysts, a groundmass mineral, and a vapor-phase mineral in cavities.

ASSOCIATED THERMAL FLUORIDE WATERS AND THE SOLUBILITY OF CaF_2

Moderately alkaline fluoride waters, which White (1955, p. 147) regarded as probably being largely meteoric but with volcanic contributions, were analyzed from the Colorado-American mine workings and from two thermal springs southwest of the mine and within 650 feet of the fluorspar-bearing fault zone. A similar warm spring east of the Chimney Hill deposit issued 1 gallon per minute in 1943, before mining activities diverted the flow of water. Table 12 gives chemical analyses of three thermal waters from a spring, from a fissure on the 100-level of the Colorado-American mine (pl. 3), and from Poncha Hot Springs at the edge of a fluorspar district about 9 miles south. Analyses of cold mine water of the western Kentucky and St. Lawrence, Newfoundland, fluorspar districts are given in table 13 for comparison. The higher values for sodium, chlorine, fluorine, and SO_4, the lower values for calcium, magnesium and NO_3, and higher total dissolved solids for the Colorado warm waters are noteworthy in comparison with the cold mine waters elsewhere. In two analyses (Nos. 267284 and 4712) of thermal spring water from the Browns Canyon district, consideration of the parts per million and combining weights of calcium and fluorine ions indicates that the calculated milliequivalents of fluorine (0.79) per liter are about twice those of calcium (0.35 and 0.38) per liter. This relative deficiency of calcium suggests that all the fluorine ions in this water could not have been derived by the dissolving of earlier formed CaF_2 unless some of the calcium had been removed from solution by deposition below. The calcite content of the Colorado-American deposit has not increased noticeably within a mining depth of 450 feet, however, and spring deposits of calcium carbonate or other calcium-bearing minerals do not occur near these fluorspar deposits. On the other hand, travertine deposits are forming from the similar thermal waters containing slightly less fluorine and more calcium (table 12) in the Poncha Springs fluorspar district, where the fine-grained tufa consists of about 95 percent calcite and a little tungsten-bearing black manganese oxide, chalcedony, opal, quartz, chlorite, muscovite, and fluorite (Russell, 1950, p. 50–52; White and others, 1963, p. F51). Russell reported that the fluorite occurs as rare, clear colorless cubes.

TABLE 12.—*Analyses of alkaline thermal waters from Browns Canyon and Poncha Springs fluorspar districts, Chaffee County*

[Data in parts per million; n.d., not determined]

	Sample			
	267284	4712	4713	4714
SiO_2	45	42	38	83
Fe (total)	n.d.	.17	.04	.05
Ca	7	7.6	7.9	17
Mg	< (5)	.7	1.8	.9
Na	156	158	151	194
K	5	6.8	4.8	8
CO_3	0	4.9	4.9	0
HCO_3	126	128	127	215
SO_4	146	141	142	204
Cl	55	55	53	51
F	15	15	13	12
NO_3	n.d.	.0	.0	.1
BO_3	n.d.	.3	.3	.2
Dissolved solids	n.d.	489	474	669
Specific conductance (micromhos at 25°C)	754	761	739	959
pH	8.5	8.2	8.2	7.9

267284. Analyzed by W. D. Goss and I. C. Frost, U.S. Geological Survey; other analyses by C. S. Howard, U.S. Geological Survey.

267284 and 4712. Water from spring issuing from fissure in rhyolitic welded tuff, NE¼NW¼ sec. 34, T. 51 N., R. 8 E., Browns Canyon fluorspar district. Temperature 22°C; flow estimated by D. C. Cox to be 5 gallons per mintue in November 1945. Sample 267284. Collected by D. H. Richter, J. J. Hemley, and R. E. Van Alstine in August 1958. Sample 4712. Collected by D. C. Cox in November 1945.

4713. Water from fissure in mineralized breccia composed of gneiss, pegmatite, microcrystalline quartz, and fluorite on 100-level of Colorado-American fluorspar mine, Browns Canyon district (pl. 3). Temperature 18.5°C; flow estimated by D. C. Cox to be 2 gallons per minute in November 1945.

4714. Water from central sump at Poncha Hot Springs, Poncha Springs fluorspar district, about 9 miles south of Browns Canyon district. Water issued from shear zones in Precambrian gneiss and schist. Temperature 67°C in November 1945, measured by D. C. Cox. Rate of flow for the many springs has been variously estimated at 100 gallons per minute (George and others, 1920, p. 229), 500 gallons per minute (Stearns and others, 1937, p. 133), and 50 gallons per minute (White and others, 1963, p. F51). A similar analysis on a sample of this water collected in 1958 has in addition Al, 0.53; Mn, 0.10; Sr, 0.4; Ba, 0.1; and PO_4, 0.02 ppm (White and others, 1963, p. F50).

TABLE 13.—*Analyses of alkaline, cold mine waters from western Kentucky and St. Lawrence, Newfoundland, fluorspar districts*

[Data in parts per million; Tr., trace; n.d., not determined]

	Sample		
	33255	33257	1
SiO_2	11	10	25.2
Fe	.02	.01	Tr.
Ca	51	69	36.8
Mg	21	21	1.4
Na	23	14	18.1
K			Tr.
HCO_3	251	227	100.0
SO_4	45	85	10.7
Cl	3.8	5.1	28.0
F	2.4	2.6	1.6
NO_3	.4	.2	8.2
Al_2O_3	n.d.	n.d.	2.7
Mn	n.d.	n.d.	2.0
Zn	n.d.	n.d.	.0
Pb	n.d.	n.d.	.0
PO_4	n.d.	n.d.	.0
Dissolved solids	275	324	184
pH	7.3	7.7	7.6

33255. Water from 210-level of Senator fluorspar mine, northeast of Princeton, western Kentucky. Inflow from vein and adjacent limestones, shales, and sandstones. Collected by W. R. Thurston, May 1944; analyzed by E. W. Lohr, U.S. Geological Survey.

33257. Water from 550-level, Kentucky-Babb fluorspar mine, 1.8 miles north of Salem, western Kentucky. Inflow from vein and adjacent limestones, shales, and sandstones. Collected by G. C. Hardin, Jr., June 1944; analyzed by E. W. Lohr, U.S. Geological Survey.

1. Water from 150-level, Director fluorspar mine, St. Lawrence district, Newfoundland (Van Alstine, 1948, p. 37). Inflow from vein and adjacent granite. Collected by R. E. Van Alstine, July 1940; analyzed by G. A. Abbott, Department of Chemistry, University of North Dakota.

The fluorine content of the thermal waters of the Browns Canyon and Poncha Springs fluorspar districts is high in comparison with that of other thermal springs closely associated with epithermal mineral deposits (White and others, 1963, p. F20). Fluoride concentrations of 10 ppm or more are rare in natural waters (Hem, 1959, p. 113), and waters high in fluorine generally are high in sodium, low in calcium, and have a high pH. Lindgren (1933, p. 69–73) pointed out the association of fluoride with sodium bicarbonate spring water in volcanic regions and cited evidence for the deposition of fluorite from thermal waters at Wagon Wheel Gap, Colo.; Ojo Caliente, N. Mex.; Carlsbad Springs, Germany; Teplitz, Bohemia; and Plombières, France. The association of such thermal waters with fluorite deposits suggests, but does not prove, a genetic relation.

Fluorite is one of the least soluble fluorides; its solubility is 11 mg/l fluorine at 0°C, 13 mg/l fluorine at 10°C, 15 mg/l fluorine at 20°C, and 30 mg/l fluorine at 100° C (Kazakov and Sokolova, 1950). For water of unit density, these values correspond approximately to 23 ppm, 27 ppm, 31 ppm, and 62 ppm of CaF_2, respectively. The overall effect of the constituents of the Browns Canyon thermal waters on the solubility of CaF_2 is not known. The solubility of CaF_2 increases in the presence of CO_2 (Rankama and Sahama, 1950, p. 763). Experiments by Kazakov and Sokolova (1950), however, indicate that calcium salts decrease the solubility of CaF_2 because of the common-ion effect and that Na_2SO_4 does not have any noticeable effect on the solubility of CaF_2. At 10°C, increasing the NaCl content to 100 g/l resulted in a gradual increase in the solubility of CaF_2 to a maximum of 18 mg/l fluorine; the fluorite solubility decreased with further increase of the NaCl content.

ORIGIN

Evidence cited below indicates the Browns Canyon fluorspar deposits are epithermal; such deposits form at rather shallow depth, under moderate pressures and temperatures between 50° and 200°C± (Lindgren, 1933, p. 212). According to Schmitt (1950, p. 209–210) few deposits of this type exceed a depth of 3,000 feet, and most originated in a fumarolic–hot springs environment. The following are especially indicative of the epithermal origin of the Browns Canyon deposits: (1) their occurrence near thermal springs; (2) laboratory evidence for deposition of the fluorite from very dilute solutions at about 119°–168°C; (3) the abundance of nodular ore associated with breccia fragments; (4) the presence of vugs lined with fluorite and other minerals that have botryoidal and colloform structures; and (5) the association of fine-grained, fine-layered fluorite with barite, microcrystalline and chalcedonic quartz, opal, manganese oxides, and clay minerals. According to Hewett (1964) such mineral associations are typical of epithermal veins throughout southwestern United States. White (1955, p. 100, 104, 121), in reviewing the relation of thermal springs to ore deposits, found that opal seldom forms at a temperature much greater than 100°C and below a depth of 100 feet in sinter and veins at Yellowstone Park, Wyo.; Steamboat Springs, Nev.; and Wairakei, New Zealand. Similarly, chalcedony and microcrystalline quartz are phases that generally form under conditions present at shallow depths.

Fluorine is a common constituent of igneous rocks (Rankama and Sahama, 1950, p. 757) and is about the fifteenth most abundant element in the earth's crust. Estimates of the quantity of fluorine in the crust range from 260 to 900 parts per million (Fleischer, 1953, p. 4); according to Fleischer and Robinson (1963, p. 67) the average fluorine content of the continental rocks of the earth's crust is 650 ppm. Fluorine, the most reactive element known, nearly always occurs in intrusive and volcanic rocks as a constituent of fluorite, apatite, micas, amphiboles, tourmaline, topaz, and other minerals. Fumarolic exhalations of steam and acid gases in the Valley of Ten Thousand Smokes, Alaska, annually yielded hundreds of thousands of tons of fluorine-containing gases in concentrations of 0.032 percent HF, and incrustations around the vents contained as much as 15 percent fluorine as silicofluorides (Zies, 1929).

Regardless of whether the ore fluids that formed the Browns Canyon deposits had a high halogen-acid content at a magmatic source, there is little evidence that the solutions were acid at the site of fluorite deposition. Effects of argillic alteration, probably by acid solutions (Lovering, 1950), were noted in some of the wallrocks, but there is little evidence for highly acid alteration effects such as those at the Valley of Ten Thousand Smokes, Alaska. In Alaska, rhyolitic ash next to a fumarole that emitted HCl and HF was altered chiefly to magnetite, hematite, goethite, hydromica, opal, montmorillonite, and kaolinite, and the inner and outer zones of alteration were leached of silica by the halogen gases and halogen-acid solutions, respectively (Lovering, 1957). Silicification and fluoritization were the major types of alteration in the Browns Canyon district, and the presence of fluorite interlayered with late opal and intergrown with calcite suggests that the solutions were alkaline, at least during the late stages of mineralization. Stilbite, a zeolite in rhyolitic welded tuff next to the Chimney Hill deposit, may have formed from an alkaline type of water similar to that found in the nearby thermal springs. White(1957, p. 1649–1651) recorded the formation of zeolites from sodium-bicarbonate waters and proposed the genesis of such thermal waters of volcanic origin, some of which are high in fluorine and low in calcium, by several possible mechanisms, depending upon the depth of penetration of meteoric water and density of the gas phase. The open fractures and breccia along the mineralized faults of the Browns Canyon district suggest that circulating meteoric water may have been a significant component of the mineralizing fluid that formed the near-surface fluorspar deposits. Dilution of hydrothermal fluids by meteoric water would decrease the temperature and salinity and may have caused precipitation of the vein minerals.

Based upon the composition of the vein minerals, the heated mineralizing fluid contained calcium, fluorine, silicon, manganese, aluminum, iron, barium, hydrogen, oxygen, and sulfur. Analyses of brines from primary fluid inclusions in coarse fluorite and associated minerals from other localities have shown that sodium, chlorine, potassium, and magnesium also may have been important elements of the ore-forming fluids (Grushkin and Prikhid'ko, 1952; Ames, 1958; Roedder, 1963; Hall and Friedman, 1963); however, the freezing temperatures of primary fluid inclusions in fluorite from the Colorado-American mine and workings to the northwest in the Browns Canyon district indicate that the fluid is essentially fresh water (Edwin Roedder, U.S. Geological Survey, oral commun., Mar. 1966). Roedder (1963, p. 171, 177, 179) also reported low salinities in inclusions in fluorite from similar Tertiary, near-surface, hot spring-type deposits at the Wagon Wheel Gap mine, Mineral County, Colo., and the Cougar Spar mine, Beaver County, Utah.

The fluorite in the Browns Canyon district evidently was deposited at about 119°–168°C, the temperatures at which primary fluid inclusions homogenized in five samples, including both gray and octahedral, early green types of fluorite (Edwin Roedder, written commun., Aug. 11, 1966); two of the samples were collected from the Colorado-American mine and three from areas to the northwest—from the Delay adit, at a cut about 800 feet northwest of the Delay adit, and at a shaft about 400 feet east-southeast of the Chimney Hill mine. (See pl. 1 for locations.) No correlation exists between these two color varieties of fluorite and the temperatures at which the vapor phase in the inclusions disappears upon heating. Inclusions in extremely fine-grained and fine-layered fluorite, the most common type in the Browns Canyon district, are too small for such temperature investigations. Temperature corrections for the pressure that existed when the fluorite was deposited apparently would be very small, as the fluorite formed essentially in a hot spring environment. The above temperature range is slightly greater than the 100°–150°C range that fluid-inclusion study suggests as the temperatures at which similar fluorite in the Northgate district, Jackson County, Colo., formed (Steven, 1960, p. 409–411).

The heat and fluoride, although regarded as volcanic contributions to the mineralizing fluid, cannot be attributed to any known igneous body within the area. The Nathrop Volcanics of late Oligocene age, remnants of which are exposed 6–7 miles north of the fluorspar deposits, were emplaced close to the period of fluorspar mineralization; the rhyolite flow contains the fluorine minerals, topaz, and rare fluorite, and the underlying perlitic glass contains 0.23 percent fluorine, twice as much as that in any of the analyzed older Tertiary volcanic rocks of the area. As described later, however, fluorspar mineralization at several deposits in the Browns Canyon district is younger than the Browns Canyon Formation of Miocene age. The principal faulting and mineralization preceded deposition of the Dry Union Formation of Miocene and Pliocene age and are definitely older than gravels 3 and 4, of early to middle Pleistocene age. Gravel 3 lies upon the major fluorspar vein near the north boundary of sec. 34, T. 51 N., R. 8 E., and gravel 4 contains boulders of rhyolitic welded tuff with fluorspar veinlets at an altitude of about 7,560 feet in NW ¼ sec. 2, T. 50 N., R. 8 E.

GRADE, SIZE, AND RESOURCES

The grade of the fluorspar deposits depends chiefly upon the relative quantities of fluorite, microcrystalline quartz, and brecciated wallrock in the mineralized fault zones. Channel samples more than 5 feet long range from 93 percent CaF_2 and 5 percent SiO_2 to less than 1 percent CaF_2 and more than 80 percent SiO_2. The grade of mined ore bodies ranges from less than 25 percent CaF_2 to more than 75 percent CaF_2; some of the largest ore bodies contain 50–55 percent CaF_2. During World War II, when four mills were active in the Browns Canyon district, mill heads ranged approximately from 15 to 75 percent CaF_2. Published analyses (Batty and others, 1947, p. 12) of ore-dressing samples from several veins in the district are given in table 14.

TABLE 14.—*Analyses of typical ores of the Browns Canyon fluorspar district*

[From Batty, Havens, and Wells (1947, p. 12)]

CaF_2	SiO_2	$CaCO_3$	Fe	MgO	Al_2O_3	R_2O_3
67.8	20.4	0.45	0.7	0.3	1.95	2.95
42.1	36.0	.09	1.35	.3	6.0	7.9
21.1	50.2	1.1	2.0	....	11.0	13.8

NOTE: In each analysis the balance of the constituents should probably be attributed chiefly to CaO, K_2O, and Na_2O of feldspars and other minerals of the wallrocks.

Analyses of ores indicate that fluorspar from the Colorado-American mine generally contains less microcrystalline quartz, clay, and iron oxides and fewer breccia fragments of the wallrocks than are found in fluorspar from other parts of the district. The greatest content of $CaCO_3$, about 4 percent, was found in reddish microcrystalline fluorite from the Last Chance deposit (Norman Davidson, analyst, Feb. 9, 1943). Generally, the $BaSO_4$ content of district ores is less than a few tenths of a percent, and the sulfur content is less than a few hundredths of a percent. Nine spectrographic analyses (COL-51-1 to 9) of ore, concentrates, and tailings from the Colorado-American deposit have been published (Kaiser and others, 1954, p. 40–41). The analyses show as much as 0.0005 percent BeO and 0.0005 percent NiO in the flotation mill heads, which contained about 45 percent CaF_2; 0.0003 percent BeO and 0 percent NiO in the flotation concentrates that contained about 95 percent CaF_2; and 0.0005 percent BeO and 0.004 percent NiO in the tailings, which contained about 10 percent CaF_2.

The Browns Canyon fluorspar deposits are large and have extensive mine workings. As shown on plate 1, one of the fault zones that contains fluorspar ore bodies is more than 3.5 miles long; fluorspar ore is almost continuous for about 3,000 feet along the east branch of this major fault zone at the Colorado-American deposit and has been mined for more than 1,600 feet. About 40 feet of ore was exposed underground here at the intersection of a small fault with the west branch of the main fault; the average thickness in the workings, however, is less than 10 feet. The veins commonly are lower grade and contain more breccia fragments of wallrock where they are narrow. The greatest vertical distance through which any of the veins in the district has been exposed is about 450 feet, at the Colorado-American deposit. Ore shoots elsewhere in the district range from lenses several tens of feet long and a few feet thick to sheeted zones more than 1,000 feet long and about 25 feet thick. The sheeted ore body mined in an open cut at the Last Chance deposit had a maximum thickness of about 25 feet and averaged about 30 percent CaF_2.

Estimated fluorspar resources of the Browns Canyon district, totaling about 2 million short tons of crude fluorspar, are given in table 15. Resources containing more 35 percent CaF_2, estimated to a depth of 100 feet below the workings, average about 50 percent CaF_2. Resources containing 15–35 percent CaF_2 average about 20 percent CaF_2.

TABLE 15.—*Estimated fluorspar resources, Browns Canyon district, Chaffee County, expressed as short tons of crude fluorspar*

	>35 percent CaF_2	15–35 percent CaF_2	Total
Measured and indicated	250, 000	150, 000	400, 000
Inferred	150, 000	1, 500, 000	1, 650, 000
Total	400, 000	1, 650, 000	2, 050, 000

SUGGESTIONS FOR PROSPECTING

Bodies of fluorspar similar to those already discovered probably would be found by exploring: (1) the known deposits at greater depths; (2) northwest and southeast extensions of the east and west branches of the main fault zone that localized the Colorado-American deposit; (3) the main fault zone that displaces the Tertiary volcanic and Precambrian rocks between the Chimney Hill and Manganese Hill deposits; (4) the fault extending northwest from the Alderman deposit; (5) shorter faults in the gneissic quartz monzonite, similar to the fault that localized the Last Chance deposit; and (6) the fault that bounds a major horst on the northeast and extends southeast from sec. 22, T. 51 N., R. 8 E., as this fault also may be mineralized locally with fluorspar, similar to the productive deposits along the fault bounding the horst on the southwest. (See pl. 1 for all mine and fault locations.)

Although no changes in the mineralogy have been detected in the veins to a mining depth of about 450 feet in this district, other investigators (Steven, 1960, p. 415; Hewett, 1964, p. 1460–1463) have suggested that such low-sulfide, epithermal fluorspar deposits may contain valuable metal sulfides or precious metals at greater depths.

Geochemical-prospecting investigations in the district (Van Alstine, 1965) revealed abnormal fluorine concentrations in residual soil directly above, and downslope from, the principal fluorspar vein, and in alluvium downstream from the vein. The largest anomalies are approximately 6 to 20 times the background in the soil and 3 times the background in the alluvium. Fluorine values in soil near a concealed fault are too low to suggest the presence of an underlying fluorspar deposit. The study of the geochemical anomalies suggests that further investigation of the fluorine content of soil and alluvium in this district might be profitable in the search for additional fluorspar deposits.

FLUORSPAR MINES AND PROSPECTS

By RALPH E. VAN ALSTINE and DOAK C. COX

The following descriptions of the fluorspar mines and prospects are based largely upon data acquired when they were accessible between 1943 and 1945. Written permission for publication was obtained from Colorado Fluorspar Mines, Inc., American Fluorspar Corp., Kramer Mines, Inc., and United States Fluorspar & Manganese, Inc.

COLORADO-AMERICAN MINE

About 90 percent of the fluorspar concentrates shipped from the Browns Canyon district came from the Colorado-American mine (No. 2 on pl. 1), about half a mile east of the former route of Colorado State Highway 291. American Fluorspar Corp. acquired the northwestern part of the deposit from Stephen Trefone and associates in 1930 and was a steady producer from 1939 through 1945. The southeastern part of the deposit was worked by Colorado Fluorspar Co. in 1934 and 1935, by Colorado Fluorspar Corp. from 1936 through 1944, and by Colorado Fluorspar Mines, Inc., from 1945 to 1948; these organizations accounted for about 60 percent of the production from the Colorado-American deposit. Development work by Allied Chemical Corp., General Chemical Division, which acquired the mine from American Fluorspar Corp. in 1946 and Colorado Fluorspar Mines, Inc., in 1948, was localized chiefly in the northwestern part of the mine.

The geology and workings of the Colorado-American mine are shown on plates 2, 3, and 4. Mine workings and surface cuts accessible in 1945 exposed the fluorspar deposit from an altitude of about 7,270 to about 7,720 feet, a vertical range of 450 feet. Since most of the mapping in 1945, the open pit was enlarged and deepened approximately as shown on plate 2; the American shaft, shown on plate 1 along the boundary between secs. 27 and 34, was sunk and a level was driven on the vein southeast to connect with the Trefone adit (pls. 2, 3) and also northwest for about 125 feet. Plate 3 shows about 4,700 feet of drifts and 1,200 feet of crosscuts in the southern part of the Colorado-American deposit. Most of the shrinkage stopes shown on plate 4 are on the thicker and richer parts of the veins. Although the southeastern part of the deposit is largely stoped above the Colorado 100-level, ore is exposed below and in most of the working faces at the ends of the levels.

The mine workings expose three main veins—the East vein, the West vein, and the Branch or Collins vein. The East and West veins strike about N. 40° W., and dip 65°–85° SW.; the Branch vein strikes west and dips about 45° S. The East and West veins are 120–200 feet apart, and the West and Branch veins intersect near the south end of the mine.

The East vein is along a fault zone within Precambrian rocks, and the West and Branch veins follow fault zones between the Precambrian rocks and the Tertiary volcanic rocks. Striations and grooves on slickensided fault planes along the walls of the East vein rake 20°–75° S. The walls of the fault zones are chiefly devitrified rhyolitic welded tuff and Precambrian gneissic quartz monzonite, banded gneiss, hornblende gneiss, and pegmatite. Near the mineralized normal fault zones the wallrocks are schistose and brecciated in places; locally, wallrock alteration has made it difficult to recognize some of these rocks in the mine workings. Along the fault occupied by the West vein, the Tertiary volcanic rocks may have been dropped down at least 350 feet, which is the approximate thickness of the welded tuffs above the 100-level of the Colorado-American deposit.

The East vein, the principal ore body, is exposed almost continuously in the workings shown on plates 3 and 4 for about 1,600 feet and has been explored at least an additional 660 feet to a point 125 feet northwest of the new American shaft, shown on plate 1, at the boundary between secs. 27 and 34. The vein southeast of the mine workings is covered by alluvium. In the mine workings the vein ranges in width from 3 to 15 feet and averages less than 10 feet. Approximately 300 feet northwest of the American shaft, the East vein is about 8 feet thick and contains an estimated 50 percent CaF_2, considered to be average for the East vein in the workings to the south. Higher grade parts of the vein are known; for example, a 300-foot section in the Trefone adit is about 6 feet thick and averages about 75 percent CaF_2. Increasing the mining width by 5–10 feet to include more mineralized breccia probably would lower the grade of ore more than 20 percent.

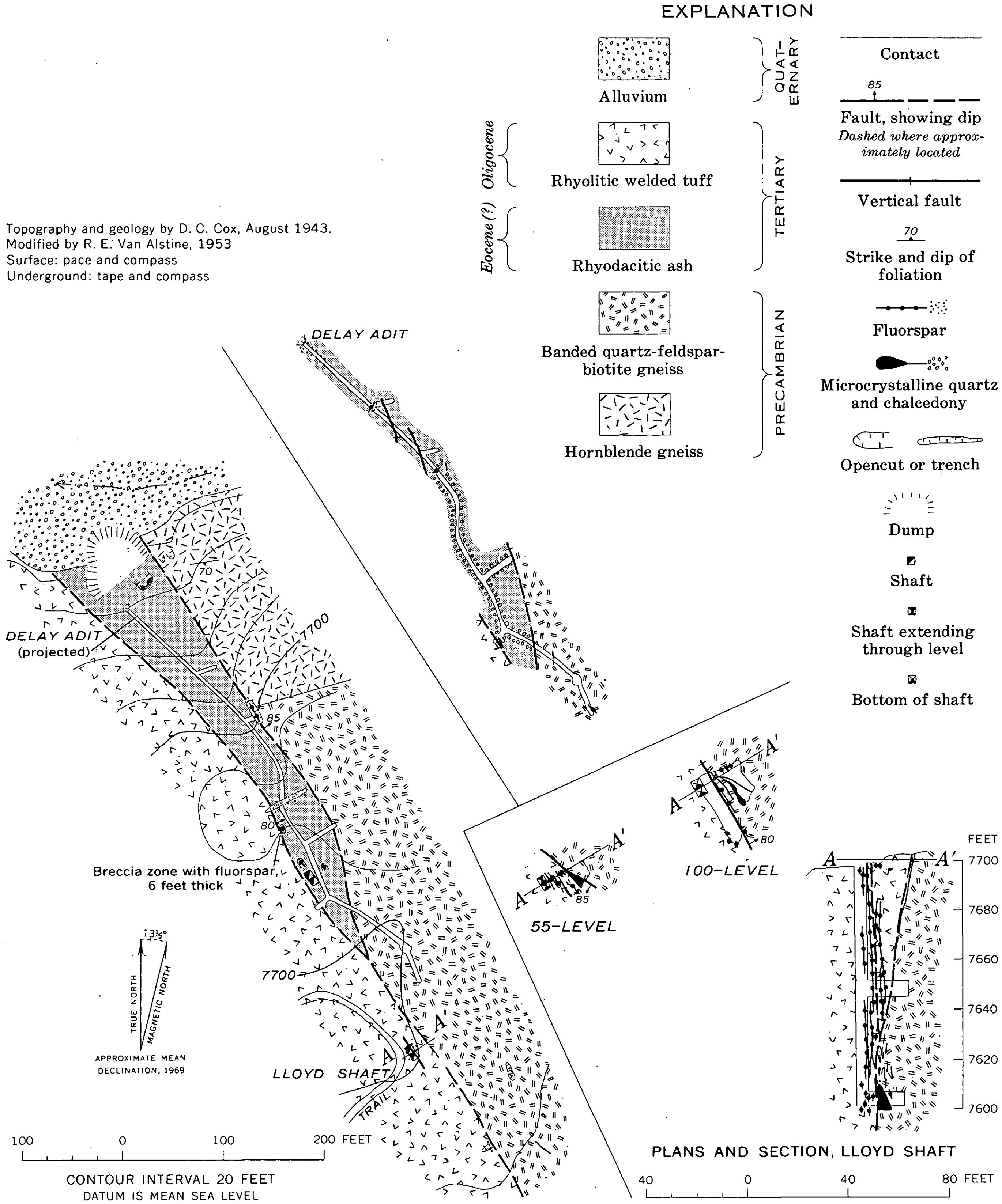
The West vein is explored underground in the Mill adit (pl. 3) near the intersection with the Branch vein, where a drift exposes a 150-foot segment of high-grade ore 6–8 feet thick and a 70-foot segment of low-grade breccia to the southeast. The fault that localized the West vein is well exposed (fig. 9) at the northeast edge of the large open pit shown on plate 2.

The Branch vein, which was worked mainly in the open pit, contains the thickest fluorspar body in the Browns Canyon district; in the open pit between the Mill adit and the original surface the ore body is 40–50 feet thick. The ore body in the open pit consists largely of shells of fluorite coating rounded blocks of rhyolitic welded tuff that are discarded in mining. In 1948 flotation-mill feed from the open pit contained 35–40 percent CaF_2. The vein was drifted on for about 300 feet in the Mill adit, and in this length it ranges in thickness from 5 feet to nearly 40 feet. (See pl. 3.) On the Colorado 100-level about 6 feet of fluorspar containing less than 30 percent CaF_2 is exposed in the Branch vein for 50 feet along the fault contact of the Precambrian rocks with welded tuff.

DELAY ADIT AND LLOYD SHAFT

The Delay adit and Lloyd shaft (No. 4, pl. 1), northwest of the Colorado-American mine and southeast of Chaffee County Road 60, explore breccia zones nearly 20 feet thick that are mineralized sporadically with fluorspar (fig. 10). Fault surfaces dip 80° S. to 80° N. along the main fault zone between Precambrian gneisses and Tertiary volcanic ash and rhyolitic welded tuff exposed in these workings and adjacent trenches excavated by American Fluorspar Corp. Although the

FIGURE 9.—View northwest in open pit at Colorado-American fluorspar mine, showing mineralized fault contact of Tertiary volcanic rocks at left and Precambrian metamorphic rocks at right.



Topography and geology by D. C. Cox, August 1943.
Modified by R. E. Van Alstine, 1953
Surface: pace and compass
Underground: tape and compass

FIGURE 10.—Geologic maps and section of the Delay adit and Lloyd shaft, Browns Canyon fluorspar district, Chaffee County, Colo.

ash commonly is silicified and argillized, euhedral biotite plates are still recognizable.

MANGANESE HILL AND CHIMNEY HILL MINES

Several thousand tons of fluorspar have been extracted from the various shafts, winzes, inclines, adits, pits, and trenches (pl. 5) at the Manganese Hill (No. 6, pl. 1) and Chimney Hill (No. 5, pl. 1) mines of United States Fluorspar & Manganese, Inc. The mines are at an altitude of about 7,600 feet, and are about 2,000 feet from U.S. Highway 285 by way of Chaffee County Road 60 and a company access road to the north. The deposits, known originally as the Morgan Ranch deposits, were first worked about 1936. In 1939 Chaffee County Fluorspar Corp. acquired the deposits and shifted most of the mining activity from the Chimney Hill mine to the Manganese Hill mine. United States Fluorspar, Inc., superseded this company in 1945 and completed a flotation mill on the property. In 1950 United States Fluorspar & Manganese, Inc., acquired the property and expanded the capacity of the mill to about 100 tons a day.

The deposit at the Manganese Hill mine is mainly in gneissic quartz monzonite of Precambrian age; the rock is highly weathered in this part of the district and contains much hematite and clay and traces of manganese oxide as stains, especially in the upper part of the workings. Locally the wallrock is the Browns Canyon Formation, which here consists of tuffaceous siltstone, claystone, lithic tuff, and generally a basal conglomeratic arkose. At the southeast edge of the open pit (pl. 5) brown siltstone is composed of angular or subrounded grains of quartz, microcline, sanidine, and biotite in a matrix of finer quartz, chlorite, sericite, kaolinite, magnetite, hematite, limonite, barite, and fluorite. Fluorspar, which forms discontinuous lenses and veinlets more than 6 inches thick in sheeted zones as much as 12 feet thick, was exposed in 1945 in workings through a strike length of more than 250 feet and a depth of about 100 feet. The mineralized fault zone strikes about N. 70° E., and dips 75°–80° N.

Three inclines were driven eastward from the same portal at angles of about 10°, 20°, and 30° from the horizontal. The third or lowest incline (pl. 5) slopes about 30° in the westernmost 100 feet of workings and is nearly level eastward to the face, which is nearly 100 feet below the east edge of the open pit. The workings expose several types of fluorite—soft, fibrous, fine-layered greenish to purplish fluorite, and dense brown fluorite, which is partly earthy and partly hard and granular. The brown fluorite is later than the other types, contains manganese-oxide minerals as small pockets and coatings, and forms the main body of fluorspar exposed in the lowest incline.

The grade of the mineralized zone averages about 20 percent CaF_2, which is also the grade of a 15-foot channel sample taken in a bulldozer cut in 1943. Analyses of individual lenses of fluorspar in the incline give as much as 56 percent CaF_2 for a 5-foot channel sample. Some of the higher grade ore was hand picked and shipped as metallurgical-grade fluorspar containing at least 85 percent CaF_2. The lower grade ore was processed chiefly into ceramic-grade concentrates in the mill on the property. Some acid-grade concentrates from Manganese Hill ore were made in the mill at the Last Chance mine.

The workings at the Chimney Hill mine, about 650 feet south of the Manganese Hill mine, are shown on plate 5. The main adit is 34 feet below the collar of a two-compartment shaft, and the lower level is 51.5 feet below the main adit at this shaft. In 1953 the lower workings were flooded, and the water level in the shaft was 10 feet below the main adit. The workings are almost entirely in silicified and chloritized rhyolitic welded tuff; locally, sanidine phenocrysts are altered to quartz, fluorite, and calcite. Breccia and gouge, cut by veinlets of microcrystalline quartz, fluorite, and barite, were exposed at the north end of the lower level. Thin sections of this breccia and gouge show angular fragments of gneissic quartz monzonite and rhyolitic welded tuff in a matrix of quartz, sericite, green biotite, chlorite, a clay mineral, pyrite, limonite, and a manganese-oxide mineral.

Fibrous and massive fluorite, microcrystalline quartz, and calcite occupy the mineralized zone that strikes N. 60°–75° W. and dips steeply south. Most of the calcite is coarsely crystalline, and some is lamellar and partly replaced by quartz. Examination of the vein minerals in the workings and in specimens indicates that some of the calcite is earlier than quartz and fluorite.

The Chimney Hill workings expose at least four bodies of fluorspar, some more than 50 feet long, through a strike length of 350 feet along the mineralized zone. The main zone splits west of the shafts, where the content of microcrystalline quartz appears to be higher. The greatest thickness of fluorspar, about 15 feet, was observed in the pit on the southernmost split. The larger bodies contain about 30 percent CaF_2; most of the remaining content is silica, and calcite forms less than 3 percent of the exposed fluorspar bodies. Although examination of ore specimens under the microscope indicates the fluorite contains minute quantities of quartz, chalcedony, and iron-oxide and clay minerals, both metallurgical-grade and ceramic-grade fluorspar concentrates have been made from the small quantity of ore mined at the Chimney Hill deposit.

Diamond drilling of the Manganese Hill and Chimney Hill deposits reportedly (Engineering and Mining Journal, 1953) revealed more than 1 million tons of fluorite-bearing material, which contains about 20 percent CaF_2. The adjacent northwest-trending fault zone between the Tertiary and Precambrian rocks might profitably be explored where it is concealed. (See pl. 5.)

LAST CHANCE MINE

The Last Chance fluorspar mine (No. 10 on pl. 1) was the source of nearly 1,000 tons of metallurgical-grade concentrates before 1942 and about 10,000 tons of flotation concentrates between 1942 and 1944. This mine, known as the Kramer mine during the World War II period of mining activity, is at an altitude of about 7,800 feet. The workings extend beneath Chaffee County Road 60 and are almost entirely in claims of Commercial Minerals, Inc. (formerly Universal Mines, Inc., and Mansheim-Salida Fluorspar Co.), that were leased to Kramer Mines, Inc., from 1942 to 1944. Kramer Mines, Inc., completed a flotation mill on the property in October 1942, which yielded ceramic-grade and a small quantity of acid-grade concentrates before it burned in July 1944. The flotation concentrates contained 93–98 percent CaF_2 and 1–5 percent SiO_2; an earlier hand-picked metallurgical-grade product contained 80–95 percent CaF_2 and about 2.5–15 percent SiO_2.

The geology and extent of the Last Chance workings as of August 1943 are shown on plate 6. Shortly thereafter, the 90-level reportedly was extended eastward an additional 210 feet from the winze and exposed a 50-foot segment of ore 6 feet thick; the stope above the 90-level was 90 feet long, and the lower level was extended more than 150 feet west and showed mineralized segments 2–3 feet thick. None of these newer workings were mapped, however, as most of the mine is inaccessible because of caving and flooding.

The Last Chance fluorspar deposit is localized along a fault that strikes about N. 65° W. and dips about 60° NE. The fault cuts gneissic quartz monzonite of Precambrian age and a few small lenses of the older metamorphic rocks; locally, the fault consists of a sheeted zone containing many veins of fluorspar. Fluorite and silica partly replace the wallrock and fault breccia, and in places fluorspar veins as much as 6 inches thick extend into the hanging wall. Fluorspar is exposed intermittently along the fault through a strike length of about 1,500 feet and a depth of about 300 feet.

Two main ore bodies were found along the fault. The eastern ore body, which was developed by open pits, Adit No. 1, Adit No. 2, the Lower Adit, and the 90-level, is about 460 feet long in the adits. The western ore body, worked from open pits and the Lower Adit, is about 450 feet long. The maximum thickness of the ore bodies is about 25 feet, which is the thickness of the mineralized sheeted zone mined in the large open pit west of Chaffee County Road 60. The width of the stoped sections ranges from 2 to 12 feet, and the average width of ore in the stopes is nearly 8 feet.

The vein minerals at the Last Chance mine are fluorite, microcrystalline quartz, chalcedony, pyrite, calcite, hematite, and manganese oxides. Most of the fluorite is very fine grained and white to red; some is colorless, brownish, or greenish. The silica minerals commonly are finely intergrown with fluorite in the veins and also replace fault breccia, gouge, and the wallrock. Pyrite occurs as rare disseminations in the silicified wallrock. The black manganese-oxide minerals locally line vugs in the fluorspar ore and form a narrow vein cut by fluorite veinlets in the hanging wall of the eastern ore body.

The average grade of the ore mined and treated in the flotation mill between 1942 and 1944 was about 30 percent CaF_2. A 4-foot channel sample cut at the face of the west drift on the Lower Adit level contained 55.9 percent CaF_2, and a 4.3-foot channel sample cut in the top of the stope mapped on the 90-level contained 41.3 percent CaF_2; the remaining content of these two samples is mainly silica. A specimen of red ore contained 59.2 percent CaF_2, 24.6 percent Fe_2O_3, 9.8 percent SiO_2, 3.8 percent $CaCO_3$, and 1.7 percent H_2O (Norman Davidson, analyst, written commun., Feb. 3, 1943); most ore from the Last Chance mine, however, contains less than 1 percent $CaCO_3$.

OTHER FLUORSPAR DEPOSITS

A small quantity of metallurgical-grade fluorspar was mined and shipped in 1944–1945 from the Alderman deposit (No. 1 on pl. 1) by John Alderman and associates of Denver. This mine, owned then by James Bopp, is at an altitude of about 7,400 feet, northeast of Colorado State Highway 291 and southwest of the Arkansas River. In 1945 a crosscut adit, now caved, extended east-southeast about 210 feet to a 90-foot drift along a steep mineralized zone that strikes about N. 85° E. in rhyolitic welded tuff. Many steep northwest-trending faults in the crosscut transect altered volcanic ash. One fault zone, about 145 feet from the portal, separates the ash from the rhyolitic volcanic rocks on the northeast. Some of these faults are mineralized locally with calcite and a small quantity of fluorite.

The ore body in the drift consists of a partly mineralized fissure containing loose blocks of rhyolitic welded tuff several feet in diameter that are cemented by fluorite, chalcedonic quartz, and black manganese oxide. Vugs between the blocks are as much as 3 feet wide and are lined with botryoidal and columnar white to yellowish fluorite less than an inch to several inches thick.

The mineralized zone is about 10 feet thick and less than 50 feet long and contains an estimated 30 percent CaF_2.

Botryoidal fluorite is abundant on the dump at the Alderman deposit; with the aid of a binocular microscope, various combinations of seven isometric crystal forms can be seen on the fluorite. Many specimens of this botryoidal material consist of alternating layers of fluorite and psilomelane; a spectrographic analysis of the psilomelane is given in table 11.

The White King, Blue Stone, and Puzzle deposits along Chaffee County Road 60 in the NW¼ sec. 27, T. 51 N., R. 8 E., yielded a total of about 1,700 tons of fluorspar as a hand-picked metallurgical-grade product and ceramic-grade flotation concentrates. Nearly half of this production was in 1929–1934 and 1943–1944 from the White King deposits (No. 7 on pl. 1), which Allied Chemical Corp. later acquired from American Fluorspar Corp. Several caved workings, consisting mainly of a 220-foot adit and a shallow shaft, are localized along steep northeast-trending mineralized faults in the gneissic quartz monzonite. Several hundred feet southwest of the adit, the mineralized faults cut the Browns Canyon Formation, which overlies the gneissic quartz monzonite. The ore bodies, 6 inches to 5 feet thick, consist of a network of veins averaging about 30 percent CaF_2 and some higher grade lenses containing about 70 percent CaF_2. The fluorite is chiefly white, pale green, or pink and sugary, and the gangue is fine-grained quartz.

Southeast of the White King deposits, the adjacent Blue Stone deposits (No. 8 on pl. 1) of Commercial Minerals, Inc., were the source of about 600 tons of fluorspar in 1943–1944. A shallow shaft, an adit, and several cuts form the workings, which are on irregular vein zones trending northeast and northwest in the gneissic quartz monzonite. Mineralized zones are locally more than 5 feet thick and contain 25–40 percent CaF_2.

East of Chaffee County Road 60, the Puzzle deposit (No. 9 on pl. 1), owned by E. Lionelle and J. H. Lionelle, yielded about 400 tons of metallurgical-grade fluorspar between 1937 and 1949. Workings from a 135-foot shaft expose about 4 feet of fluorspar along an east-trending vein in the gneissic quartz monzonite. The overlying tuffaceous siltstone of the Browns Canyon Formation exposed on the south side of a hill east of the Puzzle deposit also is locally mineralized with fluorite, which constitutes about 50 percent of one thin section of the rock. Fluorite is associated with barite and a brownish-yellow iron-oxide mineral in veinlets and blebs less than 0.05 mm in diameter. Some of the fluorite forms pale-purple cubes that have edges truncated by dodecahedrons.

The Snowflake deposit (No. 3 on pl. 1) was the source of about 400 tons of fluorspar between 1933 and 1943. This deposit, owned by E. Lionelle and J. H. Lionelle, is an east-trending vertical vein in rhyolitic welded tuff. Several lenses of fluorspar, 2–5 feet thick and estimated to contain 40–70 percent CaF_2, are exposed in a short adit and in a lower incline about 15 feet below the portal of the adit. The incline slopes westward about 15° and is about 220 feet long. Fluorite veinlets cut 1-inch veinlets of manganese-oxide minerals at the end of the incline.

DEPOSITS OF OTHER MATERIALS

COPPER PROSPECT

A magnesian skarnlike aggregate of silicate minerals locally contains copper minerals near the southeast corner of the quadrangle and about 700 feet above Railroad Gulch (NW¼ sec. 32, T. 51 N., R. 9 E.). The inactive prospect can be reached by an access road branching from the road to Turret, which is half a mile east of the quadrangle; it is known as the Ace High and Jack Pot prospect, according to a claim notice by Glen R. Lemberg and Son of Salida, Colo. The deposit does not crop out but is probably a lenticular mass in metasomatized hornblende gneiss between two north-trending faults that localized a narrow chalcopyrite-quartz vein dipping 85° W. and a vertical pegmatite dike (pl. 1). The foliation of adjacent unaltered fine-grained hornblende gneiss, consisting of hornblende, bytownite, cordierite, and small quantities of biotite, quartz, epidote, and apatite, dips gently toward the east. The following information is based largely upon a study of specimens collected from the dump next to an inaccessible shaft that has underground workings of unknown extent, and from an incline driven north along the chalcopyrite-quartz vein.

The hornblende gneiss is reorganized into a skarnlike, coarse-grained, locally schistose aggregate composed chiefly of hydrous magnesium, calcium, iron, and aluminum silicates, which possibly formed by retrograde metamorphism. Specimens consist of layers containing one or more of the following minerals, which were identified by microscopic study of crushed fragments in index oils: actinolite, anthophyllite, apatite, biotite, calcite, chlorite, cummingtonite, gahnite, phlogopite, quartz, sphene, talc, tremolite, and zoisite. Prisms of tremolite and anthophyllite ($nZ = 1.650$ approx.) form radial growths; fibrous tremolite is cut by veinlets of phlogopite and talc. Magnetite and chalcopyrite locally impregnate the rock-forming silicates as tiny grains or fracture fillings. Magnetite is almost completely altered to limonite and hematite. Chalcopyrite is altered chiefly to fibrous and botryoidal malachite and to small quantities of chalcocite, azurite, chrysocolla, brochantite, and chalcanthite. The presence of malachite, brochantite, azurite, and chalcanthite was confirmed by X-ray investigation (Mary Mrose, oral commun., Feb. 18, 1966). Specimens from the dump show that chalcopyrite-quartz veinlets were brecciated, cut by malachite veinlets, and then coated by botryoidal clusters of calcite and opal. A psilomelane-type black manganese oxide mineral contains small patches of barite and tiny grains of calcite.

Gahnite, the zinc spinel, occurs in tremolite-talc rock and in quartz veinlets as blue-green subhedral to euhedral octahedra as large as 0.5 cm; it forms nearly 10 percent of some specimens. The index of refraction of this gahnite is slightly less than 1.780, and a_0 is 8.12 A (D. B. Stewart, oral commun., Dec. 10, 1964). Some grains contain microscopic inclusions of apatite and sphene, and others are slightly magnetic. A qualitative X-ray fluorescence investigation of the gahnite indicated zinc and lesser amounts of iron as major constituents, traces of calcium and titanium, and no cobalt (F. J. Flanagan and H. J. Rose, Jr., written commun., Jan. 29, 1962).

This deposit resembles other Precambrian skarnlike assemblages in Colorado, especially some gahnite-bearing copper-zinc deposits once worked in adjacent areas, which Lindgren (1908) regarded as magmatic segregates in gabbro dikes regionally metamorphosed to amphibolite. More recently, however, one of these deposits, the Cotopaxi, about 20 miles southeast of Salida, has been described as a pyrometasomatic skarn deposit in an amphibolite layer between biotite gneiss and sillimanite gneiss (Heinrich and Salotti, 1959); galena from the Cotopaxi deposit is probably not much younger than 1,300 ±100 million years old (Phair and Mela, 1956, p. 428). In the northern part of the Front Range, a copper-zinc deposit in layered anthophyllite-cummingtonite-actinolite skarn probably formed by metasomatism of regionally metamorphosed sedimentary rocks (Sims and others, 1958, p. 184–185). Similarly, layered but unmineralized anthophyllite-cordierite rocks associated with amphibolite and paragneisses in the Central City area may have formed from metasomatism of metasedimentary rocks (Sims and Gable, 1963).

GOLD

At the Browns Creek placer deposit, gravels along the Arkansas River in Browns Canyon yielded a small quantity of gold from sluicing, rocker, and panning operations intermittently during 1906–17 and 1931–39 (U.S. Geological Survey, 1907–17; U.S. Bureau of Mines, 1934; U.S. Bureau of Mines, 1933–40; Vanderwilt, 1947, p. 43). Possibly gold was recovered from this deposit also between 1859 and 1906, when about 90 percent of the total production of placer gold in Chaffee County was made (Vanderwilt, 1947, p. 42). The fineness of some placer gold recovered from the Browns Canyon area averaged 0.836 gold and 0.158 silver (U.S. Bureau of Mines, 1934, pt. 1, p. 521–522).

According to Vanderwilt (1947, p. 43), the Browns Creek placer deposit is 2–3 miles south of Nathrop, but the writer observed an old sluice, screens, shovels, and worked gravels about 4 miles south of Nathrop; this locality is south of the mouth of Browns Creek where T. 15 S. and T. 51 N. join. The worked gravels, containing some very large boulders of gneissic quartz monzonite, came from a narrow, low Pleistocene terrace along the west bank of the Arkansas River.

Much more extensive gravels are in the older Pleistocene pediment, alluvial-fan, and outwash deposits at levels above the Browns Creek placer, west of the Arkansas River and east of the large Tertiary intrusive bodies and associated base and precious metal deposits in the Sawatch Range (Dings and Robinson, 1957). It it not known whether these gravels and the immediately underlying thick section of Dry Union sediments have been tested for metals.

Mine workings, consisting of several short adits and a shaft, possibly explored for gold or tungsten between Stafford Gulch and The Reef (sec. 30, T. 51 N., R. 9 E.). The workings are in north-dipping banded gneiss and hornblende gneiss, south of the large body of gneissic quartz monzonite and the overlying Tertiary rhyolitic welded tuff. Specimens from the dumps are chiefly the two types of gneiss; some are cut by pegmatite, and others are aplitic, brecciated, cemented and veined by quartz and gray calcite, and stained yellow brown with limonite. Fluorescence tests on the specimens, using an ultraviolet light, are negative for scheelite. The semiquantitative spectrographic analysis in table 16 indicates that brecciated and veined aplitic gneiss from the adit nearest Stafford Gulch contains small quantities of metals. X-ray examination of this material found orthoclase, quartz, and calcite as the major minerals and a possible trace of hematite (Marie L. Lindberg, written commun., Nov. 4, 1966).

TABLE 16.—*Semiquantitative spectrographic analysis, in weight percent, of aplitic gneiss, brecciated and veined by quartz and calcite*

[J. L. Harris, analyst; lab. No. W-167073]

Si	>10	Mn	0.07	Nb	0.002
Al	3	Ag	<.0001	Ni	.003
Fe	3	Ba	.01	Sc	.002
Mg	.07	Co	.0015	Sr	.003
Ca	>10	Cr	.01	V	.007
Na	.05	Cu	.0007	Y	.003
K	7	Ga	.0007	Yb	.0003
Ti	.15	Mo	.001	Zr	.003

NOTE: Elements looked for but not detected: As, Au, B, Be, Bi, Cd, Ce, Eu, Ge, Hf, Hg, In, La, Li, P, Pb, Pd, Pt, Re, Sb, Sn, Ta, Te, Th, Tl, U, W, Zn.

GRAVEL AND SAND

West of the Arkansas River, extensive deposits of gravel and sand are worked intermittently, and on a small scale, as sources of material for road construction by the State and County Highway Departments. Six roadside pits have been excavated in recent years in the quadrangle, chiefly in four older Pleistocene deposits, in which the ratio of gravel to sand is very high. Younger Pleistocene outwash and Holocene alluvium also are large potential sources of gravel and sand in the area. The Dry Union sediments, however, contain thinner and less desirable gravel and sand deposits that are generally mixed with silty material, bentonitic clay, or volcanic ash.

The four Pleistocene gravels, worked as bank deposits at the edges of topographic benches, are largely pediment and terrace deposits that consist of fragments of Precambrian and Tertiary granitic rocks, fine-grained and porphyritic Tertiary intrusive and volcanic rocks, Precambrian metamorphic rocks, and Paleozoic sedimentary rocks in a sandy and silty matrix. Many of the abundant boulders of granitic rocks in these older Pleistocene deposits are highly weathered and crumble readily; these weathered boulders are not regarded as objectionable in gravel for use as road-building material, whereas excessively large and hard boulders of similar rocks in younger Pleistocene deposits are avoided. The locations of six gravel pits and the Pleistocene units represented are given in table 17; another pit in gravel 1 is about 500 feet west of the quadrangle at the southwest edge of sec. 28, T. 15 S., R. 78 W. The four gravel units are exposed over an area of about 7 square miles in the northwestern part of the quadrangle (pl. 1); these units represent a resource of several hundred million cubic yards of gravel and sand, even though an average depth of only 25 feet is assumed for workable deposits.

TABLE 17.—*Gravel pits in the Poncha Springs NE quadrangle, Chaffee County*

Location	*Pleistocene unit represented* [1]
SW¼; sec. 27, T. 15 S., R. 78 W	Gravel 5
NW¼; sec. 35, T. 15 S., R. 78 W	Gravel 3
NW¼; sec. 35, T. 15 S., R. 78 W	Gravel 2
NE¼; sec. 34, T. 15 S., R. 78 W	Gravel 2
SW¼; sec. 9, T. 51 N., R. 8 E	Gravel 2
NE¼; sec. 15, T. 15 S., R. 78 W	Gravel 1

[1] Stratigraphic position and possible correlation given in table 10.

PEAT DEPOSIT

A Holocene peat deposit, previously described in this report, has been excavated for several years along Gas Creek, about a mile east of Centerville and U.S. Highway 285. The peat rests on glacial outwash of early Wisconsinan Age immediately north of terraces composed of older Pleistocene gravels. Climatic conditions here were favorable for the accumulation of slightly humified vegetation in the poorly drained depression. The ground, which is being worked on a small scale, is said to be on the property of Joseph Nachtrieb, who leased this part of the deposit for mining.

The limits of the area underlain by peat (pl. 1) were determined from trenches and by examination of aerial photographs, on which the boggy terrain is darker gray than the adjacent area. The peat deposit covers about half a square mile and extends about 3 miles along the creek, approximately from the west edge of sec. 34 to the middle of sec. 25, T. 15 S., R. 78 W.; the peat lies between altitudes of 8,050 and 7,600 feet. The thickness of the peat ranges from less than 1 foot at the east edge of the deposit to about 10 feet where it is being mined and to the west where it was excavated along U.S. Highway 285; the average thickness seems to be about 5 feet.

The peat is readily extracted by power shovel from the open, grassy and swampy area. Other factors favoring low production costs are the scarcity of interbedded sediments, roots, and large parts of trees. Furthermore, the deposit is readily accessible and close to major highways and a railroad serving the larger cities of Colorado. The peat is ground, screened, and used chiefly as a soil conditioner; peat adds vegetable matter to soil, increases soil porosity, and lightens heavy clay soils.

PEGMATITE MINERALS

Precambrian pegmatites within the Poncha Springs NE quadrangle have had no appreciable production of minerals. In contrast, similar pegmatites in the quadrangle to the south and in the Turret district (Hanley and others, 1950) immediately to the east have been the source of potash and soda feldspars, muscovite, beryl, and columbite-tantalite, chiefly during World War II and at intervals thereafter. The quarry at the Homestake mine, 2.5 miles east of the quadrangle, operated on a large scale between 1950 and 1963 as a source of soda spar processed for the glass industry, and for several years it was the State's largest feldspar producer (U.S. Bureau of Mines, 1951–64). The maximum annual production figure published (Baillie, 1962, p. 9) is for 1955, when 29,650 tons was quarried there.

The poorly zoned pegmatite dikes and sills in the Poncha Springs NE quadrangle occur chiefly as tabular bodies, generally 2–20 feet thick. Some of those in the northeastern and eastern parts of the quadrangle have been explored by excavating shallow pits or by stripping adjacent to the outcrops. These exploratory workings yielded much of the information on pegmatites previously presented in this report under the description of the Precambrian rocks.

The pegmatites probably are of greatest value as potential sources of potash feldspar (microcline). The soda feldspar, muscovite, beryl, and columbite-tantalite are either of poor quality or too scarce in the pegmatites examined to be of commercial importance. Most of the muscovite is in small flakes, clusters, or books, generally less than 1 inch in diameter; some books are as much as 3 inches in diameter but are hard to split and have wedge structure, A-structure, inclusions, or iron-oxide stains. Weathering of the pegmatites and wallrocks locally yielded surface concentrations of resistant magnetite and red-brown garnet that form small accumulations on the slopes below and in adjacent stream beds; the commercial value of these deposits has not been demonstrated.

PUMICE AND PERLITE

Pumiceous volcanic rocks and perlite at the north edge of the Poncha Springs NE quadrange are possible sources of lightweight aggregate. The pumice and perlite are thicker and somewhat more extensive areally than previously recognized (Bush, 1951, p. 314–315, 326–327). The southernmost extensions of these rocks are found on Ruby Mountain and in a smaller area about 2.75 miles southeast. (See pl. 1.) Information on lithology, chemical composition (table 6), and structure was presented under the description of the Nathrop Volcanics of late Oligocene age. The Ruby Mountain deposits are less than a mile east of U.S. Highway 285 and the Denver & Rio Grande Western Railroad in the Arkansas Valley; these deposits are accessible by road. The Ruby Mountain perlite locality has been assigned incorrectly in various publications to Fremont County (Vanderwilt, 1947, p. 253; Jaster, 1956, p. 384; Sharps, 1961, p. 6).

White to tan pumiceous tuff about 70 feet thick, overlain by about 20 feet of pink pumiceous breccia and 110 feet of black and gray perlite containing small black pellets of obsidian, rests on Precambrian gneissic quartz monzonite along the east side of Ruby Mountain (NW¼ sec. 13, T. 15 S., R. 78 W.). The lower pyroclastic unit dips about 30° W.; the dip gradually increases in the overlying units and is 50°–70° W. in a rhyolite flow above the perlite. Although they are locally covered by talus, the pumiceous and perlitic rocks were traced for about 1,500 feet from the northeast end of Ruby Mountain to the southeast end.

Southeast of Ruby Mountain (NW¼NW¼ sec. 29, T. 15 S., R. 77 W.) at an altitude of about 8,900 feet, an east-trending narrow graben in the gneissic quartz monzonite has preserved the same, but much thinner, sequence of volcanic rocks. From south to north, exposures show about 4 feet of gray pumiceous tuff and breccia, 8 of gray-black perlite, and 10 feet of light-gray vesicular porphyritic rhyolite; all dip approximately 60° N. These volcanic rocks were traced for about 200 feet along the fault zone, in outcrops and in pits.

Small quantities of pumiceous and perlitic materials were removed from the pits at Ruby Mountain and the locality to the southeast; it is not known if any tests were performed on these rocks. The deposits seem to be moderate to small in size, and additional exploration and testing of samples would be needed to estimate exploitable tonnages of material suitable for lightweight aggregate. Such work would indicate whether impurities in the rocks would make them unsuitable for this use. Impurities in the pumiceous rocks in different places consist of opal, chlorite, and calcite in vesicles; debris from the underlying Precambrian rocks; fragments of phenocrysts and silicified tuff; spherulites; and devitrified and altered glass. The perlite contains mineral fragments and hard pellets of obsidian with feldspar microlites and magnetite dust, which locally might prove to be objectionable if the rock were heated and expanded for use as a lightweight material.

QUARTZITE DEPOSITS

Two quartzite deposits in pendants within the large body of gneissic quartz monzonite east of the Arkansas River were quarried on a small scale in 1961–62. The quartzite was used chiefly for aggregate, roofing granules, and decorative material in gardens and landscaping. Both deposits are accessible from Salida over Chaffee County Road 180 (Ute Trail) in the adjacent Cameron Mountain quadrangle and a recently bulldozed route extending north and west from Turret, an old mining camp in Cat Gulch about half a mile beyond the east margin of the quadrangle.

A quartzite deposit south of Green Gulch is exposed along strike for nearly 500 feet on a conspicuous white knob at an altitude of about 8,500 feet along the boundary between secs. 18 and 19, T. 51 N., R. 9 E. Layers of banded gneiss in a pendant within the gneissic quartz monzonite strike N. 40° E. and dip 50°–70° SE; two principal sets of joints are oriented N. 10° W., 70° W., and N. 70° E., 85° S. Near the south end of the knob the gneissic quartz monzonite cuts the banded gneiss and contains small inclusions of it. The pendant of leucocratic quartz-feldspar-mica gneiss includes a few small pegmatites and contains 40–60 feet of coarse, gray to white, granulose quartzite. Impurities within the quartzite consist of minor microcline, albite, biotite, muscovite, and magnetite, and a thin discontinuous chloritized zone. The quartz grains are medium to coarse and elongated and have serrated, interlocking margins. Quartzite was quarried and trucked to a plant in Salida, where it was crushed and sized for shipment.

The second quartzite deposit, on a hill and at an altitude of about 8,880 feet near the east edge of the quadrangle and south of Sawmill Gulch (south-central part of sec. 8, T. 51 N., R. 9 E.), similarly is associated with thin pegmatites and banded quartz-microcline gneiss within the gneissic quartz monzonite. The units strike N. 0°–50° E. and dip steeply westward. In a bulldozer cut near the crest of the hill, the quartzite is about 150 feet thick, and in a lower cut to the north nearer Sawmill Gulch, it is about 65 feet thick. The quartzite is gray to white and granulose and contains rare tiny grains of albite and thin books of muscovite less than one-fourth inch in diameter; it is cut by north-trending shears that dip about 80° W. An unknown but small quantity of quartzite was mined from this deposit.

VERMICULITE DEPOSIT

A vermiculite deposit of unknown dimensions is localized in a small pendant of biotitic hornblende gneiss within the large body of gneissic quartz monzonite, about 3.3 miles southeast of Nathrop. The foliation in both rocks strikes approximately N. 50° W. and dips 50° NE. The deposit has not been worked extensively, partly because of its grade and location in an area of difficult accessibility. The workings are at an altitude of about 8,130 feet along the south edge of a gulch in SW¼SW¼ sec. 29, T. 15 S., R. 77 W. This prospect has been called erroneously the Tung Ash deposit (Bush, 1951, p. 333), a vermiculite deposit southeast of Turret in the Cameron Mountain quadrangle to the east, where a jefferisite (Henahen, 1914, p. 135–139) or hydrobiotite (Sterrett, 1923, p. 50) variety was produced.

A shaft, inclined about 65° S. and filled with water to about 20 feet below the collar, exposes the gneissic quartz monzonite and two layers of vermiculite-bearing hornblende gneiss. About 5 feet of gneissic quartz monzonite separates a 2-foot layer of vermiculite-bearing gneiss from a mass of similar rock at least 12 feet thick. The gneissic quartz monzonite clearly cuts the hornblende gneiss and contains inclusions of the older rock; locally the quartz monzonite is pegmatitic.

Thin, flexible and inelastic plates of pale-green and yellowsh-brown vermiculite form more than 50 percent of the crumbly hornblende gneiss; quartz, microcline, green hornblende, sphene, and apatite are the impurities. The vermiculite exfoliates readily into tiny silver- to bronze-colored books when heated in the flame of a match. It is optically negative and has a 2V of less than 10°; nZ is between 1.595 and 1.600. Some of the basal plates observed under the microscope have the hexagonal outline of biotite, from which much of the vermiculite probably was derived. Vermiculite deposits in Precambrian rocks of Colorado (Goldstein, 1946, p. 17; Bush, 1951, p. 332) and Wyoming (Hagner, 1944, p. 10–14) are considered to have formed by the action of hydrothermal solutions from granitic or pegmatitic intrusives upon rocks bearing hornblende, biotite, phlogopite, or serpentine.

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