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Geologic Studies of Union County, New Mexico

by Brewster Baldwin and William R. Muehlberger

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Figure 9

FELTED LIMESTONE IN GRANEROS SHALE

Weathered bedding surface, x 8.5. Inset: thinsection view, plane light, x 8.5. Insoluble residue of sample, 8 percent.

Abstract

Union County, 3,817 square miles in area, is in the northeast corner of New Mexico. Mesozoic formations recognized at the surface include the Baldy Hill formation (newly named), Travesser formation (newly named), Sloan Canyon formation, and Sheep Pen sandstone, all of the Triassic Dockum group; the Jurassic Exeter (Entrada) sandstone and Morrison formation; and the Cretaceous Purgatoire formation, Dakota formation, Graneros shale, Greenhorn limestone, Carlile shale, and Niobrara formation. These units aggregate nearly 3,000 feet.

Undifferentiated upland deposits consist largely of the Pliocene Ogallala formation and include caliche and algal limestone. Basaltic rocks cover a fifth of the county and rest on upland deposits. The flows are subdivided into the Raton, Clayton, and Capulin units of Collins. However, the "type Clayton" may in fact be of younger Raton age. Capulin flows are Recent, whereas Raton flows are possibly of Pliocene age. About 80 volcanic centers, including cinder and shield cones, occur in alined sets.

Locally, Exeter sandstone truncates open folds of the Dockum group. Mesozoic formations dip eastward from the Sierra Grande arch, with local interruptions by a monocline, an anticline, and other warpings. Possible warping in late Ogallala time may have triggered volcanic activity.

Mineral resources include scoria, gravel, and possibly clay. There has been intermittent production of carbon dioxide from wells and of copper from several pre-Exeter sandstone plugs.

The report contains a colored geologic map (125,000 scale), 44 columnar sections, and 115 lithologic logs of water wells. A summary of subsurface stratigraphy appears in the report, together with structure contour and isopach maps.

Introduction

PURPOSE AND SCOPE OF INVESTIGATION

Union County, with an area of 3,817 square miles, occupies the northeast corner of New Mexico. Little geologic information was available for this Great Plains region, and the community of Clayton, the county seat, had been requesting information on ground water. Therefore, study of the geology and ground-water resources of Union County was begun early in 1953. Field work was essentially completed by the end of 1955.

In its previous countywide studies of ground-water resources, the New Mexico Bureau of Mines and Mineral Resources has participated on a cooperative basis with the U. S. Geological Survey and the State Engineer; such studies were conducted by personnel of the U. S. Geological Survey. The Union County study, however, has been undertaken by Bureau personnel; by F. X. Bushman, as ground-water hydrologist, and the writer, as geologist.

This report summarizes the main stratigraphic and structural features of the county. Plate 1, the geologic map, and Plate 2, the columnar sections, are the principal contributions of the report. The text serves to describe the geologic features and to indicate certain geologic problems. Although the geology has not been studied in detail, the report should contribute to the efficient development of ground-water resources, and also to the search for oil and gas, mineral deposits, and constructional materials.

Incorporated in the report are geologic maps and measured sections by W. R. Muehlberger, B. B. Cooley, and others.

LOCATION NUMBERING SYSTEM

Localities in Union County are referred to by the numbering system used in New Mexico by the U. S. Geological Survey for the location of wells and springs. This system is equally adaptable for reference to outcrops or general areas. The system places the township and range numbers first, thereby giving the general location before the specific location. In Union County, all townships are north, and all ranges are east, so that these directions can be omitted from the location number.

For example, a clastic plug that has been worked for copper is exposed at 31.35.12.442. The more familiar designation of this location would be the NE¼SE¼SE¼ sec. 12, T. 31 N., R. 35 E. The numbering system consists of four sets of numbers:

Township	Range	Section	Location within section		
31 .	35 .	12 .	4	4	2
			160-	40-	10-acre tract

For locations within a section, the following abbreviations are used: northwest (NW), 1; northeast (NE), 2; southwest (SW), 3; southeast (SE), 4. Where the 10-acre tract is not determined, the last digit is 0; where the 40-acre tract is not determined, the last two digits are 00; and where the location within a section is not determined, the last three digits are omitted. Some locations are described merely with reference to a particular township, such as "near the northeast corner of 31.32," meaning near the northeast corner of T. 31 N., R. 32 E.

Locations given in this report refer to the land lines shown in Plate 1, which may be at variance with the actual position of the surveyed lines.

LOCATION AND ACCESS

Union County is in the northeast corner of New Mexico. It is bounded on the north by Colorado and on the east by Oklahoma and Texas (fig. I). The population, which was 7,372 in 1950, is concentrated at Clayton, the county seat. Paved highways extend from Clayton in six directions (fig. 2). Access to areas within the county is provided by a network of improved and unimproved roads and many pickup trails (pl. 1). The U. S. Highway 64 of older reports is now New Mexico Highway 325. The Colorado and Southern (Fort Worth and Denver) Railway serves Clayton, Mt. Dora, Grenville, Des Moines, and Folsom.

GEOGRAPHIC FEATURES

Union County is in the Great Plains province of the Interior Plains. According to Fenneman (1946), most of the county lies within the Raton section of the province ("trenched peneplain surrounded by dissected, lava-capped plateaus and buttes"), although the eastern edge is in the High Plains section ("broad intervalley remnants of smooth fluviatile plains").

The county is the most scenic of those along the eastern border of New Mexico, owing largely to the many volcanic features and to the deep canyons that have exposed variously colored sedimentary rocks.

The northern and southwestern parts of the county are characterized by deep canyons with as much as 1,000 feet of relief; the remainder of the county is a gently rolling upland with about 100 feet of relief. About 80 inactive volcanoes occur in linear groups in a wedge-shaped area that extends from the western border of the county to an apex just north of Clayton. The volcanoes and some lava-capped mesas rise above a plain that slopes eastward from about 6,600 feet above sea level in the northwest to 4,300 feet above sea level in the southeast, in the panhandle of the county. Sierra Grande, an extinct volcano, is the most prominent topographic feature. It rises to an altitude of 8,720 feet above sea level, 2,100 feet above the surrounding plain. Approximate altitudes were

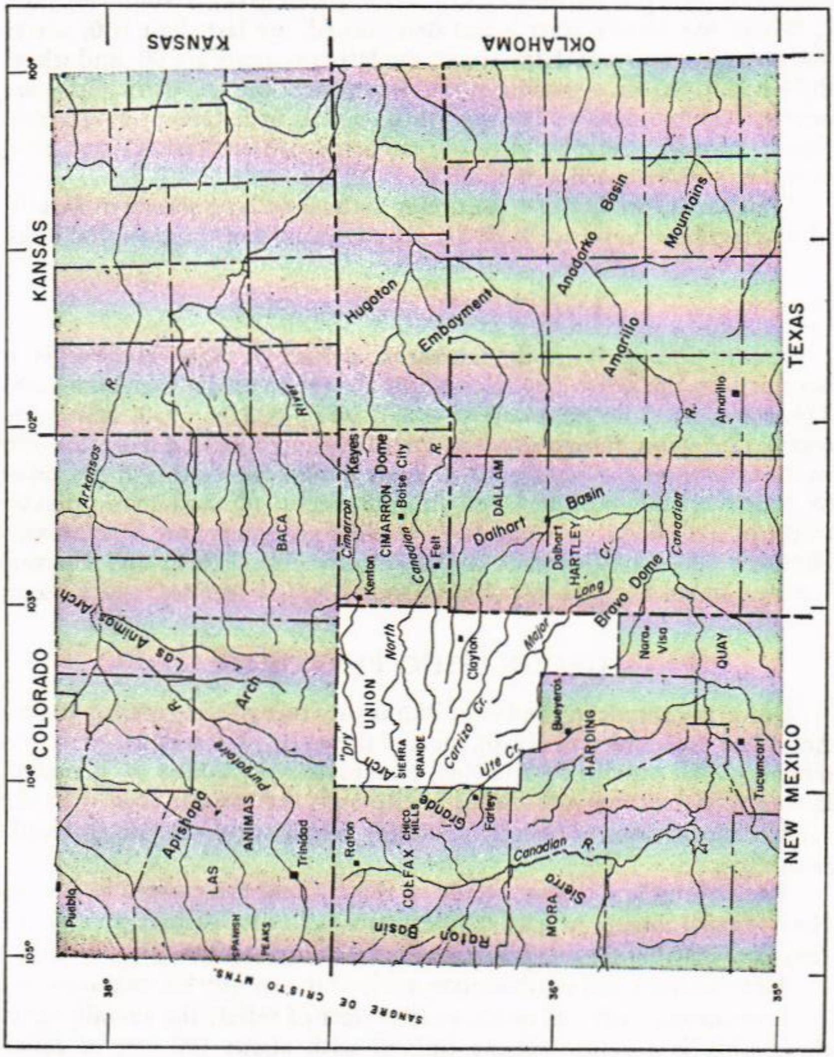


Figure 1

REGIONAL SETTING OF UNION COUNTY, SHOWING MAJOR STRUCTURAL ELEMENTS determined for several other volcanic peaks: Sierra Clayton, 6,665 feet; Burro Mountain, 6,295 feet; and Rabbit Ear Mountain, 6,070 feet.

The county is drained by the Canadian, North Canadian, and Cimarron Rivers and their tributaries. Clayton is on the divide between the first two of these rivers. The Cimarron River of northern Union County is here referred to as the Dry Cimarron River, in order to avoid confusion with the Cimarron River that is located southwest of Raton. Drainage characteristics are indicated in Figures 1 and 2.

Most of the geographic names in Union County referred to in this report are shown in Figure 2 and on the geologic map (pl. 1). The local usage is at some variance with the names shown on maps prepared by the New Mexico State Highway Department and by the U. S. Geological Survey. For example, the names Corrumpa and Tramperos are carried east to the State line, although official usage (State Highway Dept. and U. S. Geol. Survey) indicates that those creeks become the North Canadian River and Major Long Creek, respectively, in their eastern reaches. Similarly, Seneca Creek is labeled on official maps as Cienequilla Creek. The local usage is followed in the text of this report, and both names are shown in Figure 2 and Plate 1. Several abandoned communities, such as Guy, Thomas, and Centerville, are also shown on the maps of this report.

The climate of Union County is semiarid; annual precipitation averages about 16 inches at Clayton. Precipitation data for Clayton are summarized by Baldwin and Bushman (1957a, fig. 2). Most of the county is covered with range grass, and trees are sparse except on the walls of canyons and in upland areas where sandstone beds crop out.

EPHEMERAL LAKES

Ephemeral or "dry" lakes are formed in natural depressions which stand above the water table; they are filled with water only after rains. The many depressions in Union County have formed in several ways.

The Hayden basin (20.34), which is 6 miles across, and the two to the east in 20.35, which are 1 mile across (pl. Id), could have formed by solution of salt or gypsum beds in formations at moderate depth, and the subsequent collapse of the overlying beds.

Most of the depressions, however, probably were formed as a result of wind erosion, which has blown out loose particles of sand and clay. This origin is suggested for those developed in the Dakota and Graneros formations (pl. 6C), because beds of soluble rock lie more than 1,000 feet below. Even if there were solution at that depth, it is not likely that collapse would reach the surface to form the numerous small depressions so common in the Dakota and Graneros formations. These depressions are on the order of 20 feet to a quarter of a mile across.

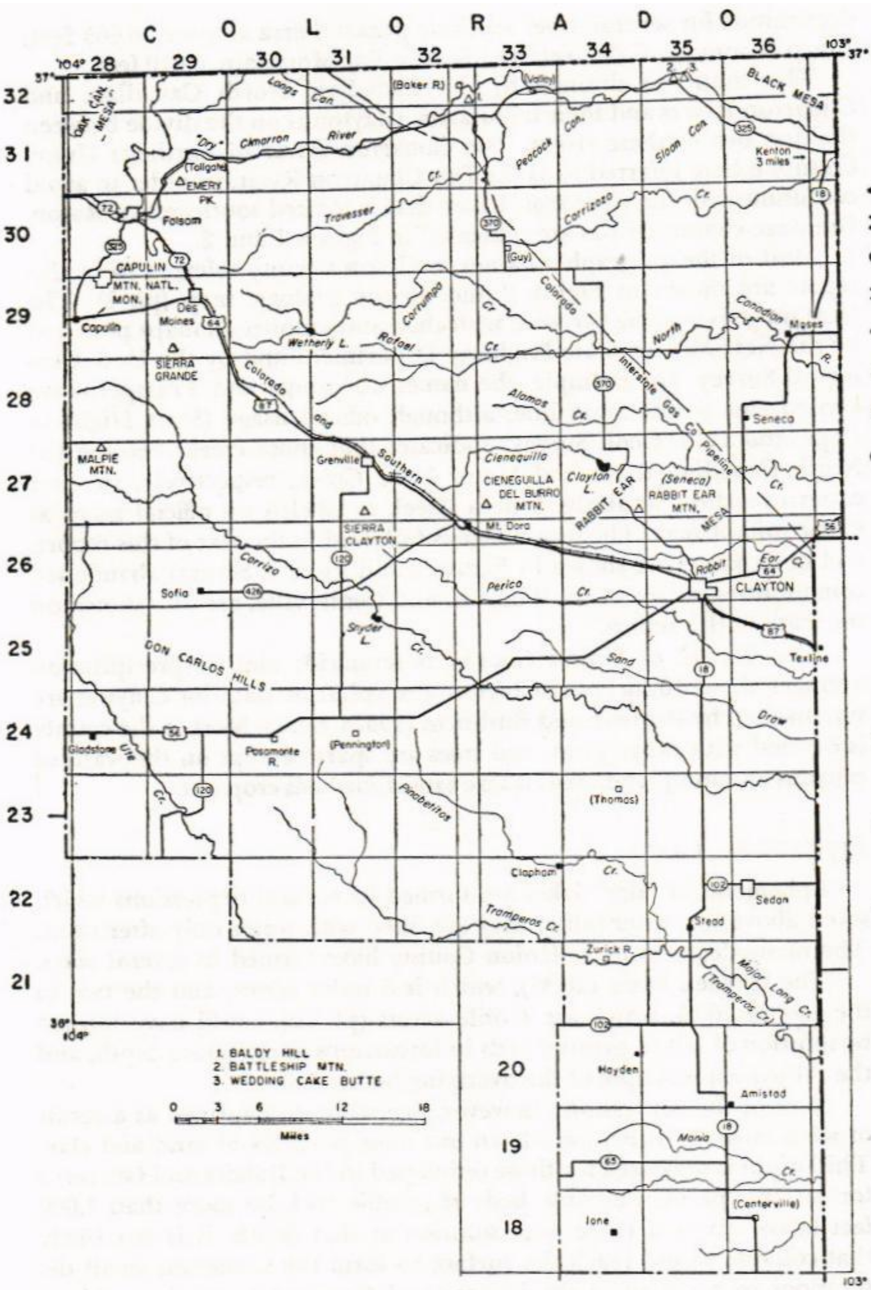


Figure 2

INDEX MAP OF UNION COUNTY

A large depression (24.31.4) north of Pennington is developed in the Ogallala formation, but stock tanks dug in the floor have yielded sandstone and shale of the Dakota formation. Wind erosion is here credited with forming most of the depressions in Union County, even though there is little evidence of a mound of wind-deposited material on the lee side of depressions. However, the depressions west of Des Moines (W. R. Muehlberger, oral communication, June 22, 1958) on the crest of the Sierra Grande arch are floored with shaly beds of the Dakota formation and have small sand-dune accumulations on the downwind side (pl. 6C).

The string of six lakes just north of Carrizo Creek and east of New Mexico Highway 120 (27.31.33; 26.31.4) appear to be the result of the westward encroachment of basaltic alluvium across a tributary that once drained south into Carrizo Creek. Damming by slope wash appears to be the origin of the depressions along the north edge of 25.29, which are on the contact between basaltic alluvium from the Don Carlos Hills and the Dakota formation.

The ephemeral lakes in the town of Clayton represent areas where the crust of lava flows has collapsed; the depressions elsewhere on lava flows have a similar origin.

PREVIOUS WORK

In the spring of 1953, at the beginning of the project, there were few reports on the geology of the region that includes Union County. Lee (1902) described the general character of Mesozoic formations in the Dry Cimarron Valley and named the Exeter sandstone. He published several other general descriptions of the region, including one with Mertie (Lee, 1922). Stanton (1905) distinguished Lower Cretaceous beds from the Morrison formation. Parker (1933) described the clastic plugs and subdivided the Triassic of the Dry Cimarron Valley. In the report on Cimarron County, Oklahoma, Schoff and Stovall (Schoff, 1943) included specific field criteria for recognizing the contacts between geologic formations; the writer has noted the absence of such criteria in other reports.

Griggs (1948) described the geology and ground-water resources of eastern Colfax County. Collins (1949) named and described the subdivisions of the late Cenozoic volcanic rocks. Stobbe (1949) described the petrology of the volcanic rocks of the area covered by Collins. Levings (1951) made a thorough study of the literature of the region.

After field mapping had begun, two other reports of adjacent areas were published. Wood, Northrop, and Griggs (1953) presented a geologic map of eastern Colfax County, and McLaughlin (1954) described the geology and ground-water resources of Baca County, Colorado. In the past 10 years, the U. S. Geological Survey has *been* revising the older understanding of stratigraphic relationships in the region; the above two reports reflect some of their findings.

METHOD OF WORK

In all, the writer worked about 380 days in Union County, mostly in the years 1953-1955. About 250 days were spent in mapping and 40 days in determining altitudes of geologic contacts. The remainder of the time was spent in measuring sections, studying well samples, locating bench marks, and conferring with geologists and residents of the area.

The writer's field work in Union County was devoted primarily to making a geologic map. The mapping was recorded on photomosaics of 7½-minute quadrangles, which were prepared by the Soil Conservation Service of the Department of Agriculture. The scale of the photomosaics, 0.5 mile to 1 inch, was adequate to show geologic and cultural features. The geology of the county is simple, and access is good; therefore, the county could be mapped at a rate of 10 to 15 square miles a day.

One or two geologic contacts were too obscure to be mapped at this rate and so were not mapped. In general, the features shown are those which were easiest to map. Although cross-country traverses by jeep gave access to most exposures, little time was available to walk over the rocks, other than at the places where sections were measured. Sections (pl. 2) were measured by hand level.

The many cultural features that appear on the map (p1. 1) will serve as landmarks. No distinction is made between houses that are occupied and ruins or abandoned houses. Many. wells were located during geologic mapping, in order to simplify the procedure of ground-water inventory; no distinction is made in Plate 1 between wells in use and abandoned wells. Roads and trails were mapped to indicate the access. Much of the mapping of cultural features was done by F. X. Bushman.

Drainage lines are classified (pl. 1) according to permanent streams, intermittent streams, and ephemeral streams. Permanent streams are those with perennial flow; intermittent streams include short reaches of perennial flow, reaches characterized by waterholes or saturated alluvium, and extensive seep areas; ephemeral streams are those with flow only from runoff after rains.

Map data on the photomosaics were projected onto a latitude-longitude grid that was constructed on a scale of 1 mile to 1 inch according to geographic tables (Gannett, 1924). The geologic map of Union County (pl. I) was prepared on this scale and was reduced to 2 miles to 1 inch for publication. With this reduction, distortion of drainage and cultural features has essentially been eliminated.

Distortion in the compiled map was tested by comparing the plotted position of 20 triangulation stations with the latitudes and longitudes as given by the U. S. Coast and Geodetic Survey. Two stations (Grande and Branson) in areas of strong relief were more than 400 feet in error in each coordinate and may have been plotted inaccurately on the photo-mosaics. Fifteen stations were plotted within 200 feet of their true position, and 3 were between 200 and 300 feet in error. Distortion is negligible in the extensive level areas but is detectable in the canyon areas.

Section lines were plotted by inspection of the photomosaics, according to fence lines and roads. Fence lines are not distinct on the photomosaics of the canyon areas, and so in those areas the section lines as shown on the geologic map may be several hundred feet from their true position. No attempt was made in the field to recover section corners. For the purposes of this report the section lines as shown are adequate as a reference grid for wells and outcrops.

Altitudes of geologic features were determined within about 20 feet in two ways. Altimeter traverses from bench marks have been corrected according to diurnal curves constructed from repeated readings at key stations or bench marks. Additional elevations were determined from points of known altitude by reading vertical angles with a telescopic alidade, in conjunction with distances measured on the photomosaics.

PARALLEL WORK

Both the writer and others have published preliminary reports and abstracts, and treatments of geologic aspects incidental to the present work.

A preliminary report on the Union County study was presented to the New Mexico Geological Society (Baldwin, 1957). Baldwin prepared some material on the Dry Cimarron Valley for a guidebook (Oklahoma City Geological Society, 1956, p. 12-13, 23-31).

Baldwin and Bushman (1957a) prepared a semitechnical report on the geology and ground-water conditions near Clayton. The text and figures of the report were republished in the *Union County Leader,* July 3, 1957. The report was written for ranchers and farmers, and its most important geologic contribution was to indicate by 50-foot contours the base of the Ogallala formation (upland deposits of the present report). The contours were controlled by logs from more than 1,000 shot holes; the contours are incorporated in Figure 12. A summary of that work was presented before the New Mexico Geological Society (Baldwin and Bushman, 1957b).

Some geologic problems in Union County were reviewed by Baldwin (1958a, b).

In 1954, Professor William R. Muehlberger, University of Texas, mapped in detail the Des Moines quadrangle in the northwest corner of Union County for the New Mexico Bureau of Mines and Mineral Resources. Most of Muehlberger's sections are included in Plate 2, and some of his descriptions of bedrock units are incorporated in the present text. He established a sequence of lava flows and carried the study west a few miles into Colfax County to the site of Folsom Man to establish the approximate age of eruption of Capulin Mountain (Muehlberger, 1955). Muehlberger's report on the Des Moines quadrangle, and on the volcanic rocks in the remainder of Union County, is presented in this bulletin as a separate paper (part II).

Muehlberger's interest in paleomagnetism as applied to the basaltic lava flows of Union County has resulted in a summary of preliminary results (Muehlberger and Baldwin, 1957) and in a fuller statement of those results (Muehlberger and Baldwin, 1958).

In 1954, Beaumont B. Cooley (1955), a student of Muehlberger's, mapped 50 square miles just east of the Des Moines quadrangle and measured a number of sections of Mesozoic formations along the Dry Cimarron Valley. Most of those sections are included in Plate 2.

Another student of Muehlberger's, Charles J. Mankin (1958a, b), has made a detailed stratigraphic study of formations exposed south of Union County in the Bueyeros area. Mankin also studied the samples collected by Cooley along the Dry Cimarron Valley.

MISCELLANEOUS

HISTORY

Union County historically has been an agricultural area with closer ties to Colorado and Texas than to New Mexico. It was settled and developed while the Sangre de Cristo Mountains were still a formidable barrier to communications with central and western New Mexico. The following highlights of the development of the Union County area are taken largely from a study by Alvis (1934), three chapters of which are published (Alvis, 1947).

Development of the area began in the 1820's with the first wagon train across the Cimarron Cutoff of the Santa Fe Trail. The cutoff route was well established by 1824, and in 1825-26 Joseph C. Brown surveyed the route (Gregg, 1952; Riddle, 1949). Trading along this route was particularly hazardous until General Carleton took command in the 1860's. Even as late as 1868-69, Plains Indians killed 160 men in 5 months. The trade was heaviest in the years 1822-1843 and 1852-1866.

Township plats were surveyed in the late 1870's. The cost, charged to individuals, was about $400 per township for field work and $35 per township for office work; in some cases a few dollars was refunded. Union County was Government domain before 1881; from 1881 until about 1902, most of Union County was under the control of large cattle concerns, such as the Prairie Cattle Co. Ranching dates back at least to 1874, and by 1890, some crops were being grown for feed. Dry-land farming attracted a number of homesteaders, but with the dust-bowl conditions of the 1930's the population of the area dropped appreciably.

Many of the buildings and wells shown on the geologic map (pl. 1) are abandoned. The drought years in the 1930's caused the abandonment of many of the homesteads, and many other individuals and families left in the early 1940's because of the demands of World War II. With the development of better roads, a number of farmers and ranchers moved into Clayton, the county seat. Thus, though the population of the county has declined, the population of Clayton has remained fairly constant. Changes in county boundaries before 1921 make it difficult to compare population figures before that date. The population of the county dropped from 11,036 in 1930 to 7,372 in 1950; it is estimated to be 6,600 in 1959.

The decrease in county population reflects a basic change from dry-land farming back to grazing. Although much of the cultivated land was abandoned during the dust-bowl years, it was not until the abnormal rainfall year of 1941, when 37 inches was recorded at Clayton, that vegetation again stabilized the soil. The subnormal precipitation after 1950, and the regional increase in the practice of irrigation from wells, encouraged the development of some irrigation wells in Union County. In 1930 (Alvis, 1947), some 6,000 acres were under irrigation, presumably by diversion of creeks with permanent flow. Many of the irrigation systems of that period have not been maintained, but in 1950 about 7,000 acres were under irrigation, in part from wells.

Clayton was named after the son of Senator Stephen W. Dorsey, of Arkansas. Senator Dorsey had a vast cattle ranch that extended well into the present area of Union County from its headquarters in the Chico Hills. Clayton was surveyed in 1887 along the route of the Denver and Fort Worth (Colorado and Southern) Railway, then under construction. The site was one of the few along the route that was level and broad enough for the proposed division point between Trinidad, Colorado, and Amarillo, Texas. Water was to be obtained at a spring north of town, presumably spring 26.35.23.411. The first train was operated in March 1888, and Clayton rapidly assumed an important position as a shipping and supply center. For some years, cattle were driven to Clayton from as far south as Roswell and Capitan. In 1907, the Atchison, Topeka & Santa Fe Ry. completed a branch road between Raton and Des Moines; in 1931, it completed a branch between Felt, Oklahoma, and Farley, New Mexico, using the Denver and Fort Worth tracks between Clayton and Mt. Dora. Both these branch roads were discontinued during World War II.

Coan (1922) shows the changes in boundaries of counties in New Mexico from 1851-52, when counties were first established in the Territory, until 1921. Before Union County was created, the area was in Taos and San Miguel Counties, and later in Colfax, Mora, and San Miguel Counties. The move to create a new county as a union of parts of Colfax, Mora, and San Miguel Counties began in 1889 (Alvis, 1947). A bill to this effect was passed in the Territorial council but was defeated in the lower house in 1891. A similar bill in 1893 was passed in the council but met at first with a tie vote in the lower house. The San Miguel delegate, however, changed his vote to support the bill, and Union

County was created. In subsequent years, the county lost some of its area to the newly formed Quay and Harding Counties. No changes have been made in the boundaries of Union County since 1921.

BASE MAPS

In addition to Plate 1, which is in part a detailed base map of Union County, several other kinds of base maps are available.

Petroleum Exploration Map 10, prepared and distributed by the New Mexico Bureau of Mines and Mineral Resources, shows section lines, communities, and oil and gas tests in Union County.

The New Mexico Highway Department has prepared base maps of Union County dated 1938, 1950, and 1956. The last two were compiled from aerial photographs, assuring accuracy of the drainage data. The same maps are available as 30-minute quadrangles. The 1950 and 1956 maps were compiled on a scale of 1 mile to 1 inch and have been reduced to 2 miles to 1 inch for publication purposes. For a list of map scales and costs of quadrangle and county maps, inquiry should be addressed to the New Mexico State Highway Department, Santa Fe, New Mexico. The county maps are also sold, at cost, at the New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico.

Photomosaics prepared by the Soil Conservation Service of the U. S. Department of Agriculture are available at nominal cost. The photomosaics were compiled in 1947-48 from aerial photographs taken in 1937 and 1942. They are on a scale of 0.5 mile to 1 inch and are prepared for 7½-minute quadrangles, which cover about 7 miles east-west by 8½-miles north-south. The quality of detail varies, but even the poorest is usable. Distortion is negligible, particularly away from the canyon areas. An index to the S. C. S. numbering system for 15-minute quadrangles is given in Plate lc. Photomosaics must be ordered according to State and the 7½-minute quadrangle number (e.g., New Mexico 21 NE, New Mexico 47 SW, etc.). Inquiries should be addressed to the Cartographic Division, Reproduction Branch, Soil Conservation Service, Beltsville, Maryland.

Much of New Mexico is now (1958) covered by the 1:250,000-scale series (4 miles to 1 inch) of topographic maps prepared by the Army Map Service and distributed by the U. S. Geological Survey, Federal Center, Denver, Colorado. Each sheet covers an area 2 degrees east-west by 1 degree north-south. The Dalhart sheet covers almost all of Union County. This series of maps was prepared from recent high-altitude aerial photographs on a scale of 1:40,000.

GEODETIC DATA

The Coast and Geodetic Survey of the U. S. Department of Commerce has set a number of triangulation stations and more than 800 bench marks in Union County. These are brass caps set in concrete or rock.

A triangulation station is a point whose position in latitude and longitude has been determined precisely. Triangulation stations are located on high points of ground, with good visibility in most directions. The brass caps are stamped with a name or abbreviation of a name of a local geographic feature. One azimuth mark, pointing toward the station, and two reference marks a few hundred feet from the station, are set to help locate the triangulation station itself. Stations in Union County have been set as parts of 4 nets; data on triangulation of three of these nets are given in Culley (1940).

A bench mark is a point whose altitude above sea level has been determined precisely by spirit leveling. Bench marks do not indicate land lines, though they are commonly set near section corners in order to be found more readily. The numbers of the bench mark or level lines in Union County are given in an index map in Plate lc. Bench marks in the colored areas of this index map were set in 1955 at the request of the Director of the New Mexico Bureau of Mines and Mineral Resources. Bench marks are stamped with a letter and a two- or three-digit number. The initial letter and the altitude to the nearest foot are shown in Plate 1 for all the bench marks set in 1955 and for all other bench marks that have been recovered. Bench marks that are known to have been destroyed by highway construction have been omitted.

Complete descriptions of the location and precise altitude of bench marks, and of the location and latitude and longitude of triangulation stations, are available on request to the Director, U. S. Coast and Geodetic Survey, Washington 25, D. C. Such request should be accompanied by as much information as possible on the location and designation of the particular brass cap, or on the particular area within the county. Similar information is on file at the New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico.

ACKNOWLEDGMENTS

The writer wishes particularly to thank the residents of Union County for their interest and cooperation in furthering the study of the geology of their county. Manson Edmondson (city manager of Clayton), Foster Zimmerman (county agent), J. R. Morgan (former manager of the Southwestern Electric Cooperative), J. S. Dickens and his colleagues of the Soil Conservation Service, J. J. Harlan, John Lindsey, Frank Vale, Paul W. Payton, and many others gave valuable information and assistance. Billy Dean Bobbitt was an excellent field assistant.

Eugene Callaghan, former director of the New Mexico Bureau of Mines and Mineral Resources, set up the project and gave the writer support for the fairly detailed treatment of geology on a countywide basis. F. X. Bushman, R. W. Foster, and other staff members of the Bureau of Mines offered valuable suggestions. W. R. Muehlberger and C. J. Mankin clarified many of the stratigraphic relationships.

R. W. Foster *prepared* the section on subsurface geology; also that on carbon dioxide. Both field work and manuscript have profited from his and Muehlberger's critical review.

A number of other geologists also made helpful suggestions. Among these are Elmer Baltz, Carle H. Dane, and George 0. Bachman, of the U. S. Geological Survey.

Mrs. Joann Huenergardt and Miss Shirley Farrar assisted in preparing the index.

Stratigraphy

Exposed rocks in Union County are of Mesozoic and late Cenozoic age. The structure and thicknesses of pre-Mesozoic units are summarized by R. W. Foster, of the New Mexico Bureau of Mines and Mineral Resources, in the following section, which includes regional maps and a table of wells drilled in Union County. Mesozoic rocks are described in some detail. Rocks of early and middle Cenozoic age are not found **in** Union County, but published reports on adjacent areas permit a general statement of geologic events of the region for that part of geologic time. Units of late Cenozoic age are treated in some detail, and an alternative interpretation of correlation between volcanic and sedimentary units is presented.

The report is primarily descriptive, though comments are made concerning some geologic problems. The general lithology of each formation, and the contacts between the formations as they have been mapped in the field, are described. Regional correlations are summarized adequately in published reports, such as those by Schoff and Stovall (Schoff, 1943) and McLaughlin (1954), and so have not been emphasized here. In regional studies, a problem arises from the fact that the thicknesses of formations vary according to where the contacts are placed. An attempt is made in the text to state the exact basis for placing contacts, in order that others can integrate the geology of Union County into regional studies.

Mesozoic rocks exposed in Union County are listed in Table 2; upper Cenozoic units are classified in Figure 13. Two unconformities are conspicuous: one, an angular unconformity between Triassic and Jurassic units, is exposed in the Dry Cimarron River valley; the other, a regional unconformity between Mesozoic and upper Cenozoic units, is recognizable throughout the county.

The term mudstone is used as a general reference to clayey and silty material lacking the thin-bedded character of shale.

Color terms of this report follow the scheme presented in the appendix and are based on a generalization of the Munsell system.

PRE-MESOZOIC UNITS—SUBSURFACE STRATIGRAPHY OF UNION COUNTY

(by Roy W. Foster)

INTRODUCTION

This part of the Union County report provides a brief summary of the various geologic units not exposed in the area, but which have been encountered in drilling for oil. These units include representatives of the Precambrian and of all the Paleozoic periods except the Silurian and Devonian.

Isopach maps have been prepared for four intervals, which can best be defined as prearkosic, arkosic, postarkosic, and Triassic. The prearkosic interval includes Cambrian, Ordovician, Mississippian, and Pennsylvanian marine sediments. For the most part, these sediments are restricted to the eastern part of Union County. Arkosic sediments are Pennsylvanian and Permian in age, although locally they may be entirely Permian. This interval is called the Sangre de Cristo formation. Postarkosic sediments include the Cimarron anhydrite, and the Yeso, San Andres, and Whitehorse formations, all of Permian age. An isopach map of the Triassic gives a general idea of the thickness of this interval, the base of which is not exposed in Union County. A relief map on the surface of the Precambrian and a structure map on the top of the San Andres formation are included to show the difference in relief between these two units. Table 1 lists the oil tests that have been drilled in Union County.

PRECAMBRIAN ROCKS

Precambrian rocks have been penetrated in about 12 of the 30 oil tests drilled in Union County and may have been reached in three others. Drill cuttings of Precambrian rocks, examined with a binocular microscope, consist of biotite, feldspar, and quartz. Most of the feldspar appears to be orthoclase, with plagioclase abundant in a few wells. The plagioclase-rich rocks, however, also contain a high percentage of quartz. Based on well cuttings, the Precambrian rocks underlying Union County are classified as granite.

The highest part of the present Precambrian surface (fig. 3) in Union County is in the Des Moines area, where Precambrian rocks are almost 4,900 feet above sea level. This high area, the Sierra Grande arch, continues southwest through eastern Colfax County, eastern Mora County, the central part of San Miguel County, and across the northwestern corner of Guadalupe County. South of the northeast-trending Sierra Grande uplift, the Precambrian surface slopes gradually to more than 2,000 feet below sea level in the extreme eastern part of San Miguel County. Directly east of the Des Moines area, a gradual east slope brings the Precambrian surface down to about sea level along the New Mexico-Oklahoma State line.

There is a possibility that the highest part of the Sierra Grande uplift in Union County during Permo-Pennsylvanian time was not in the Des Moines area, but in the southwestern part of the county. This is suggested by the less than 500 feet of arkosic sediments in this area, and by a northward thickening into the Des Moines area. The arkosic sequence continues thin into the Bueyeros area of Harding County.

Considerable relief on the Precambrian surface is apparent in several areas in Union County. The most pronounced of these areas is in the southeastern part of the county between the Olson No. 1 Zurick and the Oil Exploration No. 1A Irwin tests, where the relief is almost 4,900 feet

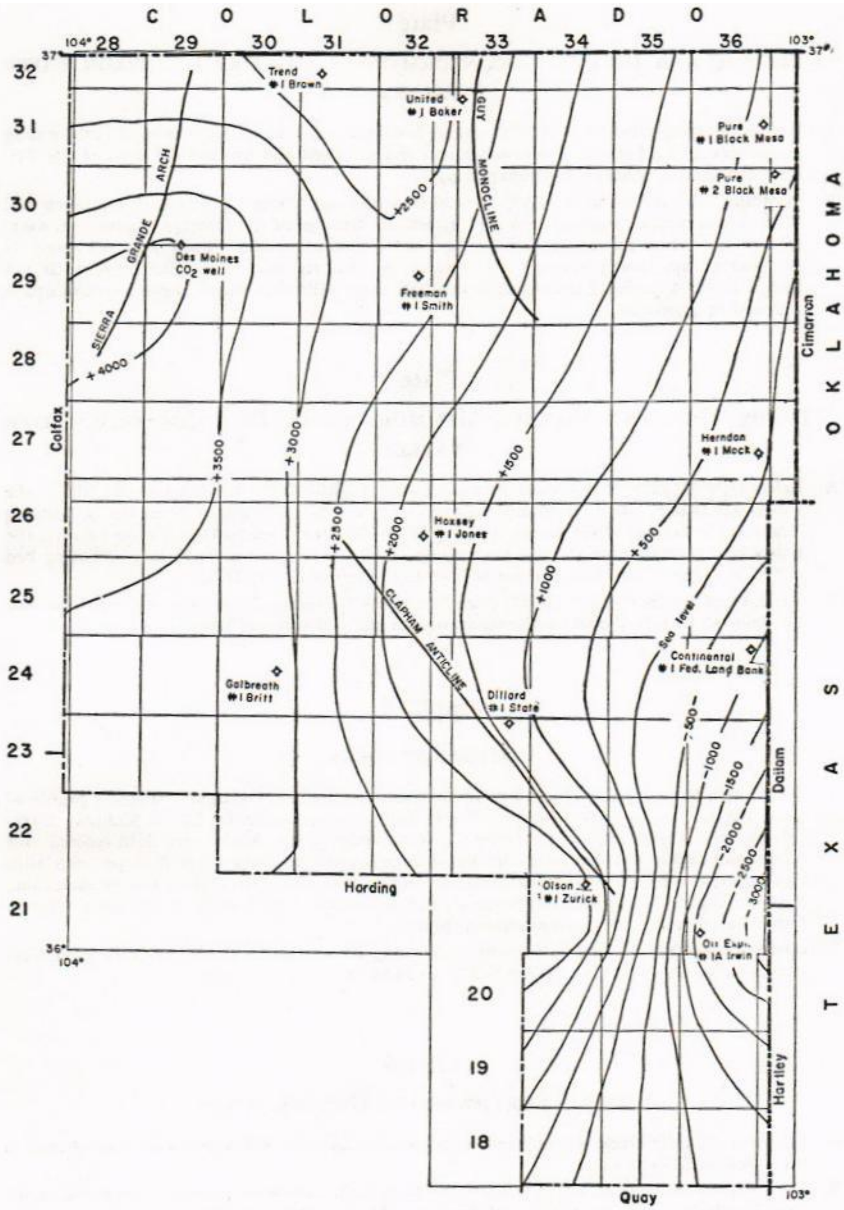


Figure 3

RELIEF OF PRECAMBRIAN SURFACE

Contour interval, 500 feet.

Plate 3

TRIASSIC AND JURASSIC UNCONFORMITY IN THE DRY CIMARRON RIVER VALLEY

A. Battleship Mountain (32.35.28.400) viewed from the west. Thick light-colored cliff-forming sandstones of the Jurassic Exeter sandstone rest on tilted and beveled red beds of the Triassic Travesser formation (Dockum group).

B. Wedding Cake Butte (32.35.27.300) viewed from the east. Units exposed from top down are: Morrison formation, light-colored cap; brown-silt member of the Morrison formation, dark-colored shoulder; Exeter sandstone, light-colored double cliff; Sheep Pen sandstone of Dockum group, mostly covered under talus, so that its dip toward the observer is not recognizable. A geologic cross-section through these hills that shows these relationships is included in Figure 10.

Plate 4

BALDY HILL AND FAULTED MESOZOIC ROCKS, DRY CIMARRON RIVER VALLEY

A. Baldy Hill (32.32.36.400) viewed from the west. Light-colored band across the hill is the Exeter sandstone, which separates the overlying Morrison formation from the underlying Travesser formation of the Dockum group. The oldest exposed rocks in Union County, the Baldy Hill formation of the Dockum group, crop out below the basal ledge-forming bed of the Travesser formation in front of, and to the left of, Baldy Hill.

B. South-trending fault (32.35.32.211) near Battleship Mountain. Downthrown toward the east by about 40 feet, as shown by the separation of the cliff-forming Exeter sandstone.

Plate 5

MESOZOIC ROCKS

A. View north from a point about 6 miles northeast of Kenton, Oklahoma. Typical profile of units exposed along Dry Cimarron River valley in northeastern Union County. Dark-colored mesa cap is Dakota formation; covered slope (Kiowa shale) and light-colored cliff (Cheyenne sandstone) comprise the Purgatoire formation; long covered slope with thin cliff-forming ledges is Morrison formation; lower massive white cliff is Exeter sandstone. Roadcut exposes Sheep Pen sandstone (brown sandstone), which rests on the Sloan Canyon formation (maroon and green mudstone) beyond.

B. Castellate-weathering Dakota formation, showing torrential cross-bedding. View near Corrumpa Creek along N. Mex. Highway 370, in 29.34.33.

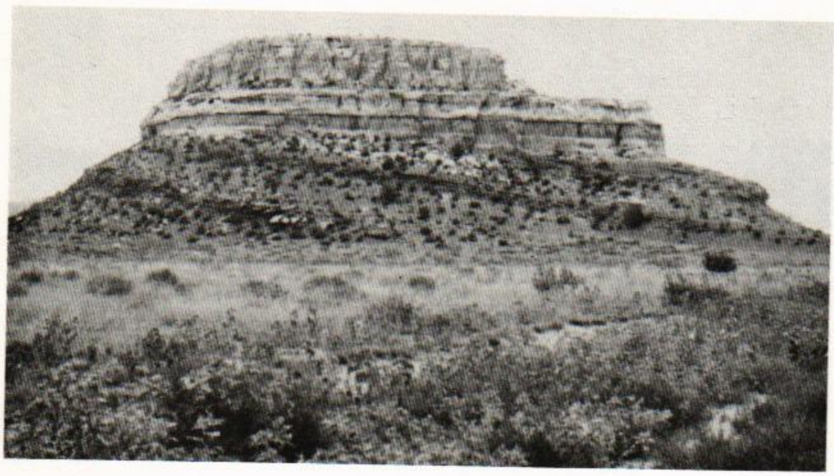
Plate 6

VIEWS IN NORTHWESTERN UNION COUNTY

A. Graneros shale (in creek bottom) and ledge-forming Greenhorn limestone (in wall of creek). View west in 32.28.36.400.

B. View east from head of Tollgate Canyon (31.29.8.220), showing forested Greenhorn limestone overlying Graneros shale (gullied slopes). Thin sandstone used as top of Dakota shale can be seen on lower slope in middle distance.

C. View west toward Capulin Mountain (on skyline). Lake (ephemeral) is in wind-scoured depression in Dakota sandstone.

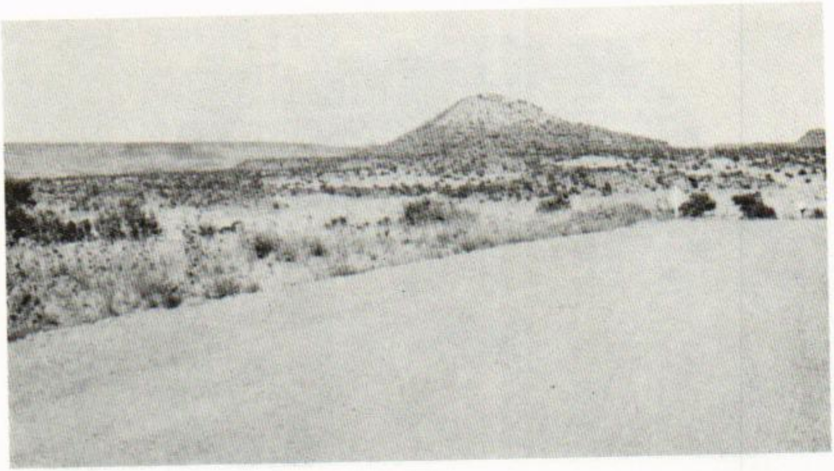


A

B

Plate 3

A



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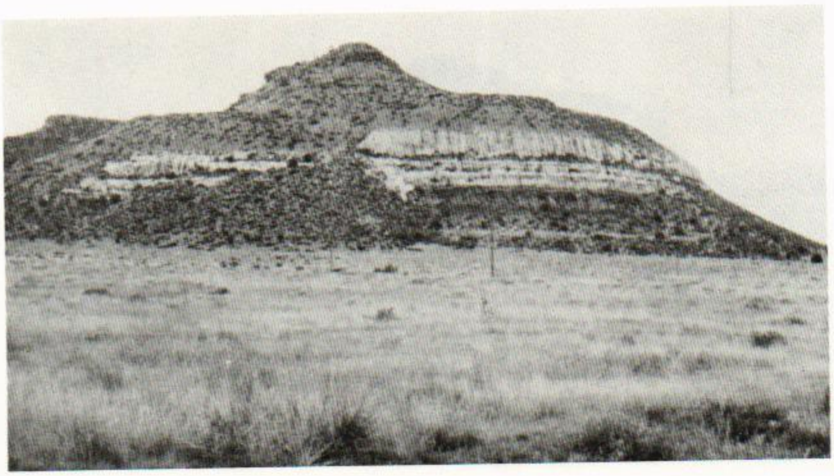
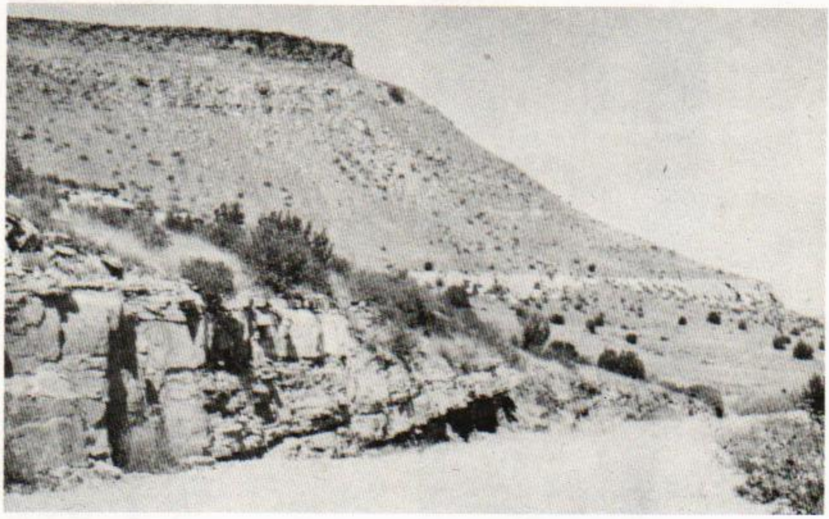


Plate 4



A

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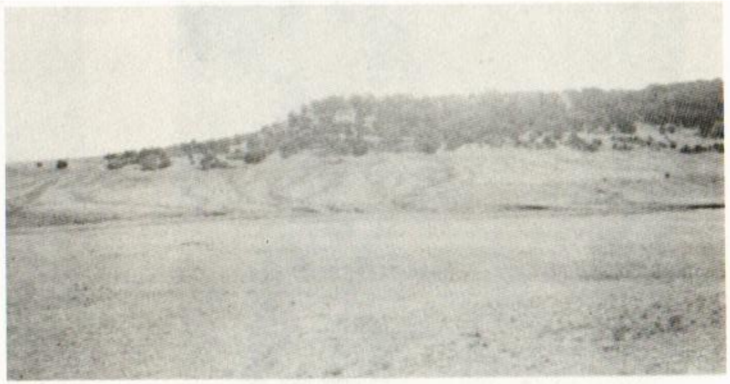
Plate 5

A

B



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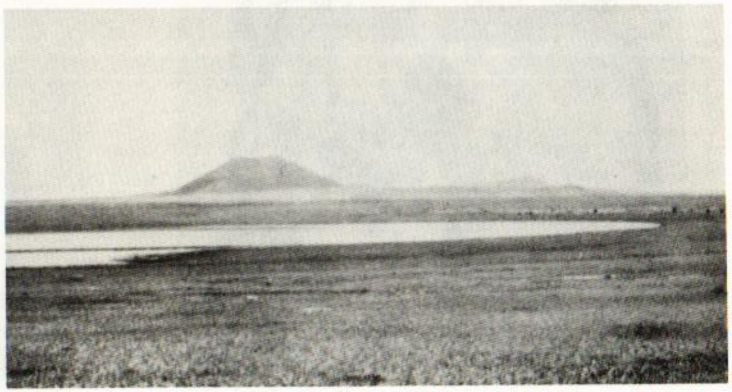


Plate 6

in only 8 miles. In northwestern Union County, there is 2,000 feet of relief between the Des Moines wells and the Trend No. 1 Brown test. East of the Brown well, there is a reversal in the general east slope of the surface, as it rises about 500 feet to the vicinity of the United No. 1 Baker well. In each of the above cases, the higher parts of the Precambrian surface were encountered in wells drilled on surface anticlinal structures, indicated in Figure 3 as the Sierra Grande arch, Guy monodine, and Clapham anticline. The relief on these surface structures, however, is not nearly as much as that on the buried Precambrian surface. These relatively young surface structures (Laramide?) apparently occur along the same axes that controlled sedimentation during much of Pennsylvanian and early Permian time, and possibly during older Paleozoic periods.

The similarity between the Laramide(?) and Permo-Pennsylvanian structural features is particularly evident on the isopach maps of prearkosic and arkosic sediments (fig. 5 and 6). Prearkosic sediments (early Pennsylvanian and/or older) are preserved in the Oil Exploration, Freeman, and Trend tests, but are absent in the Olson and United tests and in the wells near Des Moines. Thick sections of arkosic sediments were encountered in the Oil Exploration and Trend tests, with much thinner sections in the Des Moines wells and the Olson and United tests.

A comparison of Figure 3 and the isopach map of Permo-Pennsylvanian arkosic sediments shows that the major period of uplift of the Sierra Grande arch occurred during parts of Pennsylvanian and Permian time. Both the isopach map of postarkosic Permian sediments (fig. 7) and the structure map on the top of the San Andres formation (fig. 4) reflect a relatively subdued relief following arkosic deposition. The present relief on the Precambrian surface is about 7,000 feet, whereas on the top of the San Andres formation and on the base of the Dakota formation (fig. 14), the relief is only 2,600 to 2,800 feet, a difference in maximum relief of about 4,400 feet. Almost all of this variation can be accounted for by the thickness of Permo-Pennsylvanian arkosic sediments, which in southeastern Union County, the area of greatest relief, are over 3,800 feet thick.

Some of the uplift on the east edge of the Sierra Grande arch during Permo-Pennsylvanian time was probably related to faulting. This is particularly evident between the Oil Exploration and Olson tests. In the 8 miles between these 2 wells, prearkosic sediments thin northwestward from 818 feet in the Oil Exploration test to zero feet in the Olson test, and arkosic sediments from 3,815 feet to 560 feet in the same direction. Based on this limited information, the direction of the suggested fault cannot be determined, but it would seem likely that it follows the axis of the Clapham anticline. Some additional evidence for this is provided by the 1,600 feet of relief and the increasing thickness of arkosic sediments between the Galbreath No. 1 Britt and the Hoxsey No. 1 Jones tests. Buried faults may also be present on the northeast edge of the

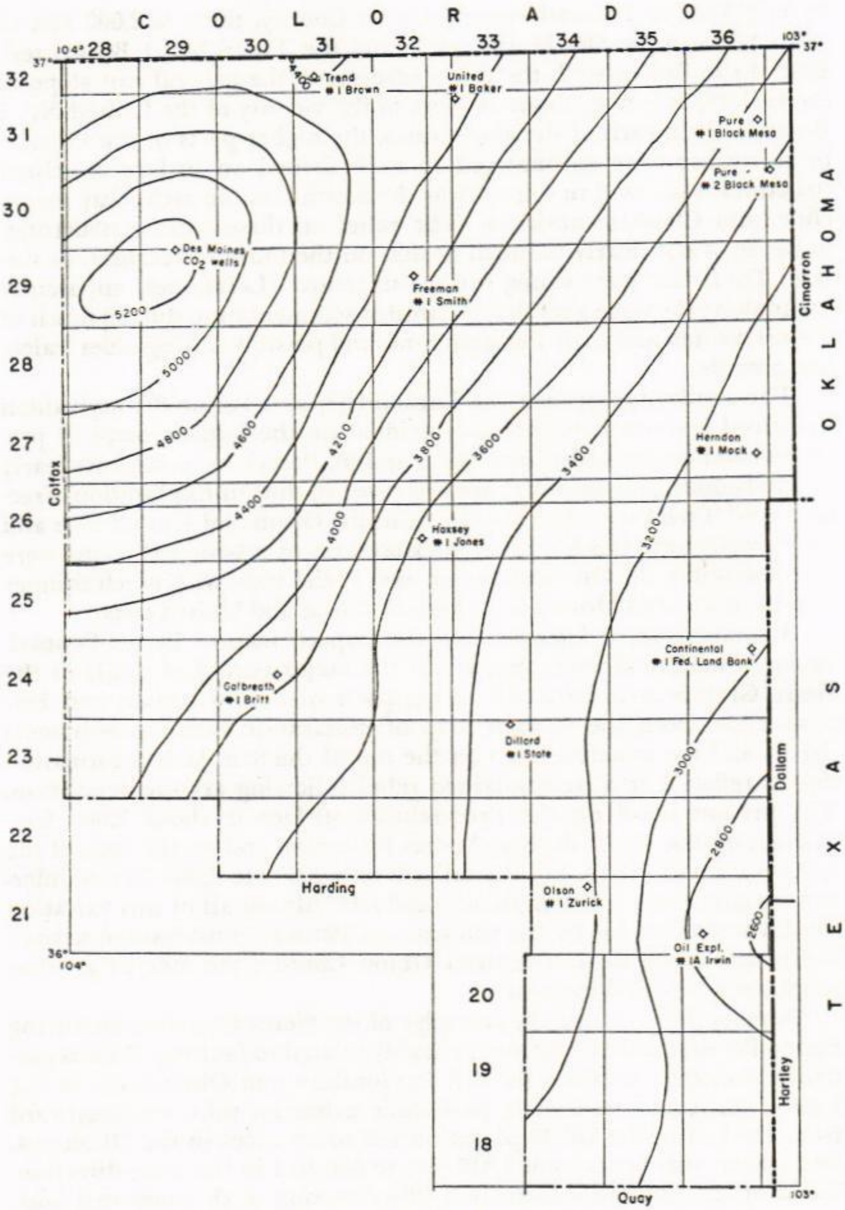


Figure 4

STRUCTURE ON TOP OF SAN ANDRES FORMATION

Contour interval, 200 feet.

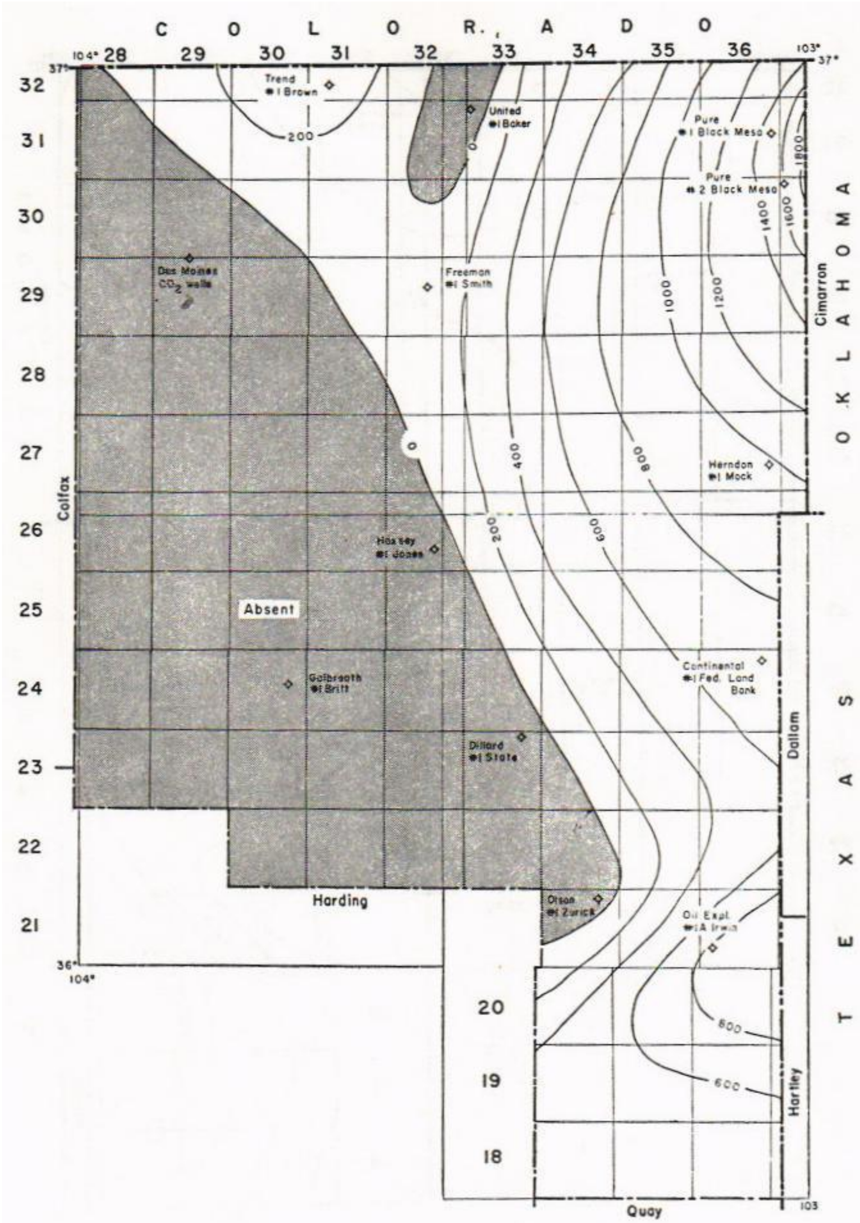


Figure 5

THICKNESS OF PREARKOSIC SEDIMENTS

Contour interval, 200 feet.

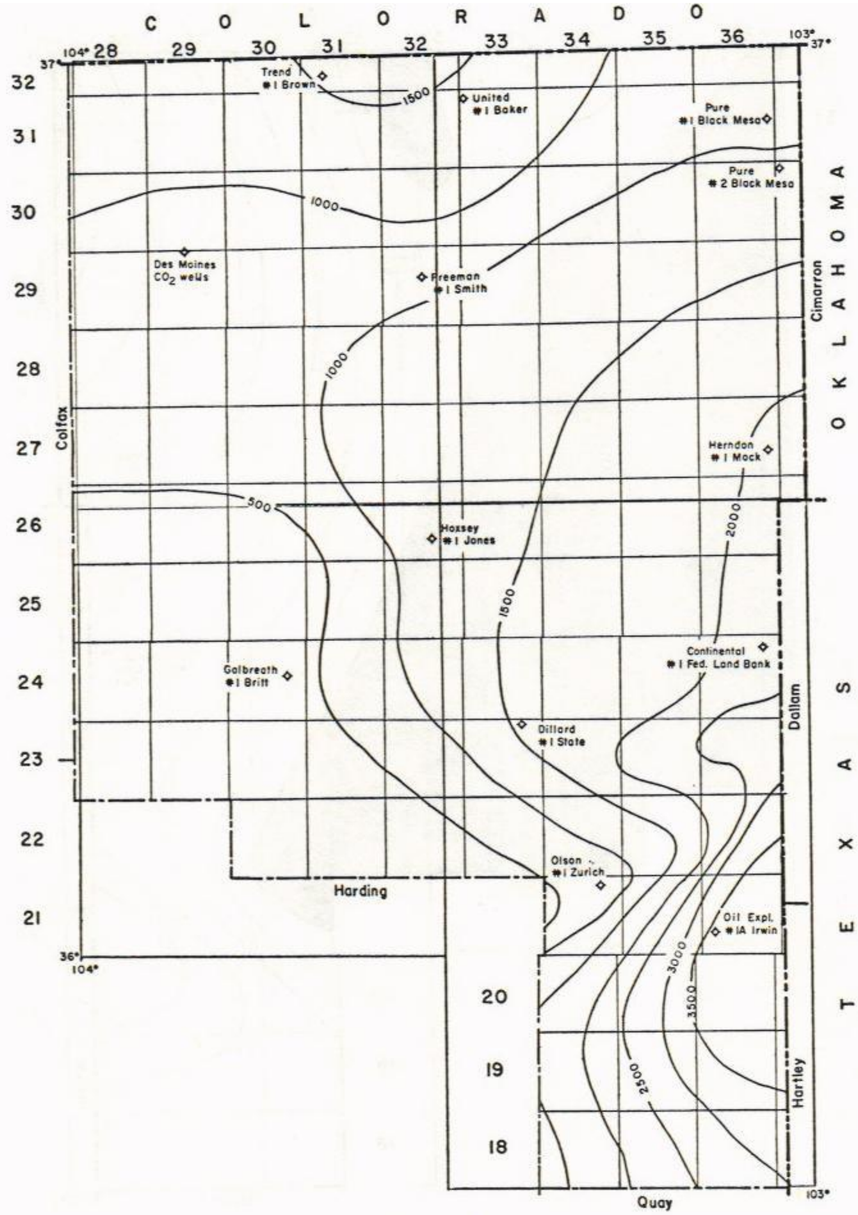


Figure 6

THICKNESS OF ARKOSIC SEDIMENTS

Contour interval, 500 feet.

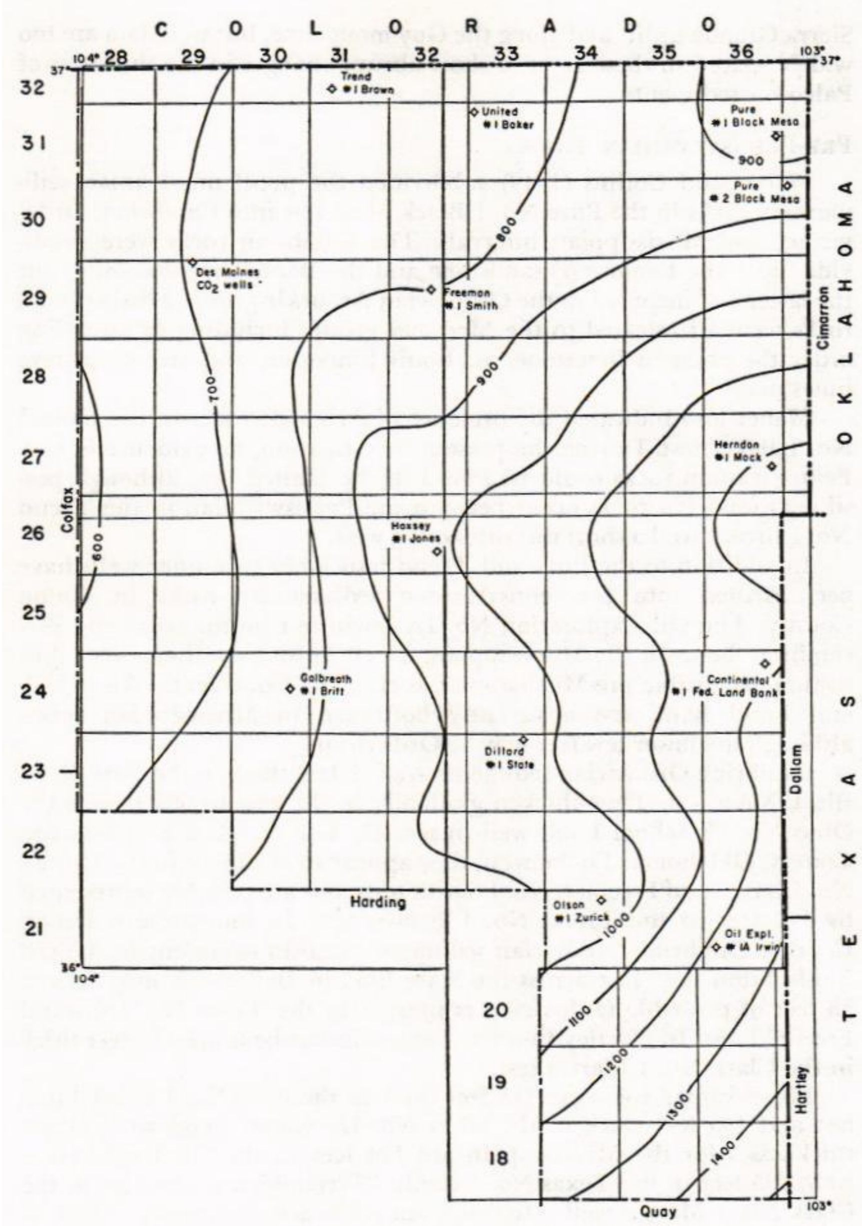


Figure 7

THICKNESS OF POSTARKOSIC PERMIAN SEDIMENTS

Contour interval, 100 feet.

Sierra Grande uplift and along the Guy monocline, but well data are too widely spaced in these areas to show abrupt changes in the thickness of Paleozoic sediments.

PRE-PENNSYLVANIAN ROCKS

Maher and Collins (1949) subdivided the pre-Pennsylvanian sedimentary rocks in the Pure No. 1 Black Mesa test into Cambrian, Ordovician, and Mississippian intervals. The Cambrian rocks were subdivided into the Lamotte(?) sandstone and the Bonneterre dolomite, but the latter was included in the Ordovician Arbuckle group. Mississippian rocks were all referred to the Meramec group, including in ascending order the Spergen limestone, St. Louis limestone, and Ste. Genevieve limestone.

Maher also indicated the presence of Arbuckle rocks in the United No. 1 Baker test. During the present investigation, no evidence of pre-Pennsylvanian rocks could be found in the United test, although possible Ordovician rocks occur beneath the Pennsylvanian in the Trend No. 1 Brown well a short distance to the west.

In addition to the Pure and Trend tests, only two other wells have been drilled into pre-Pennsylvanian sedimentary rocks in Union County. The Oil Exploration No. IA Irwin test bottomed in the Precambrian beneath the Mississippian, which in turn overlies a very thin section of possible pre-Mississippian rocks. The Continental No. 1 Federal Land Bank test apparently bottomed in Mississippian rocks, although the lower few feet may be Ordovician.

Cambrian-Ordovician sediments are 515 feet thick in the Pure No. 1 Black Mesa test. They thicken gradually to the east to 605 feet in the Ohio No. 1B School Land well in sec. 23, T. 6 N., R. 2 E., Cimarron County, Oklahoma. To the west, they appear to be absent in the United No. 1 Baker and Freeman No. 1 Smith tests, but are possibly represented by 140 feet in the Trend No. 1 Brown test. In southeastern Union County, Cambrian-Ordovician sediments are thin or absent in the Oil Exploration test. Just across the State line, in Dallam County, Texas, 55 feet of probable Ordovician is present in the Texas No. 1 Capitol Freehold test. In Hartley County, Texas, similar beds are 115 feet thick in the Clark No. 1 Martin test.

Mississippian rocks are 315 feet thick in the Pure No. 1 Black Mesa test and 435 feet thick in the Ohio No. 1B School Land well. Other thicknesses for the Mississippian are 174 feet in the Oil Exploration well, 285 feet in the Texas No. 1 Capitol Freehold, and 205 feet in the Clark No. 1 Martin well. Mississippian rocks are apparently absent in the Freeman, Trend, and United tests.

Present data, largely from wells outside Union County, suggest that Mississippian rocks overlap Ordovician sediments to the west in northeastern New Mexico. Ordovician rocks may once have covered a much larger area, as indicated by the Trend test, but if so, they were widely stripped prior to Mississippian sedimentation. Mississippian rocks probably once covered the area of the Sierra Grande uplift. This is suggested by the westward thinning of the Spergen limestone compared with the uniform thickness, where present, of the overlying St. Louis limestone; the absence of a pronounced shoreline facies in the Mississippian marine limestones; the widespread presence of similar marine Mississippian beds essentially surrounding the Sierra Grande uplift; and early Pennsylvanian erosion, which would account for the local absence of Mississippian rocks.

PREARKOSE PENNSYLVANIAN ROCKS

This part of the Pennsylvanian sequence is restricted to the dominantly marine section underlying the arkose-mudstone sediments of the Sangre de Cristo formation. An unknown portion of the Sangre de Cristo formation is of Pennsylvanian age in most of Union County, but the contact between the Pennsylvanian and Permian cannot be determined in the relatively uniform sequence of clastic sediments derived from the nearby Sierra Grande uplift. The upper limit of the Pennsylvanian in this restricted sense is based on the highest occurrence of gray to black fine-grained clastics, contrasting with the red and green clastics of the overlying Sangre de Cristo formation. The restricted Pennsylvanian beds intertongue with the Sangre de Cristo formation, and some arkose is included in the Pennsylvanian sequence. There is a very pronounced lithologic break between the lower clastics and thin limestones of the basal Pennsylvanian and the thick lighter colored limestones of the Mississippian, the dolomites of the Ordovician, or the Precambrian granites. This contact is readily identified on electric and radioactive logs.

The Pennsylvanian sediments consist of medium dark-gray and greenish-gray claystone, black carbonaceous claystone, very light-gray to white conglomeratic sandstone, light-gray aphanitic to finely crystalline limestone, in part oolitic, and some thin impure coal seams.

Restricted Pennsylvanian rocks are found primarily in eastern Union County, the zero isopach in Figure 5 representing the western edge of the interval. Sediments of this type are absent in the wells in the Des Moines area, and in the Hoxsey No. 1 Jones, Galbreath No. 1 Britt, Dillard No. 1 State, and Olson No. 1 Zurick tests. Northeast from the Des Moines area, Pennsylvanian sediments are 145 feet thick in the Trend No. 1 Brown test and measure 50 feet in the Freeman No. 1 Smith well. They are absent, however, a short distance to the east in the United No. 1 Baker well. East from the United test, the restricted Pennsylvanian thickens to 610 feet in the Pure No. 1 Black Mesa and to 570 feet in the Pure No. 2 Black Mesa. In the Continental No. 1 Federal Land Bank test, sediments of this type are 365 feet thick. Farther south, they are absent in the Olson No. 1 Zurick but thicken rapidly to 644 feet in the Oil Exploration No. IA Irwin. This may be due to preservation on the downdropped side of the fault suggested above.

The presence or thickness of restricted Pennsylvanian in the southern part of the Union County panhandle is not known, but farther south, in central Quay County, this interval is absent or less than 100 feet thick. It is absent in the Bueyeros area in Harding County, in eastern Colfax and Mora Counties, and in most of central and eastern San Miguel County. Pennsylvanian sediments are from 1,000 to 1,300 feet thick along the southern edge of eastern San Miguel County and measure over 3,000 feet in northern Guadalupe County.

PENNSYLVANIAN AND PERMIAN ARKOSE

The vertical limits of the arkosic interval here called the Sangre de Cristo formation are based primarily on the presence of arkosic conglomerates. The base is limited by the highest dark-gray to black fine-grained clastics which are included in the underlying Pennsylvanian sequence. As mentioned previously, some arkosic conglomerates are thus excluded from the Sangre de Cristo interval.

The top of the unit is at the base of the Cimarron anhydrite, thereby including some fine-grained sands that in areas farther removed from the Sierra Grande uplift would be considered part of the Tubb sandstone. The Tubb apparently intertongues with the Sangre de Cristo formation, as similar sandstones are found below the highest arkosic conglomerate. Over parts of the Sierra Grande uplift, such as in the Des Moines area, the Cimarron anhydrite is not recognizable. Here the top of the Sangre de Cristo formation is chosen as the top of the highest arkosic conglomerate. The beds immediately above the conglomerate are fine-grained dolomitic sandstones. Their relationship with the Cimarron anhydrite is not known. They may represent a near-shore facies of the Cimarron, or they may be a Tubb or post-Cimarron equivalent.

The Sangre de Cristo formation as here defined includes a relatively limited variety of clastic sediments. The section consists almost entirely of red arkosic conglomerates and mudstones. Feldspar fragments in the arkosic conglomerates are generally angular and are often fresh in appearance. Quartz grains are angular to subangular; mica is rare. Mudstones are moderate to dark reddish brown, mottled greenish gray or very light gray, and vary from sandy to silty. Other rock types include moderate reddish-orange to brown siltstone and very fine- to fine-grained sandstone, some claystone, and a few thin beds of aphanitic very light-gray limestone.

Sangre de Cristo beds apparently underlie all of Union County, the thinnest sections occurring in the southwestern part of the county (fig. 6). In the Olson No. 1 Zurick test, Sangre de Cristo beds total 560 feet, whereas in the Oil Exploration test only about 8 miles to the east, the arkosic section measures slightly over 3,800 feet in thickness. The Galbreath No. 1 Britt well penetrated only a little over 240 feet of Sangre de Cristo above reported Precambrian. The Sangre de Cristo formation thickens slightly to the north to almost 900 feet in the Des Moines area, and then abruptly to over 1,500 feet in the vicinity of the Trend No. 1 Brown well. In northeastern Union County, it is only 590 feet thick in the Pure No. 1 Black Mesa test but thickens rapidly to over 1,100 feet in the Pure No. 2 Black Mesa.

It is suggested from the abrupt variation of thickness of the Sangre de Cristo beds that much of the thick arkosic interval found in parts of eastern and northern Union County was derived from adjacent uplifted areas in the western part of the county. From the isopach map of the Sangre de Cristo interval, it would appear that the highest part of the Sierra Grande uplift during Pennsylvanian and Permian time was in the southwestern part of Union County. The Des Moines area, which is the present highest structural part of the Sierra Grande arch, was also probably a source area for Sangre de Cristo sediments. To judge, however, from the northward increase in thickness of the Sangre de Cristo formation, the Des Moines area apparently was not as high as the southwestern part of the county. The western part of Union County was probably buried during a late stage of arkosic deposition by sediments derived from adjacent parts of Colfax, San Miguel, and possibly Harding Counties. In Colfax County, Sangre de Cristo beds are less than 200 feet thick and in Harding County total only about 150 feet. Farther west, in San Miguel County, arkose is locally absent, and younger Permian beds directly overlie the Precambrian. The foregoing data and the isopach map of prearkosic sediments suggest that in areas of thick arkosic accumulation, the Sangre de Cristo may represent a considerable part of Pennsylvanian time as well as early Permian time, whereas in the areas of thin accumulation, the arkose may be entirely late Pennsylvanian and early Permian, or entirely Permian, in age.

POSTARKOSE PERMIAN ROCKS

Permian rocks above the Sangre de Cristo formation have been subdivided into the Cimarron anhydrite, and the Yeso, San Andres, and Whitehorse formations.

In Union County, the Cimarron anhydrite consists of anhydrite with minor dolomite. This interval was found in all wells except those on the Sierra Grande uplift, where it may be represented by thin fine-grained dolomitic sandstones. Its position a short distance above arkosic conglomerates, and below a thick interval of reddish sandstone and mudstone, makes it one of the most distinctive and easily recognized units in the subsurface in Union County. In general, the Cimarron anhydrite is less than 35 feet thick in northeastern Union County, but ranges from 115 to 155 feet in the southeastern part of the county and in adjacent areas of Hartley County, Texas.

The Yeso formation as used in this report excludes the Tubb sandstone and the Cimarron anhydrite, which elsewhere are considered parts of the Yeso formation. Included are some sandstone beds that are litho-logically similar to the Glorieta sandstone. These beds, however, are present in only a few of the oil tests in Union County and are absent in other nearby wells. This lack of continuity, plus a pronounced eastward thinning of the Glorieta sandstone in San Miguel and Guadalupe Counties, limits the advantages of attempting to differentiate a Glorieta interval in Union County. Bates (Dobrovolny et al., 1946) shows a probable eastern limit of the Glorieta sandstone in Quay County, which would exclude the unit from Union County.

The Yeso formation consists of interbedded very fine- to coarse-grained moderate reddish-orange sandstone and moderate to dark reddish-brown mudstone. Some of the coarse sandstones in the Yeso are arkosic, containing abundant well-rounded, oblate grains of light-gray feldspar and well-rounded, equant grains of quartz. The fine-grained sandstones are commonly gypsiferous, and in eastern Union County there are some thin beds of anhydrite and dolomite.

Yeso beds as defined here attain a maximum thickness in southeastern Union County, where they are 500 feet thick in the Oil Exploration No. lA Irwin, 470 feet in the Olson No. 1 Zurick, and 440 feet in the Continental No. 1 Federal Land Bank (fig. 7). In western Union County, including the Sierra Grande uplift, the interval varies from 300 to 400 feet. The slight thinning of Yeso sediments over the Sierra Grande uplift reflects the subdued nature of the positive area during Yeso deposition. The thinnest sections of Yeso beds found in Union County are in the Pure tests, where only 190 to 205 feet was drilled.

San Andres sediments consist primarily of dolomite and anhydrite, with some light-gray fine-grained sandstone near the base. The dolomites are pale to moderate yellowish brown and medium to dark gray, aphanitic to fine granular, often oolitic and gypsiferous, argillaceous, and silty to sandy. The unit is distinctive throughout Union County, being overlain and underlain by generally fine-grained red clastics. Farther south in New Mexico, the lower part of the Whitehorse formation intertongues with dolomites and anhydrites similar to those in the San Andres, and the contact is less obvious. As a lithologic unit, the San Andres is readily traced in the subsurface to outcrops in central New Mexico.

The thickest sections of the San Andres formation occur in eastern Union County, where it is 200 to 400 feet thick. It thins in western Union County to less than 100 feet and is absent in eastern Colfax County.

Whitehorse beds are overlain in Union County by Triassic sediments. The contact is placed at the base of a conglomeratic sandstone interval considered equivalent to the Santa Rosa sandstone. The upper part of the Whitehorse formation consists of a thin section (15-65 feet) of very fine-grained moderate reddish-orange sandstone, which is often very similar in appearance to some of the overlying Triassic sediments. The base of this upper unit is at the top of the Alibates dolomite, which forms a distinctive marker bed in Union County. The Alibates is very light-gray to white very finely crystalline silty dolomite, 10 to 40 feet thick in Union County. Below the Alibates, the Whitehorse formation consists of an upper part of moderate to dark reddish-brown and moderate reddish-orange mudstone and claystone, which is gypsiferous and contains small (< 1 mm) crystals of dolomite near the base. Underlying this upper sequence is an interval of very fine- to fine-grained moderate reddish-orange friable gypsiferous sandstone.

The Whitehorse formation is over 400 feet thick in parts of eastern Union County, thinning westward, slightly, to between 200 and 300 feet. The interval is lithologically similar to the Bernal formation in central New Mexico and occupies the same stratigraphic position.

As can be seen in Figure 7, the postarkose Permian beds thin fairly uniformly from east to west over the Sierra Grande uplift. They also change slightly in lithologic character in this direction, becoming more sandy and containing fewer carbonates and evaporites. In eastern Colfax County, this part of the Permian is represented by about 400 feet of fine- to medium-grained sandstone, with minor mudstone. South of Union County, in northern Quay County, the interval thickens to as much as 2,500 feet and contains a considerable amount of salt.

BASAL TRIASSIC ROCKS

Subdivisions of the Triassic rocks, except for the lowermost beds, are discussed on p. 32-43. The oldest Triassic unit exposed in Union County is the Baldy Hill formation, which in the subsurface overlies a conglomeratic sandstone tentatively correlated with the Santa Rosa sandstone. This interval is 60 to 180 feet thick in Union County, and consists mostly of pale-red fine- to coarse-grained and conglomeratic friable quartz sandstone. The sandstone generally contains a high percentage of coarse-grained, well-rounded, frosted quartz grains. Some dark reddish-brown sandy mudstone also is included in the unit.

The Triassic isopach map (fig. 8) is similar in certain aspects to the isopach maps of the Paleozoic intervals. This is particularly evident in the marked thinning of Triassic rocks to about 500 feet in the Des Moines area on the Sierra Grande arch.

The thickest drilled intervals of Triassic rocks were encountered in the Dillard No. 1 State test, with 1,200 feet, and in the Hoxsey No. 1 Jones, with 1,140 feet. In southwestern Union County, where Paleozoic sediments are thin, 965 feet of Triassic was encountered in the Galbreath No. 1 Britt well. East of the Dillard and Hoxsey wells, the Triassic thins to 680 feet in the Continental No. 1 Federal Land Bank and to 510 feet in the Herndon No. 1 Mock.

In northern Union County, 675 feet of Triassic was drilled from

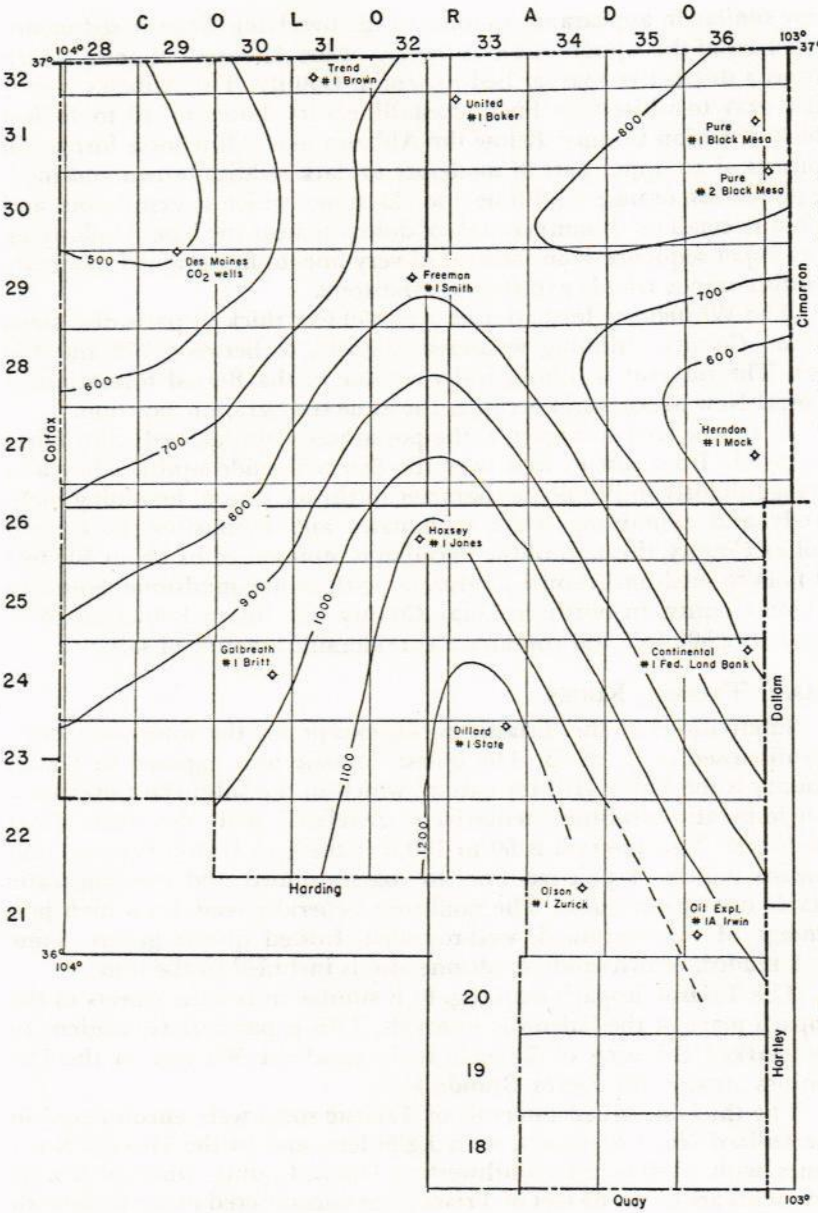


Figure 8
THICKNESS OF TRIASSIC SEDIMENTS
Contour interval, 100 feet.

TABLE 1. OIL TESTS IN UNION COUNTY

WELL	LOCATION*	COMPLETION YEAR	ELEV. † (FEET)	TOTAL DEPTH (FEET)	SURFACE FORMATION	BOTTOM FORMATION
Trend No. 1 Brown	32.31.29.420	1957	5,354	3,586	Travesser	Precambrian
Hopkinson No. 1 Hopkinson	32.31.34.121	1955	5,292	302	Travesser	Baldy Hill
United No. 1 Baker	31.33. 6.110	1919	5,062	2,725	Baldy Hill	Precambrian
Atkinson No. 1 Quimby	31.36.15.210	1957	4,432‡	3,014	Travesser	1
Pure No. 1 Black Mesa	31.36.13.422	1947	4,373	3,514	Travesser	Precambrian
Farrell No. 1	30.28. 5.330	1925	?	480	Benton(?)	?
Nelson Moore No. 1 Fee	30.29.33.433	1952	6,710	2,685	Dakota	Precambrian
Gruemmer No. 1 Gruemmer	30.29.33.440	1954	6,675	2,461	Dakota	Sangre de Cristo
Pure No. 2 Black Mesa	30.37. 6.214	1947	4,424	3,564	Sheep Pen	Mississippian
Sierra Grande No. 1 Rogers	29.29. 4.320	1935	6,705	2,800	Dakota	Precambrian
Stockley No. 1 Schmitt	29.29. 4.440	1955	6,664	2,800	Dakota	Precambrian
Gruemmer No. 2 Gruemmer	29.29. 3.210	1954	6,687	2,765	Basalt	Precambrian
Freeman No. 1 Smith	29.32.22.111	1952	5,570	2,959	Morrison	Precambrian
Snorty-Gobbler No. 1	28.31.35.220	1924	5,890?	527	Ogallala	?
Skelly No. 1 N. Mex. Van Pelt	28.35. 9.310	1958	5,162§	4,387	Ogallala	Precambrian
Morad No. 1 Campbell	28.35.25.220	1956	4,980?	600+	Ogallala	?
Herndon No. 1 Mock	27.36.25.111	1945	4,802	4,555	Ogallala	Sangre de Cristo
Hoxsey No. 1 Jones	26.32.27.240	1956	5,509	3,898	Ogallala	Precambrian
Galbreath No. 1 Britt	24.30.14.410	1957	5,811	2,603	Ogallala	Precambrian(?)
Blankenship No. 1 Herringa (Pasamonte)	24.30.14.444	1924	5,815	2,787	Ogallala	Precambrian
Thomas No. 1 Cook Ranch	24.33.26.244	1927	5,300	455	Ogallala	Dockum
Buffalo No. 1 Odiorine	24.36. 3.400	1924	4,687	2,171	Ogallala	?
Continental No. 1 Fed. Land Bank	24.36. 2.440	1957	4,688$	5,308	Ogallala	Ordovician(?)
Dillard No. 1 State	23.33. 2.122	1949	5,119	4,037	Purgatoire	Precambrian
Nunn No. 1 Hopson	23.35.26.320	1952	4,743	969	Ogallala	?
Olson No. 1 Zurick	21.34. 2.341	1936	4,610	2,925	Morrison	Precambrian
Haynes No. 1	21.35. 5.000	1931(?)	?	1,400	?	?
Oil Exploration No. 1 Irwin	21.36.29.110	1956	4,517	1,008	Ogallala	Dockum
Oil Exploration No. IA Irwin	21.36.29.110	1956	4,526	7,360	Ogallala	Precambrian
Nunn No. 1 Wallace	20.36.30.110	1952	4,490	762	Ogallala	Dockum

* Explanation of well locations used in this report is given on p. 4-5. †
Elevations refer to ground level except where indicated.

‡ Derrick floor.

§ Kelly board.

the surface in the Trend No. 1 Brown, with a possible 50 feet of additional Triassic exposed at the surface. The 860 feet of Triassic in the Pure No. 2 Black Mesa includes the Sheep Pen and Sloan Canyon intervals; this is the only oil test to encounter these units in Union County.

MESOZOIC UNITS

Geologic units of Mesozoic age that are exposed in Union County are listed in Table 2. Sandstones of the various formations are not readily distinguished in hand specimen; the color of the mudstones has been used, however, as a differentiating criterion. In general, mudstones of Triassic and Jurassic age are gray green or red brown, whereas those of Cretaceous age are medium to dark gray.

The Triassic and Jurassic rocks are believed to have been deposited as nonmarine sediments, mostly in flood-plain environment. The Exeter sandstone may represent dune deposits near a shallow sea or lake, and the brown-silt member of the Morrison formation may have formed in lakes. The Purgatoire formation is marine in origin, but the Dakota formation may represent nonmarine deposits that were formed during retreat and readvance of the Cretaceous seas. The Dakota formation grades up into a marine sequence that begins with the Graneros shale and continues through the Niobrara formation, which is the youngest Cretaceous formation recognized in Union County.

Discussion of Mesozoic units is guided in part by the mappability of geologic contacts. Although the Dakota group, for example, is a sequence of sandstones and shales that are related in origin and lithology, the base of the Dakota group is not readily mapped, whereas the base of the Dakota formation is. The Purgatoire formation, therefore, was mapped with the Morrison formation instead of with the Dakota formation; as a result, the Purgatoire formation and the Dakota formation are considered separately.

The thickness, lithologies, and variations of each Mesozoic unit are given in the text and are illustrated in the columnar sections of Plate 2. Gross features of the units are indicated in many of the well logs, which are in the appendix.

Correlations of Triassic formations are given by Reeside et al. (1957). A regional study of the Jurassic rocks of the United States is presented by McKee et al. (1956); the study includes a discussion of the agate bed of the Morrison formation and a discussion of the Morrison-Purgatoire contact. Correlations of Cretaceous formations are given by Cobban and Reeside (1952). Merriam (1957) has summarized the nature of Mesozoic rocks in Kansas.

DOCKUM GROUP

The Dockum group as used in this report includes all beds of Triassic age exposed in Union County. With only one or two exceptions, ex-

TABLE 2. SUMMARY OF MESOZOIC UNITS EXPOSED IN UNION COUNTY

PERIOD	STRATIGRAPHIC UNIT	THICKNESS (FEET)	LITHOLOGY
Cretaceous	Niobrara formation		
	*Smoky Hill marl member	1,000	Black shale with some thin beds of limestone and marl
	*Fort Hays limestone	50	Light-tan limestone
	Benton group		
	*Carlile shale	200	Dark-gray shale, with thin beds of limestone in top 30 ft
	*Greenhorn limestone	30	Light-tan limestone with thin beds of shale
	Graneros shale	125	Dark-gray shale with two or three thin beds of limestone
	Dakota group		
	Dakota formation	90-190	Lenticular to parallel-bedded gray shale, shaly sandstone, and sandstone; basal unit is a persistent massive sandstone
	Purgatoire formation	6-100	Upper member, dark-gray shale; lower member, massive sandstone; either is locally absent
Jurassic	Morrison formation	170-550	Gray-green and gray-red mudstone with local thick beds of sandstone; brown-silt member at base and agate bed just above
	Exeter sandstone	0-80	Massive white to pink fine-grained sandstone
	ANGULAR UNCONFORMITY		
Triassic	†Clastic plugs		Vertical cylinders of sandstone surrounded by breccia of siltstone; some are mineralized
	Dockum group		
	†Sheep Pen sandstone	0-107	Thin-bedded light-brown sandstone
	†Sloan Canyon formation	0-150	Light-green and red mudstone
	†Travesser formation	245-550	Red-brown mudstone and sandstone
	†Baldy Hill formation	100	Purple-mottled mudstone; base not exposed

* Preserved only in Des Moines quadrangle in the northwest corner of the county.
† Recognized only in Dry Cimarron River valley.

posures of the Dockum group are restricted to the drainage area of the Dry Cimarron, where the grdup is divided into four formations. Parker (1933) named the Sheep Pen sandstone and the Sloan Canyon formation, and this report names the Travesser formation and the Baldy Hill formation. The Travesser formation is exposed almost continuously from near Tollgate eastward to the former Valley school and is exposed intermittently from there eastward to the Oklahoma State line. The other formations are more restricted in occurrence. The variation in thickness of the Triassic in Union County is shown in Figure 8.

Before deposition of the overlying Exeter sandstone, the beds of the Dockum group were gently folded and then eroded to a fairly even surface; a few residual hills of Sheep Pen sandstone may have stood above the plain during deposition of the Exeter sandstone. The Sheep Pen sandstone and the Sloan Canyon formation, which are treated as one map unit (pl. 1), are preserved in broad pre-Exeter synclines. The Baldy Hill formation is exposed in a limited area on the former Baker ranch, on the axis of the post-Graneros Guy monocline.

The Dockum was named in 1890 by Cummins for the community of Dockum in Dickens County, Texas (Wilmarth, 1938, p. 616). Lee (1902) applied the term to beds exposed under the Exeter sandstone in the Dry Cimarron River valley. Parker (1933) limited the Dockum group to the red beds and named the Sheep Pen sandstone and Sloan Canyon formation for the overlying beds in the Dry Cimarron River valley. Other authors, however, have included these formations of Parker in the Dockum group.

Some vertebrate fossils have been found in the Dockum group of the Dry Cimarron River valley. Stovall and Savage (1939) collected a skull of a phytosaur at 31.36.12.232 in Sloan Canyon, just east of the slab crossing of New Mexico Highway 325. The phytosaur, it is reported, was found about 100 feet below the top of the Sloan Canyon formation and about 35 feet above the base. McLaughlin (1954, p. 85) states that other Triassic fossils have been found in the Dockum group in Cimarron County, Oklahoma, and in Baca County, Colorado. The writer found fragments of bones and teeth in sandy siltstones in the northeastern part of Union County, at 31.35.12.131 and 32.36.31.444. The reptilian tracks reported by Parker (1933, p. 42) are exposed in Peacock Canyon in a creek bed on a stripped sandstone surface at 31.34.19.343.

Colbert and Gregory (Reeside et al., 1957, p. 1464 and table 3) date the Dockum group of the Dry Cimarron River valley as Upper Triassic; they correlate the Sheep Pen sandstone and the Sloan Canyon formation with the Wingate sandstone of Arizona, and the underlying shale unit (probably the Travesser formation of this report) with the upper part of the Chinle formation of Arizona.

Subdivisions of the Dockum group in general cannot be recognized south of the Dry Cimarron River valley. The Sheep Pen sandstone and Sloan Canyon formation appear to be local in extent; they were mapped separately from the Travesser formation to show some of the pre-Exeter structure. The Baldy Hill formation, however, has been recognized in cuttings from several oil tests in Union County. Moreover, it is similar in lithology to some beds exposed near Las Vegas, New Mexico, and to some of the lower beds of the Chinle formation in the Zuni Mountains area and in Arizona (C. H. Dane and R. W. Foster, oral communication, Nov. 14, 1957).

The Dockum group in most of Union County consists of red-brown mudstone and orange sandstone. In the southern part of Union County, reddish sandstone and mudstone beneath the "agate bed" of the Morrison formation are exposed in a number of places. Most of the outcrops represent the brown-silt member of the Morrison formation, but several are probably Dockum. Outcrops of strata beneath the "agate bed," in the southern part of the county, are described individually in the appendix.

Baldy Hill Formation

The unit of purple-mottled mudstone, here named the Baldy Hill formation of the Dockum group, represents the oldest beds exposed in Union County. It was first recognized by R. W. Foster (1956, p. 137) in cuttings of oil tests in northwestern Union County. The Baldy Hill formation is exposed in an area of about 8 square miles on the former Baker ranch, just north of the junction of New Mexico Highways 325 and 370. This area, which is in the eastern part of 32.32 and the western part of 32.33, is on the northwestern, higher part of the post-Graneros Guy monocline. The formation is best exposed near Baldy Hill, from which it takes its name. Baldy Hill proper (pl. 4A) is composed of the Morrison formation, Exeter sandstone, and red beds; the Baldy Hill formation is poorly exposed on slopes beneath the low bench that forms the base of the red beds.

The type section of the Baldy Hill formation was measured 2,000 feet north of Baldy Hill (pl. 2, section 10b), at 32.32.36.224. The top of the formation is taken as the base of the pebbly sandstone that forms the persistent rim of a low bench; the base is not exposed. The Baldy Hill formation is 115 feet thick in the measured section and consists of silty mudstone, with beds of ledge-forming sandy mudstone and very fine-grained sandstone. A 13-foot interval of claystone is present near the bottom of the section. The formation is characterized by its purple color, which mottles orange, gray red, light to medium gray, and light olive. Under the hand lens, angular white fragments can be seen in much of the purple mudstone. In some places, the interior of chips of purple mudstone is colored red brown. Nodules of red and yellow chalcedony, similar to the "agate bed" of the Morrison formation, and some silicified wood, are present about 15 feet below the top of the unit.

One or two miles east and northeast of the type section (from the center of 32.33.31 to the center of 32.33.29), several sandstone beds crop out beneath the low bench that is the base of the Travesser formation. These sandstone beds are absent at the type locality; therefore, the Travesser formation may rest on the Baldy Hill formation with angular unconformity. The sandstone beds are mentioned by Parker (1933) as being possibly equivalent to the source beds of the clastic plugs.

Medium-gray mudstone, containing questionable plant fragments, is exposed in a cutbank a mile east of Baldy Hill, at 32.33.31.224.

Travesser Formation

The Travesser formation is here named for red beds of the Dockum group exposed along the Dry Cimarron River valley. The formation underlies slope wash and alluvium from Tollgate eastward to the Oklahoma State line. Except for a few miles on the south side of New Mexico Highway 325, the Travesser formation extends up into the lower slopes of the steep valley walls from Tollgate east to Wedding Cake Butte. The formation is named for exposures near Travesser Creek, and its type section is taken at 31.32.12.243-232 (pl. 2, section 11), 2 miles south of Baldy Hill.

The formation is 400 feet thick in the Des Moines area and thickens eastward to 550 feet in the northeast corner of Union County (Foster, 1956, p. 137). At the type section, however, the Travesser formation is only 245 feet thick; an unknown thickness of the Travesser formation was removed by pre-Exeter erosion. Parker (1933) gives a thickness of 400 feet for the red beds in the Dry Cimarron River valley.

The base of the Travesser formation is exposed in a limited area near Baldy Hill, where it is underlain with possible angular unconformity by the Baldy Hill formation. In this area, the base is taken as the base of the ledge-forming pebbly sandstone that holds up the low bench beneath Baldy Hill (pl. 4A). Two miles to the south of Baldy Hill, at the type locality of the Travesser formation, pebbly sandstone forms a small outcrop in the slope wash at the base of the steep slopes; this sandstone is interpreted as the top of the ledge-forming sandstone that is the basal unit of the Travesser formation near Baldy Hill.

The Travesser formation consists largely of clayey silt and very fine-grained sandstone. The sandstone beds, which are as thick as 20 feet in the measured section, range from massive to thin bedded, and from parallel bedded to crosslaminated. Conglomeratic lenses that consist of small pebbles of calcareous mudstone and of fine-grained sandstone in a limy matrix are common. Some fissile clay is present in the measured section. Individual sandstone beds can be followed by eye along the valley walls for distances of several miles. The color of the Travesser formation is most commonly medium red brown, although at Battleship Mountain (32.35.28.414; pl. 3A) a prominent sandstone is orange and some beds are dark red brown. Some of the variations in lithology of the formation are illustrated in the columnar sections of Plate 2.

Sloan Canyon Formation

The Sloan Canyon formation was named by Parker (1933, p. 41-42) for exposures along Sloan Canyon near the slab crossing of U. S. Highway 64 (now New Mexico Highway 325), in northeastern Union County. He described the formation as consisting of 125 to 150 feet of variegated argillaceous and calcareous shales, with beds of siltstone and marl, and with a red sandstone near the base. The formation rests conformably on the red beds (Travesser formation).

The Sloan Canyon formation crops out from Peacock Canyon (western part of 31.34) eastward and northward to the Oklahoma and Colorado State lines. It forms the lower slopes of the valley walls in the Peacock Canyon area (31.34), but it was removed from the pre-Exeter anticline (west half of 31.35) west of Wedding Cake Butte (fig. 10; pl. 3B). Stovall and Savage (1939, fig. 3) incorrectly extend the Sloan Canyon west of Wedding Cake Butte and beneath Battleship Mountain. East of Wedding Cake Butte, the Sloan Canyon formation forms intermittent outcrops and low benches surrounded by slope wash and alluvium. The formation is recognized only in the Dry Cimarron River valley, although it may have been encountered in some of the oil tests.

Two low mesas in the north half of 31.35.12, near the slab crossing, probably represent Parker's type locality. The exposures on the slopes below the mesas are good. The Sloan Canyon formation in these exposures is mostly light gray-green mudstone, with minor beds of limestone and conglomerate.

A section of the Sloan Canyon formation was measured 4 miles southwest of Battleship Mountain at 31.34.2.224 (pl. 2, section 13). Most of the formation is clayey silt. Colors include light green, light gray green, light gray brown, light brown, red brown, and gray red. The base of the formation was picked at the base of a 1-foot bed of light-green calcareous siltstone, the lowest green bed in the section. The underlying 11 feet consists of mottled red and green mudstone that is arbitrarily put in the top of the Travesser formation. The Sloan Canyon formation is 93 feet thick in this section, measured between the Travesser formation and the Sheep Pen sandstone.

In general, the base of the Sloan Canyon formation is considered to be at the lower limit of the light gray-green beds and at the upper limit of the predominantly red-brown beds. Although adequate for mapping purposes, this designation is not entirely satisfactory in the area just east of Wedding Cake Butte, where a massive bed of orange mudstone or fine-grained sandstone about 20 feet thick separates the underlying red-brown mudstone of the Travesser formation from the overlying light gray-green Sloan Canyon formation.

The phytosaur that was obtained near the slab crossing (Stovall and Savage, 1939) was probably collected from the orange bed noted above.

The orange bed may be the same as the red sandstone that Parker recognized near the base of the Sloan Canyon formation.

The Sloan Canyon formation, with its light gray-green mudstone, has been mistaken by some geologists for the Morrison formation, leading them to place the Sloan Canyon formation, the Sheep Pen sandstone, and the Exeter sandstone in the Morrison formation (Rothrock, 1925; Darton, 1928; Sanders, 1934; Soule, 1956). However, Lee (1902), DeFord (1927), Parker (1933, 1934), and Stovall and Savage (1939) have recognized that the Exeter sandstone lies under the Morrison formation and that the variegated mudstones of the Sloan Canyon formation are pre-Exeter. The angular unconformity beneath the Exeter sandstone in the vicinity of Battleship Mountain (fig. 10; pl. 3A) is convincing evidence of the true relationship.

Along the Dry Cimarron River valley, the position of variegated to light gray-green mudstones in relation to the Exeter sandstone and to the brown-silt member of the Morrison formation is sufficient to distinguish the Sloan Canyon formation from the Morrison (pl. 5A). In addition, the Sloan Canyon formation locally has vivid colors, such as pale green and medium gray red; vivid colors are not common in the Morrison below the uppermost part of the formation.

Sheep Pen Sandstone

The Sheep Pen sandstone was named by Parker (1933, p. 41) for exposures on a butte in the east half of 32.35.35 (fig. 10), 1.6 miles east of Wedding Cake Butte. The name was taken from Sheep Pen Canyon, which drains south into the Dry Cimarron River at the west base of Black Mesa. At the type section, Parker measured 68 feet of thin-bedded to massive tan to buff sandstone which caps the small butte.

The Sheep Pen sandstone is exposed from Peacock Canyon (western part of 31.34) eastward to the Oklahoma State line, though it is absent on the pre-Exeter anticline in the vicinity of Battleship Mountain. Although Stovall (Schoff, 1943, p. 47) did not recognize the Sheep Pen sandstone in Oklahoma, units 15-21 of their measured section 30 (Schoff, 1943, p. 260) may be Sheep Pen sandstone (pl. 5A).

The Sheep Pen sandstone rests with a fairly distinct contact on the Sloan Canyon formation. At those outcrops where thin beds of light-green or red mudstone are interbedded with the sandstone, the base of the Sheep Pen is taken as the base of the lowest sandstone in a predominantly sandstone sequence; the underlying Sloan Canyon formation has few sandstone beds. At one outcrop (31.35.24.324), the red mudstones of the Sloan Canyon formation appear to be slightly tilted beneath the Sheep Pen sandstone, although the two formations are generally conformable.

The contact between the Sheep Pen sandstone and the overlying Exeter sandstone is not so distinct. The former is commonly a brownish thin-bedded angular-weathering sandstone that is distinct from the mas-

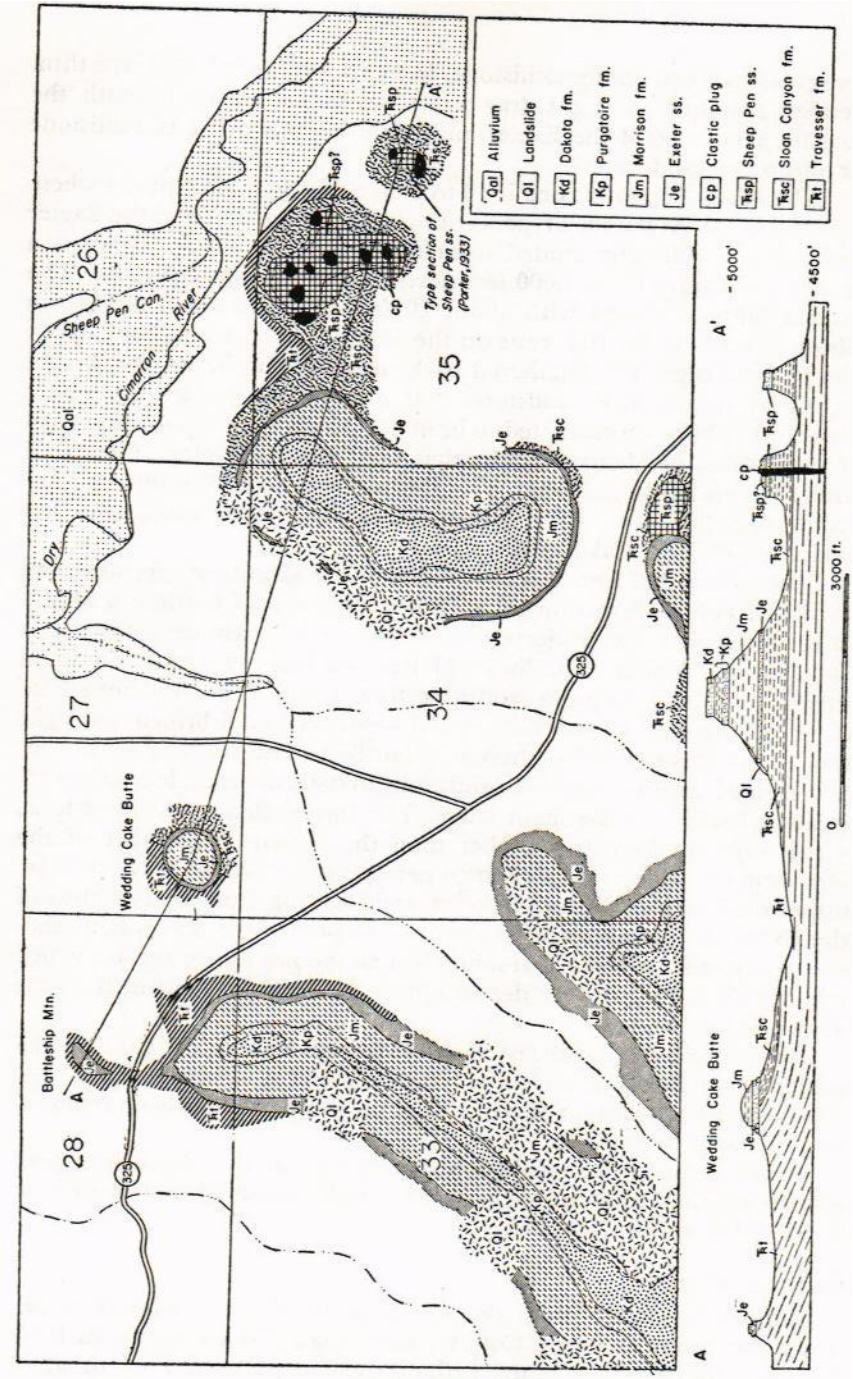


Figure 10

GEOLOGY IN THE VICINITY OF WEDDING CAKE BUTTE

Northeastern Union County, T. 32 N., R. 35 E. Blank areas on the map are covered; vertical exaggeration of the cross-section is $\times$ 2.

sive cream-colored Exeter sandstone. In many localities, however, a thin-bedded light-gray or light gray-brown sandstone occurs beneath the massive sandstone of the Exeter and could be either Exeter sandstone or Sheep Pen sandstone.

The Sheep Pen sandstone is 10 to 20 feet thick in most places where it is preserved. At Parker's type section, it is 68 feet thick, and the Exeter sandstone is evidently eroded from the top of the butte. There is a second and larger butte 1,000 feet northwest of this butte (fig. 10). The second butte is ringed with about 20 feet of thin-bedded red-brown Sheep Pen sandstone that rests on the Sloan' Canyon formation. Above the 20-foot ledge, and weathered back from the rim, there are beds of light-gray crossbedded sandstone that may be the Exeter sandstone; these upper beds are estimated to be 40 feet thick. The top of this broad butte consists of about 8 knobs that may be clastic plugs (described under Clastic Plugs, p. 40-43). The Sheep Pen sandstone is absent 1,000 feet west of the second butte, at the northeast base of the small mesa that is east of Wedding Cake Butte.

A section of 107 feet of probable Sheep Pen sandstone was measured at 31.34.1.113 (pl. 2, section 13) 3.7 miles southwest of Battleship Mountain, on a bench that projects westward from the main steep slope of a Dakota-capped mesa. The lower 21 feet is a fine- to very fine-grained thin-bedded ledge-forming sandstone that is typical of the Sheep Pen; it is light olive on a fresh surface and weathers to red brown and light tan. Above this sandstone, there is about 86 feet of orange fine- to very fine-grained medium-bedded sandstone that forms rounded ledges retreating back from the main ledge. The top of this upper sandstone, which caps the bench, is higher than the brown-silt member of the Morrison formation that is exposed nearby on the main steep slope. The upper sandstone is distinct in color and bedding from nearby cliffs of the Exeter sandstone and is interpreted as part of the Sheep Pen sandstone. Evidently, this was a residual hill on the pre-Exeter surface which was not buried until after deposition of the brown-silt member of the Morrison formation.

About 1,000 feet northeast of the measured section, the Exeter sandstone rests on the lower 20 feet of typical Sheep Pen sandstone, and 1,000 feet farther northeast, at 32.34.36.341, the Sheep Pen has been removed by pre-Exeter erosion.

In addition to the residual hill suggested at the above measured section, residual hills are suggested 3½ miles south of that section, at 31.35.19.130 and at 31.34.24.

CLASTIC PLUGS

Numerous clastic plugs dot the floor of the Dry Cimarron valley in northeastern Union County; more than 170 are shown in Plate la. The plugs are distributed without evident pattern. They occur in groups that are found from Peacock Canyon east to the Oklahoma State line, and some occur in the Carrizo Creek drainage. In addition, several plugs are present in the northwest corner of Oklahoma, north of Black Mesa. Many of the plugs form isolated knobs that stand 20 to 50 feet above the slope wash, at a level below the base of the Exeter sandstone. Some of the plugs are mineralized.

Parker (1933) has described in detail the characteristic features of the numerous clastic plugs. From his study of 138 plugs and 18 systems of clastic dikes, he concluded that the plugs were formed by postDockum, pre-Exeter intrusion of mobile sand. The sand moved 400 to 1,000 feet upward, along the intersection of fractures. The source beds are equivalent to four sandstone beds exposed in 32.33.31 (part of the Baldy Hill formation of this report). The brecciated material associated with many plugs represents the country rock, primarily the Sheep Pen sandstone and the Sloan Canyon formation. The few instances of upward drag of the country rock and the absence of downward drag substantiate this origin. The few plugs that stand above the base of the Exeter sandstone are residual hills. (Parker, 1933.)

Parker (1933, p. 48) listed hematite, malachite, azurite, chalcocite, and barite as products of mineralization of the plugs, hematite being the most common. Parker noted about 50 mineralized plugs. He stated that the Pittsburgh Copper Co. sank a 285-foot shaft in a plug located in 31.36.7. Mr. Ray Sumpter, resident of the immediate area, identified this as the plug in the southeast corner of the section; the shaft had previously been reported as being in the plug in the southwest corner of the section.

Harley (1940, p. 36-39), in a report that covers the Black Mesa mining district of northeastern Union County, did not mention a Pittsburgh Copper Co. but stated that the Fort Pitt Copper Co. took over all holdings in 1907; most of the development was located in 32.35.33-34. This location appears to be in error, for the writer found no plugs in those sections (fig. 10).

In the past, a number of clastic plugs have been prospected for copper. More recently, slight concentrations of uranium have been noted at several plugs, although none are known to approach commercial grade.

The writer has examined a few plugs in detail. The following relationships are based on observations that are described below:

1. Some plugs appear to have a floor.
2. Some plugs appear to be truncated above by the Exeter sandstone.
3. Many plugs consist of a central core of light-colored sandstone, surrounded by a breccia of brown siltstone and fine-grained sandstone.
4. Some brecciated masses appear to consist of a single kind of sandstone, rather than of a mixture of many rock types.
5. The brecciated material associated with many plugs does not resemble the Travesser or Sloan Canyon formations; the breccia fragments do resemble the Sheep Pen sandstone.
6. The sandstone in the core resembles the Exeter sandstone.

7. Vertical movement is suggested by slickensides, fluting, vertical contacts, and cylindrical tubes.
8. Whether the plugs were intruded from below, collapsed into depressions from above, or formed somehow during deposition of the Sheep Pen sandstone, is not known.
9. The clastic plugs are probably pre-Exeter in age.

Certain features of clastic plug 31.35.12.442, near the Sloan Canyon crossing of New Mexico Highway 325, are well exposed by recent stripping and small-scale mining of copper. Several truckloads of handpicked copper ore were shipped in 1956 and 1957. The entire knob of the plug is several hundred feet across and consists of fine- to medium-grained sandstone that weathers dark brown. The knob stands about 30 feet above a bench that is underlain by the Sheep Pen sandstone; the bench is about 40 feet above the road.

On the north side of the plug, a bulldozed trench revealed the following section:

	(FEET)
Top of bench	
Sheep Pen sandstone	
White laminated friable fine-grained sandstone	18
Light-tan fine-grained sandstone; in the middle of the interval about I foot of laminated light-green mudstone	5.5
Sloan Canyon formation	
Red and green siltstone and mudstone	15
Floor of trench	

The sandstone of the plug is cemented with, and stained by, hematite, particularly along vertical, somewhat contorted lines. Along the southwest side of the plug, some parts of the sandstone are brecciated in 2-inch fragments. The margins of the plug dip steeply and are in sharp contact with the country rock. In an old prospect on the northwest side, the contact dips about 42° SSE. On the southeast side, the contact has been exposed by recent development and here strikes N. 70° E. and dips 50° S.

Vertical fluting in light-gray fine-grained sandstone on the north side of the plug is either in the outer margin of the plug or in a remnant of the country rock. The flutings are several inches high and 3 to 8 inches wide; they are convex outward. On the south-facing wall of the plug, there are vertical slickensides with horizontal steps on the upper end of the slickensides. The flutings and slickensides suggest vertical movement of the plug after it was consolidated, but it is not clear whether the plug moved up or down.

Chalcocite, with malachite staining, occurs in discontinuous veins 3 to 6 inches wide just inside the outer margin of the plug. Thin seams (one-eighth inch thick) of chalcocite extend several feet outward from the plug along the bedding planes of the Sheep Pen sandstone. Mineralization on the southwest side extends perhaps 10 feet from the plug.

Several other plugs were examined by the writer. The plugs commonly have two parts: a core of light-colored sandstone and a surrounding mass of breccia of brown sandstone or siltstone. The plug in 31.36.21.232 is typical in this respect. This plug has a cylindrical core of fine-grained light-gray sandstone with vertical contacts. There is horizontal jointing but no bedding. Slickensides are found on the south side. The more resistant core is surrounded by low outcrops of a breccia of brown silty shale, light-brown sandstone, and light-gray laminated to crosslaminated fine-grained sandstone.

Brecciated masses of light-brown siltstone or very fine-grained sandstone were also noted on the larger butte in 32.35.35, at the plug in 32.36.31.434, and in the roadcut at 31.36.24.314. The plug in 31.34.26.443 consists of light-brown fine-grained sandstone that faintly shows brecciation. This material appears to rest on green-stained horizontally bedded Exeter sandstone, although the contact may dip northwest into the hill. The plug in 31.35.4.344 (not shown in pl. la) merits careful study in its relation to the Exeter formation.

The plugs in 30.36.9.211 and 30.36.3.233 apparently are truncated and are overlain directly by Exeter sandstone. The plugs in 31.34.1.132, 31.34.26.443, and 31.35.20.140, and plugs on the larger butte in 32.35.35, stand above the base of the Exeter sandstone. At the plug in 30.36.4.443, a coarse breccia of Sloan Canyon lithology in blocks as much as 15 feet long and 3 feet thick is cemented by a scant matrix of light-gray sandstone.

The plugs on the larger butte in 32.35.35 show several interesting features. Cylindrical tubes, ranging in diameter from less than an inch to more than 9 inches, and oriented nearly vertically, are common both in the plugs and in the bedded sandstone. These tubes have thin, smooth walls, and some have short cracks arranged radially about the margin. All the tubes are filled with sandstone indistinguishable from the sandstone outside the walls. Weathered vertical sections of the tubes show faint horizontal bands. The tubes may have been formed by fluids moving upward through unconsolidated sand. One or two of the plugs near the top of the butte faintly show brecciation of light-brown fine-grained sandstone. The sandstone of most of the knobs is crossbedded; in several, the bedding planes are fairly steep, and in one, crossbedding is vertical. On the northwest corner of the butte, a prominent plug appears to rest on the Sloan Canyon formation. The lower part gives way downward into sandstone dikes a quarter of an inch wide that cut Sloan Canyon beds. The latter are somewhat broken and displaced just below the plug. On its north or northeast side, the plug has a sharp vertical contact with the horizontally bedded Sheep Pen sandstone; on the wall of the plug here, fragments of light-colored mudstone can be seen. In general, however, the plug consists of massive uncontaminated fine-grained sandstone.

EXETER SANDSTONE

The Exeter sandstone, probably equivalent to the Entrada sandstone of Jurassic age, is best exposed along the Dry Cimarron River valley in the northern part of Union County. Along the Dry Cimarron River valley, the Exeter is mapped as a separate unit (pl. 1). The base, unconformable on tilted beds of the Dockum group, is distinct, except at Battleship Mountain, as noted below. The top of the Exeter sandstone is taken as the base of the lowest light-brown silt or sandstone bed of the Morrison formation. Exposures of the Exeter along Tramperos and Leon Creeks, and exposures of possible Exeter sandstone in the south panhandle of the county, are mapped with the brown-silt member of the Morrison formation (pl. 1). These exposures are described and discussed in the appendix. The Exeter sandstone may grade up into the brown-silt member of the Morrison.

The Exeter sandstone was named by Lee (1902, p. 45) for exposures in the vicinity of the Exeter (Exter) post office. Lee's type section, illustrated in his Figure 5, is just south of Battleship Mountain in 32.35.28.430, according to his text and photograph of the locality. The location of the Exeter post office is not known. It was possibly, however, the same post office later known as the Valley post office, which most recently was at 32.33.26.340, on the Joel Like ranch; the post office is now discontinued. Mr. Like states that in 1915 the post office was near the mouth of the canyon of Travesser Creek (31.33.8.243). Because of some uncertainty in the location of Lee's type section, Stovall (Schoff, 1943, p. 52) designated as the type section the nearly vertical cliffs south of New Mexico Highway 325 in 32.35.32, presumably .211 (pl. 4B).

Heaton (1939) measured a number of sections of Jurassic rocks in the Rocky Mountains region and was able to demonstrate that the Entrada sandstone of Utah could be carried eastward to the Front Range of Colorado and thence southward into northern New Mexico. He thus treated the Exeter sandstone of the Dry Cimarron River valley as an equivalent of the Entrada sandstone. His measured section 42, at Baker ranch, was perhaps taken in 32.33, about 2 miles west of the former Valley school.

The Exeter is considered to be Jurassic (McKee et al., 1956), probably equivalent to the Entrada sandstone of the Four Corners region, and probably equivalent to the Ocate sandstone of Mora County (Bachman, 1953) and Colfax County (Wood et al., 1953).

The Exeter sandstone is a massive fine- to medium-grained light-colored sandstone that is generally crossbedded on a large scale. The color ranges from white, through light gray brown, light tan, and tan, to orange. Along the Dry Cimarron River valley, the Exeter ranges in thickness from a knife edge to more than 80 feet. It is thickest within 4 miles of the southwest corner of 32.35, near Wedding Cake Butte. In the Peacock Canyon area, in 31.34, the Exeter is locally thin or absent.

Muehlberger (pl. lb) shows the Exeter to be absent in the vicinity of 31.29.22.430, south of Tollgate. In the remainder of the valley, and probably in the remainder of the county, the Exeter is 10 to 50 feet thick.

East of Wedding Cake Butte, the Exeter sandstone crops out at the base of the steep slopes of the valley walls and forms wide, partly covered exposures in the slope wash. To the west, the Exeter forms a cliff or ledge about halfway up the steep slopes. Near the northeast corner of 31.32, in the vicinity of Baldy Hill, the upper few feet of sandstone is cemented with gypsum, which presumably was derived from the overlying brown-silt member of the Morrison formation. In the same area, the Exeter is thin and easily eroded, and outcrops are few.

In the vicinity of Wedding Cake Butte (p1. 3B), the Exeter and Sheep Pen sandstones exhibit certain changes that suggest the possibility of a relationship between the two formations. In an area that extends 2 miles southwest from Wedding Cake Butte (fig. 10), the Exeter sandstone consists not only of the main cliff-forming sandstone, but also of a lower cliff-forming sandstone; the two cliffs are separated by a narrow grass-covered interval (pl. 4B). The lower sandstone is present only on the crest of the pre-Exeter anticline, resting on beds of the Travesser and Sloan Canyon formations; the Sheep Pen sandstone is absent. At Battleship Mountain (pl. 3A), the horizontal sandstone of the lower cliff merges without a break into the underlying orange sandstone that is part of the tilted Travesser formation. The Sheep Pen sandstone is unusually thick beyond the limits of the lower cliff-forming sandstone; at the measured section, 3.7 miles southwest of Battleship Mountain (pl. 2, section 13), it is 107 feet thick, and northeast of Wedding Cake Butte, at Parker's type section, it is 68 feet thick. C. H. Dane and G. 0. Bachman (oral communication in the field, Nov. 14, 1957) suggested that the Sheep Pen sandstone could have been deposited during the folding of the Triassic rocks, for it is quite thick on the flanks of the fold; moreover, the lower part of the Exeter sandstone could have been deposited immediately after the end of folding, but still some time before the deposition of the main sandstone of the Exeter. Careful field study of these relationships should include study of relationships farther south, in 31.34.24.

MORRISON FORMATION

The Morrison formation of this report includes the interval from the base of the brown-silt member to the base of the overlying Purgatoire formation. The "agate bed" and the brown-silt member in the basal part of the Morrison, described below, are the only subdivisions that appear to be persistent in Union County; the remainder of the Morrison is undifferentiated.

The Morrison formation was named by Eldridge in 1896 (Wilmarth, 1938, p. 1423-1424) for a town near Denver, Colorado; Waldschmidt and LeRoy (1944) redefined the type section. Lee (1902) recognized the Morrison formation in the Dry Cimarron Valley, although his Morrison formation included beds now assigned to the Purgatoire formation of the Dakota group. Comanchean fossils in the Purgatoire led Lee to assign a lower Cretaceous age to the Morrison (Stanton, 1905, p. 659-660), but the Morrison now is considered to be Upper Jurassic (McKee et al., 1956).

The Morrison formation is exposed over more of Union County than any other Mesozoic formation, except the Dakota formation. It underlies all of Union County, except in the areas where the Exeter sandstone or Dockum group is at the surface. It is best exposed along the Dry Cimarron River valley, and in a number of places the entire Morrison interval is either completely exposed or is veneered with only a thin cover of debris.

Sections of the Morrison formation have been measured in detail by Cooley at 31.32.12.330 (pl. 2, section 10a) and 31.32.20.210 (pl. 2, section 9); of these the former is somewhat more accessible and is readily visible from New Mexico Highway 370. These two sections and the columnar sections of many of the oil tests show the variable character of the Morrison formation (pl. 2).

South of the Dry Cimarron River valley, the Morrison formation is at the surface in many places. Exposures, however, are poor because of the broadly rolling topography, and a complete section of the formation is not exposed. Along Ute Creek, which has cut a deep canyon in the southwest corner of the county, talus and landslide debris obscure the Morrison interval. In the south panhandle of the county, the best exposures of the Morrison are in the southwest-dipping beds exposed about 2 miles north of Ione, in 18.34 and 18.35. There, the interval from the agate bed to the Purgatoire formation is at the surface, though exposures are poor.

The Morrison formation ranges in thickness from 170 or 190 feet in the Irwin oil test (pl. 2, section 27) to 548 feet in the Mock oil test (p1. 2, section 20). Along the Dry Cimarron River valley, thicknesses range from 200 to more than 350 feet.

Beds above the brown-silt member include light gray-green silty mudstone, locally thick white sandstone, thin light gray-brown sandstone, and some thin beds of aphanitic limestone. Gray-red mudstone is common in the upper part of the Morrison along the Dry Cimarron River valley. West of Stead and northeast of the Zurick ranch, nearly 100 feet of thin-bedded fine-grained sandstone forms low mesas and buttes. These beds are in the upper part of the Morrison formation and are overlain locally by white fine- to medium-grained sandstone with silt pebbles (pl. 2, section 44). These sandstone beds of the upper part of the Morrison are treated locally as a map unit. Although the mud-stones of the Morrison are commonly silty, about 10 feet of bentonitic claystone was found on Tramperos Creek at 22.32.25.443. Dark-gray shale was noted just above the brown-silt member on a butte in Harding

County (21.31.7), and medium-gray slightly calcareous shale, containing poorly preserved ostracodes and macerated plant fragments, is exposed less than 5 feet above road level in the roadcut of New Mexico Highway 18 (30.37.18.210). For practical purposes, however, mudstones of the Morrison formation are characteristically light gray green or gray red, whereas mudstones of the Dakota group are characteristically medium or dark gray.

The only fossils that have been found in the Morrison in Union County are the poorly preserved ostracodes noted above, petrified wood, and some plant fragments. Dinosaur bones, in part replaced by uranium, have been reported from Ute Creek south of Union County. In Cimarron County, Oklahoma, many dinosaur bones, ostracodes, and plant fragments have been collected (Stovall, in Schoff, 1943, p. 68-71).

Agate Bed

Nodular red-brown chalcedony, which forms a persistent and useful marker bed near the base of the Morrison formation, is referred to in this report as the "agate bed." Lee (1902, p. 44) noted nodular seams of agate in the Dry Cimarron River valley. Later, Lee (1917, p. 43) stated:

> A shaly zone near the base of the exposure contains red agates similar to those found in the Morrison near Canon City, where they are cut into gems.
>
> These agates were noted in the Morrison [Lee, 1901] several years ago and more recently observed in so many places that the writer has come to regard them as one of the diagnostic features of the Morrison of southern Colorado and northern New Mexico.

The agate bed, described as grains of jasper and carnelian in the upper part of the "Wanakah formation," has been noted in Mora County (Bachman, 1953) and in Colfax County (Wood et al., 1953). Ogden (1954) briefly reviewed the regional extent of the "welded chert" in the Rocky Mountain States and suggested that the chert unit is a time-surface marker, representing upper Ralston, upper Sundance, and upper Curtis time; it might have formed as a result of diagenetic changes in a volcanic ash. His description of the chert fits well with its occurrence in Union County.

In Union County, the agate bed has been noted in nearly every place examined where the basal part of the Morrison formation is exposed. Individual localities in the southern part of the county are noted in the appendix. The agate bed has also been noted in many of the measured sections along the Dry Cimarron River valley and in oil tests (pl. 2). In measured section 3 and in the Oil Exploration No. 1 Irwin and the Continental No. 1 Federal Land Bank oil tests (pl. 2, sections 27 and 24), agate is also present higher in the Morrison formation, but these upper layers are not persistent.

The agate bed in Union County is ordinarily an intermittent layer of nodules. Even fresh pieces are cracked, and the agate readily breaks down into small fragments, which form a distinctive float. The weathered surface is granular or bumpy. Calcite is intimately intermixed with the chalcedony. The most common colors range from red (5R5/4) to red-brown (10R4/6) and to orange (10R6/6), but much of the agate is light gray, and some is gray blue. The colors are distributed in a spotted, rather than in a banded, manner. The agate is commonly found in silty mudstone, though host rocks of sandstone and limestone are known. One of the best exposures of the agate is in the vicinity of 30.33.5.310, just east of New Mexico Highway 370, north of Guy; much of the surface here is stripped on the agate bed. On the steep grade about a mile farther north, the roadcut at the pipeline crossing (31.33.31.140) shows the agate bed in place in thin-bedded light gray-green silty mudstone; 10 feet below is the top of the brown-silt member of the Morrison.

Brown-Silt Member

The brown-silt member is the distinctive basal unit of the Morrison formation and is present in essentially every exposure of this interval. The top is about 10 feet below the agate bed; the base is interbedded with the Exeter sandstone. This interval was recognized in Mora County (Bachman, 1953) and in Colfax County (Wood et al., 1953), where it was tentatively called the upper part of the Wanakah formation. That terminology was retained in several recent reports (Cooley, 1955; Foster, 1956; Oklahoma City Geological Society, 1956; Baldwin and Bushman, 1957a). The U. S. Geological Survey has now abandoned the use of the term "Wanakah" in northeastern New Mexico (C. H. Dane, oral communication, Nov. 14, 1957). In the present report, the interval is included in the Morrison formation. The brown-silt interval is not recognized as a distinctive unit in the Cimarron County report (Schoff, 1943), and it is referred to only briefly in the Baca County report (McLaughlin, 1954, p. 95).

In Union County, the brown-silt interval consists of 25 to 70 feet of thin-bedded light-brown silt and very fine-grained sandstone. The interval forms intermittent outcrops that are bare of vegetation and slightly more resistant to erosion than the overlying mudstones (pl. 3B, 4B). One of the most accessible exposures is on the steep grade of New Mexico Highway 370 (31.33.31.140), about a mile south of the Cimarron compressor station. There, from the main switchback up to the pipeline crossing, the upper 33 feet of the brown-silt member, 10 feet of light gray-green mudstone, the agate bed, and overlying light gray-green mud-stones are well exposed. Limestone occurs in single thin beds, according to some reports. Reports of gypsum in the eastern part of the Dry Cimarron River valley in Union County have not been substantiated, but westward from central 31.33, gypsum occurs locally as cement and as white to light-orange nodules. In some places, a light gray-green color is present in the interval, but the brown and light-brown to tan color (5YR5/4 to 10YR6 /4) is both characteristic and distinctive. In those places where the Exeter sandstone is missing, it is difficult to recognize the contact between the thin-bedded brown-silt member and the thicker bedded Dockum red beds. In oil tests, the contact may be obscure.

Parts of the interval are exposed in many places in the southern part of Union County; these outcrops are described in the appendix. To see the entire interval exposed south of the Dry Cimarron River valley, one must go to the southwest corner of the county, on Ute Creek, or into Harding County. South of Bueyeros, in the hills just east of New Mexico Highway 171, in west-central 19.31, the brown-silt member is 64 feet thick and includes thin beds of Exeter-like sandstone.

Cooley (1955) suggested that the upper beds of the Exeter sandstone are intertongued with the lower beds of the brown-silt interval. His evidence consists of the presence of light-colored sandstone beds in the brown-silt interval, although the scope of his work was not sufficient to permit tracing individual beds into an intertonguing relationship.

Exeter-like sandstone beds occur in the brown-silt member south of Bueyeros (west-central 19.31), south of Gallegos (15.31.27), west of Stead (22.34.11.24), and in the western part of the Dry Cimarron River valley (pl. 2). In the present report, the interval of interbedding of lithologies is placed arbitrarily in the brown-silt member, the base of which is taken as the base of the lowest bed of light-brown silt.

DAKOTA GROUP

The Dakota group in Union County includes the Purgatoire formation and the overlying Dakota formation. It is an interval of 150 to 250 feet of massive sandstone, shaly sandstone, and light- to dark-gray mud-stone, with local beds of carbonaceous mudstone and coal. It rests on the Morrison formation, probably with regional unconformity, and is overlain transitionally by dark-gray Graneros shale of the Benton group. It is evidently in the upper part of the Comanche series and is of Early and Late(?) Cretaceous age.

The Dakota group was named by Meek and Hayden in 1862 (Wilmarth, 1938, p. 566) for exposures near Dakota City, Nebraska, just west of Sioux City, Iowa. Since then, the term Dakota has been used in a variety of ways until it has become ambiguous. Lee (1902) recognized the rimrock of the Dry Cimarron Valley as the Dakota; underlying beds now assigned to the Purgatoire formation were placed in the Morrison formation. Shortly afterward, Stanton and Lee (Stanton, 1905) found Early Cretaceous fossils of the Comanche series (Washita) in the Purgatoire beds along the Dry Cimarron Valley in New Mexico and Oklahoma. In 1912, Stose (Wilmarth, 1938, p. 1746) named the Purgatoire formation for Purgatoire Canyon in eastern Las Animas County, Colorado, and the name was carried south to the Dry Cimarron River valley (DeFord, 1927). The Lower Cretaceous Cheyenne sandstone and overlying Kiowa shale in Kansas have been traced westward in the subsurface to the type section of the Purgatoire formation. The Cheyenne and Kiowa are now treated as members of the Purgatoire formation in southeastern Colorado (McLaughlin, 1954), as had been the case earlier in Oklahoma (Schoff, 1943).

For a number of years, the Dakota formation was considered to be of Late Cretaceous age, based on the study of plants; beds of known Early Cretaceous age were, therefore, excluded from the Dakota formation. In the past few years (Cobban and Reeside, 1951; Katich, 1951), some Early Cretaceous fossils have been found in the Dakota formation in western Colorado and elsewhere; in southeastern Colorado (Waage, 1955, p. 41), the base of the Upper Cretaceous is in the lower part of the overlying formation. Now, the U. S. Geological Survey has extended the Dakota group to include the Dakota and Purgatoire formations and has practically abandoned the use of Dakota in its more restricted sense (Waage, 1955). Waage has reviewed the confusion of terminology and of the subdivisions of the Dakota group:

> The first source [of confusion] was the taxonomic change from the use of the terms formation and group as synonyms to their use as terms for separate ranks of rock units. A more critical source was the tendency to separate the Early Cretaceous from the Late Cretaceous parts of the pre-Benton Cretaceous sequence. . . . Introduction of terminologies from other areas is a recent source of confusion in the Colorado Pre-Benton Cretaceous classification. (Waage, 1955, p. 18.)
>
> . . . a basic difficulty is that none of the terminologies now in use accurately express the principal natural lithogenetic subdivisions and stratigraphic breaks that occur in the pre-Benton Cretaceous sequence throughout eastern Colorado. (Waage, 1955, p. 15.)

For practical reasons, the Dakota group is treated in this report as consisting of the Purgatoire formation and the overlying Dakota formation. Ideally, the two should be treated as one map unit. However, the basal sandstone of the Dakota formation is a persistent and resistant unit with characteristic weathering features. It has been traced by reconnaissance methods from the Dry Cimarron River valley to the southern part of Union County. It forms an important reference interval in the Dakota group. Moreover, the basal sandstone of the Purgatoire formation does not crop out so boldly and in some places appears to be absent; indeed, in other places, such as near Folsom, the entire Purgatoire formation may be absent. Therefore the base of the Dakota formation was mapped (pl. 1) rather than the base of the Purgatoire formation, and the two formations are treated as separate units in this report, the Purgatoire formation being mapped with the Morrison formation.

Dakota formation is here preferred to Dakota sandstone, because much of the interval is shaly. Dakota sandstone is used locally for the massive sandstones but not for the shaly beds.

Problems of picking the exact contact between the Purgatoire and Morrison formation are discussed under the Purgatoire formation. The upper limit of the Dakota formation is taken as the top of the highest sandstone. This may not be consistent with the practice of others in adjacent areas, but, as noted in the section on the Benton group, it is well suited for mapping purposes.

Purgatoire Formation

Along the Dry Cimarron Valley, the Purgatoire formation consists of an upper member of slope-forming light- to dark-gray silty mudstone, and a lower member of massive sandstone that forms discontinuous cliffs (pl. 5A). The Purgatoire formation is immediately under the rimrock of the canyon walls. Some fossils have been collected from the mudstone interval or from the top of the sandstone (Stanton, 1905; Schoff, 1943).

During the present study, poorly preserved *Gryphaea* were found in many measured sections (pl. 2). Near Folsom, the *Gryphaea* bed is a 3-foot chert-bearing coarse-grained sandstone, in which molds of *Gryphaea* are preserved. The sandstone is at the top of the sandstone member of the Purgatoire formation, and it becomes finer grained to the east. In eastern Union County, *Gryphaea* have been collected about 15 feet above the base of the mudstone member. The fossils are better preserved to the east along the Dry Cimarron River valley.

The Purgatoire formation is not readily accessible, because of its position high on the valley walls. However, the black-topped road along the Dry Cimarron River valley crosses the Purgatoire formation in three places in Oklahoma within 9 miles east of the New Mexico State line. The exposure 6 miles east of the State line is the most complete, and *Gryphaea* can be collected from the dark-gray mudstones in the roadcut. As for exposures in northern Union County, the butte at 31.36.34.144 (p1. 2, section 16) is fairly accessible, and the exposures are good. In the western part of the Dry Cimarron Valley, some bulldozed trails ascending to the mesas have fair exposures. In the remainder of the county, the most accessible good exposures are at 22.33.21.323, 22.35.29.310, and 25.31.11.211 (pl. 2, sections 43, 44, and 36).

Along the Dry Cimarron River valley, the upper, slope-forming part of the Purgatoire consists of light- to dark-gray silty to sandy mudstone and silt. In Cimarron County, Oklahoma (Stovall, in Schoff, 1943), and locally in the northeast corner of Union County, the upper few feet of the Purgatoire formation is a fine-grained shaly sandstone. Carbonaceous material, similar to that at 22.33.19.221 (pl. 2, section 42) in the southern part of the county, is present locally. Sandstone beds occupy part of the mudstone interval in some places. The lower part of the Purgatoire formation is a light-colored sandstone about 20 feet thick and possibly as much as 90 feet thick, depending on the choice of the Purgatoire-Morrison contact. In the western part of the valley, the upper few feet of this sandstone is pitted with external molds of Gryphaea. In some measured sections (pl. 2), granules and small pebbles of quartz and chert are present. The sandstone is fine to coarse grained and, in general, is somewhat coarser than the basal sandstone of the Dakota formation. Conglomeratic beds near the base are described by Stovall (Schoff, 1943) and McLaughlin (1954).

In other parts of the county, shaly sandstone beds below the mudstone interval commonly have fucoidal markings, which are considered to be a feature of the Dakota group and Graneros shale but not of the Morrison formation. Erosional unconformities are indicated in several measured sections (pl. 2), but they are probably not significant and may represent merely intraformational channeling.

The Purgatoire formation rests on the Morrison formation with regional unconformity and with local angular unconformity, as a result of warping and erosion of the Morrison before deposition of the Purgatoire formation (Schoff, 1943, p. 60-61, 66). A quarter of a mile south of the black-topped road between Kenton, Oklahoma, and the New Mexico State line, a tilted sandstone of the Morrison formation is apparently beveled beneath horizontal sandstone of the Purgatoire formation. The contact is exposed in a roadcut of New Mexico Highway 18 at 30.37.18.232. There, the Purgatoire overlies a surface with 3 feet of relief.

The Purgatoire appears to be less than 10 feet thick west and northwest of Stead (pl. 2, section 44); also north of Bueyeros in 21.31.5.110, just south of the Union County line. Near Folsom, typical Dakota sandstone lies on gray-red and light gray-green siltstone beds of the Morrison formation, and the Purgatoire formation is evidently absent.

Purgatoire-Morrison contact. The contact between the Purgatoire and Morrison formations is difficult to pick in Union County. Measurement was made of a number of sections (pl. 2) of the interval between unquestioned Morrison and unquestioned Dakota beds, in an effort to clarify the lower limit of the Purgatoire formation. The problem in the field is to determine whether a particular sandstone belongs in the Morrison formation or in the Purgatoire formation. It is a temptation to state that throughout Union County the Purgatoire formation consists of mudstone in the upper part and sandstone in the lower, equivalent to the Kiowa shale and Cheyenne sandstone members of adjacent areas of Colorado and Oklahoma. However, the twofold division of the Purgatoire formation cannot be carried very far south of the Dry Cimarron River valley, and in some places a sandstone that at first thought might represent the lower member of the Purgatoire formation is more probably a sandstone in the upper part of the Morrison formation.

The one criterion for distinguishing Purgatoire from Morrison that is here considered reliable is the color of the mudstones. Medium to dark gray is characteristic of the Dakota group, whereas light green and red are characteristic of the Morrison formation; light neutral gray is not considered diagnostic. Where sandstone without fossils or fucoidal markings intervenes between the two colors of mudstones, the sandstone cannot be assigned definitely to the Purgatoire or Morrison formation.

On Plate 2, therefore, such sandstones between known Purgatoire and known Morrison are treated separately as a queried interval. The sandstones in question are at least 20 feet thick and have a distinctive lithology. They are fine to coarse grained, with scattered granules and small pebbles of quartz, weathered chert, and siltstone. They are friable, white to mottled red, and crossbedded. In some places, beds of sandstone of this character are known to be in the upper part of the Morrison formation.

In the town of Clayton well No. 6, light-gray, gray-red, and light gray-green sandy clay is present from 270 to 300 feet; from 310 to 372 feet, cuttings are of fine- to medium-grained sandstone. In well No. 7, light-gray sandy clay is present from 370 to 385 feet, and fine- to medium-grained sandstone from 385 to 480 feet. The sandstones in both wells are interpreted as Morrison (see logs of wells, p. 101-102).

Stovall (Schoff, 1943, p. 66) reported a Morrison sandstone 114 feet thick that is overlain with angular unconformity by Cheyenne sandstone north of Kenton, Oklahoma. Thick sandstones in the upper part of the Morrison have been noted north of Black Mesa in the northeast corner of Union County, in Des Moines city well 29.29.10.324, in the area just west of Stead, in 22.31.35.300 and vicinity, and in the vicinity of the northeast corner of 22.31.

A thick white sandstone, probably Morrison, is overlain by red and light-green mudstone at 21.34.23.320, southwest of Stead, on the Zurick ranch. The mudstone is in turn overlain by a thin sandstone that is evidently at the base of the Dakota formation. At the windmill 2,000 feet farther north, what is probably the same white sandstone contains white siltstone pebbles and is directly overlain by 10 feet of medium-gray silty mudstone that includes in its lower part reddish mudstone possibly reworked from the Morrison. The gray mudstone is overlain by a 5-foot bed of fucoidal fine- to medium-grained sandstone that may be the basal sandstone of the Dakota formation.

An identical white sandstone with white siltstone pebbles is exposed west of Stead at 22.35.29.310 (pl. 2, section 44). There, it is overlain by a 6-foot interval that may be reworked material, possibly of Purgatoire age:

	(Farr)
Basal sandstone, Dakota formation	
Gray soft muddy sandstone	1
Fine-grained ledge-forming fucoidal sandstone	1.5
Thin-bedded silty to very fine-grained sandstone	3.5
White sandstone	

At 31.29.2.121 (pl. 2, section 5a), 3 miles north of Tollgate, two sandstones underlie the mudstone interval of the Purgatoire formation. The upper sandstone is 10 feet thick and contains Gryphaea molds and chert

granules in its upper few feet. It is separated from the lower, thicker sandstone by a persistent 1-foot bed of light-gray mudstone that forms a notch in the cliff. The lower sandstone, which is 40 feet thick and is fine to medium grained, could be Morrison or Purgatoire, based on field characteristics, although Mankin (W. R. Muehlberger, oral communication, January 25, 1958) regards it as Purgatoire.

These examples indicate the nature of the problem in picking the contact between the Purgatoire and Morrison formations. The lithology of the pebbles in the sandstone may be a useful guide. Abundant silt-stone pebbles may be more typical of the Morrison, and quartz and chert pebbles may be more typical of the Dakota group.

In the southwestern part of the county (22.30), a massive resistant sandstone rests on light gray-green mudstone of the Morrison formation. It is not clear whether the sandstone is Purgatoire or Dakota, but it is not Morrison. The sandstone is overlain along Ute Creek by lenticular sandstone, shaly sandstone, and mudstone. In 22.30.36, the sandstone is overlain by a less resistant, somewhat lenticular sandstone that may be the basal unit of the Dakota formation. In both localities, the massive sandstone is parallel bedded. If the sandstone is Dakota, then the Purgatoire formation is absent.

Dakota Formation

The Dakota formation of this report is an interval of sandstone, shaly sandstone, and light- to dark-gray mudstone, with a persistent and distinctive cliff-forming sandstone at the base. It rests on beds of the Purgatoire formation and is overlain transitionally by Graneros shale of the Benton group.

The Dakota formation forms the rimrock of the Dry Cimarron River valley and is at the surface in large areas of Union County. The persistent basal sandstone is one of the more resistant rocks in the county. The overlying beds, which are more shaly and thin bedded, form benched to gently rolling uplands retreating from the rimrock; outcrops are poor, and in large areas the beds are covered.

With few possible exceptions, the interval of the Dakota formation cannot be studied in one set of exposures. The best indication of the thickness and lithology of the formation is found in cuttings from water wells and oil tests (pl. 2). The Bray water test at 30.35.27.313 (pl. 2, section 35) started at least 25 feet below the top of the formation and went 164 feet to the top of the Purgatoire formation; the Dakota formation here is, therefore, about 190 feet thick. Near Tollgate (pl. 2, section 3), however, the Dakota formation is less than 90 feet thick. In most of Union County, it is on the order of 180 feet in thickness. In the northeast corner of 22.29 (near the reentrant corner of southwestern Union County), the Dakota formation is only about 130 feet thick.

The basal part of the Dakota formation generally consists of a massive sandstone as much as 30 feet thick. This sandstone ranges in color from light gray and cream to dark brown and is commonly somewhat darker than sandstones of the underlying Purgatoire and Morrison formations. It is most readily identified by its weathering characteristics. Where streams have cut below it, the sandstone forms the rimrock; elsewhere, it forms bold outcrops. Torrential crossbedding is common; it consists of units of steeply inclined bedding as much as 2 feet thick separated by units of horizontal bedding an inch or so thick. In the northwest corner of Union County, the torrential crossbedding dips southwest in the lower 20 feet of the basal sandstone, and northeast in the upper part (W. R. Muehlberger, written communication, March 25, 1955). In some exposures, the basal sandstone is weathered into fascinating castellate forms. Torrential bedding and castellate weathering are well exposed on New Mexico Highway 370 (29.34.33.412; pl. 5B), just north of Corrumpa Creek. The sandstone is commonly fine to medium grained, though streaks of coarse-grained sand and scattered pebbles of quartz, chert, and siltstone are present in places.

Although the basal sandstone is fairly persistent, it is somewhat variable. For instance, near the southwest corner of 29.33, the lowest beds of the Dakota formation consist of parallel-bedded fine-grained sandstone. In the water-well test 29.34.22.343 (pl. 2, section 34), the lowest beds of the Dakota formation may be sandy mudstones; there, the Dakota-Purgatoire contact is uncertain. In 30.32.29 and in parts of 22.30, the basal sandstone is inconspicuous. On the other hand, the cliff-forming basal sandstone is locally overlain by a similar massive sandstone; in these cases, the two sandstones either form a single cliff more than 50 feet high, or they are separated by a covered interval as much as 30 feet thick, the upper sandstone having retreated from the rim to form a second cliff.

A geologic contact was mapped (pl. 1) at the base of the Dakota formation instead of at the base of the Purgatoire formation. The contact outlines the rimrock of valleys cut below the Dakota formation and so serves to approximate the topography. The contact was drawn at the base of the lowest persistent and resistant sandstone, the position of the Morrison formation and the nature of the Purgatoire interval being used as guides. In several parts of Union County, the contact inadvertently may have been drawn on the base of the Purgatoire formation or on a sandstone higher in the Dakota formation. Along the headwaters of Pinabetitos Creek in the southwest quarter of 24.32, the lower cliff of white sandstone may belong to the Purgatoire formation, although it is taken as the base of the Dakota formation. Within 3 miles of the southwest quarter of 23.32, access is difficult, and vegetation obscures the bedrock; in that area, the mapped extent of the Dakota formation is only approximate. The contact at the base of the Dakota formation could be modified by more detailed mapping in those localities and in a number of smaller areas, but the contact is generally reliable.

Reports of areas adjacent to Union County describe the Dakota formation as consisting of a lower sandstone, a middle shale, and an upper sandstone. Muehlberger (oral communication, January 25, 1958) accepts this broad grouping for Des Moines quadrangle, modifying it to include the basal cliff-forming sandstone, the middle shaly and coaly interval, and the upper thin-bedded lenticular sandstone (pl. 6B).

In the remainder of Union County, the threefold subdivision of the Dakota formation was not obvious to the writer. Rather, the beds above the basal sandstone are characterized by their variability. Bedding is commonly parallel, and thin, though lenticular, beds are found in places. Common lithologies above the basal unit include fine- to medium-grained tan sandstone, tan silty sandstone, thin-bedded fine-grained sandstone and interbedded medium- to dark-gray mudstone, light-gray silt, purple siltstone, dark-gray carbonaceous and silty mud-stone, lenses of lignite or coal, and thick massive crossbedded channel-filling sandstone. The roadcut (29.36.35.331) just south of the bridge across Corrumpa Creek on New Mexico Highway 18 shows many of these lithologies. Half a mile northwest of the bridge, thick massive sandstone forms a bold outcrop; the log of a shothole drilled in the flood plain at the bridge shows that the base of the Dakota formation here is at a depth of 125 feet. White kaolinitic clay is associated with some part of the Dakota group north of Amistad; this deposit is described on p. 85-86.

Angular discordance in bedding in the Dakota formation, possibly caused by truncation of crossbedding, is exposed in a number of places. These include outcrops at 21.36.33.330, 25.36.34.242, 28.32.5.441 to 28.32.8.221, 28.35.14.332, and 30.34.16.434. These outcrops are on creeks and arroyos, and so the underlying beds and lateral extent of beds cannot be seen. For the present, it is assumed that crossbedding, lenticular deposition, and erosion could have caused the observed discordance.

BENTON GROUP

The Benton group consists of several hundred feet of gray shale, with a few beds of limestone. It was named in 1862 by Meek and Hayden (Wilmarth, 1938, p. 164) for Fort Benton, near Great Falls, Montana. It is in the lower part of the Gulf series of the Late Cretaceous (Cobban and Reeside, 1952).

The Benton group consists of the Graneros shale, the Greenhorn limestone, and the Carlile shale, named in ascending order; these formations are recognizable in Union County. The Graneros shale is at the surface in many parts of the county, but the Greenhorn limestone and the Carlile shale have been recognized only in the northwest corner. Outcrops are restricted almost entirely to the 2 or 3 limestone beds of the Graneros, to the Greenhorn limestone, to shale immediately below these limestones, and to Carlile shale immediately below the Niobrara formation. In most of the outcrops; less than 20 feet of beds is well exposed.

For map purposes, the Graneros shale and the Greenhorn limestone are treated as one map unit (pl. 1), and the Carlile shale is mapped with the Niobrara formation. Description of the Greenhorn and Carlile is based on notes by Muehlberger (written communication, March 25, 1955).

The contact between the Graneros shale and the overlying Greenhorn limestone, as used in this report, probably does not conform to that used in Kansas or southeastern Colorado, but it serves as **a** mappable horizon. This contact is discussed under the Graneros shale.

Graneros Shale

In Union County, the Graneros shale consists of light- to dark-gray clay-shale and silty mudstone, with two distinctive beds of limestone. The lower limestone is felted on a weathered surface, and the upper is laminated; each is only about 2 feet thick. Bentonite beds may be present in the Graneros, but none were noted in the few exposures examined. Crystals of selenite (gypsum) are found in 23.32.34.400 and 31.29.8. Remnants of the Graneros are at the surface in many parts of upland areas in the county, but the entire interval is preserved only in the northwest corner, where it is 125 feet thick (pl. 2, section 1). No good sections of the Graneros are exposed in the county. Outcrops are limited largely to the thin limestone beds, which hold up low benches and form characteristic float. Mudstones are exposed in some cutbanks, particularly along Perico Creek, and locally beneath the limestone beds. In few places, however, is more than 20 feet of section exposed.

The Graneros shale was named in 1896 by Gilbert (Wilmarth, 1938, p. 856) for Graneros Creek in Pueblo County, Colorado. The original definition excluded most of the sandy and limy beds, which were placed in the Dakota sandstone and Greenhorn limestone, respectively. More recently, the Greenhorn limestone of Kansas has been extended downward to include several thin limestone beds in a shale sequence (McLaughlin, 1954, fig. 42). The usage of the present report agrees in principle with Gilbert's definition of the Graneros. The base is taken as the top of the highest sandstone, which is locally only a foot thick; the top is taken as the base of the lowest limestone in a sequence of interbedded limestone and shale (pl. 6A, B). Two, and possibly more, thin limestones (fig. 11) are thus retained in the Graneros shale. The upper persistent limestone (the laminated limestone of this report) is possibly the equivalent of the lowest limestone (Lincoln limestone member) of the Greenhorn limestone of Kansas. The base of the Upper Cretaceous is probably in the lower part of the Graneros shale; in southeastern Colorado, earliest Late Cretaceous fossils are found as low as 40 to 60 feet above the base of the Benton shale (Waage, 1955, **p.** 41).

Mudstone. Mudstone, commonly as a somewhat silty clay-shale,

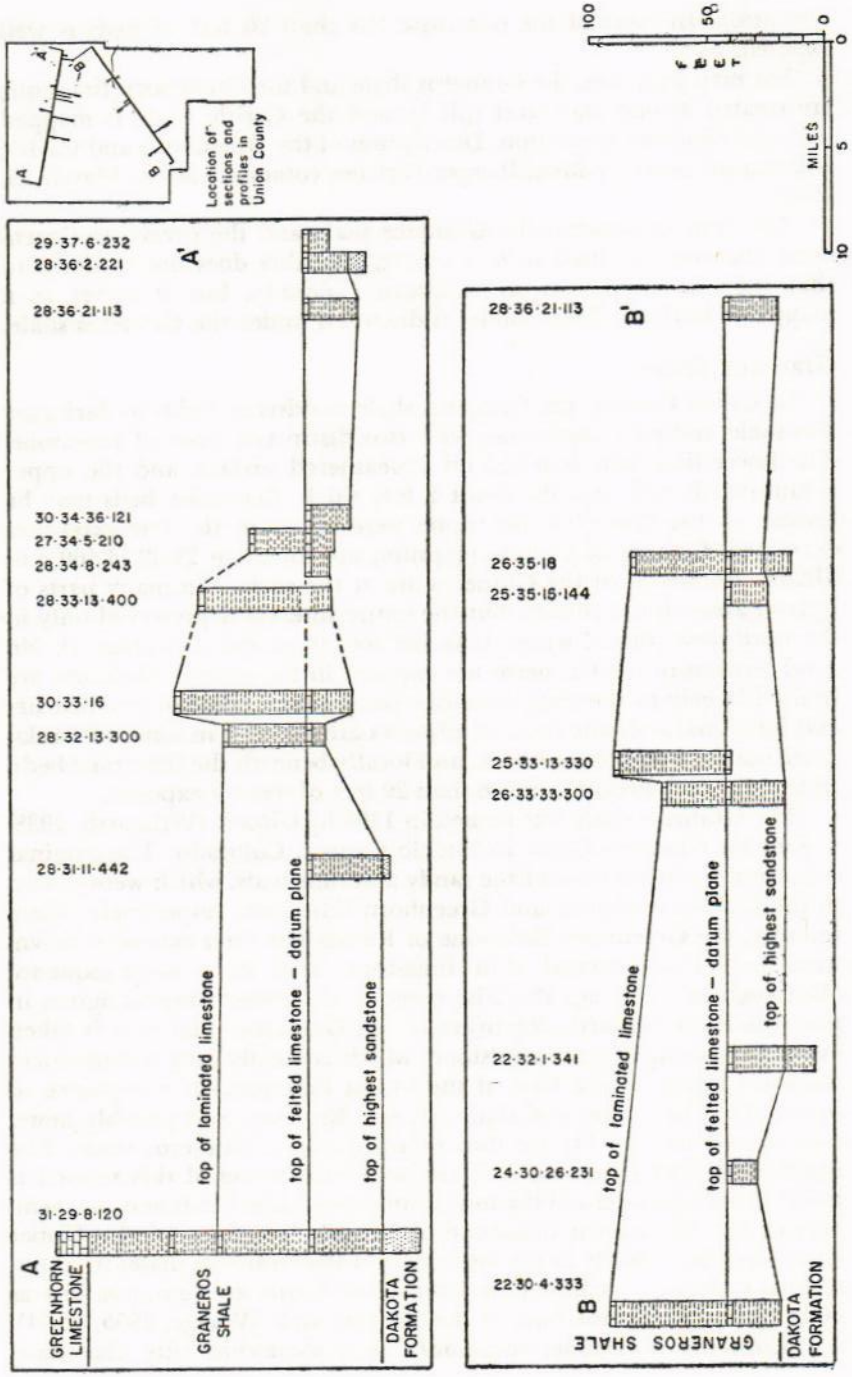


Figure 11

POSITION OF LIMESTONE BEDS IN THE GRANEROS SHALE forms all but a few feet of the Graneros shale. Colors range from light to dark gray, with some yellow-brown staining on weathered surfaces; the darker grays are most typical. The lower beds are generally not calcareous, but some beds just above or below the laminated limestone are very limy. Light-gray calcareous shale, with *Inoceramus,* crops out in Apache Canyon at 26.35.16.110 along New Mexico Highway 370, and again at 26.36.30.110. In a gully at 30.33.25.332, there is 5 feet of calcareous shale with *Inoceramus* and prints of a small cephalopod; these beds are possibly just above the laminated limestone. Slightly calcareous shale immediately above the felted limestone at 26.34.35.443 contains high-spired gastropods, a winged gastropod, fish scales, and *Inoceramus;* very limy shale forms the upper part of the cutbank and is probably not far below the laminated limestone.

Felted limestone. The felted limestone is about 2 feet thick and somewhat crossbedded in thin layers. Its position in the Graneros shale is shown in Figure 11. It is characterized by light gray-brown slabby float and by the felted appearance of weathered surfaces. Fucoidal markings are fairly common. The rock is composed of detrital grains of calcite and aragonite(?) (fig. 9). The latter is in the form of needles about 1 mm long, presumably derived from the destruction of shells of clams, such as *Inoceramus.* The insoluble residue of 3 samples amounts to 5, 8, and 18 percent, respectively, and consists of clay and very fine angular grains of quartz. Fragments of shells are present in places, but in most outcrops recognizable fossils are absent. Small oysters and clams are present at 25.35.15.144. The felted limestone crops out as the rim of a low bench in many parts of the county. In the southwestern part of the county, pickup trails commonly are on the gentle slope just below the bench but above the sharp gullies in the Dakota formation.

Carbonate needles are not entirely restricted to the felted limestone, however. Near Guy, at 30.33.25.144, the laminated limestone has carbonate needles, and at 30.33.16.200, along the road, there is more than one thin limestone with carbonate needles. Carbonate needles were noted also in the Niobrara along New Mexico Highway 72 west of Folsom, at the west edge of the county.

Laminated limestone. The upper persistent limestone of the Graneros shale is also only about 2 feet thick. It is characterized by light-gray color and by *its* laminations, which are best developed in the upper 1 or 2 inches of the limestone. Weathering produces an uneven upper surface that crosses the laminations; this gives a pronounced undulatory banding. Float is more blocky than float of the felted limestone. An insoluble residue of clay and very fine quartz grains forms 5 percent in each of two samples. Although generally unfossiliferous, the laminated limestone in places contains *Inoceramus* shells 4 inches in diameter. The laminated limestone is 35 to 70 feet above the base of the Graneros shale (fig. 11). It underlies low benches and stripped surfaces in a broad area in the north half of 22.30 and southwest quarter of 23.30, south of the headquarters of the Pasamonte ranch. It forms a knoll (26.35.18.211) in Apache Canyon 4 miles northwest of Clayton. It may be equivalent to the Lincoln limestone member, which is the lowest part of the Greenhorn limestone of Kansas.

Graneros-Dakota contact. The contact between the Graneros shale and the underlying Dakota formation has been taken as the top of the highest sandstone. In Des Moines quadrangle, Muehlberger placed the contact at a thin quartzitic siltstone that is just beneath the felted limestone and 30 feet above the highest sandstone (pl. 6B). The Graneros shale and the upper beds of the Dakota formation commonly are covered, and so the contact was mapped largely on float of the felted limestone and of sandstone. The Graneros was mapped only where float of the felted limestone was found; there are probably some areas where the Graneros is present but not mapped. Figure 11 illustrates the range in thickness from the top of the highest sandstone up to the felted limestone. The thickness ranges from 2 to 30 feet, but it is commonly 15 feet. The variations are more apparent than real, for in several sections the highest sandstone is less than a foot thick and is underlain by mudstone similar to that above the sandstone. The contact is actually transitional, and stray sandstones are to be expected. Nonetheless, for the purposes of this report, float of the limestone and of the highest sandstone are adequate to define the contact.

Greenhorn Limestone

The Greenhorn limestone was named in 1896 by Gilbert (Wilmarth, 1938, p. 870) for Greenhorn Creek and Station in Pueblo County, Colorado. It is recognized only in the northwest corner of Union County, although it may be present in the subsurface in the central and western parts of the county. It forms low cliffs and benches in the slopes below the high lava-capped mesas and buttes near Folsom. The Greenhorn there is 20 to 30 feet thick and consists of cream to light-tan limestone in beds 1 to 2 feet thick, with some thin beds of shale (pl. 2, section 1). *Inoceramus,* the only common fossil, is preserved as fragments and as complete shells. Outcrops are marked by the float of light-colored limestone and by numerous trees (p1. 6A, B). The base is taken as the base of the lowest limestone in a predominantly limestone sequence. Limestone beds of the underlying Graneros shale are only 1 to 3 inches thick and are subordinate in amount to the shale.

Carlile Shale

The Carlile shale was named in 1896 by Gilbert (Wilmarth, 1938, p. 347-348) for Carlile Station west of Pueblo, Colorado. It is recognized only in the northwest corner of Union County, where it is about 200 feet thick. The base is taken as the top of the highest limestone bed of the underlying Greenhorn limestone. The Carlile consists of black shale, with numerous thin limestone beds in the upper 30 feet. The upper 30 feet is exposed in a number of places; the lowest part of this interval has septarian concretions as much as 5 feet across, which are overlain by thin-bedded dark-gray to black limestone that contains ammonites, oysters, and clams.

NIOBRARA FORMATION

The Niobrara formation was named in 1862 by Meek and Hayden (Wilmarth, 1938, p. 1500) for Niobrara River in Nebraska. It is preserved beneath the high, lava-capped mesa and nearby buttes north of Folsom, in the northwest corner of Union County. The lower 40 to 50 feet is the Fort Hays limestone member, which is a cream to light-tan limestone that is almost devoid of fossils, except for a few *Inoceramus*. The limestone weathers into little blocky to angular pieces less than an inch on a side, in contrast to the slabs, 2 to 4 inches thick, of the dark-gray limestone in the upper part of the underlying Carlile shale. The most accessible outcrops are along New Mexico Highway 72 at the west boundary of Union County. The beds above the Fort Hays limestone are assigned to the Smoky Hill marl member, which is about 1,000 feet thick in Colfax County (Wood et al., 1953). The Smoky Hill marl member consists of black shale with a few thin limestone and marly beds; it is covered almost completely by landslides flanking the lava-capped mesas. The overlying Pierre shale probably is not preserved in Union County.

EARLY AND MIDDLE CENOZOIC EVENTS

Rocks of early and middle Cenozoic age are not found in Union County, but events of that part of geologic time can be inferred from studies of areas to the west, in and near the Sangre de Cristo Mountains.

The Late Cretaceous *sea,* in which were deposited the Benton group, Niobrara formation, and Pierre shale, began to drain off near the end of the Cretaceous period. Uplift in or west of the Sangre de Cristo Mountains area evidently began late in the Cretaceous period and continued to the end of the Eocene epoch of the Tertiary period. The nonmarine sediments of latest Cretaceous and early Tertiary age were derived from rocks in the uplifted area and were spread as littoral and continental deposits eastward toward, and perhaps into, Union County. Although the uplifting at first may have consisted largely of upwarping, it later involved intense folding and thrusting, which is dated as late Eocene. By the end of the Eocene epoch, the gross features of the eastern part of the Sangre de Cristo Mountains were outlined. Piedmont deposition east of those mountains continued until about the end of the Eocene epoch, after which the region was subjected to erosion by streams. This paragraph is based on a report by Johnson and Wood (1956).

The mild deformation of the Mesozoic rocks in Union County presumably occurred at the time of folding and thrusting in the mountains to the west.

In the Chico Hills area of eastern Colfax County (Wood et al., 1953), there are thick sills, presumably intruded in the early Cenozoic at the time of folding and thrusting in the mountains. These sills are estimated to be 300 to 500 feet thick, on the basis of divergence of structure contours on the Niobrara formation from those on the Dakota sandstone. The sills commonly intrude the Carlile shale and the Niobrara formation. They include gray-green porphyritic andesite, light-gray dacite, light-tan soda trachyte, and green phonolite. Previously (Collins, 1949), these rocks had been grouped with the Red Mountain dacite and had been considered to be late Cenozoic extrusive rocks (Wood et al., 1953).

East of the Sangre de Cristo Mountains, erosion during the Oligocene(?) and Miocene(?) epochs of the Tertiary produced a rolling plain—the Raton surface of Levings (1951, p. 59)—that sloped eastward and possibly southeastward. Local relief of this plain in the vicinity of Clayton is as much as 200 feet (Baldwin and Bushman, 1957a, fig. 6). In the area of Union County, streams removed most of the marine shales and exposed the Dakota formation. In some places, however, limestone beds served as protective caps for hills of the soft Graneros shale, whereas on the monoclinal warps streams cut down to the Morrison formation. In parts of the south panhandle, erosion exposed beds of the Dockum group.

UNITS OF LATE CENOZOIC AGE

From late Miocene into the Pliocene epoch of the Tertiary period, and indeed almost to the present, there was uplift of mountain blocks, forming the present-day mountains of north-central New Mexico. As a result of this mountain building, the Rio Grande structural trough was formed and was filled with sediments of the Santa Fe group eroded from the rising mountains (Baldwin, 1956; Kelley, 1952, 1956). The streams that drained the eastern flanks deposited an extensive blanket of upland deposits—clay, silt, sand, and gravel—east of the mountains. This material, mostly the Ogallala formation, was deposited at first in valleys and later, as valleys filled, across the hills of the mid-Cenozoic piedmont plain. As a result, the late Cenozoic sediments rest on different Mesozoic formations in different places. Volcanic activity probably began late in the Pliocene epoch and has continued almost to the present day; downcutting and the formation of local alluvial deposits have accompanied the volcanic activity.

Units of late Cenozoic age include both volcanic rocks and poorly consolidated sediments. The sediments include units mapped as upland deposits, terrace deposits, and alluvium; volcanic rocks include basalt flows and volcanic centers. Relationships between the upper Cenozoic units are suggested in Figure 13.

The bedrock contours shown in Figure 12 are drawn at the base of the upland deposits; in places, the bedrock surface that is contoured has

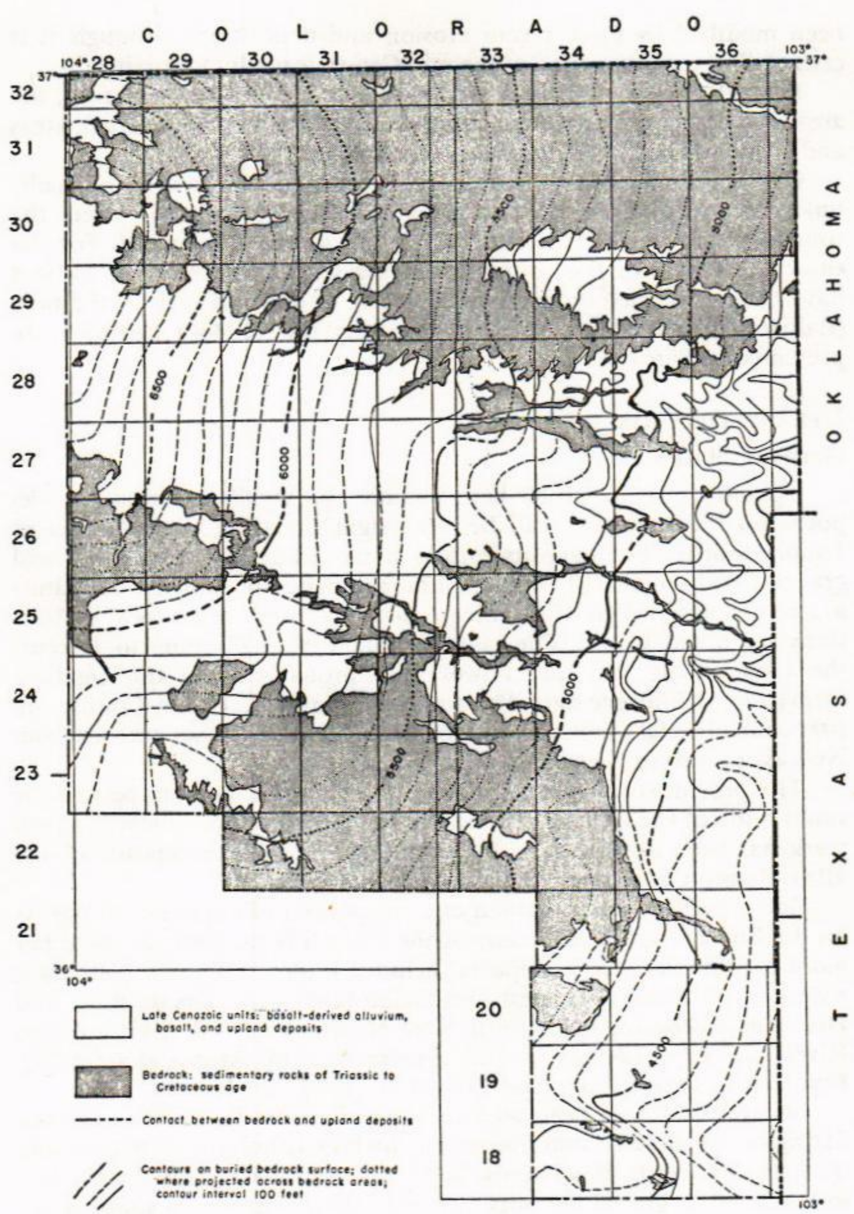


Figure 12

BURIED BEDROCK SURFACE OF UNION COUNTY

been modified by more recent erosion and deposition, although **it is** essentially a reconstruction of the mid-Cenozoic piedmont plain.

Figure 12 shows the limits of bedrock areas. In most instances, the areas of alluvium are ignored. Contours are dotted in the bedrock areas and are controlled by high points on bedrock.

Contours of the buried bedrock surface are dashed in areas of inadequate control and are solid in areas of adequate control. Where the contours have sharp bends, control points are closely spaced. For the east-central part of the county, contours with an interval of 50 feet have been published on maps with a scale of one-half inch to the mile (Baldwin and Bushman, 1957a), but only the 100-foot contours are presented in Figure 12.

UPLAND DEPOSITS

General Statement

Upland deposits, which here include the Ogallala formation, deposits on high terraces, caliche, and algal limestone, cover much of Union County. The deposits consist of tan sandy clay, silty sand, and gravel, locally cemented with calcium carbonate and caliche. The units are not subdivided on the geologic map, although some local distinctions are noted below. The deposits range from Pliocene to Recent; the bulk of the material, however, is probably from the Ogallala formation of Pliocene age. The upland deposits of Union County are part of an alluvial apron east of the Rocky Mountains that extends from Nebraska south to New Mexico and Texas.

The present study of Union County is not of a scope to permit the subdivision of the upland deposits. In the past 20 years, however, much work has been done on the Pliocene and Pleistocene deposits of the alluvial apron in adjacent States and areas.

Colbert (1948) was chairman of a symposium of a number of papers on the Pliocene and Pleistocene of the Great Plains. Some of the other more notable and recent reports include: Lugn (1939), for Nebraska; Evans and Meade (1944) and Van Siclen (1957), for Texas; Bretz and Horberg (1949a, b), for eastern New Mexico south of the Canadian River; and Frye (1945), Frye and Swineford (1946), Moore et al. (1951), Frye and Leonard (1952), and Frye et al. (1956), for Kansas.

Criteria that have been used in adjacent States for subdivision and dating of the Pliocene and Pleistocene include lithology, vertebrate and invertebrate fossils, fossil seeds, beds of volcanic ash, land forms, and soils related to glacial deposits. Many of these criteria are summarized by Frye et al. (1956).

The upland deposits of Union County generally are not exposed, for the material is poorly consolidated and is protected only by scattered lenses of caliche or by overlying basalt flows. The relatively few outcrops are found along steep gullies, in cutbanks and roadcuts, and beneath caliche-capped or lava-capped buttes and mesas. In few places is more than about 20 feet of beds exposed. Some of the better localities of outcrops of upland deposits include: 18.34.12.200, 19.35.34-36, 19.36.35.320, 21.35.13 (and generally along Tramperos Creek, east of New Mexico Highway 18), 22.35.7.400, 23.29.22 (and vicinity along Ute Creek), 24.33.12, 25.36.25.400, 25.36.35.410, 26.33.29.100, 27.29.30, 28.34.25.400, 28.36.22.100.

The base of the upland deposits is difficult to map accurately, particularly where the underlying formation is the easily eroded Graneros shale. In several parts of Union County, long covered slopes that are devoid of bedrock outcrops have been mapped as upland deposits. Two such slopes are found along Perico Creek, 6 miles west of Clayton. Bedrock exposures are limited to within about 30 feet above creek level. On the south side of the creek, the slope rises some 70 feet above the bedrock outcrops. On the north side, it rises 150 feet above bedrock outcrops along the creek, but two small outcrops of Dakota formation are mapped about 100 feet above creek level. Southwest of Mt. Dora, in the southwestern part of 26.32, long covered slopes below the lava-capped mesa are also mapped as upland deposits, although in fact a considerable part of the slopes may be underlain by Graneros shale.

In areas of extensive lava flows, it has been possible to outline at least some places underlain by upland deposits instead of lava. Such areas of upland deposits were recognized by the presence of gravel of Precambrian material and by the absence of pebbles and boulders of basalt. Some of these areas are west and southeast of Grenville and again west of Clayton Lake. The upland deposits are at about the same upper level as the basalt flows on either side, although faint drainage lines are formed along the borders in most cases.

The mapped extent of upland deposits beneath lava-capped mesas is somewhat generalized, because of talus from the lava flows, and because of their relative inaccessibility. Upland deposits, presumably of the Ogallala formation, underlie nearly all the older basalt flows in Union County. Upland deposits are absent, however, under the flow in 25.31.13-14 at the Snyder ranch and are absent beneath the western quarter of Black Mesa.

The upland deposits include streaks and lenses of gravel. The generalized distribution of gravel as shown in Plate 1 is based on notes incidental to field mapping of geologic contacts and, therefore, is somewhat incomplete. Pebble types include a variety of Precambrian rocks, locally derived sedimentary rocks, and Cenozoic volcanic rocks. The geographic distribution of the volcanic pebbles merits detailed study. Pebbles of basalt were noted in gravel at 15 localities north of the latitude of Seneca and east of Mt. Dora; some of the localities are remote from basalt flows. A pebble of basalt was found in gravel beneath the basalt-capped Black Mesa, and similar pebbles have been reported by Lee (1922) and Levings (1951). Pebbles of green volcanic rock with white feldspar phenocrysts were noted at 12 localities south of the latitude of Seneca and east of Grenville; some were noted in 26.35.25 just east of Clayton. The green pebbles probably were derived from the phonolite of the Chico Hills in eastern Colfax County. Volcanic rocks are present in gravel at many other localities, which, however, were not recorded in the course of mapping. Study of the source and distribution of pebbles of distinctive volcanic rocks should be of value in working out the late Cenozoic history of the region.

Ogallala Formation

The Ogallala was named in 1898 by Darton (Wilmarth, 1938, p. 15301532) for exposures near Ogallala in Keith County, Nebraska, and was dated as Miocene(?) and Pliocene. The Nebraska Geological Survey (Lugn, 1939) divides the Ogallala group into the Valentine, Ash Hollow, Sidney, and Kimball formations, in ascending order. The Kansas Geological Survey recognizes the Valentine, Ash Hollow, and Kimball members of the Ogallala formation (Moore et al., 1951). Both surveys date the Ogallala as Pliocene in age. In Texas, Pliocene deposits are placed in the Couch (older) or Bridwell formations (Van Siclen, 1957).

The Pliocene sediments were deposited on a stream-dissected surface, and so the older units are restricted to the ancient valleys, whereas the younger units were spread over the ancient hills and valleys alike. In Kansas, sediments at the level of or below beds of volcanic ash are locally cemented with opaline silica that has replaced calcium carbonate; the silica probably was derived by leaching of the ash (Frye and Swineford, 1946). Lithologies, which include clay, silt, sand, and gravel, are too variable to be diagnostic of one unit or another; fossils and ash beds are most useful in distinguishing the units. A caprock of "algal limestone" is considered by the Kansas Geological Survey to be the youngest unit of the Ogallala and to be of late Pliocene age; it was formed in a series of small depressions with a high water table (Frye, 1945; Swine-ford et al., 1958).

Most of the upland deposits of Union County belong to the Ogallala formation. The Ogallala of Union County is correlated with that of Kansas on such general features as topographic position, stratigraphic position, and lithologic similarity. It was deposited on a stream-dissected surface of moderate relief, as noted above, and consists of tan sandy clay, silt, sand, and gravel. Lithologies are discontinuous, and samples from two holes drilled only a few hundred yards apart are apt to be dissimilar. Sand and gravel most commonly are found near the base of the formation, particularly along pre-Ogallala valleys. The Ogallala formation ranges from 0 to about 400 feet in Union County. It is thickest along the east side of the county.

The sediments are partly to completely cemented with calcium carbonate, and beds of caliche several feet thick are common. However, the caliche of Union County is not considered here to be diagnostic of the Ogallala formation and is treated below as a chemical deposit somewhat independent of the Ogallala, even though much of it may have formed during deposition of the Ogallala.

Pleistocene Deposits

Late Pliocene warping of the piedmont region, which accompanied uplift of the mountains to the west, caused the end of deposition and the beginning of erosion. In Kansas, Pleistocene deposits are found as local bodies of sediments in basins and depressions and along ancient and modern streams, below the depositional surface of the alluvial apron. The complexity of Pleistocene stratigraphy in Kansas is shown by Frye and Leonard (1952, fig. 1).

Deposits on high terraces have been recognized in a few parts of Union County, and these may be of Pleistocene age. One such example is developed on the north side of Tramperos Creek, along New Mexico Highway 18. The upper surface is about 15 feet below the flat upland and extends 1.2 miles north of the creek. The deposits crop out in the bowl-shaped depression a mile northwest of the bridge over Tramperos Creek, along the highway north of the creek, and along the north side of the creek as far east as the horseshoe bend, a mile and a half east of the bridge. The sediments are poorly sorted and include blocks of Mesozoic sandstone.

A second example of a high-terrace deposit of possible Pleistocene age is found along Seneca Creek, from New Mexico Highway 18 east to the State line. That terrace is about 70 feet above the flood plain of Seneca Creek and 40 feet below the upland. It is about 2.3 miles in original total width at the highway and is best preserved north of the creek. Soil cover and sand dunes obscure the deposits beneath the high terrace. Gravels along Ute Creek and extending as far as Gladstone may also be of Pleistocene age. Near Gladstone, as much as 67 feet of "dirt" rests on malpais; the lava may be the same as that exposed in cliffs along Ute Creek farther to the southeast.

Muehlberger (pl. lb) mapped a number of terraces graded to the younger lava flows of the Folsom sequence of Clayton basalts. It is not known whether those terrace deposits are equivalent to the high-terrace deposits of Tramperos and Seneca Creeks, or whether they are instead equivalent to deposits of younger terraces.

Caliche and Algal Limestone

Caliche and algal (or pisolitic) limestone are characteristic features of the alluvial apron deposits. There is disagreement in published reports as to whether the banded calcium carbonate that is called "algal limestone" has stratigraphic significance.

Caliche is a calcareous hardpan that forms in arid or semiarid regions. Breazeale and Smith (1930) described the mechanism by which caliche could be formed by the evaporation of soil water, how the hardpan would migrate downward if the soil were eroded, and how the hardpan would build upward if more sediments were deposited on the surface. They also described the formation of caliche by organic action, by evaporation of pools of water, and by evaporation of near-surface water.

Algallike limestone is a prominent feature of the caliche caprock in many parts of Kansas, New Mexico, and Texas. It is about 3 feet thick and is composed of dense, finely banded limestone; the banding is commonly concentric to form bunlike masses. Swineford et al. (1958) have illustrated the characteristic features of the limestone.

The Kansas Geological Survey considers the pisolitic limestone to be a key bed—the youngest unit of the Ogallala formation—and to have been formed in the late Pliocene to early Pleistocene. Frye (1945) reviewed earlier reports and suggested that the limestone formed as the result of evaporation of small ponds that existed under conditions of a high water table on the surface of the alluvial apron.

Bretz and Horberg (1949b) made a careful and detailed study of various features of late Pliocene and Pleistocene caliche deposits. Caliche profiles that were studied on four distinct physiographic surfaces had similar features except for the thickness of caliche. The oldest profile is developed on the Ogallala formation and is considered to be late Pliocene and post-Ogallala in age. Brecciation and recementing of caliche is common in all four sets of caliche profiles and may be due to drying or to addition of calcium carbonate. The finely banded travertine that resembles the algal limestone of others was recognized in all four sets of profiles; it was considered to be inorganic in origin. After reviewing the many theories of the origin of caliche, Bretz and Horberg (1949b, p. 509) concluded that caliche is concentrated in the B-zone of a soil profile by evaporation of soil water, as a result of "alternating saturation and desiccation in a relatively dry climate with periodic rains."

Brown (1956) studied late Pliocene caliche. He concluded that thick deposits form as an accumulation in an aggrading soil profile and that successive layers of caliche reflect variations in climate. He described briefly the algallike banded caliche.

In Union County, lenses of caliche a few feet thick are common. Caliche is developed most commonly in the Ogallala formation; it is also formed directly on the Dakota formation and on basalt flows. For instance, caliche is present on the uplands northeast of Des Moines, in 30.30, although no Ogallala-like material is known and sandstones of the Dakota formation crop out not far below the upland surface. Caliche rimrock and a number of small buttes capped with caliche are found in many of the areas that are mapped as upland deposits.

In 28.31.20.400, northwest of Grenville, a caliche-capped bench is at the same level as the basalt flow just to the north. Levings (1951, fig. 17) illustrates this area with a stereopair of air photographs. He states incorrectly that the white rim of caliche shows clearly beneath the basalt that caps the mesa. His stereopair is a negative rather than a positive, and the white rim of the mesa is actually basalt talus. The caliche-capped bench shows as a black rim on the stereopair. Similarly, in his Figure 18, of Mt. Marcy (Malpie Mountain), the stereopair is a negative, and the white areas are areas of shadow and of exposed basalt, not caliche.

Stringers of opaline silica in caliche were noted as minor occurrences in six localities in Union County: 21.34.15.133, 21.36.34.210, 26.35.31. 214, 27.34.4.111, 28.32.24.140, 28.34.29.210. These are all in areas of upland deposits.

Caliche composed of bunlike masses of light-orange concentrically banded calcium carbonate, presumably equivalent to the algal limestone of Kansas, was noted at 14 localities in Union County:

23.28.6.444 (QTb?), 24.28.28.313 (QTb), 24.29.14.433 (Kd), 24.29.18. 434 (Qbal), 24.30.7.300 (Kd), 25.30.23.311 (QTb), 25.31.8 (QTb, along N. Mex. 120), 25.31.17.244 (Tu), 26.29.6.133 (Tu?), 26.29.24.133 (Tu?), 26.29.24.331 (Kd?), 26.31.17.111 (Qbal), 27.34.8.333 (Tu?), 28.32.27.333 (Tu). (The symbols, explained in pl. 1, indicate the underlying mapped formation.)

In addition, Levings (1951) reported algal limestone at 26.29.6, 28.31.35, and 28.33.18.

The algal limestone is developed locally on the Dakota formation and on basalt flows of possible Clayton age. Therefore, the algal limestone should be considered a lithologic unit by itself, rather than a part of the Ogallala formation, even though it is commonly coincident with the upper surface of the Ogallala.

VOLCANIC ROCKS

Volcanic rocks cover about 725 square miles of Union County, almost one-fifth of the entire county. The rocks consist of basaltic lava flows—commonly called "malpais"—and piles of cinders at volcanic centers, with only minor variations in composition. They are part of a larger volcanic province, which extends westward into Colfax County and northward into Colorado. Nonbasaltic rocks, largely alkaline, are found in Colfax County, as well as the basaltic units that extend into Union County. The volcanoes, some 80 of which have been mapped in Union County, were active intermittently from Pliocene(?) to Recent time, and there is no reason to believe that activity has finally ceased.

Classification of the volcanic rocks of northeastern New Mexico is summarized in Figure 13. The sequence of Lee and Mertie (Lee, 1922) of four periods of eruption was treated by Collins (1949) as the Capulin, Clayton, and two sets of Raton flows. In this report, it is suggested that much of the Clayton basalt of Collins may be equal to the younger of the Raton basalts, the second period of eruption of Lee and Mertie.

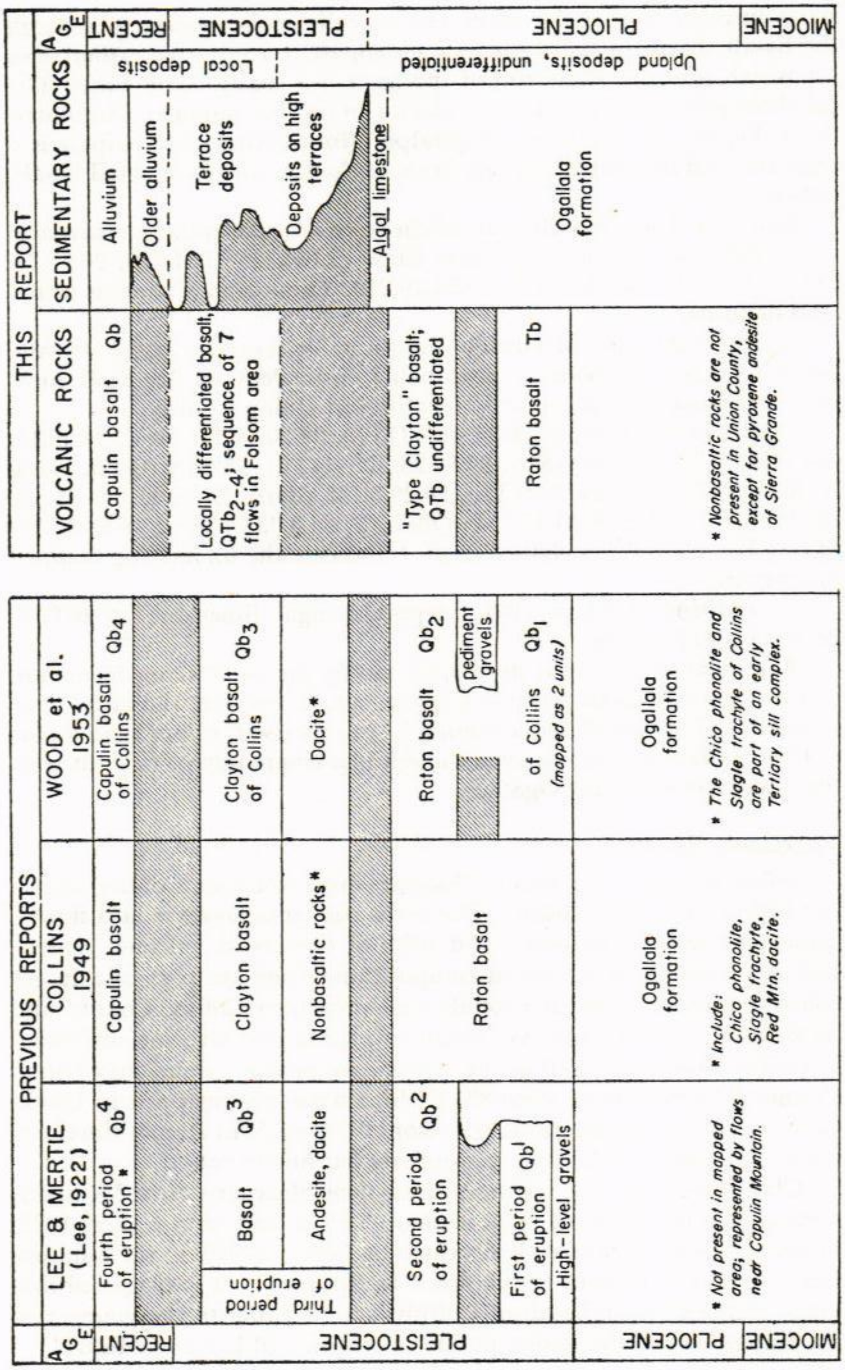


Figure 13

CLASSIFICATIONS OF LATE CENOZOIC UNITS IN NORTHEASTERN NEW MEXICO

Surface Expression

Morphologically, the volcanic rocks can be grouped into broad sheets, long narrow flows, cinder cones, and shield cones. These groups are essentially the same as those noted by Collins (1949, p. 1023-1024). Examples of the broad-sheet type are the vast lava-covered area west of Grenville, and the area south of Grenville. The long narrow flows are illustrated by the flow north of Carrizo Creek, the remnants south of Rafael Creek, the flow north of Corrumpa Creek, the basalt capping Black Mesa, and the recent flow from Baby Capulin Mountain down the Dry Cimarron River. Cinder cones, characterized by steep sides and an abundance of cinders, include many of the volcanic centers; Capulin Mountain is the best preserved. Shield volcanoes, which are composed largely of lava flows and which, therefore, rise at low angles, include Sierra Grande, Rabbit Ear Mesa, and (Cieneguilla del) Burro Mountain (locally known as Mt. Dora). The flanks of Sierra Grande rise at an angle of about 8 degrees.

The surface expression of the basalt flows and volcanic centers depends largely on how much their original features have been modified by erosion and weathering, and by deposition of windblown silt. Probably all the flows originally had a rough surface—the true "malpais"— characterized by pressure ridges and natural levees. These features can still be recognized in the most recent lava flows, such as those from Capulin Mountain and Baby Capulin Mountain. These flows have covered the broad flats and valleys of the present land surface and have scarcely been modified by geologic processes in the few thousand years since they were formed. Similarly, the most recent volcanoes are scarcely modified by erosion; Capulin Mountain has been set aside as a National Monument because it is such a perfect example of a cinder cone.

In contrast, the older flows, those of Clayton and Raton age, are considerably modified. They too were originally formed on the flats and in the valleys of a land surface, but streams subsequently have cut down into the bordering, less resistant rocks, leaving the flows on mesas and benches from 20 to 800 feet above the present valley floors. Their upper surface is smooth and grassed over, with only scattered outcrops of basalt. The basalt cliff that rims each basalt mesa represents only the lower part of the flow, for the ground rises beyond the cliff. Evidently, the more porous and broken basalt in the upper part of the flow has been weathered back from the margin, pressure ridges have been weathered down, and low places have been largely filled. Ditches for sewer lines in the town of Clayton have shown that the surface of the malpais is uneven, although the land surface is smooth.

Whereas the most recent volcanic centers are intact, the older volcanic centers are considerably modified by erosion. Rabbit Ear Mountain is a good example; the plate that slopes southwest on the southwest flank is all that remains of the outer surface of the original volcano.

Sierra Clayton is better preserved, although the crater has been breached by streams. On the other hand, some of the older volcanoes are nearly destroyed by erosion, and these have been recognized as volcanic centers only because they stand somewhat above the surrounding land and because loose cinders are found in the vicinity. The volcanic centers in Union County are associated with Capulin and Clayton basalt flows; none are known to be of Raton age.

The craters of many volcanoes open to the southwest or west. This breaching of the craters, indicated by the hachuring of the centers in Plate 1, suggests that when the volcanoes were active, the prevailing winds were from the southwest or west, and the cinders tended to accumulate on the opposite flank.

Distribution

The writer's mapping of the basalt flows was directed primarily toward outlining the areas underlain by basalt. The distribution of basalt was generally obvious and was readily mapped for most of the county. There are three situations, however, where the distribution was not so obvious.

Within the limits of those broad upland areas that seem to be underlain by a continuous sheet of basalt, there are actually "islands" of upland deposits, where a well could be drilled without encountering basalt. The islands are topographically inconspicuous because erosion has not proceeded far enough to etch out the limits of the flows. There may be many more such areas of upland deposits than are shown in Plate 1. In fact, much of the broad-sheet type of basalt may consist of long narrow flows separated by narrow ridges or islands of upland deposits.

An example of such an island is the area in and near 27.33.12, on Rabbit Ear Mesa, west of Clayton Lake. That area is covered with gravel of Precambrian pebbles, but no outcrops or loose pieces of basalt are found in the area. The margins of the ancient ridge or island are mapped along minor drainage lines, for streams tend to develop initially at the margins of resistant basalt flows. Other examples can be found within the limits of the basalt-capped upland near Grenville; well 27.32.8.143 was drilled in such an area, and its log (appendix) shows that basalt is absent.

On the other hand, there are also areas in Union County where basalt is not present at the surface but is present at depths as great as 67 feet. One such area is south of Clayton in 24.36.19 and adjacent sections (pl. 1), where several drill holes encountered basalt beneath 20 to 40 feet of upland deposits. Another is in the vicinity of Gladstone, where several wells are reported to have encountered basalt at depths of 20 to 67 feet. The source and limits of this basalt are not known, and so no indication of basalt at depth is given in Plate 1. It is probably continuous, however, with the basalt that crops out in places along the west side of Ute Creek Canyon, southeast of Gladstone.

Basalt-derived alluvium. The third situation where the distribution of basalt is not obvious is an area where no outcrops of basalt are seen, but where the surface is mantled with cinders and with fragments of basalt. This type of area is mapped as basalt-derived alluvium; the alluvium was washed down from nearby volcanic centers or flows. Basalt-derived alluvium masks the extent and position of basalt flows, and some areas mapped as basalt-derived alluvium may not be underlain by flows. A water well that is drilled in such an area may or may not encounter solid basalt, but it probably will encounter cinders and boulders of basalt.

Basalt-derived alluvium occurs on the west, north, and east sides of Sierra Grande and thus obscures the relationships between Sierra Grande and lava exposed near Sierra Grande. It is also found in the volcanic area southwest of Gladstone and again in the vicinity of the Don Carlos Hills. The well at 25.29.4.333, north of the Don Carlos Hills, was reportedly dug through 40 feet of basalt-derived alluvium into 20 feet of thin-bedded sandstone and shale of the Dakota formation. This well has since filled in.

Subdivisions

The basalt flows mapped by the writer were subdivided (pl. 1) on the basis of topographic position. The extensive sheets and tongues of basalt that are labeled "Clayton basalt, undifferentiated" are possibly equivalent to the second period of eruption as designated by Lee and Mertie (Lee, 1922). Locally, some flows could be differentiated from the main mass of basalt, and these may be more truly representative of the third period of eruption of Lee and Mertie.

The Raton, Clayton, and Capulin basalts of Collins are shown in Plate 1 by the use of solid, medium, and thin red lines, respectively. Subdivisions of the Clayton and Capulin units are indicated in a less distinct way by orientation of the lines, as noted in the explanations for Plate 1.

A fourfold subdivision of the basalt was established in the Don Carlos Hills by reconnaissance methods. The Don Carlos Hills are a series of volcanic centers alined in a west-northwest direction and surrounded by a platform of basalt. The oldest basalt, tentatively called Raton basalt (Tb of pl. 1), caps a cliff that forms the south side of the hills; the top of the cliff is nearly 500 feet above U. S. Highway 56, which is 3 miles to the south. Five points of altitude were determined for the base of the oldest basalt; these suggest that the base slopes south-southeast about 70 feet per mile. The oldest basalt is characterized by phenocrysts of augite that are readily visible. A younger basalt (QTb of pl. 1) issued from the northeast end of the hills and flowed south around the east end of the hills. This basalt, which does not contain prominent phenocrysts of augite, stands about 50 feet above the creek to the east and forms the low mesa just west of the Pasamonte ranch. The youngest basalt (QTb_2 of pl. 1) is found largely in the west half of the Don Carlos Hills and forms some of the higher parts of the hills. This basalt flowed down over the scarp of the oldest basalt (25.29.28.300). Although it is cut by gullies, the youngest basalt (QTb_2) has rounded rather than cliffed margins and on this basis is distinguished from the younger basalt (QTb). It does not have prominent phenocrysts of augite. The fourth subdivision, QTb_3, is reserved for minor local flows that appear to be younger than the QTb_2 flows.

LOCAL SURFACE DEPOSITS

TERRACE DEPOSITS

Terrace deposits have been mapped in places, particularly along Tramperos, Seneca, and Corrumpa Creeks. Muehlberger (oral communication, June 7, 1958) has demonstrated that some of the terrace deposits of the Folsom area are graded to several of the younger flows in the Clayton sequence. The terrace deposits are probably Pleistocene in age, though some might be Recent.

ALLUVIUM

Alluvium has been mapped (pl. 1) along the main streams. The alluvium locally includes slope-wash material, and along minor streams alluvium is shown as covered areas. The older, calichified alluvium is a unit recognized by Muehlberger (1955) in the Folsom area; it contains the artifacts of the Folsom Man site and underlies a flow from Capulin Mountain. Younger alluvium in that area is dark and rich in humus, and has been dated (Muehlberger, 1955) as about 2400 B. C.; it rests on top of a flow from Capulin Mountain.

LANDSLIDES

In areas of abrupt relief, particularly in the western part of the Dry Cimarron River valley and on the flanks of the older lava-capped mesas, landslides obscure the bedrock units. The larger landslide areas are indicated on the geologic map (pl. 1), although geologic contacts at the margins of the landslides are omitted.

COVER

Some attempt has been made to show the areas where bedrock is covered by slope wash, particularly along the Dry Cimarron River valley. Contacts at the margins of the covered areas are omitted. In addition, many areas shown as upland deposits may in fact be areas where a bedrock unit of soft shale, such as the Graneros shale, is covered by slope wash.

AGE AND CORRELATION OF LATE CENOZOIC UNITS

Classifications of late Cenozoic sedimentary and volcanic units in northeastern New Mexico are summarized in Figure 13. Lee and Mertie (Lee, 1922) indicated evidence for four periods of eruption of basalt, separated by intervals of erosion. Dacite and basaltic andesite were erupted during or before the third period of basalt eruption. Collins (1949) gave the name Raton to basalt of the first and second periods of eruption, and gave the name Clayton to basalt of the third period and Capulin to that of the fourth. Wood et al. (1953) combined the subdivisions of Lee and Mertie with those of Collins and stated that some of the nonbasaltic rocks which Collins had placed in the third period of eruption were in fact sills of early Tertiary age. Muehlberger (1955) demonstrated that "Capulin Mountain erupted between 8000 B. C. and 2400 B. C."

In the present report, the following suggestions are offered: (1) The type Clayton basalt, which was named for "the outcrops on the large Folsom-Clayton Mesa near Clayton, New Mexico" (Collins, 1949, p. 1023), may in fact have formed during the second period of eruption; (2) the Sierra Grande region may have been upwarped in late Ogallala time, before or during the early stages of basaltic eruption; and (3) the Pleistocene age of the older basalts is questioned.

DISTINCTION BETWEEN CLAYTON AND RATON BASALT

The basalt flows of Union County were mapped (pl. 1) according to the subdivisions of Collins (1949). It now appears, however, that the bulk of the Clayton basalt, undifferentiated, could have formed during the second period of eruption. According to Muehlberger (oral communication, August 28, 1954), the base of the older Raton basalt flows, as projected southeastward beyond Des Moines, is nearly coincident with the base of the basalt east of Sierra Grande; it is possible, therefore, that the base of the younger Raton basalt (which in Lee's area is somewhat lower in elevation than the older Raton basalt) does coincide with the basalt east of Sierra Grande. Muehlberger's sequence of Clayton basalt in the Folsom area, and the differentiated flows ($QTb_{2, 3, 4}$) of the Folsom-Clayton Mesa (pl. 1), may be more properly representative of the third period. However, direct correlation between the basalts of the Folsom area and basalts east of Sierra Grande is not now possible.

It must be emphasized that subdivision of the basalt flows is based primarily on surface expression, such as topographic relief. Although Collins (1949) and Stobbe (1949) recognized minor differences in the mineralogy between their Clayton and Raton basalts, they imply (e.g., Stobbe, 1949, p. 1051) that petrographic characteristics of the basalts are not diagnostic of one or the other group. Paleomagnetic characteristics of each group of basalt flows have not yet been clearly established

(Muehlberger and Baldwin, 1957, 1958), although this approach, upon refinement, might be of future value.

Relative topographic relief is of real value in a limited area. A classic example is that described by Lee (1912, p. 359; quoted in Levings, 1951, p. 34) for the area northeast of Folsom. There, the high mesas are capped with older Raton basalt that is some 800 feet above the valley floor. Basalt from Emery Peak—the oldest basalt in Muehlberger's sequence of 7 Clayton basalt flows—has flowed down over the Raton basalt and is now preserved as remnants on mesas nearly 200 feet above the valley floor. A flow from Baby Capulin occurs in the stream bottom of the Dry Cimarron River. Thus, three separate times of basalt eruption can be established northeast of Folsom, in the vicinity of Tollgate.

But even the criterion of relative topographic relief has its limitations. The basalt underlying the town of Clayton stands about 150 feet above the floor of Apache Canyon. Apache Canyon, however, is not being eroded by a master stream, and so the relief here should not be compared with the 200 feet of erosion by the Dry Cimarron River since eruption of the Emery Peak basalt. The amount of erosion depends not only on time, but also on the rate of erosion, which in turn depends on the size of the stream.

The subdivisions of Lee and Mertie (Lee, 1922) and of Collins (1949) imply that volcanism in the region was periodic: there were times of widespread volcanism separated by times of erosion with no volcanism.

There is a good possibility, however, that volcanic activity was essentially continuous in the region but that the locus of volcanism shifted, so that in any particular area the volcanism appears to have been periodic. Although near Tollgate there was about 200 feet of down-cutting between the Emery Peak flow and the Baby Capulin flow, there is a less obvious erosional break in the Folsom area between the youngest flow of Clayton age and the oldest flow of Capulin age.

POSSIBLE LATE OGALLALA UPWARPING

Directions of the streams in western Union County may have been changed in late Ogallala time. Green pebbles occur in Ogallala gravel near and north of Clayton, due east of their probable source, the Chico phonolite of the Chico Hills in eastern Colfax County. Thus, the pebbles evidently were moved by eastward draining streams in Ogallala time. However, the present drainage pattern of the region radiates southeastward toward the Canadian River, eastward along the North Canadian and Dry Cimarron Rivers, and northeastward toward the Arkansas River (fig. 1). Smith (1940, p. 80-94, fig. 9) noted semiradial drainage north of the Arkansas River and suggested post-Ogallala warping east of the mountains.

The radiating drainage in Union County evidently was established before extrusion of the long narrow flows that are parallel to Carrizo Creek, Apache Canyon, Seneca Creek, and Corrumpa Creek. The radiating drainage is here interpreted as the result of uplift along, or west of, the Sierra Grande arch in late Ogallala time, possibly during the eruption of the older Raton basalt. Indeed the warping may have triggered the volcanic activity.

Stream gradients, and therefore amounts of erosion, were probably greater in western Union County than in eastern Union County. It is also possible that during uplift and erosion on or west of the Sierra Grande arch, there was continued deposition of the Ogallala formation in eastern Union County, because the eastern end of the Carrizo flow is buried beneath as much as 40 feet of Ogallala-like material.

PLIOCENE-PLEISTOCENE BOUNDARY

The Pliocene-Pleistocene boundary, which has been placed by others at the beginning of volcanic activity, is here arbitrarily placed between the second and third periods of eruption. Evidence regarding the position of the time boundary is ambiguous and is not opposed to the arbitrary placement followed here.

The inferred Pliocene age for the long narrow flows, such as that on the north side of Carrizo Creek, is suggested by the occurrence of algal limestone on some of these flows. The stratigraphic value of the so-called algal limestone is debatable, as noted earlier in the report, but if the algal limestone of these occurrences is stratigraphically equivalent to that of Kansas, as is possible, the flows are Pliocene in age.

In previous reports, the Quaternary age of the basalts is based on two items: First, the older Raton basalt rests on gravels that are correlated with the Ogallala formation, which is of Pliocene age in Kansas. Second, the older Raton basalt forms the caprock of mesas ranging from nearly 1,000 feet above the present valleys to more than 2,000 feet above. This, according to Lee (1922, p. 13), is no more than the downcutting below Pleistocene glacial deposits in mountainous parts of Colorado and Montana.

The above reasoning is weak. In the first place, the fact that the older Raton basalt rests on Pliocene deposits does not rule out the possibility that the basalt is Pliocene too. In the second place, the large amount of Pleistocene erosion in Colorado does not indicate per se the same amount of Pleistocene erosion in New Mexico.

In summary, the basis for distinguishing the type Clayton basalt from Raton basalt is questioned in this report, even though they may have been formed in distinctly different periods of eruption. The placing of the Pliocene-Pleistocene boundary at the base of the Raton basalt is also questioned.

Structure

REGIONAL STRUCTURE

Oil tests are too scattered in and adjacent to Union County to permit the accurate delineation of arches, domes, and basins, but the approximate positions of the axes of the major structural elements are shown in Figure 1. The location of the features is taken from several published reports, including one by Roth (1949).

Most of Union County lies between the axis of the Sierra Grande arch on the west and the axis of the Dalhart basin on the east. As Foster has indicated (fig. 5), the Paleozoic units wedge out westward toward the arch. The Dalhart basin may extend westward into Union County.

STRUCTURAL FEATURES OF UNION COUNTY

Structural features of Union County are modest, for the bedrock formations are essentially flat lying, with a regional dip to the east of about 30 feet to the mile. However, the regional dip is interrupted and steepened locally by monoclinal and anticlinal warps. Some minor faulting is recognized, and alinement of volcanic centers indicates the presence of one or more sets of late Cenozoic fractures in the earth's crust. Pre-Jurassic folding was long ago (Lee, 1902) recognized along the Dry Cimarron River valley. The principal post-Cretaceous structural features of Union County are summarized in Figure 14.

PRE-OGALLALA STRUCTURE

Pre-Exeter Folding

In the Dry Cimarron River valley area, the Triassic Dockum group was folded and eroded before deposition of the Jurassic Exeter sandstone. The classic example is illustrated by Battleship Mountain (Lee, 1902, fig. 4), where the Exeter rests on tilted beds of the Travesser formation (fig. 10; pl. 3A). This pre-Exeter anticline has more than 200 feet of structural relief, for the Sheep Pen sandstone, the Sloan Canyon formation, and part of the Travesser formation have been removed from its crest. No attempt was made in this study to map the structure of the Dockum group, other than to show the distribution of the Sheep Pen-Sloan Canyon map unit. Pre-Exeter folding can be seen as far west as 31.32 but has not been recognized south of the Dry Cimarron River valley.

Structure Contours

The reliability of the structure contours in Figure 14 varies in different parts of Union County, as suggested by the use of solid and dashed lines. In areas of upland deposits or basalt flows, the contours are con-

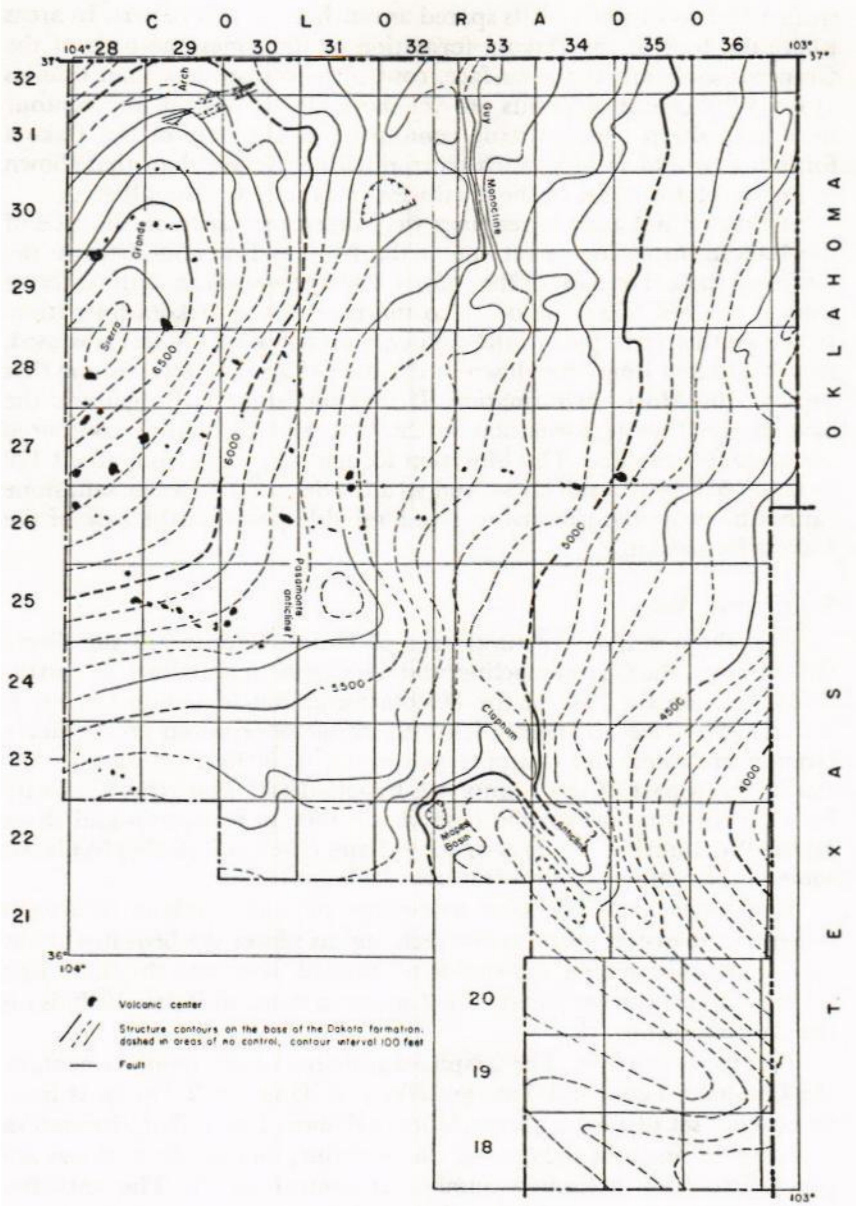


Figure 14

STRUCTURAL FEATURES OF UNION COUNTY

trolled by logs of water wells spaced as much as 12 miles apart. In areas where the base of the Dakota formation or the limestone beds of the Graneros shale are at the surface, control points are less than 6 miles apart. Where control points are yet more closely spaced, the contour lines have sharp bends; a true contouring of the base of the Dakota formation would yield a much more intricate picture than that shown in Figure 14. Contours in the northwest corner are by Muehlberger.

Altimeter and alidade readings were taken primarily on the base of the Dakota formation or on one of the two key limestone beds in the Graneros shale. For most of the county, 200 feet was taken as the interval from the felted limestone down to the base of the Dakota formation. In the southwestern part of the county, an interval of 170 feet was used, from the felted limestone down to the base of a massive sandstone that rests on the Morrison formation. If that sandstone is Purgatoire, the base of the Dakota formation in 22.30-31 and 23.30-31 is contoured about 40 feet too low. The Morrison formation ranges from about 170 to about 550 feet in thickness, and so altitudes on the Exeter sandstone cannot be projected upward to give a reliable point on the base of the Dakota formation.

Structural Axes

The three major structural axes of Union County are the Sierra Grande arch, the Guy monocline, and the Clapham anticline. The structural relief on the base of the Dakota formation in Union County is shown as 2,800 feet in Figure 14, but the 6,700-foot contour on the Sierra Grande arch and the contours below the 4,300-foot contour in the southeastern part of the county are hypothetical. The gross similarity between the contours on the base of the Dakota formation and those on the Precambrian (fig. 3) is striking. Bates (1942, p. 155-158) has listed some of the main structural features of Union County.

Guy monocline. The Guy monocline steps the Dakota formation down on the east as much as 400 feet, and in places the beds dip about 10 degrees. The monocline trends northward, but near the State line it turns toward the northeast. The Cimarron dome of Bates (1942) is on the Guy monocline.

Clapham anticline. The Clapham anticline of this report consists of the Clapham, Leon, and Tate anticlines of Bates (1942, fig. 9). It is an en echelon set of two or three elongate domes. The Dakota formation is eroded in much of the area of the anticline, and so the contours are generalized from a limited number of control points. The anticline merges southeastward with another anticline that is somewhat hypothetical. In the field, the dip on the northeast flank of the Clapham anticline is more conspicuous than that on the southwest flank.

Minor structures. The syncline southwest of the Clapham anticline is not clearly defined by control points, but the Mapes basin, in the northeastern part of 22.32, is recognizable in the field because of the pocket of Graneros shale preserved in it. The basin is on the south side of a monocline that has stepped the Dakota formation down about 200 feet from the upland to the north. The monocline may be an eastern extension of the one in the southern part of 23.31.

The approximate position of the Pasamonte anticline of Bates (1942, p. 157) is shown in Figure 14 by lettering. The dashed contours of the figure do not suggest an anticline, but they are controlled by very few points in that area.

The Cimarron Valley anticline of Bates (1942, p. 157) is reported to be in 31.36; it is not indicated by the structure contours of Figure 14.

Minor Faulting

Minor normal faulting of bedrock formations is fairly common in Union County, though it is difficult to map. Muehlberger (pl. lb) has mapped a number of normal faults that trend east-northeast from 31.29; the faults have a throw of about 40 feet, and several of them outline grabens. A fault with a throw of about 20 feet was mapped in 30.31. A fault is prominently displayed in the Exeter sandstone at 32.35.32.211 pl. 4B); it has reportedly been traced southward for 8 miles (Oklahoma City Geological Society, 1956, p. 27). Other faults have been recognized in single outcrops but could not be traced any distance. In general, the bedrock formations have been warped rather than faulted.

LATE CENOZOIC STRUCTURES

Alinement of Volcanic Centers

The volcanic centers in Union County are clearly set in lines, indicating that they are located on fractures. The main trend of the fractures is northwest to west-northwest; the Rabbit Ear Mountain set of centers, the Burro Mountain set, the Don Carlos Hills set, and the set in the southwest corner of the county are good examples. There is some suggestion of an echelon pattern of the sets. However, a northeast trend may also be recognized. A possible example of this is the set of centers from Capulin Mountain to Emery Peak. Many of the centers appear to be located at the intersection of fractures in the main set with other fractures in a minor set.

Late Ogallala Warping

Possible late Ogallala warping has been suggested above because of the discrepancy between present drainage directions on the one hand and distribution of pebbles in relation to their inferred sources on the other. It is possible, on the basis of the limited evidence, that the Sierra Grande arch and Chico Hills areas were uplifted late in Ogallala time, and that this uplift caused the tension fractures that have given rise to the sets of volcanic centers. The upper reaches of the Canadian River

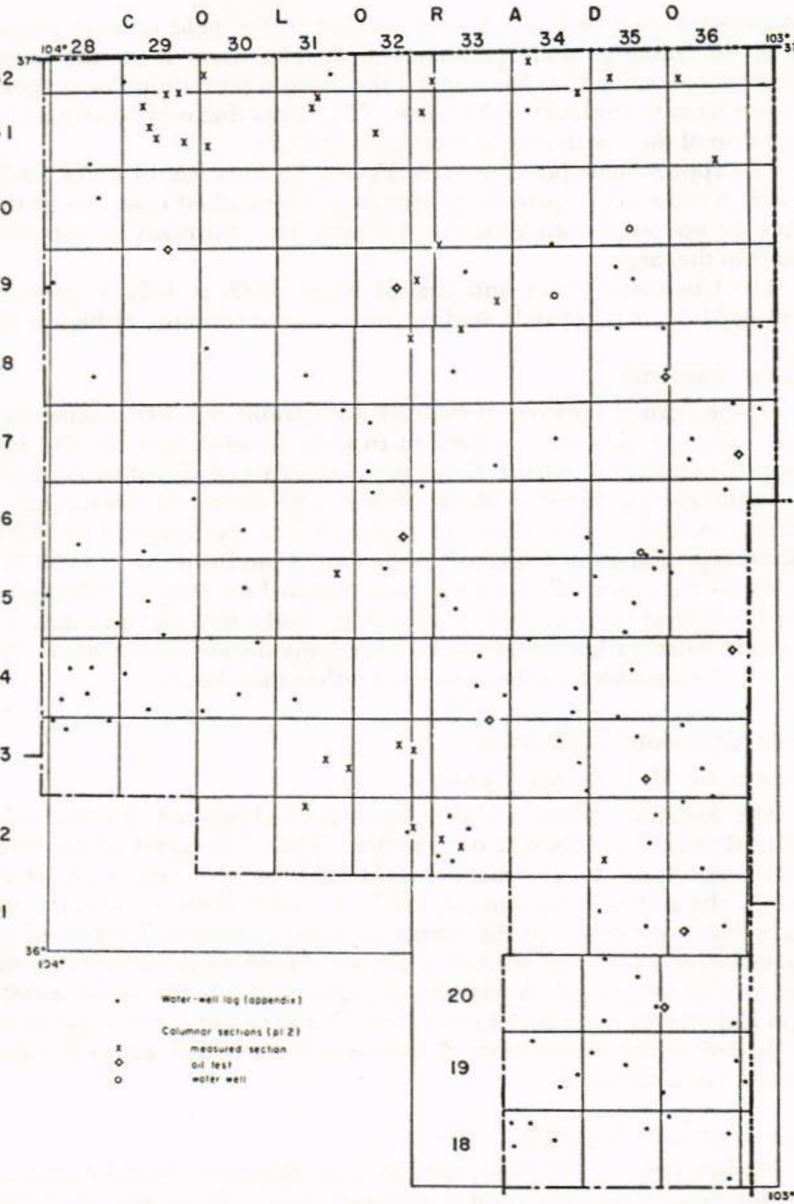


Figure 15

INDEX MAP OF STRATIGRAPHIC SECTIONS IN UNION COUNTY have beheaded the eastward drainage (Sellards et al., 1932, fig. 51); the beheading may have resulted from such an upwarping as is here inferred.

AGE

The warping of the bedrock formations, shown by structure contours, is probably of Laramide age—latest Mesozoic and early Cenozoic. There are suggestions that the structural elements may also have been positive areas before the Late Cretaceous. Foster has summarized above the geology of the pre-Mesozoic formations; his maps indicate that the Sierra Grande arch was a positive area in the late Paleozoic and perhaps through much of the Paleozoic era. At 31.29.21.400 (pl. 2, section 3), on the axis of the arch, the Dakota formation has only half its normal thickness, and so the arch may have been a positive element through the Cretaceous. The Guy monocline may have been an active area in the Triassic, for the Travesser formation has only half its normal thickness at 31.32.12.240 (pl. 2, section 11). About 10 miles to the east, in several parts of 31.34, the Exeter sandstone is thin to absent, though it is about 30 feet thick on the monocline. The Clapham anticline may have been an active element from late in the Jurassic period to the middle of the Cretaceous, for the upper part of the Morrison formation consists of sandstone, and the Purgatoire formation is thin or absent. The normal faults may also be of Laramide age, for those in 31.28-29 cut units as young as the Niobrara formation of Late Cretaceous age but apparently do not cut the Raton basalt.

The fractures that gave rise to the eruption of lava were active during much of the late Cenozoic. Muehlberger (pl. lb) has shown that lava of both Clayton and Capulin age issued from centers that are in line. For example, Gaylord Mountain and one of the Augite Vents, both of Clayton age, are in line with Purvine Hills, Twin Mountain, and Baby Capulin Mountain, all of Capulin age.

Economic Geology

Certain mineral and rock deposits of Union County have been, are, or might be, of value. Deposits of scoria, gravel, and clay appear to offer the most reasonable chance for economic use.

The distance of Union County from possible market areas means that the cost of transportation will be an important factor in determining the success of developing mineral deposits. The possible market areas for clay have been outlined (Glassmire, 1957); the same market areas would supply the potential demand for other commodities.

Field study and laboratory testing of individual deposits are needed before there is any mining. No such study or testing has been made in connection with the present report. The following notes, however, are intended to draw attention to some of the materials and individual deposits that have possible value. The particular deposits that are mentioned are not necessarily the best of each type; they are merely the ones that the writer noted in the course of field mapping.

CALICHE

Caliche has been used in many parts of Union County as road metal. The occurrence of caliche in the county is summarized above (p. 69-71). No attempt was made to map the areas underlain by caliche.

CARBON DIOXIDE

(by Roy W. Foster)

Carbon dioxide gas was discovered in Union County in 1935 in the Sierra Grande No. 1 Rogers test. The well was abandoned after encountering a reported 1 million cubic feet of gas at a depth of 2,245 feet in the Sangre de Cristo formation. The gas contained 98.6 percent carbon dioxide. From 1952 to 1955, four additional wells were drilled in the Des Moines area of Union County. Carbon dioxide gas was found in all these tests, with potentials ranging up to 488,000 cubic feet. Zones containing gas included the Whitehorse, Yeso, and Sangre de Cristo formations. The Des Moines field is not being exploited at the present time (1959).

Carbon dioxide gas has been reported from the Mississippian in the Skelly No. 1 Van Pelt test to the east of the Des Moines area.

CLAY

Considerable local interest in Union County has been aroused in the possibility of developing clay deposits for commercial use. This interest is due to two factors. First, the Clayton High School has long had an active ceramics department, which has successfully used local clays in the production of slip-cast novelty ware. Second, a deposit of white kaolin northeast of Amistad has been examined recently by a major clay-producing company.

The writer and Robert H. Weber, also of the New Mexico Bureau of Mines and Mineral Resources, visited several outcrops of clay in eastern Union County in 1957. The following notes are based on this reconnaissance and on the writer's general experience with the geology of the county.

CLAY ON THE WARREN THOMAS RANCH

About 22 feet of laminated white clay is exposed in a gully tributary to Gavalon Canyon (21.36.33.330), northeast of Amistad. The clay is being used at Clayton High School for ceramic glazes.

The clay appears to lie in a pocket, possibly a channel, in the Dakota formation. It probably rests on the basal sandstone, which strikes N. 60° E. and dips 5 degrees southeast. It is overlain by thin-bedded sandstone, which strikes N. 35° E. and dips 5 degrees southeast. The dip in the basal sandstone may be large-scale crossbedding. In one place, the clay has minor folds and is in vertical contact with a vertically oriented block of sandstone; the clay also fills a crack in the sandstone block. In one part of the outcrop, the dip of the lamination in the clay changes from 45° E. to 12° NE. within a distance of 5 feet.

The deposit was known by Mr. Thomas for nearly 30 years, but no attempt was made to develop it until about 10 years ago. In 1948, a sample of clay near Amistad, presumably from this deposit, was sent to the New Mexico Bureau of Mines. R. A. Matuszeski, analyst, reported the following analysis:

	PERCENT
Silica ($Si0_2$)	40.83
Alumina ($A1_20_,$)	36.96
Iron oxide (Fe_20_3)	trace
Calcium oxide (Ca0)	1.58
Magnesia (Mg0)	trace
Loss on ignition	20.37
	99.74

In 1953, a sample collected by the writer was determined by X-ray at the New Mexico Bureau of Mines to be halloysite, one of the kaolin minerals. Also in 1953, another sample collected by the writer was determined by the Aluminum Company of America to contain about 48.5 percent alumina, the material being identified as a mixture of gibbsite and kaolin.

In 1954, the deposit was explored by 10 test holes drilled for the Filtrol Corporation. One of the holes encountered about 20 feet of white clay and several encountered no clay; most of the holes found only a few feet of clay. Drilling extended to 800 feet north of the outcrop, though most of the holes were within 300 feet. The deposit was estimated to contain less than 5,000 tons of clay.

The halloysite deposit may be similar in origin and occurrence to those of south-central Colorado (Waage, 1953), which are ascribed to weathering during a hiatus in deposition of the Dakota group. Although the halloysite deposit was partially stripped by bulldozing in 1957, the critical contacts were not exposed, and so the shape and occurrence of the clay deposit are uncertain. Similar deposits might be found in the Dakota group in other parts of the county.

CLAYTON HIGH SCHOOL CLAY

Slip clay used by the ceramics department of the Clayton High School is obtained from a small pit on New Mexico Highway 18 (29.36.35.331), just south of the bridge across Corrumpa Creek. The pit is at the top of the north end of the roadcut, on the east side of the highway. The bed is nearly 3 feet thick, but it changes character a hundred feet to the south of the pit, and there is appreciable overburden just south of the pit. The supply is adequate for present purposes but is not adequate for large-scale production.

The clay is a calcareous silty clay that has just the proper composition to fire without shrinkage. It has high plasticity and fires to a cream color. Mr. 'William Kirby, ceramics teacher, reports that this clay equals or exceeds in quality many of the commercial clays that are sold for slip-casting and shaping on the potter's wheel.

GRANEROS MUDSTONE

The largest volume of clay in Union County is in the Graneros shale. The Graneros is marine in origin, and the mudstone tends to be essentially constant in character from one locality to the next. Mud-stone underlies all the areas shown on the geologic map (pl. 1) as Graneros shale. Whether the mudstone has commercial value must be determined by thorough testing.

The mudstone under the felted limestone is more widely distributed than the mudstone above the limestone. The locality closest to Clayton is in Apache Canyon in 26.35.18, where the interval from the top of the Dakota sandstone to the laminated limestone is preserved; about 50 feet of dark-gray mudstone occurs in this interval. This locality is 4 miles from Clayton and 1 mile from the railroad.

Simple tests by Robert H. Weber indicate that the clay slakes moderately in air and slakes rapidly and completely in water. It appears to have good plasticity and bonding properties. Firing tests at 1,750°F for 12 hours gave a strong body of attractive light-orange color.

COAL

Thin beds of coal have been used locally in Union County in past years, but none of the deposits are likely to be of commercial value. Coal occurs in the following localities:

27.35.13.433—About 16 inches of coal in the upper part of the Dakota formation is exposed in the south bank of Seneca Creek, west of New Mexico Highway 18. This locality is shown by Darton (1928b) on the geologic map of New Mexico.

28.32.11.320—Frank Thomas reported that about 2½ feet of coal occurs on the west side of Sand Gap, presumably in the Dakota formation.

30.32.3.430—Coal, possibly in the Purgatoire formation, is reported by V. Wilkinson to be 15 feet thick and to crop out in the bottom of the canyon. Coal was encountered in a *water* well drilled half a mile to the south.

There are undoubtedly other places in Union County where similar thicknesses of coal are exposed. The Dakota group, and particularly the upper part of the Dakota formation, is the most likely stratigraphic unit in which to find lenses of coal.

COPPER

Copper minerals occur in a number of small, moderate to low-grade deposits in the Dry Cimarron River valley. The copper is generally associated with clastic plugs, although some mineralization is found in the Sheep Pen sandstone and Exeter sandstone. Soule (1956) has described some of these deposits; his naming of the host stratigraphic unit was incorrect, as noted above (p. 38).

The San Miguel mine of the Cimarron Mining Co. is a 2-man operation. The deposit is described above (p. 42). A small truckload of handpicked ore was reported to assay 11.70 percent copper and 2.6 ounces per ton of silver. Chalcocite, in part oxidized to malachite, is the main ore mineral.

In the year ending June 30, 1957, a ton of copper ore, with a value of $307, was produced from Union County (Garcia, 1957).

GRAVEL

Gravel in the upland deposits could supply construction material of probable value. Some of the areas that could be tested for gravel are shown in Plate 1 by a modification of the pattern for upland deposits. The areas so indicated were not mapped in the field but were sketched according to rough notes after the completion of field work. The geologic map should serve, therefore, merely to indicate possible places to test for gravel. Some of the areas may be underlain by sand, with only scattered pebbles.

The most likely use for gravel is in the construction of roads and highways and for domestic and commercial construction.

In general, gravel in the upland deposits is not likely to contain deleterious rock fragments. Various crystalline rocks of Precambrian age and fine-grained white and green volcanic rocks make up most of the gravel. However, gravel from the beds of creeks, such as Perico Creek, contains a significant amount of sandstone and shale.

MISCELLANEOUS MINERALS

Several minerals occur in Union County in minor quantities; they are not considered to have economic value, but they should be of interest to "rockhounds."

AGATE (CHALCEDONY), S102

The agate bed is described above (p. 47-48) and in the appendix. The rock has an attractive appearance, although it is readily broken.

BARITE, $BaSO_4$

Barite in layers less than a foot thick is found above the agate bed in the south panhandle of Union County. It was noted at 18.35.7.110 and at 18.35.27.441. At the latter locality, the barite is associated with crystals of calcite. The barite is characterized by its moderately high specific gravity (about 4.0), platy crystals, light color, and good cleavage.

SELENITE (GYPSUM), $CaSO_4 \cdot 2\,H_2O$

Crystals of selenite, a transparent variety of gypsum, weather out of the Graneros shale in several localities. The crystals have mistakenly been called mica because of their excellent basal cleavage. Gypsum can be recognized because it can be scratched readily by the fingernail, whereas mica is of about the same hardness as the fingernail. Selenite crystals several inches long were noted at 23.32.34.443 and 31.29.8.122. Small crystals of gypsum are scattered through a soft mass of calcium carbonate in the ground silo of Fred Mapes, at 22.32.11.312.

Nodules of light-orange to white gypsum occur in the brown-silt member of the Morrison formation in some localities (p. 48).

OIL AND GAS

Foster's summary of subsurface stratigraphy (p. 15-32) indicates some of the main features that would control the occurrence of oil and gas in Union County. About 30 oil tests are listed by him, and none of these encountered more than a show of oil.

The more conspicuous anticlinal structures—the Sierra Grande arch, the Clapham anticline, and the Guy monocline—have been tested by one or more holes, with no success. Union County is still considered, however, to be a generally favorable area for the occurrence of oil and gas, because in the past 10 years 5 major oil companies have conducted exploration programs in the county. Exploration has included seismic, gravity, magnetic, and surface geologic studies, and one company has drilled three stratigraphic tests. Some of the work is designed to give a better regional picture and some to give a detailed picture of parts of the county. Much of the exploration is apparently in the western limits of the Dalhart basin. Although structural highs have not yielded production, it may be that there are stratigraphic traps east of the Clapham anticline and the Guy monocline which contain oil and gas; such traps are difficult to find.

SANDSTONE AND SAND

Some beds of sandstone and some alluvial sands may have commercial value. The wide, sandy channels east of New Mexico Highway 18 contain large volumes of sand, which is in general fairly clean and well sorted.

Beds of friable white sandstone, which occur in the Dakota, Purgatoire, and Morrison formations, are a possible source of commercial sand. Such sandstones were noted at: 21.34.23.100, south of the Zurick ranch headquarters; 22.35.29.310, west of Stead; 24.32.20.140, on Pinabetitos Creek, south of U. S. Highway 56; 25.28.17.141, north of Gladstone; and 28.34.2.143, south of Corrumpa Creek, east of New Mexico Highway 370.

SCORIA

Scoria, or volcanic cinders, can be obtained from many of the 80 volcanic centers in Union County. Some is now being used for railroad ballast and for cinder blocks. In the year ending June 30, 1957, 380,590 cubic yards of scoria, with a value of $191,244, was produced from Union County (Garcia, 1957).

The Twin Mountain rock quarry, northwest of Des Moines, supplies large volumes of ballast for the Colorado and Southern Ry. Other cinder cones in the Folsom area, including Capulin Mountain, have been prospected as possible sources of cinders. In other parts of the county, the following volcanic centers are composed largely of cinders:

26.32.17.200—This cone supplied ballast for the railroad grade from Mt. Dora to Farley.

26.35.2.122—This is the easternmost volcanic center in Union County and is just a few miles northeast of Clayton.

27.33.30.400—The highest part of Burro Mountain is a cinder cone.

URANIUM

Some prospecting for uranium has been done in Union County, with negative results. Small "hot spots" have been reported from the Morrison formation on Corrumpa Creek (near the northwest corner of 29.33) and on Tramperos Creek. Some of the clastic plugs in the Dry Cimarron River valley are reported to be slightly radioactive. In Harding County, near Bueyeros and along Ute Creek, radioactive dinosaur bones have been collected.

In 1955, the eastern part of the Dry Cimarron River valley was tested by an exploration company. The valley walls were flown by a helicopter that carried an airborne scintillometer with high sensitivity. One flight pattern, level with the top of the sandstone member of the Purgatoire formation, extended from Oklahoma 6 miles west into Union County. A second flight pattern, level with the base of the Exeter sandstone where possible, extended from Oklahoma west to Peacock Canyon. Union County north of Black Mesa was not tested. Only two minor anomalies were found. The Morrison formation proper and the upper part of the Dakota formation were not tested, but significant deposits of uranium in those positions would have given some anomaly. The geologist in charge of the exploration concluded that although local "hot spots" might be found, the Dry Cimarron River valley from Peacock Canyon east is not a favorable area for uranium deposits.

GROUND WATER

Ground water is an important resource of Union County. Throughout the county, with a few local exceptions, domestic and stock wells will encounter adequate supplies within several hundred feet of the ground surface. Wells yielding more than 100 gallons per minute have been drilled in different parts of the county and have been completed in the Ogallala, Dakota, and Exeter formations. These wells range in depths from less than 100 feet to more than 900 feet.

Baldwin and Bushman (1957a) summarized ground-water conditions near Clayton, indicating that additional irrigation supplies could be developed. The countywide inventory of ground water has been completed, and the results are now being prepared for separate publication.

Appendix

COLOR TERMS

Most of the colors given in this report were compared with the Rock-Color Chart, distributed by the Geological Society of America. On the chart, each color is represented by a symbol in the Munsell system of color identification and by a 2- or 3-word color name. The Munsell system standardizes the description of colors, but it has limited meaning for the reader who does not have the color chart at hand. Moreover, the color names are too lengthy for use on columnar sections. In this report, therefore, a simpler system of color terms is used. Table 3 indicates the range in colors for each term.

The Munsell system is based on a sphere, and each symbol represents a point within the sphere. The "equator" of the sphere ranges through 10 major *hues;* 5 marks the middle of each hue, and 10 marks the boundary between hues. The 10 hues are: red (R), yellow-red (YR), yellow (Y), green-yellow (GY), green (G), blue-green (BG), blue (B), purple-blue (PB), purple (P), and red-purple (RP). The vertical axis ranges in *value* (lightness) from white (N9) at the top through gray to black (N1) at the bottom. The colors range in *chroma* (saturation) from gray (0) near the axis outward to vivid colors (/6).

The table of color terms used in this report is organized according to the pattern in the Rock-Color Chart. For some hues, chroma designations /3-6 are not represented by color terms; these are not common colors of rocks. In the text, the color term is written out (e.g., light red, medium red, dark red), but in Table 3 and on the columnar sections (pl. 2), the distinction between light, medium, and dark colors is abbreviated (e.g., 1. red, light red).

EXPOSURES OF AGATE BED AND UNDERLYING STRATA IN SOUTHERN UNION COUNTY

In the southern part of Union County, a map contact is drawn at the agate bed instead of at the base of the Morrison formation. There are many exposures of the brown-silt member of the Morrison formation, but few of the underlying Exeter sandstone or the Triassic. Therefore, by including the brown-silt member with the Exeter sandstone as a map unit, several structurally high areas can be indicated in Plate 1.

The agate bed is a helpful marker, but some outcrops of beds beneath the agate bed could be either the brown-silt member or the Dockum. The identification of some of these outcrops in Plate 1 may be in error; therefore, each outcrop is briefly described below.

18.34.2—Two nodular beds of agate crop out near the arroyo in the northern part of section; the lower bed is orange and the upper is light gray red.

TABLE 3. COLOR TERMS OF THIS REPORT, RELATED TO MUNSELL SYSTEM

	/1–2	/3–6		/1–2	/3–6
5R8	l. pink	l. pink	10R8	l. pink	l. orange
7	l. gray red	m. pink	7	l. gray red	l. orange
6	l. gray red	l. red	6	l. gray red	m. orange
5	m. gray red	m. red	5	m. gray red	m. red brown
4	m. gray red	m. red	4	m. gray red	m. red brown
3	d. gray red	d. red	3	d. gray red	d. red brown
2	d. gray red	d. red	2	d. gray red	d. red brown
	/1–2	/3–6		/1–2	/3–6
5YR8	l. pink	l. orange	10YR8	cream	l. tan
7	l. gray brown	l. brown	7	l. gray brown	l. tan
6	l. gray brown	l. brown	6	l. gray brown	m. tan
5	m. gray brown	m. brown	5	m. gray brown	yellow brown
4	m. gray brown	m. brown	4	m. gray brown	—
3	d. gray brown	d. brown	3	d. gray brown	—
	/1–2	/3–6		/1–2	/3–6
5Y8	cream	l. yellow	10Y8	cream	—
7	l. olive	m. yellow	7	l. olive	l. yellow green
6	l. olive	—	6	l. olive	m. yellow green
5	m. olive	—	5	m. olive	m. yellow green
4	m. olive	—	4	m. olive	—
3	d. olive	—	3	d. olive	—
	/1	/2		/1–2	
5GY8	l. gray green	l. green	5BG8	—	—
10GY7	l. gray green	l. green	10BG7	l. blue green	—
5G6	m. gray green	m. green	6	l. blue green	—
10G5	m. gray green	m. green	5	m. blue green	—
4	d. gray green	d. green	4	m. blue green	—
	/1–2	/3–6		/1–2	/3–6
5B8	—	—	5P8	—	—
10B7	l. blue	—	5RP7	l. purple	—
5PB6	l. blue	—	6	l. purple	—
5	m. blue	—	5	m. purple	—
4	m. blue	—	4	m. purple	—
N9	white		N4	d. gray	
N8	l. gray		N3	d. gray	
N7	l. gray		N2	d. gray	
N6	m. gray		N1	d. gray	
N5	m. gray				

18.35.6.111—Abundant float of agate along the creek.

18.35.7—In the north half of the section, agate crops out in many places along the arroyo. Here, the upper bed is orange and the lower is light gray. North of the arroyo and beneath the agate bed, there is a 2-foot bed of yellow sandstone underlain by red-brown mudstone and orange sandstone. These beds are the lowest exposed and are probably the brown-silt member of the Morrison formation.

18.35.26.412—In the cutbank, massive red-brown clayey mudstone to the southeast is separated from light gray-green silty mudstone to the northwest by a northwest-dipping layer of breccia. The breccia consists of rounded pieces of light-gray fine-grained sandstone. This layer of breccia appears to extend to the upper part of the outcrop, where it merges with about 3 feet of lenticular sandstone and shale that rest on the red-brown mudstone. The breccia cuts obliquely across the indistinct bedding of the red-brown mudstone and also across that of limestone lenses in the light gray-green mudstone. The red-brown mudstone is probably Dockum; the breccia may be a post-Dockum slope accumulation, later buried under the light gray-green beds of possible Morrison age.

18.35.26.432—A low ridge of large blocks of sandstone extends southeast from the creek for 500 feet. The origin of this jumble of blocks is obscure. Lithologies are similar to those of the Dakota-group sandstones, but the adjacent bedrock is probably the lower part of the Morrison formation. The top of the low ridge is about level with the base of the Ogallala formation, as if the Ogallala once covered a pre-Ogallala talus deposit.

18.35.27—The agate bed is exposed along the sides of the arroyos in this section. At .210, the agate bed and adjacent beds of the Morrison formation appear to be faulted against the Ogallala formation; the fault is just east of the earth dam, and the east side of the fault is downthrown.

19.35.21.140—Exposures along Monia Creek of light-brown (5YR7/6) coarse silt to very fine-grained sandstone are mapped as the brown-silt member but may be Dockum:

	(FEET)
Caliche	13
Mudstone, gray-red with green mottlings, sandy, silty; light gray-green in bottom 2 feet	10
Mudstone, red-brown	7
Sandstone, light-brown, massive, very fine-grained	13
Mudstone, red-brown	5
Sandstone, light-brown, massive, very fine-grained	6

21.34.1—Red-brown mudstone with indistinct bedding is exposed in cutbanks .112, .131, .143, and .443. These are mapped as Dockum but may be the brown-silt member of the Morrison.

21.34.2—The agate bed is exposed in the north-central part of the section. Cutbank .444 exposes red mudstone on 3 feet of calcareous sandstone, probably of the Dockum group.

21.34.11—Cutbank .322 exposes about 40 feet of light-brown (5YR6 /4) to light gray-green silt, clayey to sandy mudstone, and thin beds of light-gray fine- to medium-grained sandstone. These beds are the brown-silt member of the Morrison formation, with interbeds of Exeter lithology. Some float of agate occurs nearly a mile due east, in 12.312.

22.30.30-32—Exeter sandstone and the brown-silt member of the Morrison formation total nearly 100 feet in thickness along Ute Creek. The base of the Exeter is exposed in the creek bed 0.6 mile south of Union County. The upper few feet of the Exeter is parallel bedded.

22.31.10.111—About 10 feet of light-brown silt is exposed in the cut-bank. There is much float of agate in the next half mile to the west, and some float in the center of section 10. The outcrop is the brown-silt member of the Morrison.

22.32.30.123—Small outcrop of the agate bed.

22.34.11.300—About 20 feet of beds of Exeter sandstone and of the brown-silt member is exposed along the creek. White sandstone in 1-foot beds is interbedded with ripple-marked red-brown sandy shale in 3-foot beds. The agate bed is exposed in a gully northwest of the creek.

22.34.24.111-244—Interbedded white sandstone and red-brown shale, as above. The agate bed crops out at .223.

22.34.28.240—The agate bed and brown-silt member are exposed in a gully.

22.34.33.232—About 9 feet of white sandstone, possibly Exeter, is exposed on the northeast side of the creek. It is overlain by light-green sandy mudstone.

22.34.35—The agate bed is exposed at .124 and .410.

23.33.13.24—Several exposures on Leon Creek of thin-bedded red-brown and orange mudstone and sandstone are mapped as the brown-silt member of the Morrison. Float of agate is found at 13.244.

LOGS OF WELLS

The logs of 114 water wells and tests are given below. They are listed in order by township, range, section, and location within section. The owner of the well is given for each well, and the altitude in feet above sea level, as determined by altimeter traverse, is given for many of the wells. The 44 columnar sections of Plate 2—oil tests, water wells and tests, and measured sections—are also listed according to their locations.

The logs were selected to indicate the thickness of the Ogallala formation, the presence or absence of basalt, the variable nature of the Dakota group, the thickness of some bedrock formations, or the possibility of obtaining small supplies of ground water from the Morrison formation and Dockum group.

The logs have been compiled from several sources. Some are based on study by the writer of samples of at least part of the hole. Others are reported by D. H. Griswold, who was formerly with the Soil Conservation Service. Some are reported from memory by ranchers and farmers. Most were obtained from copies of the drillers' records: some of these represent the generalized logs filed with the Production and Marketing Association (P. M. A.) office in Clayton.

The formation units listed in the logs are interpretations by the writer, and, for some wells in northwestern Union County, by W. R. Muehlberger. Outcrops near wells, logs of adjacent wells and shotholes, and the drillers' logs themselves are all used as an aid in interpretation of the formation limits. Where there is reasonable doubt, queries have been used.

For some wells, the term bedrock is used for the deepest units encountered. This is particularly true of the logs of wells drilled in the southern part of the county, where red clay could be either the Morrison formation or the Dockum group. Similarly, a few feet of dark-gray shale beneath the Ogallala formation might be either Graneros shale or the Dakota group. The term Dakota group is used in the interpretation of the logs because the Dakota formation and Purgatoire formation are not readily distinguished in the subsurface. Thin sandstone beds reported for the Graneros shale may be limestone beds. The beds of lime reported in several logs are possibly beds of siltstone rather than limestone.

The logs have been somewhat simplified from the original record. Notes in parentheses that are queried are by the writer. For some wells the notations of water sands are retained. Confined water (water which is under pressure and which will rise in the well) is noted for some wells in the Gladstone area and along Tramperos Creek.

LOCATION	OWNER	ALTITUDE
18.34. 7.122	H. H. Tate	4,814 feet

Ogallala formation: caliche, 90; sand, 118.
Bedrock: red shale at 118.

18.34. 9.111	H. H. Tate	4,849 *feet*

Ogallala formation: (?), 20; caliche, 170; sand, 180. *Bedrock:* red shale at 180.

18.34.15.422	lone P. 0.	4,760 feet

Ogallala formation: sand and caliche, 135.
Dakota group: sandstone, 160 (?); light- to dark-gray shale, 205; sandstone, 210. *Morrison formation:* light gray-green and light-brown shale, 218.

18.34.18.444	Wamble	4,733 *feet*

Ogallala formation: (1), 90; sand, 100. *Bedrock:* blue shale, (?); (?), 200.

18.35.11.422	0. K .Gamble	4,485 *feet*

Ogallala formation: sandy clay, 210; water sand, 220. *Bedrock:* red beds, 260; water sand, 267.

18.36. 6.322	J. Copeland (tests)	4,464 feet

Ogallala formation: tan sandy clay, 50; sand, 175; sand and gravel, 210; tan silty sand with some gravel, 238.
Bedrock (Dockum group 7): red-brown and gray-green clayey silt, 290.

18.36.12.333	H. A. George	4,294 feet

Surface: black dirt, 20.
Ogallala formation: caliche, 30; sand, 150; water sand, 170.
Bedrock: day, 173.

18.36.36.113	G. W. Jones	

Ogallala formation: sand, 170.
Bedrock (7): sandstone, 190; sand and water, 200; sandstone, 210. *Bedrock:* red beds, 218.

LOCATION	OWNER	ALTITUDE

19.34. 4.300 G. C. & C. Hutcherson

Ogallala formation: soil and clay, 20; caliche, 30; clay and sand, 60; sand, 90.

Bedrock (Morrison formation 7): sandrock, 100; red clay, 110; gray shale, 140; water sand, 150; gray shale, 200; blue shale, 210; water sand, 217.

19.34.24.234 C. E. Kimber 4,671 feet

Surface: soil, 10.

Ogallala formation: hard clay, 32; hard sand, 50; clay, 80; soft sand with layers of clay, 95; soft sand, 107; sandstone, 110; soft sand, 120.

Bedrock: red beds, 150.

19.34.26.100 W. G. Bola

Ogallala formation: caliche, 20; sand, 100; sandstone, 104; sand, 160; coarse sand, 180; sand and thin clay layers, 200; coarse sand, 225.

Bedrock: red beds, 227.

19.35. 7.400 J. H. Anglin

Ogallala formation: (?), 30; sand, 40.

Bedrock (Morrison formation 7): blue clay, 50; red beds, 80; water sand at 80.

19.35.15.312 0. Earle

Ogallala formation: caliche, 20; pack sand, 60; water, 90.

Bedrock: red clay at 90.

19.36.13.200 V. P. Hobson

Ogallala formation: caliche, 20.

Bedrock (7): red clay, 50; red beds, 70; yellow clay, 100; light sand, 130; light clay, 160; sand-rock, 180; water sand, 200.

19.36.30.313 J. Copeland (test) 4,475 feet

Ogallala formation: silty sand, 25; caliche, 35; silty sand, 45; medium sand, 50; silty sand, 98; yellow plastic clay, 99; silty sandstone, 105.

Bedrock (Dockum group 7): red-brown silty mudstone, 219; fine sandstone, 268; fine sandstone and gray clay, 295; blue-gray clay and lignite, 300; red-brown silty mudstone, 340.

19.37.19.334 V. P. Hobson 4,284 *feet*

Ogallala formation: (?) 110; sandy soil, 120; light sand, 140.

Bedrock (7): sandrock, 150; water sand at 150.

20.35. 5.421 K. Perschbacher

Ogallala formation: pack sand, 30; sand and clay, 40.

Bedrock (Morrison formation 7): sandrock, 50; rock, 60; rock and water at 60.

20.35.11.333 J. Nix 4,577 feet

Ogallala formation: caliche, 30.

Bedrock (7): sandrock, 70; water sand, 86; water gravel at 86.

20.35.25.210 H. A. Whitaker 4,500 feet

Surface: top soil, 20.

Ogallala formation: caliche, 40.

Bedrock (7): sandstone, 50; blue mud, 100; some water, 110; blue mud, 130; quicksand, 140; water underneath, 150; red beds, 170.

20.35.32.200 0. Earle

Ogallala formation: caliche rock, 40; sand, 80.

Bedrock: red clay, 110; sandstone, 120; water sand, 130; red beds, 140.

20.36.30.110 Nunn No. 1 Wallace; see Plate 2, 28 4,480 *feet*

20.36.36, center V. and H. Meadows

Ogallala formation: caliche, 30; pack sand, 110; sand, 140; water sand, 150.

21.35.18.442 B. Deinken 4,726 feet

Ogallala formation: soil and clay, 20; sand and clay, 40.

Dakota group: hard sand, 70; gray shale, 130; black shale, 150; water sand, 175; blue shale at 175.

21.35.23.343 J. Deinken 4,604 ***feet***

Surface: soil and clay, 20.

Ogallala formation: caliche, 40; clay and sand, 50.

Dakota group: sandrock 90; sand and shale, 150; blue shale, 180; water sand, 197.

LOCATION OWNER ALTITUDE

21.36.23.333 R. Connell 4,467 feet

Surface: soil, 10.

Ogallala formation: sandrock, 20; sand, 50; clay and gravel, 70; caliche, 80; sand. 110; clay and gravel. 120; water in quicksand, 138; lime rock and gravel, 140; water in coarse sand and gravel at 140; (1), 178.

21.36.29.110 Oil Exploration No. 1 Irwin: see Plate 2, 27 4,519 feet

22.31. 4.323 Measured section; see Plate 2, 37

22.32.14.231 Measured section; see Plate 2. 41

22.32.14.313 F. B. Mapes 4,909 feet

Surface: sand, 28.

Morrison formation: blue shale (rock at 98), 115.

Exeter sandstone: sand and yellow clay, 169. *Dockum group:* red beds, 340.

22.33. 8.143 M. D. Smithson 5,035 feet

Ogallala formation: dirt, 20.

Dakota group: sand and clay, 70; shale, 150; sandrock, 170. *Morrison formation (7):* soapstone, 250.

22.33.16.241 M. D. Smithson

Ogallala formation: dirt and white rock, 30.

Dakota group: sand and clay, 60; sandrock, 160; black shale, 220.

Morrison formation (?): white sandrock, 235.

22.33.19.200 Measured section; see Plate 2, 42

22.33.21.323 Measured section; see Plate 2, 43

22.33.29.434 M. D. Smithson

Surface: soil, 13; water sand, 18.

Morrison formation: shale and sandstone, 190. *Exeter sandstone:* sand (confined water), 240. *Dockum group:* red-brown mudstone, 255.

22.33.30.322 M. D. Smithson

Surface: soil, 13; water sand, 18.

Morrison formation: shale and sandstone, 70; water sand, 75; shale and sandstone, 170. *Exeter sandstone:* water sand (confined water), 208.

Dockum group: green shale, 220; (?), 230.

22.35.12.131 R. Vandiver 4,652 feet

Ogallala formation: soil and caliche, 20; caliche, 30; sandrock, 40; pack sand, 50; sand, 90; cave sand, 100; sand, 140; rock sand, 150; cave sand, 160; sand. 180.

Dakota group: sandstone, 190; water sand at 190.

22.35.23.322 A. D. Jenkins

Ogallala formation: caliche, 30; sand, 120; red clay, 130; sand, 150; water sand, 160; sand, 170. *Dakota group:* rock water at 170.

22.35.29.310 Measured section; see Plate 2, 44

22.36. 5.131 E. J. Walker 4,646 feet

Ogallala formation: soil and caliche, 25; clay. 140; clay and sand, 182.

Ogallala formation (?): hard white rock (water beneath), 185; sand and some gravel, 224. *Bedrock:* rock at 224.

22.36.33.411 A. B. Hughes 4,518 feet

Ogallala formation: (?). 129; gravel. 175.

Bedrock: day soapstone and sandstone, 185; white sand (water), 210; sandstone, 240.

23.28. 1.111 W. Wilkinson

Surface: dirt, 35.

Basalt: 130.

23.28. 5.424 J. Krizan 6,045 *feet*

Surface: caliche, 6.

Basalt: malpais, 11; cinders, 275.

Ogallala formation: gravel, 295.

Graneros shale (1): gumbo, 385.

Dakota group: sandstone, 429; sand and some water, 432; (?), 488.

LOCATION	OWNER	ALTITUDE
23.28. 6.222	A. Bada	6,052 feet

Surface: soil and caliche, 10.
Basalt: 156.
Bedrock (1): clay, red shale, water, and hard sandstone to 412.

23.31.22.222	Measured section; see Plate 2, 38	
23.31.24.432	Measured section; see Plate 2. 39	
23.32.14.230	Measured section; see Plate 2. 40	
23.33. 2.122	Dillard No. 1 State; see Plate 2, 25	5,119 feet
23.34.10.442	W. R. Morgan	4,993 feet

Ogallala formation: soil, 2; white rock. 18; sand, 47; clay, 52.
Graneros shale: shale, 80; hard sand (limestone bed?), 86; shale, 135.
Dakota *group:* gray sand, 220; shale, 226; red sand and shale, 298; shale, 306; water sand, 322; gray shale, 326.

23.34.24.114	A. T. Wisdom	4,846 feet

Graneros shale: sand and rock, 20.
Dakota group: black shale, 70; sandstone, 150; yellow sandstone, 190; black shale, 220; blue shale, 230; gray sand, 240; black shale, 250; gray sandrock, 260.
Morrison formation (2): red shale, 280; yellow sandrock, 290; water sand, 300.

23.34.36.422	E. L. Leighton	

Ogallala formation: soil and clay, 20; caliche, 40; sand and clay. 60.
Dakota group: sandrock, 80; blue shale, 90; gray shale, 120; sand, 130; sandrock, 150; gray shale, 180; blue shale, 220; sandrock, 230; water sand, 256.

23.35.10.232	W. J. Lewis	4.761 feet

Ogallala formation: sand and clay, 190; sand and gravel, 207.
Bedrock: rock bottom at 207.

23.35.26.321	Nunn No. 1 Hopson; see Plate 2, 26	4,743 feet
23.36. 5.133	K. Butt	

Ogallala formation: sand and clay, 150; water sand, 175.

23.36.21.434	M. Adams	4,665 feet

Surface: top soil. 20.
Ogallala formation: brown clay, 30; red lime sand, 40; brown clay and gravel, 60; caliche and sand, 100; sand and gravel, 110.
Bedrock (1): caliche and sandstone, 170; dry sand, 180; hard sandstone, 190; brown shale, 220; red clay, 240; white shale, 260; brown shale, 265; water sand, 268.

23.36.34.343	E. Bush	4,600 *feet*

Surface: soil, 20.
Ogallala formation: caliche, 50; clay and sand, 90; sand, 120.
Bedrock (1): yellow clay, 170.
Bedrock: blue shale, 210; water sand at 210.

24.28.15.222	W. Wilkinson	

Surface: dirt, 10.
Basalt: malpais, 125.
Ogallala formation: gravel (confined water), 156.

24.28.16.131	D. C. Sachse	5,898 feet

Surface: dirt and clay, 67.
Basalt: malpais, 97.
Ogallala formation: water in sand below malpais at 97.

24.28.27.211	R. Bryan	5,844 feet

Surface: dirt, 20.
Basalt: malpais (did not go through). 125.

24.28.29.411	G. S. Lashley	5,939 feet

Surface: dirt, 3.
Basalt: malpais, 43.
Ogallala formation: sand and gravel, 76; (?).
Bedrock: (1); black shale at 91.

LOCATION	OWNER	ALTITUDE
24.29.18.321	Lemon. Miller, and Maness	5,869 feet

Surface: dirt, 6.
Basalt: malpais, 50.
Graneros shale (7): blue shale, 80.
Dakota group: shale and sandrock, 90; sandrock, 180; yellow clay, 200; white sandrock. 220.

24.29.33.132 — J. M. Gard

Surface: dirt, 20.
Ogallala formation: dry gravel, 40; clay, 50; water sand, 70.
Bedrock (7): brown clay at 70.

24.30. 2.231 — J. Mondragon — 5,853 *feet*

Ogallala formation: clay, 60; sand, 80.
Dakota group: shale, 170; sandstone, 180; dark shale, 190; sand, 220.
Morrison formation (?): sandy shale, 310; water sand, 320.

24.30.14.410 — Galbreath No. 1 Britt; see Plate 2, 21 — 5,811 feet

24.30.27.111 — Pasamonte Ranch — 5,711 feet

Surface: dirt, 30.
Graneros shale: sand and clay, 60; black shale, 80. *Dakota group:* yellow sandrock, 110; white sandrock, 119.

24.30.31.141 — Pasamonte Ranch

Surface: dirt, 50.
Dakota group: blue shale, 130; yellow sandrock, 180; water-bearing white sand, 200; rock at 200.

24.31.29.411 — Farber Ranch — 5,716 feet

Ogallala formation: sand and clay, 50.
Graneros shale: blue shale, 60.
Dakota group: hard sand, 62; sand, 78; water sand, 93; sandstone and gray shale, 168; sand, 251; (7), 270; water at 270.

24.33.10.221 — R. V. Bell

Ogallala formation: soil and sand, 10; sand with caliche, 20; yellow day, 30; sand, 40; sand and shells, 50; gravel, 60; gravel and sand, 70.
Dakota group: sand with shale, 80; shale, 90; dark shale, 100; shale and sand, 110; water sand, 136.

24.33.22.322 — C. Gossett

Ogallala formation: dirt, 50.
Dakota *group:* blue shale, 120; yellow clay, 130; white sand, 140; rock, 143.

24.33.25.221 — J. W. Reeser

Surface: soil and day 10; sand and clay, 30; sand (some water), 38.
Dakota group: sand and shale, 105; hard sand, 120; gray shale, 138; hard sand and red rock, 190; water sand, 214.

24.34. 5.122 — S. T. Street — 5,200 feet

Surface: soil and clay. 20.
Basalt: malpais, 30.
Ogallala formation: sand, 150.
Dakota group: gray shale, 170; blue shale, 190; sand and lime, 200; sand, 210; shale, 220; water sand, 241.

24.34.24.313 — R. E. McCarley

Ogallala formation: sand, 20; sand and clay, 60; sand, 70; sand and gravel, 80; sand, 110. *Bedrock (?):* shale, 120; sand and water, 128.

24.34.35.244 — R. Leighton

No record: clean out well, 130.
Dakota group: shale, 165; sand. 180; sand and shale, 230; water sand, 238; shale, 245; water sand, 251; sand and shale, 259.

24.35.15.114 — W. A. Rardin — 4,896 feet

Ogallala formation: soil and clay, 20; caliche. 30; sand and caliche, 40; sand and gravel, 50; soft sand, 60; hard sand, 75; sand and lime, 80; water sand, 100.

24.35.33.334 — A. T. Wisdom

Ogallala formation sand and gravel, 50; fine sand. 95; rock, 110; caliche, 120; hard rock and gravel, 135; soft rusty-colored sand, 170.
Dakota group: blue shale, 200; coal, 105; rock, 300; sand, 312.

LOCATION OWNER ALTITUDE

24.36. 2.440 Continental No. 1 Federal Land Bank; see Plate 2, 24 4,688 feet

24.36.12.244 Mrs. L. Kehoe 4,630 feet

Ogallala formation: surface caliche, 40; yellow hard sand, 50; coarse gravel, 75.
Graneros shale: blue and yellow clay, 90; coal and bluish shale, 119.
Dakota group: coarse sand, 142; bluish shale, 180; yellow and white hard sand, 220; white soft sand, 300; bluish shale, 340; white sand, 360.
Morrison formation: red shale at 360.

25.28.18.321 0. C. McDade

Alluvium: dirt, 5; gravel, 25.
Dakota group: sandrock, 30; yellow clay, 32; gray sandrock, 55; yellow sandrock, 67; black clay and shale. 80; gray sandrock, 90; yellow sandrock, 100; white sandrock, 120; yellow sandrock, 122.

25.28.25.443 A. Maness 6,066 feet

Basalt: malpais, 160.
Ogallala formation: sand and gravel, 172.

25.29. 4.333 See p. 73

25.29.21.111 A. Maness 6,372 feet

Basalt: 388 feet of malpais; 30-40 feet of water; (?), 420.

25.29.34.342 R. Largent 6,373 feet

Surface: soil. 2; caliche, 11.
Basalt: malpais, 107.
Ogallala formation: sand, 331.
Graneros shale: dark shale at 331.

25.30.15.211 B. B. Atchley 6,087 feet

Surface: dirt, 10.
Basalt: malpais. 70.
Ogallala formation: sand and gravel to bottom, 240 or 285.

25.31.11.211 Measured section, Snyder Lake; see Plate 2, 36

25.32. 4.341 Mrs. G. T. Wiley 5,573 *feet*

Ogallala formation: sand, 60.
Dakota group: shale and sandrock, 170; yellow sandrock, 210.

25.33.18.432 A. Swagerty 5,471 feet

Ogallala formation: sand, 130; sandy clay, 160.
Dakota group: black shale. 170; sandstone, 180; dark shale, 200; sandy shale, 240; dark shale, 270; sandstone, 300; dark shale, 310; sandstone, 350; gray sand, 360; water, 380.

25.33.20.441 Mrs. J. Swagerty 5,446 feet

Surface: dirt, 20.
Basalt: malpais, 40.
Ogallala formation: sand. 140.
Dakota group: day, 190; sandstone, 205.

25.34.14.442 E. B. Miller 5,102 feet

Ogallala formation: soil and sand. 5; clay, 25.
Dakota group (7): sandrock, 45; hard lime, 50; sand and shale, 58; blue shale, 90; water sand, 108; sand and shells, 160; water sand, 179.

25.35. 2.441 W. J. Winchester 4,984 feet

Surface: soil, 19.
Basalt: malpais, 53.
Ogallala formation: sandy clay, 78; gravel, 84; clay and sand, 109; sand and gravel (water), 170. *Bedrock (?):* blue shale reported. 173.

25.35. 7.123 W. N. Jackson 5,015 feet

Ogallala formation: soil and clay. 30; clay and sand, 58.
Graneros shale: dark shale. 97.
Dakota group: gray and dark shale. 128; sand and shells, 134; water sand, 161.

25.35.22.321 R. Leighton 4,928 ***feet***

Ogallala formation: soil and clay, 20; caliche, 30; sand, 60; clay, 70.
Graneros shale: shale at 70.

LOCATION	OWNER	ALTITUDE
25.35.33.423	E. J. Leavitt	4,928 feet

Ogallala formation: soil and clay, 20; caliche, 40; clay, 60; sand and clay, 70.
Graneros shale (7): blue shale, 90.
Dakota group: sand and shale, 120; sandrock, 130; sandy shale, 140; water sand, 164.

25.36. 7.111	B. J. Altman	4,907 feet

Surface: soil, 10.
Ogallala formation: red clay, 30; caliche, 40; red clay, 45; sandy clay, 50; fine soft sand, 68; clay, 70; sand, 80; yellow clay, 85.
Bedrock: black shale, 130; blue shale, 320.

26.28.28.431	C. M. Garrett	6,282 *feet*

Surface: dirt, 20; gravel, 30.
Dakota group: sandrock, 50; malpais (iron-cemented sandstone ?), 60; shale, 100; sandrock, 120; shale, 130; sandrock, 132.

26.29.12.231	E. A. Jones	6,236 feet

Surface: soil and sand, 20.
Dakota group: yellow clay, 30; brown shale, 40; shale and sand, 50; blue shale, 80; white sand, 90; sand, 95; shale, 130; sand, 140; sand and shale, 150; brown sand, 160; sand and shale, 170; white sand. 180; brown sand, 200; white sand, 235; black shale, 241.

26.29.32.241	B. Doi tchinoff	

Graneros shale (7): dirt, 50.
Dakota group: rock, 80; shale, 130; sandrock, 141.

26.30.22.324	Reed and Snyder	6,077 feet

Surface: dirt, 20.
Basalt: malpais, 50.
Ogallala formation: red sand, 70; clay and shale, 100.
Dakota group: gray rock, 160; yellow sandrock, 220; clay and sandrock, 260; white sandrock, 285.

26.32. 1.131	Colorado & Southern Ry. (Mt. Dora)	5.717 *feet*

Surface: top soil, 3; caliche, 19.
Basalt: malpais, 86.
Ogallala formation: yellow sand and clay, 180; quicksand, 215; sand and clay, 223; sand, 245.
Dakota group (?): (reported lime and shells may be siltstone beds; caliche may be caved); blue shale, 249; caliche, 255; soft sand (water), 259; gray hard sand, 262; black shale, 285; gray sandy lime and shells. 295; blue sandy shale, 300; caliche, 308; gray sandy lime and shells, 335; hard gray lime, 362; soft sand (water), 378; hard sharp sand and lime, 395; blue sandy shale, 408; pink shale, 414; gray hard lime, 428; blue shale, 432; shale and shell, 440; gray lime, 455.

26.32. 5.344	G. Jones	5,798 feet

Surface: top soil, 20.
Basalt: malpais, 40; cinders, 70.
Ogallala formation: red clay, (?); (?), 175; water in gravel, (?); (?).
Dakota group: blue shale, (?); (?), 263; Dakota sand, 303.

26.32.27.240	Hoxsey No. 1 Jones; see Plate 2, 22	5,509 feet
26.34.25.243	C. Kilgore	

Ogallala formation: soil and clay, 20; sand and shale. 70; sand, 80.
Graneros shale: dark shale, 105.
Dakota group: water sand, 115.

26.35.36.143	Clayton well no. 6	4.975 feet

Ogallala formation: silt and sand and caliche, 10; sand and gravel, 70.
Graneros shale: limestone, 72; gray shale, 90.
Dakota group: light-gray sandy siltstone, 100; gray silty shale, 130; fine-grained sandstone, 170; no sample, 180; dark-gray silty shale and light-gray fine-grained sandstone, 220; gray fine-grained sandstone, 250; no sample, 260; black silty shale, 270.
Morrison formation: light-gray to gray-red and gray-green sandy clay, 300; no sample, 310; sandstone, 320; no sample, 330; sandstone, 372; red and green clay, 374.

26.35.34.422	Clayton well No. 5; see Plate 2, 23	5,049 feet
26.35.35.313	Clayton well No. 7	5,034 feet

Surface: caliche, 20.
Basalt: malpais, 40.

LOCATION OWNER ALTITUDE

Ogallala formation: sand and caliche, 60; gravel, 70; medium- to coarse-grained sand, 80; no sample, 90; sand, 130.
Graneros shale: gray silty clay, 135; light-gray silty sandstone, 145; dark-gray shale, 175; limestone, 177; dark-gray shale, 195.
Dakota group: light-gray fine-grained sandstone. 200; dark-gray shale, 230; no sample, 240; light-gray fine-grained sandstone and medium-gray silty sandstone, 300; gray sandy mudstone, 310; light-gray fine-grained sandstone, 318; gray sandy shale, 340; gray sandstone, 360; dark-gray sandy shale, 370.
Morrison formation (7): light-gray sandy clay, 385; fine- to medium-grained sandstone (black shale at 464), 480; no sample (red and green clay reported), 497.

26.36. 2.333 Colorado Interstate Gas Co., Clayton Plant 4.762 feet
Ogallala formation: caliche. 35; clay and sand and caliche, 143; sand, 170.
Dakota group: blue clay, 175; water sand, 214.

27.31. 1.133 F. Weese 5.861 feet
Ogallala formation: sand, 112; water and sand, 122; clay, 134.
Graneros shale (7): dark shale, 168; hard sand (limestone ?), 174; dark shale, 215.
Dakota group: gray hard sand, 221; light shale, 225; dark shale, 241; gray sand (water) 255.

27.32. 8.143 J. T. Jones 5,835 feet
Ogallala formation: sand, 200.
Bedrock: blue shale, 233; sand and some shale. (2); sandy at 275.

27.32.32.113 G. Jones 5,854 feet
Surface: dirt, 10.
Basalt: malpais, 94; cinders, 124.
Ogallala formation: red clay, 175; sand and gravel (water), 190.
Bedrock: yellow clay, 205; blue shale. 235; Dakota sand, 306.

27.33.26.432 J. B. Kimble 5,505 feet
Surface: soil, 6.
Basalt: malpais, 62.
Ogallala formation: silty sand, 120; some caliche, 125; silty sand, 170; sand, 177; silty sand, 229; coarse sand (water), 245; gravel, 259.

27.34.15.341 B. P. Jordan 5.297 *feet*
Surface: soil, 8.
Basalt: malpais, 29.
Ogallala *formation:* light-yellow clay, 43.
Dakota group: light-gray sandstone, 57; red sandstone. 65; dark-gray shale, 66; mostly sandstone, 190; black shale, 193.

27.36. 2.242 C. H. Kennann
Ogallala formation: sand and clay, 170. *Bedrock (7):* rock and sand, 200.

27.36.17.434 F. Carter 4,837 *feet*
Surface: soil, 10.
Ogallala formation: clay. 30; sand. 40; gravel, 60; clay, 70; sand and gravel, 90; clay, 100; fine and coarse sand, 200.

27.36.25.111 Herndon No. 1 Mock; see Plate 2, 20 4,802 feet

27.36.29.411 C. W. Lawrence
Surface: clay, 20.
Basalt: malpais, 50.
Ogallala formation: dry sand and gravel, 120.
Dakota *group:* sandstone. 210; water sand, 220.

27.37. 6.442 J. E. Fones
Ogallala formation: sand and clay and caliche, 141; quicksand, 151; caliche, 161; quicksand, 171; caliche, 181; sand, 191.
Dakota group: yellow clay, 194; water-bearing sand, 203; Dakota sandstone, 240; hard red sand-rock, 265.

28.28.22.444 0. D. Click 6,746 feet
Basalt: malpais, 54.
Ogallala *formation:* sand and gravel, 120.
Bedrock: blue shale, 132.

LOCATION OWNER ALTITUDE

28.30. 7.414 Colorado & Southern Ry. (Grande) 6,369 feet

Basalt: malpais rock, 35.

Ogallala formation: red sand and clay, 45; gray sandrock, 64; red pack sand, 80; conglomerate (gravel ?), 120.

Dakota group: gray sand rock, 150; malpais rock (caved ?). 165; hard granite rock (sandstone ?), 170; hard ore rock (sandstone ?), 175; light sandrock (water), 185; dark sandrock (water) 200; malpais rock (caved ?), 205; black shale, 225; sandrock (water), 235; malpais rock (caved ?), 240; white sandrock (water), 264.

240; white sandrock (water), 264.

28.31.21.343 W. M. Monk 6,010 feet

Ogallala formation: soil and sand, 20; caliche, 30.

Ogallala formation (7): sand, 165; water sand at 165.

28.32.11.121 Measured section; see Plate 2, 30

28.33. 4.114 Measured section; see Plate 2, 32

28.33.20.144 B. P. Moore

Surface: dirt, 20.

Ogallala formation: sand, 60; lime, 70; sand and water, 90.

Dakota group: sandstone. 101.

28.35. 1.411 W. and 0. Harris 5,023 feet

Dakota group: sandrock, 30; sand and clay, 84; shale, 98; shale and shells, 160; sand, 192; water sand, 207; shale, 212.

28.35. 4.113 P. Miller

Surface: alluvium, 6.

Dakota group: sandstone, 18; water sand, 24; blue shale, 51.

Morrison *formation:* green and red shale, 58; hard rock, 64; green and red shale, 67; hard green sandstone, 69; green shale, 77; hard sandrock, 82; porous sandrock (water), 94; hard sand-rock, 96; green shale, 98; hard green sandrock, 100; sand (possible water), 107; hard green rock, 109; coarse sand, 112; rock, 115; hard rock, 135.

28.35.24.443 L. E. Oldham 5,030 feet

Ogallala formation: soil and sand, 20; caliche, 30; sand, 70. *Graneros shale (7):* shale, 93.

Dakota group: water sand at 93.

28.35.25.220 Morad No. 1 Campbell; see Plate 2, 19 4,980(?) feet

28.37. 6.242 R. G. Mock 4,785 feet

Ogallala formation: dirt, 20; caliche, 50; sand, 70; rock, 80. *Graneros shale:* yellow shale, 100; rock, 102; blue shale, 120. *Dakota group:* gray shale, 150; yellow sandstone, 153.

29.28.18.322 R. A. Pachta 6,803 feet

Surface: sandy soil, 5; yellow clay with some cinders, 10; gray bentonite, 13.

Basalt: red cinders, 43; porous lava flow, 45; broken lava, 49; hard lava flow, 551/2; crevice, 57.

29.28.18.343 C. Crist 6,816 feet

No record: dug irrigation well, 36.

Basalt: hard lava flow, 37; dark red cinders, 39; lava flow, 511/2; brown clinkers, 52; lava flow, 54; lava flow and crevice, 59; cinders and blocks of lava, 65; dark-red hard lava flow, 78.

29.29. 3.210 Gruemmer No. 2 Gruemmer; see Plate 2, 17 6,687 feet

29.32.14.421 Measured section 29; see Plate 2

29.32.22.111 Freeman No. 1 Smith; see Plate 2, 18 5,570 *feet*

29.33. 9.344 G. Larkin 5,412 *feet*

No record: (?), 50.

Morrison formation: shale. 220.

Exeter sandstone (7): water sand 240.

29.33.26.224 Measured section; see Plate 2, 33

29.34.22.343 McLaughlin test well; see Plate 2, 34 5,230 feet

29.35. 8.424 L. Bray 5,205 feet

Ogallala formation: soil and clay, 20.

Dakota group: sandrock, 40; sand and shale, 60; water sand, 70; shale, 100; sand and shale, 110; gray shale, 130; blue shale, 160; sand and shale, 170; water sand, 190.

LOCATION	OWNER	ALTITUDE
29.35.15.332	A. Witt	5,076 feet

Surface: gravel bed, 8.
Dakota group: sandrock, 60; pink shale, 72; sandrock, 88; dark shale, 92; brown shale, 98; black shale, 111; sand, 120.
Morrison formation: light shale, 126; red shale, 135; sand, 140; red shale, 155; sand, 160; sandy shale, 170; light shale, 180; hard sand, 188; light shale, 198; sand, 203; light shale, 210; sand, 215; light shale, 220; sand, 233; shale, 253; sand, 257; light shale, 261; (?), 265.

30.28.14.111	Johnson Cattle Co.	6,449 feet

Alluvium: soil, 3; boulders, 5; black mud, 23; brown mud, 32; gravel, 43; brown and green marl, 45; white and yellow marl. 53.
Purgatoire formation: brown sandstone, 79.
Morrison formation: green sandy shale and sandstone, 81; white sandstone. 93; red and green shale and thin sandstones, 102; white limestone, 108; green shale, 110; green sandstone, 117; green shale, 120; white clay, 122; gray sandstone, 127; white clay, 133; green shale, 134; white limestone, 136; white shale, 137; gray sandstone, 140; green shale, 143; sandstone, 145; green and white clay and shale with some limestone, 164; coarse-grained white sandstone, 174; white clay, 175; hard sandstone, 176; green sticky clay, 194; hard white sandstone, 202; white clay, 204; gray sandstone, 212; white clay. 216; green clay and shale, 223; sandstone, 230; green clay, 234; hard sandstone, 241; white and green clay, 250; green sandstone. 262; green sticky clay. 266; light-green sandstone with streaks of green clay, 300: dark-gray to green shale, 302; hard gray sandstone. 312; dark-gray shale, 320; dark-brown sandstone, 342; dark-gray shale, 348; orange feldspar sandstone, 359.
Brown-silt member of Morrison formation: brown clay and thin beds of white and pink quartz (agate bed ?), 367; sandstone and white quartzite, 394; brown shale and mud, 405; brown sandstone, 413; sandstone, 416; brown to gray sandstone, 421; sandstone, 428; brown shale, 431; sandstone, 432.

30.33.31.341	Measured section; see Plate 2, 31	
30.34.34.333	G. Everett	5,367 feet

Ogallala formation: soil and clay, 10; clay. 20; sand and gravel, 60; water sand, 80. *Bedrock:* dark shale, 91.

30.35.27.313	L. Bray test well; see Plate 2, 35	5,133 feet
31.28.34.144	W. J. Largent and Sons	7,022 *feet*

Surface: soil, 2; lava boulders in clay, 10.
Basalt: black lava, 58; brown lava, 68; blue lava, 85; black porphyry lava, Ill; blue lava, 119; crevice, 124; blue lava, 147.
Ogallala formation: coarse orange sand with some *lava* pebbles, 169.
Niobrara formation, undifferentiated: yellow to light-gray clay and shale, 261; light-gray limestone, 264; dark-gray shale, 272.
Fort Hays limestone member of Niobrara formation: light-gray limestone. 275; dark-gray shale, 279; light-gray to white limestone, 287; limestone, 301.
Carlile shale: black shale with thin limestone beds, 311; brown limestone, 324; black shale, 502.
Greenhorn limestone: black limestone, 530; gray hard limestone, 559.
Graneros shale: black shale, 595; brown to gray hard dense sandstone, 602; black shale, 670; shale and marl. 673.
Dakota group: shale and thin beds of dark sandstone, 677; light-gray sandstone, 692; light- to dark-gray hard sandstone, 728; (?), 741.
(Oil shows at 407-417, 610-620, and 670-673).

31.29. 2.121	Measured section; see Plate 2. 5a
31.29. 3.211	Measured section; see Plate 2, 4
31.29. 8.122	Measured section; see Plate 2, 1
31.29.16.310	Measured section; see Plate 2, 2
31.29.21.400	Measured section; see Plate 2, 3
3L29.23.440	Measured section; see Plate 2, 5b
31.30.30210	Measured section; see Plate 2, 7
31.31. 3.130	Measured section; see Plate 2, 8a
31.31. 9232	Measured section; see Plate 2. 8b
31.32.12.240	Measured section; see Plate 2, 11

LOCATION	OWNER	ALTITUDE
31.32.12.330	Measured section; see Plate 2, 10a	
31.32.20.210	Measured section; see Plate 2, 9	
31.34. 1.113, .2.224	Measured section; see Plate 2. 13	
31.34. 8.323	L. G. Howard	4,780 feet

Sloan Canyon formation of Dockum group (7): clay and shale, 30.
Travesser formation of Dock um *group:* red rock and shale, 80; water sand, 104.

31.36.34.144	Measured section; see Plate 2, 16	
32.29.31.111	W. J. Doherty (test)	6,486 feet

Surface: soil, 4; landslide rubble, 12.
Cathie shale (7): yellow clay. 27; shale. 32.
Greenhorn limestone: thin beds of dark-gray limestone and black shale, 55.
Graneros shale: shale with 2 thin bentonite beds, 72; black shale, 184.
Dakota group: sandstone and shale, 239; sandstone, 252; sandstone and shale, 287; silt and sandy shale, 318; sandstone, 393.
Morrison formation: green and red clay, 402; white sandstone, 4041/2; red and green clay, 406; sandstone, 415; in shale at 415.

32.30.30.323	Measured section; see Plate 2, 6	
32.31.26.314	W. Burchard	5,883 feet

Dakota group: no record. 80; sandstone, 200.
Morrison formation: shale, 230; water sand, 241.

32.32.36.224	Measured section; see Plate 2, 10b	
32.34.20.320	Measured section; see Plate 2, 12	
32.35.32.210	Measured section; see Plate 2, 14	
32.36.31.240	Measured section, Black Mesa; see Plate 2, 15	

PART II

VOLCANIC ROCKS OF
DES MOINES QUADRANGLE

Abstract

Late Cenozoic volcanic rocks cover about 725 square miles of Union County. On geomorphic criteria, the basalts have been divided by earlier workers into three major groups: from oldest to youngest, the Raton, Clayton, and Capulin basalts. The Red Mountain dacites, pre-Clayton post-Raton local silicic differentiates found in several vents in Colfax County, have as their only possible representative in Union County, Sierra Grande, the largest volcano in this region.

The Des Moines 15-minute quadrangle and vicinity were mapped in detail. The stratigraphic sequence of basalts from 11 Clayton vents and 5 Capulin vents was determined. Petrographic, petrologic, paleomagnetic, and geomorphologic methods were used to correlate the volcanic rocks over the remainder of the county, because stratigraphic relationships could not be determined across the covered areas.

The volcanic sequence in Des Moines quadrangle began with the outpouring of the extensive Raton basalt sheets that now cap the high mesas. No representative of the younger sequence of Raton basalts recognized to the west of Union County is present.

A time interval long enough to lower stream gradients several hundred feet along the Dry Cimarron River intervened prior to the initial eruption of the Folsom sequence of Clayton basalt. Emery Peak, East Emery Peak, Big Hill, and East Big Hill volcanoes erupted nearly simultaneously and thoroughly blocked the drainage of the Dry Cimarron River 3 miles east of Folsom, forming a lake. Into this lake, in succession, flowed basalt from Augite Vents and Purvine Mesa, tuff from Mud Hill and Great Wall, and basalt from Bellisle Mountain (a vent 15 miles west of Union County). Sheets of lava from Robinson Mountain and finally from Jose Butte, both lying just west of Union County, completed the filling of the lake basin.

The pyroxene andesite which forms the main mass of Sierra Grande, based on amount of cone erosion and petrologic inferences (similarity to the Red Mountain dacites of Colfax County), is believed to have erupted prior to the Folsom sequence of Clayton basalt.

The Dunchee Hill basalt, petrologically similar to the Folsom sequence, is believed, because of the destruction of its cone, to be an early member of the Clayton basalts.

The Dry Cimarron River then breached the Folsom-sequence lake deposits and regained its original level in the lake region. Farther upstream, near the Colfax County line, the stream level was lowered about 100 feet below the Clayton level. The Folsom vents, a few miles west in Colfax County, erupted and covered the pre-Folsom Man valley. This vent is here included as the earliest representative of the Capulin basalts (of Collins).

Capulin Mountain, a National Monument, is a well-preserved ex-

ample of a cinder cone. It and its associated flows are the type Capulin basalt (of Collins) and exhibit many typical volcanic features: cinder blanket on downwind side, bombs, pressure ridges, squeezeups, natural levees, tunnels, etc. Based on radiocarbon dates in the alluvial stratigraphy at the type Folsom Man locality a few miles west of Union County (Folsom Man State Park), this volcano erupted after Folsom Man occupation (ca. 8000 B. C.) and before 2500 B. C. The younger Capulin-age vents—in stratigraphic order, Twin Mountain, Purvine Hills (probably contemporaneous fissure vents), and Baby Capulin (a perfect cinder cone)—could not be related to the radiocarbon dates, although they, too, probably erupted prior to 2500 B. C.

Undifferentiated Clayton basalt caps broad mesas throughout central Union County. Individual sheets were named for ease of discussion, although they are petrographically nearly identical: Carrizo, Herringa, Clayton Mesa (the original type Clayton basalt of Collins), Apache, Seneca, and Gaps flows. The general surface on which these basalts rest, when projected westward, matches fairly closely the surface across which the younger Raton basalt flowed. Thus, the main sheets of undifferentiated Clayton basalt may have erupted at the same time as the younger Raton episode of Colfax County. Chemical analyses support this view.

Surmounting these Clayton basalt sheets are numerous younger Clayton vents that may be correlatives of the Folsom sequence.

The Don Carlos Hills, 14 alined vents and flows, surmount a basalt-capped plateau (Raton?) in southwestern Union County. The sequence resembles the Clayton basalts of the remainder of the county. Field paleomagnetic studies were made in an attempt to correlate sequences of basalts. Inconsistency of the direction of magnetization within a single flow made correlation impossible.

Eight new chemical analyses supplement earlier analyses; when used with fusion-index studies, petrographic data, volumes of eruption, and derived data (norms, etc.), distinct trends in differentiation can be shown. The initial Raton eruptions of large volumes of tholeiitic basalt with only traces of nepheline were succeeded by the less silicic late-Raton basalts, which are nearly identical in composition to the broad sheets of the later (?) undifferentiated Clayton basalts of central Union County. The late-Raton basalts of Colfax County were followed by the silicic Red Mountain dacites, of which the pyroxene andesite of Sierra Grande may be a late member. These were followed by the nepheline basanites and haüynite-nepheline basalts of the Folsom sequence, and by the local flows and vents of Clayton age resting on the broad Clayton basalt mesas. Thus, a trend of decreasing silica can be shown, the silicic differentiates being the Red Mountain dacites and associated rocks of Colfax County and Sierra Grande of western Union County.

The latest eruptions, the Capulin basalts, have the chemistry of the initial Raton magma but, unlike the Raton magmas, are of the cinder-cone rather than the fluid type.

Introduction

PURPOSE AND SCOPE OF REPORT

This study was designed to decipher the stratigraphic sequence of the extensive volcanic rocks of Union County. Because of the large number of vents and lava flows in Des Moines quadrangle (15-minute quadrangle in the northwest corner of Union County), this quadrangle was selected for detailed study. Baldwin mapped the remainder of the county by reconnaissance methods. Only the detailed volcanic geology of Des Moines quadrangle is included in this part of the report, the prevolcanic geology being included in part I.

Field work in Des Moines quadrangle and vicinity was completed during the summer of 1954. Short trips to the county for sampling were made during the succeeding summers, the most extensive being the paleomagnetic reconnaissance during the summer of 1957 by Baldwin, Longgood, and Muehlberger. Laboratory studies continued sporadically until December 1958.

Baldwin (part I) has summarized the major aspects of the volcanic sequence in Union County. This report (part II) furnishes detailed information for Des Moines quadrangle and vicinity; field, petrographic, and magnetic data for the remainder of the county; chemical and petrologic inferences; and a geologic history from the inception of Raton volcanism to the present. Petrographic studies of volcanic rocks in Union County outside Des Moines quadrangle are largely based on spot samples collected by Baldwin during his mapping and by Baldwin and Muehlberger during their paleomagnetic reconnaissance; thus, the results are necessarily incomplete.

A few of the vents and basalt-capped mesas do not have names in common local use. These are given names in this report to facilitate reference. Localities are referred to according to township, range, and section numbers, and location within the section, following the procedure outlined by Baldwin (p. 4-5).

ACKNOWLEDGMENTS

This project was initiated by E. Callaghan, former director of the New Mexico Bureau of Mines and Mineral Resources. His advice and Bureau support have made this work possible. The paleomagnetic study was supported in large part by a grant from the Geology Foundation, The University of Texas. G. E. Adams assisted during the field study of Des Moines quadrangle; T. E. Longgood, Jr., during the paleomagnetic reconnaissance. D. C. Mason, W. B. Klemt, and L. T. Rogers aided in various phases of the laboratory study. Permission to publish the aerial photographs was given by the United States Department of Agriculture, Soil Conservation Service. To each of these individuals and organizations, and to the many ranchers who permitted free access to their land, the author is exceedingly grateful.

Volcanic Rocks of Des Moines Quadrangle and Vicinity

RATON BASALT

Raton basalt forms the caprock of the high mesas of Des Moines quadrangle. Oak Canyon (Chicorico) Mesa (31.28-32.28), covering much of the northwest corner of the quadrangle, is the largest single area of outcrop. The remaining outcrop areas are Negro Mesa (32.29.27-28) and, to the east, Devoy Peak (31.30.6); the mesa underlying Emery Peak (31.29.33) and the unnamed mesa (31.30.28) farther east along the eastern margin of the quadrangle; the platform northwest of Capulin Mountain; and the small outlier (29.28.2.11) to the east of Capulin Mountain. These basalt caps are erosional remnants of a single, continuous sheet that extended from this region westward for nearly 40 miles to the vicinity of Raton, New Mexico, and Trinidad, Colorado. In this 40 miles, the elevation of the mesa top drops nearly 3,000 feet from west to east.

These basalts lie with apparent conformity on the Ogallala formation (pl. 9). Good exposures of the contact zone can be seen in the gravel pits east and south of Capulin Mountain and in the roadcuts along State Highway 72 on the southeast edge of Johnson Mesa. Elsewhere the contact, as well as the entire thickness of the Ogallala, is covered by slump blocks of Raton basalt. The basalt is dark to light olive gray, fine grained, and compact to vesicular, only small olivine phenocrysts being of common occurrence. At least 2, and commonly 3 or more, flows can be identified in a cliff exposure. The eroded edge is marked by a scarp that has retreated from the main mesa edge. Columnar jointing is common. Cross-sections through the eroded ends of flow units are well displayed at many places, especially northwest of Capulin Mountain and in the roadcuts of State Highway 72 (31.27.21.420) on the edge of Johnson Mesa, a few miles west of Des Moines quadrangle. Platy flow structure can be recognized easily in the field because of abundant elongated vesicles. Total thickness ranges from 10 feet in the southern outcrops to 50 feet in the eastern edge and nearly 100 feet along the north edge of Oak Canyon Mesa.

Because of insufficient topographic data to extend Lee and Mertie's (1922) topographic subdivisions of the high basalt-capped mesas, Collins (1949, p. 1026) has grouped their first and second eruptive periods into the Raton basalt. Based on petrographic correlations, Stobbe (1949, p. 1066) believes that representatives of only the first eruptive period of Lee and Mertie are present in this region. The Raton basalts of Des Moines quadrangle are topographically continuous with the older Raton basalts mapped by Wood (1953) in eastern Colfax County (Qb^1 of Lee and Mertie).

Olivine phenocrysts total nearly 10 percent of the rocks, although augite and occasional plagioclase phenocrysts are present as well. In some specimens, small flakes of biotite constitute a minor part of the rock. The olivine, commonly in grains 0.3 to 0.6 mm in diameter, with some as large as 1.0 mm, is partially to completely altered to iddingsite and magnetite. Along the south *edge* of the mesa underlying Emery Peak, the olivine is altered to serpentine minerals. Stobbe (1949, p. 1056) reports serpentine alteration at two points in Colfax County. The groundmass is composed of about equal amounts of tiny equant grains of augite and magnetite, and slightly more abundant labradorite needles as much as 0.1 mm long. This groundmass constitutes nearly 90 percent of the rock on Devoy Peak, according to Stobbe (1949, p. 1052). Under the microscope, the flow structure is shown by alined feldspar needles in the groundmass. Biotite flakes were observed in specimens from Emery Mesa and Negro Mesa, although the specimens from Emery Mesa more nearly resemble those from Devoy Peak. Vesicle fillings and surface crusts of calcite are present in places.

Stobbe (1949, p. 1057) notes that the older Raton basalts are fine to coarse grained and holocrystalline, with sparse olivine insets, and that the younger Raton basalts are hypocrystalline, with pyroxene and olivine insets.

Quartz inclusions with reaction rims of pyroxene and plagiodase(?) were observed in a thinsection from the south edge of Emery Mesa. In addition, Stobbe (p. 1066) reports quartz inclusions from Devoy Peak.

CLAYTON BASALT

FOLSOM SEQUENCE

Introduction

It is possible to determine the stratigraphic succession of the Clayton basalts that lie within the drainage basin of the Dry Cimarron River. These are found in the vicinity of Folsom in the northwest corner of Union County and in the adjacent portion of northeast Colfax County. Nine of the eleven source vents in the sequence are feldspathoidal and contain nepheline; a few also contain haüynite. The other two are normal basalts, with only a trace of feldspathoids.

The initial volcanic events in this sequence were eruptions from Emery Peak and East Emery Peak. Nearly simultaneously, though slightly later, Big Hill and East Big Hill erupted. These vents lie along a line that strikes slightly north of west. Flows from these vents completely blocked the ancestral Dry Cimarron River. A lake formed upstream from this lava dam, into which successive lava flows and sedimentary material were deposited. Lava from the Augite Vents and Purvine Mesa basalt, the only nonfeldspathoidal basalts in this sequence, form the oldest exposed rocks on the lake floor. Tuff, correlatable with the Mud Hill-Great Wall cinder cone and fissure vent, was then deposited. Overlying this are deltaic sands and gravels capped by the eastern tip of the 20-mile-long basalt flow from Bellisle Mountain. Successively overlying this flow with slight topographic breaks are basalts from Robinson Mountain and Jose Butte. Figures 16-18 summarize this information in pictorial form.

This series of closely spaced volcanic events was followed by an interval of quiet, during which the Dry Cimarron River once again integrated its drainage system and continued downcutting. The eruption of the very small Folsom Vents opened the later events grouped in this report with the Capulin basalts. This eruption occurred long after the Clayton sequence of events, which concluded in the Jose Butte eruption.

Emery Peak-East Emery Peak and Big Hill-East Big Hill

Although these vents are listed in the probable order of eruption (by pairs), the time interval *between* them may well have been on the order of weeks rather than years or hundreds of years. Lava from Big Hill lies on Emery Peak basalt, with a thin layer of deformed sediments

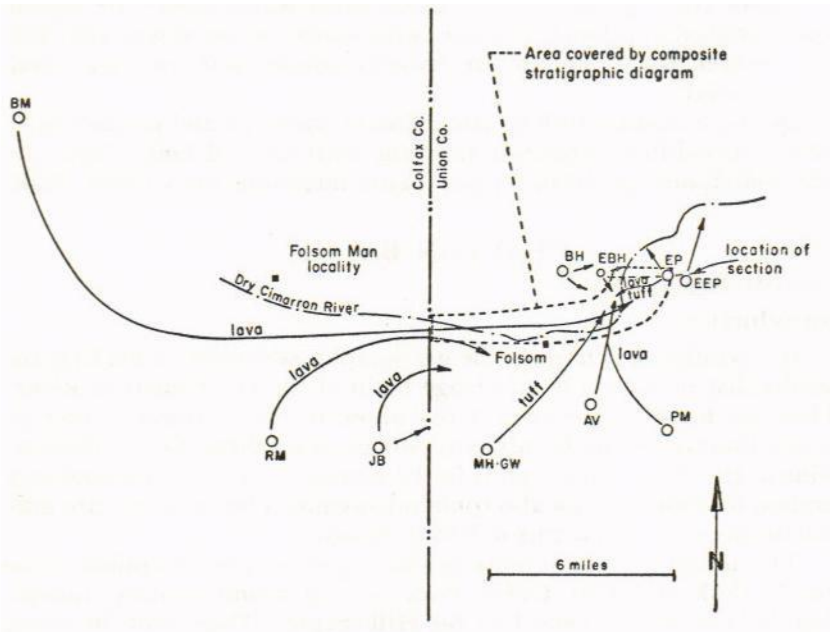


Figure 16

SOURCE AND GENERAL DIRECTION OF MOVEMENT OF LAVAS OF FOLSOM SEQUENCE OF CLAYTON BASALT, DES MOINES QUADRANGLE

Sequence: EP, Emery Peak; EEP, East Emery Peak; BH, Big Hill; EBH, East Big Hill; AV. Augite Vents; PM, Purvine Mesa; MH, Mud Hill; GW, Great Wall; BM, Bellisle Mountain; RM, Robinson Mountain; JB, Jose Butte. Stratigraphic diagram, see Figure 18; generalized section, see Figure 17.

Plate 9

RATON BASALT ON BEDDED CINDERS

Both resting on surface cut across Ogallala formation. Outlier east of Capulin Mountain at 29.28.2.111.

A

B

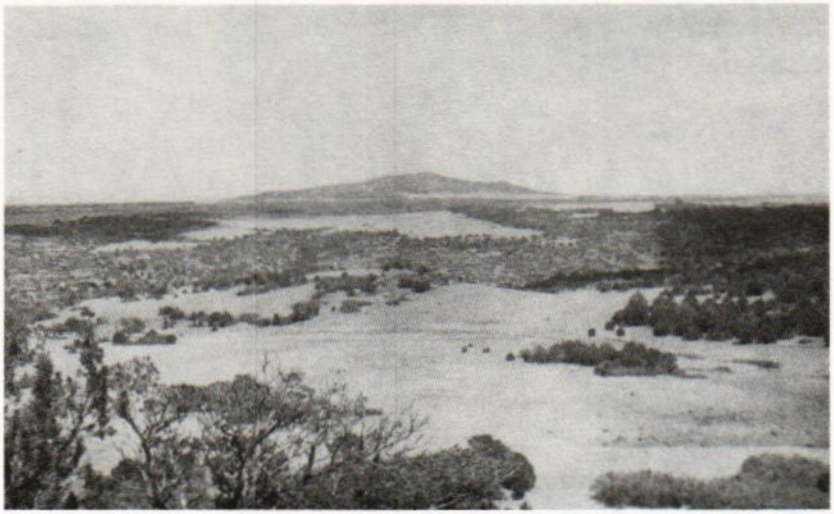
Plate 10

VOLCANIC FEATURES OF DES MOINES QUADRANGLE

A. North flank of Mud Hill cone. Clayton basalt, showing stratification of pyroclastic material that forms the cone. Locality 30.28.28.440.

B. Cinder pit at east base of Capulin Mountain. Capulin basalt, showing stratification of pyroclastic material on downwind side of cone. Man at base of slope for scale. Locality 29.28.3.10.

A



B

Plate 11

VOLCANIC AND STRUCTURAL FEATURES OF DES MOINES QUADRANGLE

A. View east along easternmost fissure vent of Purvine Hills. Capulin basalt, showing spatter rims (see pl. 12 for detail) and median trough out which lava flowed away from viewer. Edges of flow in middle distance outlined by dark vegetation bands which extend toward head of Briggs Canyon, into which the lava poured. Gaylord Mountain (Clayton basalt younger than Purvine Mesa basalt of Folsom sequence) on right skyline. Dakota formation forms rim of Briggs Canyon and surface of plains to skyline. Locality 30.29 from 22.333 (Purvine Hills fissure) to 23.440 (Gaylord Mountain).

1%. View east toward Devoy Peak (on skyline). Graben in middle distance (downthrown about 40 feet) outlined by dark vegetation on upthrown sides. Vegetation mostly restricted to Dakota sandstones. Devoy Peak is capped by outlier of earlier Raton basalt. View east from 31.29.9.133.

Plate 12

DETAIL OF SPATTER RIM

Capulin basalt. Closeup of south spatter rim of central fissure vent of Purvine Hills. Viscous nature of lava is shown by flattened shape of bombs. Location 30.29.28.124.

Plate 13

BABY CAPULIN BASALT

Waterfall over Baby Capulin basalt ((:apulin basalt). At this point, basalt of Twin Mountain and/or Purvine Hills lithology is seen near water level. Emery Peak basalt (Clayton basalt) forms ridge in background. View north from 31.29.29.424.

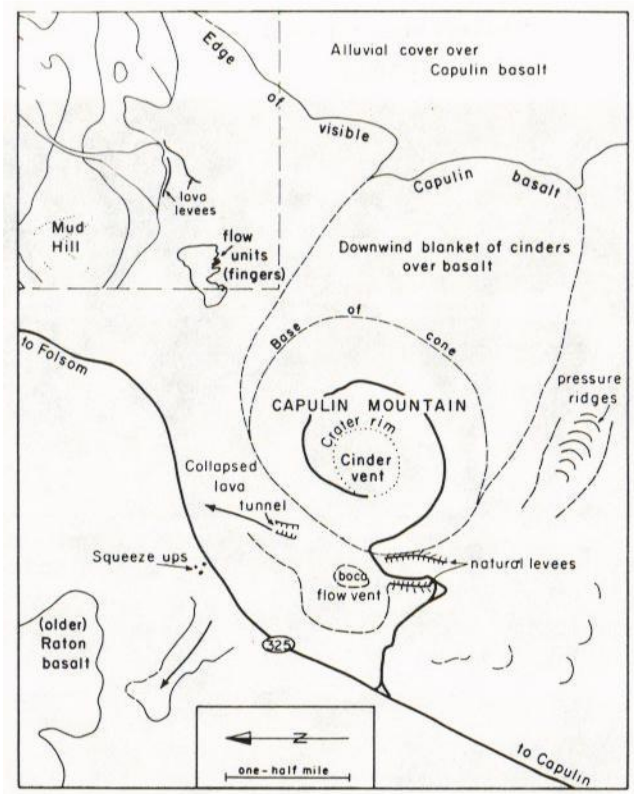
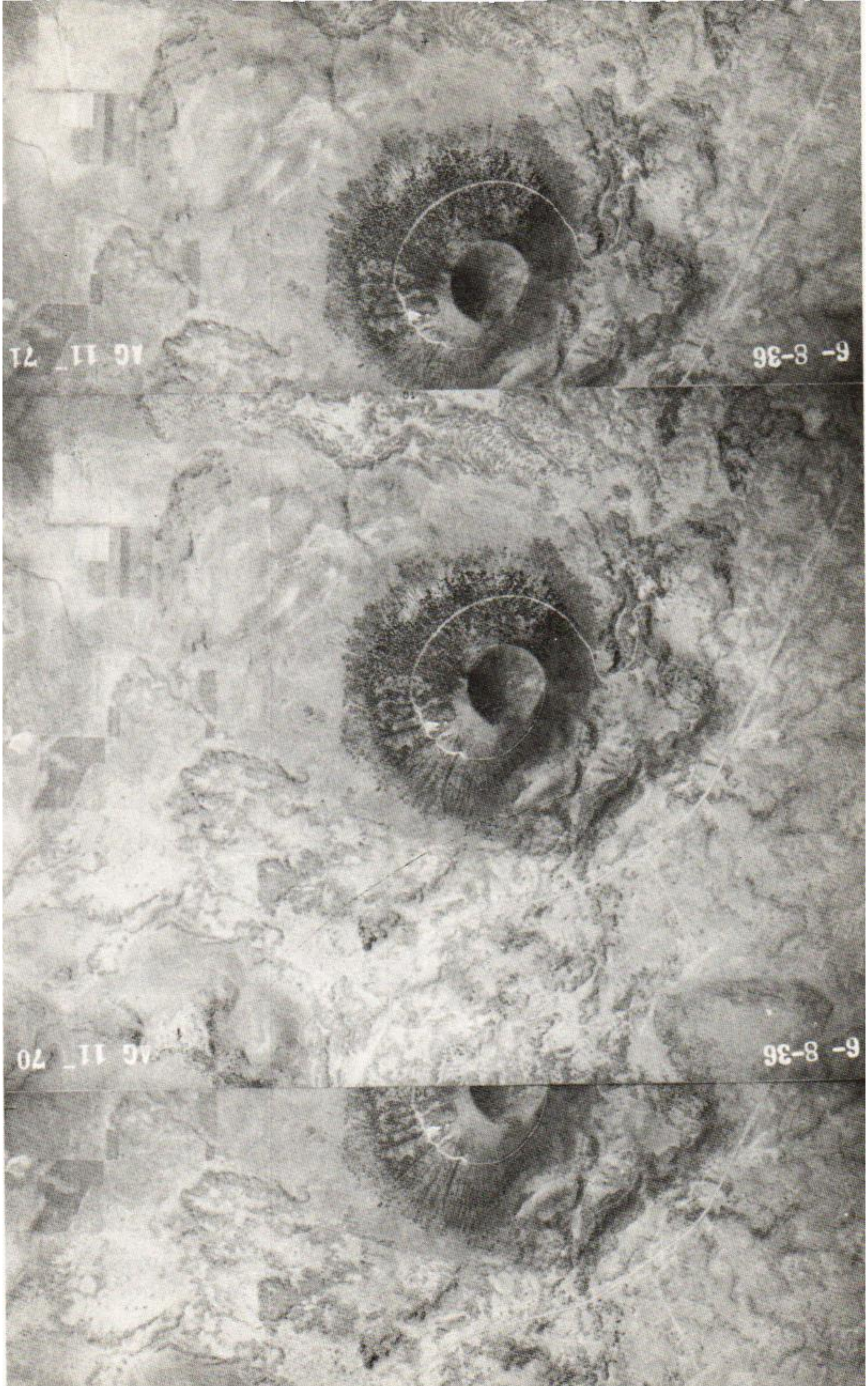


Plate 14

STEREOSCOPIC TRIPLET OF CAPULIN MOUNTAIN AND VICINITY

Soil Conservation Service photos.


AG 11 71
6- 8-36
AG 11 70
6- 8-36

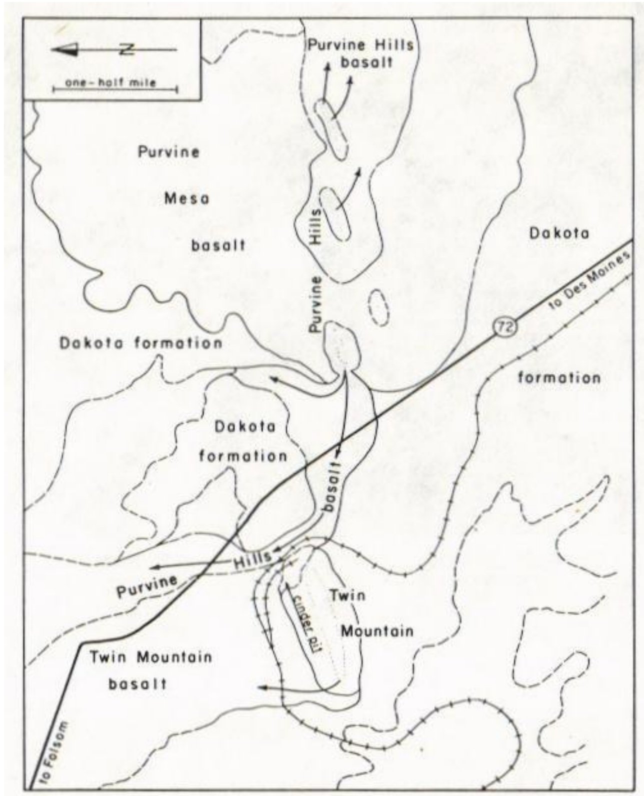


Plate 15

STEREOSCOPIC TRIPLET OF TWIN MOUNTAIN, PURVINE HILLS, AND VICINITY Soil Conservation Service photos.


6- 8-36
AG 12_103
6- 8-36
AG 12_102

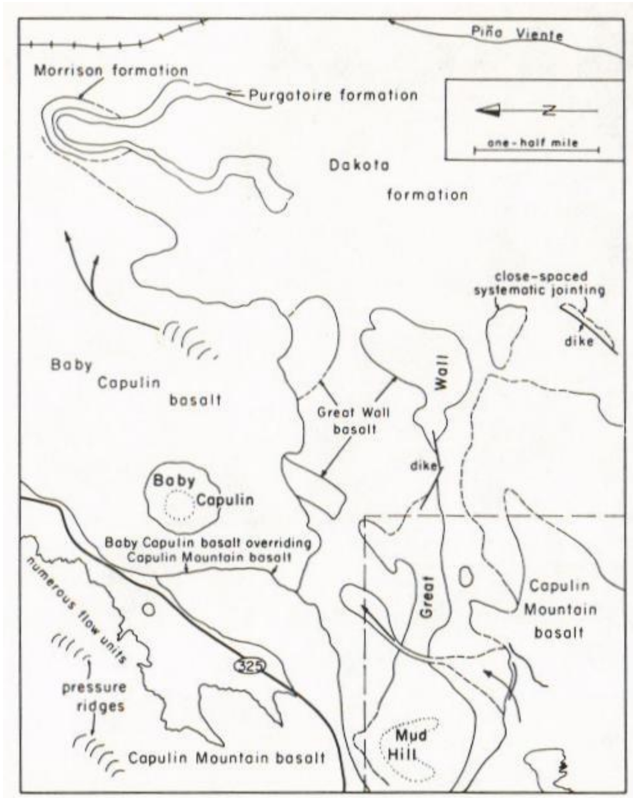


Plate 16

STEREOSCOPIC TRIPLET OF BABY CAPULIN, MUD HILL—GREAT WALL, AND VICINITY

Soil conservation Service photos.


6- 8-36
AG 12 11


6- 8-36
AG 12 10

Plate 17

CAPULIN MOUNTAIN

View northeast, showing Capulin village in middle distance, asymmetrical shape of (:apulin Mountain (east side [right) was, and still is, on downwind side), and flow source from high area to west of cinder cone. Photo by Brewster Baldwin.

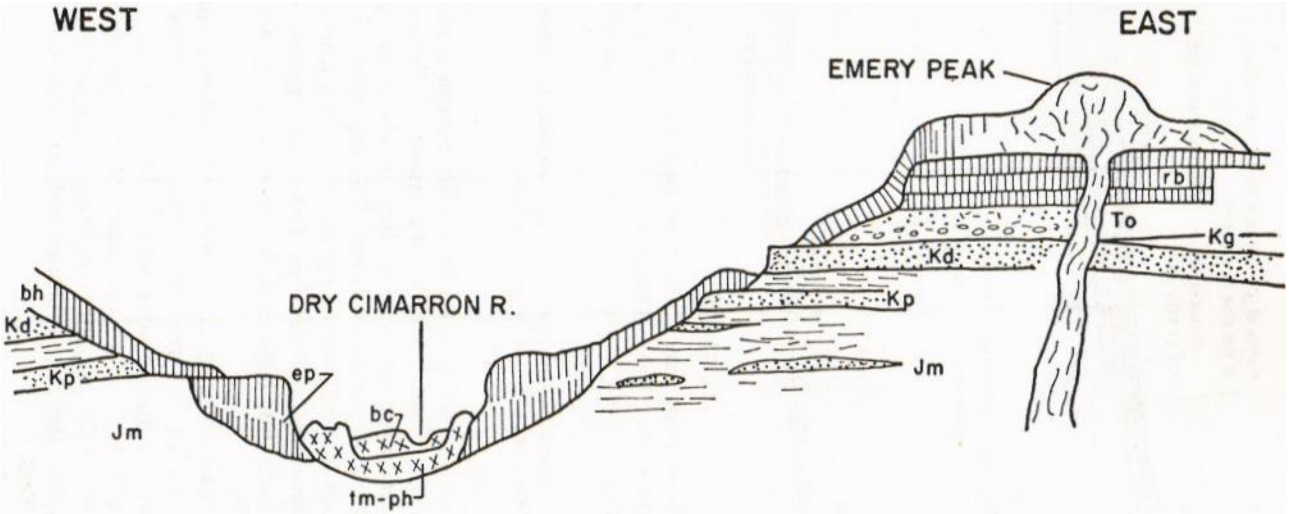


Figure 17

GENERALIZED SECTION ACROSS DRY CIMARRON RIVER AT THE GORGE DAMMED BY EMERY PEAK BASALT, 3 MILES DOWNSTREAM FROM FOLSOM, NEW MEXICO.

Symbols, from oldest to youngest: Jm, Morrison formation; Kp, Purgatoire formation; Kd, Dakota formation; Kg, Graneros shale; To, Ogallala formation; Rb, Raton basalt; ep, Emery Peak basalt; bh, Big Hill basalt; tm-ph, undifferentiated Twin Mountain–Purvine Hills basalt; bc, Baby Capulin basalt.

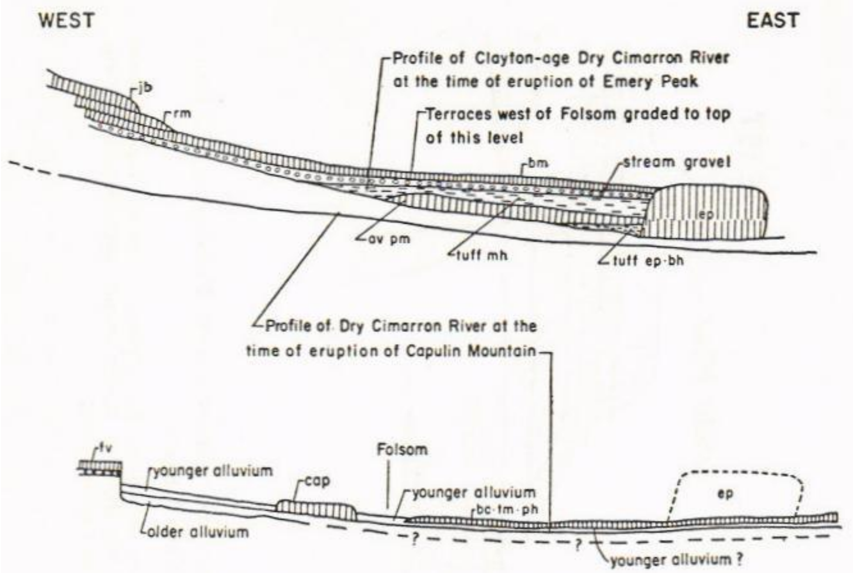


Figure 18

COMPOSITE STRATIGRAPHIC DIAGRAM ALONG THE. DRY CIMARRON RIVER FROM FOLSOM VENTS TO EMERY PEAK BASALT DAM, SHOWING FOLSOM SEQUENCE OF CLAYTON BASALT (ABOVE) AND SEQUENCE OF CAPULIN BASALT EVENTS (BELOW)

Symbols same as in Figures 16 and 17, with the following additions: fv, Folsom Vents basalt; cap, Capulin Mountain basalt.

between. This relationship can be seen in a cliff exposure north of the Dry Cimarron River about 1.5 miles northwest of Emery Peak (31.29.31.232). Elsewhere, when in contact, they appear to lie side by side, suggesting nearly simultaneous eruption. The identical character of the rocks and the fact that all four of the vents lie on a line 4 miles long suggest nearly simultaneous eruption. Other alinements, which have had successive eruptions, have a different mineralogy for each different eruptive epoch.

Lava from Emery Peak (31.29.33.23) moved north and west into the Dry Cimarron River valley, whereas that from East Emery Peak (31.29.34.32) moved north into the same valley. The large, low mesa, illustrated by Collins (1949, pl. 2), in the valley of the Dry Cimarron River, about 200 feet above the present river level, is capped by basalt. The observed topographic and flow relations indicate that this basalt came from East Emery Peak.

Hand specimens are dark gray, porphyritic, and contain a few percent of small yellowish-green olivine phenocrysts. Columnar jointing is well developed, and numerous elongate vesicles give a prominent layering in the columns.

Under the microscope, small partially serpentinized olivine (15 percent) and augite (5 percent) form phenocrysts that are 0.1 to 0.2 mm in size. (The only serpentinized Raton basalt found in Des Moines quadrangle is that underlying Emery Peak and East Emery Peak. Either the Raton basalts of this area were from a local unrecognized vent, or its olivine was serpentinized later.) A single large (2 mm) embayed and partially altered plagioclase crystal was found in one thinsection. Twin lamellae indicate a composition of An_{27}.

The groundmass has the following estimated composition (in percent); small augite crystals, 30; oligoclase (An"), 25; nepheline, 20; scattered magnetite grains, 5.

Big Hill (31.28.36.140) is a deeply eroded cone composed of tuff, spatters, and minor amounts of lava. East Big Hill (31.29.31.240) is a small tuff vent with very little topographic expression and is named herein for convenience of discussion. Hand specimens are nearly indistinguishable from Emery Peak-East Emery Peak basalt. The main differences are that Big Hill basalt has olivine that is altered to iddingsite rather than serpentine minerals, and that it contains small hauynite crystals. Under the microscope, other variations can be seen: rare, partially resorbed hypersthene rimmed with augite; zoned augite crystals that are pleochroic lemon yellow to colorless; and hauynite (nearly 10 percent in some specimens) in embayed crystals, 0.2 to 0.4 mm long, with reticulated centers caused by alined grains of magnetite, and clear rims. These differences cause this rock to be placed in a slightly less silicic, more soda-rich category labeled hauynite-nepheline-basalt, whereas the Emery Peak-East Emery Peak basalts are classified as nepheline basanites, according to the classification of Johannsen (1939).

Augite Vents

A pair of deeply eroded small cinder cones (30.28.34.110; 30.29.19.310) about 2 miles south of Folsom have erupted an augite-rich basalt characteristic of these vents; thus, the origin of their name. Although largely buried by younger basalts, exposures of augite basalt are found extending northeast from the vent to the vicinity of the Emery Peak basalt dam. North of this flow, volcanic ash (probably deposited behind the dam from Emery Peak or Big Hill eruptions) has been deformed against the resistant buttress of the Emery Peak basalt dam. This volcanic ash is well exposed in the roadcut and gully where New Mexico Highway 325 passes through a notch in the Emery Peak basalt dam.

The characteristic feature of this basalt is the presence of augite phenocrysts standing in relief on weathered surfaces. Hand specimens are medium dark gray (N4), porphyritic, and vesicular. Columnar jointing is prominent, as are elongate vesicles.

A thinsection from the western vent is highly vesicular and contains subequal amounts of olivine and augite phenocrysts (each totaling about 20 percent of the rock) ranging in size from 0.2 to 1.0 mm. The olivine is euhedral and almost completely altered to iddingsite and magnetite. The augite is commonly in groups or clusters (glomerocrysts) and is euhedral and unaltered. The groundmass is nearly opaque, with innumerable tiny magnetite grains resolvable only under high magnification. Small needles of feldspar are visible under moderate magnification. Stain tests revealed the presence of a trace of feldspathoids (probably nepheline) in the groundmass. Chalcedony fills many of the vesicles.

Purvine Mesa Basalt

Several square miles of the Purvine ranch east of Folsom are underlain by basalt identical in hand specimen to that from the Augite Vents. Only fusion index suggests that the augite basalt flow impounded behind the Emery Peak dam may actually be from Purvine Mesa. They may both be parts of the same eruptive epoch.

Fresh specimens are medium dark gray (N4), holocrystalline, porphyritic, and slightly vesicular. The olivine phenocrysts (15 percent) are yellow green and slightly iridescent, commonly embayed, and smaller in average size (0.2 to 0.6 mm) than the augite phenocrysts; they have a thin rim of iddingsite alteration. Hand specimens characteristically show the augite phenocrysts (5 percent) in relief on weathered surfaces. The augite crystals are euhedral, up to 2 mm long, and tabular to equant; the largest are zoned. The groundmass is holocrystalline and composed of tiny plagioclase needles (An_{55}?, 30 percent), tiny augite grains (40 percent), and tiny grains of magnetite (10 percent).

Mud Hill-Great Wall

This eruptive group consists of an ash cone with a fissure flow vent extending east for nearly a mile. The cone, Mud Hill (30.28.34.1; pl. 10A), is composed mostly of ash in equant fragments 1 cm across, with minor amounts of coarser material. The fissure vent, herein named Great Wall, consists of a dike core extending east from Mud Hill (to 30.28.35.21), and associated minor ash cones. Flow rock extends north from the fissure in short tongues. The larger fragments from Mud Hill are black glass, with 10 to 20 percent small olivine phenocrysts partially or completely altered to magnetite and iddingsite. Under very high power, the glass is found to contain innumerable tiny grains of magnetite which, in the brown specimens, has probably been altered to hematite.

The ash is generally brown and pumiceous, with no observable phenocrysts. Each ash particle is lightly cemented to its neighbors by calcite. Successive layering and crosscutting relationships can be seen in the walls of the cone, caused by changes in the position of the orifice and erosion of older portions of the vent.

The Great Wall flow types are small in areal extent and are micro-crystalline hauynite-nepheline basalts. Phenocrysts are composed of small subhedral olivine (15 percent), 0.2 to 0.4 mm long, with minor iddingsite rims, and haiiynite (5 to 10 percent), in 0.1-mm equant and 0.3-mm elongate embayed crystals. A minor amount of a tabular, yellow, isotropic mineral with an index below balsam (cancrinite?) is also present. In some slides, this mineral appears to be an alteration of feldspar, possibly anorthoclase (based on the presence of the grid pattern typical of anorthoclase). The groundmass has the following estimated composition (in percent): augite (aegirine-augite), 35; nepheline (with minor plagioclase?), 40; magnetite, 5. Calcite. is present, filling both vesicles and interstices.

Bellisle Mountain

Bellisle Mountain (31.26.16-17) is a small volcanic peak 10 miles west of Union County on Johnson Mesa in northeastern Colfax County. Lava from this source moved east a distance of 20 miles to the Emery Peak basalt dam. The position of the flow remnants indicates that the lava flowed down an old course of the Dry Cimarron River valley, probably before the basalt dam had been breached. Extensive terrace benches graded across this basalt level are especially prominent in the vicinity of the Folsom Man locality just west of the county line (see fig. 28).

Specimens studied are from Union County or immediately adjacent to it and are medium- to dark-gray holocrystalline porphyritic basalts. The basalt is a single flow 15 to 20 feet thick, with well-developed platy flow structure. One sample contained a few scattered, small, partially resorbed haüynite phenocrysts. Olivine phenocrysts are present in all specimens; they are generally small (0.1 to 0.5 mm) and have an iddingsite rim. Augite, possible aegirine-augite, is the only other common phenocryst and may be partially resorbed. The augite is 0.1 to 0.2 mm in size and is pleochroic green to brown. These phenocrysts total 15 percent of the rock, with the olivine twice as abundant as the pyroxene.

The fine-grained groundmass has the following estimated composition (in percent): pyroxene (with faint yellow-green pleochroism that suggests aegirine-augite), 50; nepheline, 20; magnetite, 10; glass, less than 5.

Robinson Mountain

Robinson Mountain (30.27.27.200), a prominent, deeply eroded vent, is about 5 miles west-northwest from Capulin Mountain and 3 miles west of the Union County line. Only a narrow band of Robinson Mountain basalt crops out from under the blanket of later Jose Butte basalt in Union County (pl. lb). The outcrop belt lies along the northern and eastern rim of Jose Butte basalt. The easternmost tongue of outcrop is well exposed along the north wall of a small valley about 1 mile west of Folsom; Capulin Mountain basalt forms the south wall. Here the basalt is less than 10 feet thick, and columnar jointing and elongate vesicles are well developed.

A single thinsection from this easternmost tongue was studied. The specimen is a medium dark-gray (N4) holocrystalline porphyritic vesicular olivine basalt. The small olivine phenocrysts (10 percent) are rimmed with light iddingsite alteration and range in size from 0.2 to 0.5 mm. Abundant plagioclase (An_{55}) laths (55 percent), 0.2 to 0.4 mm long, and less abundant anhedral augite (30 percent) give a well-developed ophitic texture. Some of the augite is slightly pleochroic, suggesting that it may be aegirine-augite. Small grains of magnetite (5 percent) and a trace of nepheline complete the mineralogy of the sample.

Stobbe (1949, p. 1062) describes a nepheline basalt without feldspar from Robinson's Peak (Robinson Mountain). She states that "the rock is composed of nepheline, haüyne, pyroxene, olivine, magnetite, and, in the vesicles, glass and carbonate." Stobbe's specimen may be from either Jose Butte or possibly Bellisle Mountain basalt, both of which more nearly match her description. Reconnaissance studies could easily miss the subtle topographic relationships between the basalts from these source vents.

Jose Butte

Jose Butte (30.27.24) lies along the Colfax-Union County line, and basalt from it covers several square miles northwest of Capulin Mountain (pl. lb). Both Jose Butte and Robinson Mountain have built their cones on a mesa capped with Raton basalt. The thickness of the basalt is unknown, although topographic breaks along the margin indicate at least 20 feet.

The rock is a medium-gray (N5) holocrystalline porphyritic olivine basalt. Olivine phenocrysts constitute nearly 15 percent of the rock; they are subhedral to euhedral, 0.2 to 0.5 mm long, and have minor rims of iddingsite alteration. The fine-grained groundmass has the following estimated composition (in percent): augite (in part, aegirineaugite?), 30; plagioclase (anorthite content unknown, probably near An_{55}), 25; magnetite, 10; yellow-stained pyroxene(?), 10; nepheline, 5; calcite (vesicle and fissure filling), 5.

BASALTS OF UNKNOWN STRATIGRAPHIC POSITION

Sierra Grande

By far the largest and most imposing volcanic mass in Union County is Sierra Grande (N½ 28.29; S½ 29.29). Nearly 8 miles in diameter and with its summit at 8,720 feet above sea level, it rises about 2,100 feet above the surrounding plains. Only a single geologic traverse was made over the peak—up the northwest flank and down the south flank. This traverse demonstrated that the main bulk of the vent is a pyroxene andesite or olivine-free basalt, depending on terminology (Whitman Cross in Clarke, 1900, vs. Stobbe, 1949). Parasitic cones and flows on the east and north flanks contain small amounts of olivine and are classified as basalts, although the low index of refraction suggests that they are more silicic than the typical basalts of this region.

Scattered hypersthene phenocrysts (few percent) up to 1.0 mm in diameter have pale red-brown to pale-green pleochroic cores which had been corroded prior to the deposition of clear, nonpleochroic, optically continuous rims (enstatite?). Inclined extinction on some specimens indicates that they are clinohypersthene with nonpleochroic rims of clinoenstatite(?). Glomerocrysts of augite (10 percent) 4 mm in length are composed of numerous individuals 0.1 to 0.2 mm long and one-half as wide. Occasional small hypersthene crystals are found in these aggregates. A single corroded plagioclase phenocryst (composition unknown) 1.7 mm long was found. The groundmass has a trachytic texture and is composed of small plagioclase needles (An_{40}, 60 percent), small equant euhedral augite (10 percent), magnetite grains (5 percent), and partially devitrified glass (15 percent). The paragenesis of the pyroxenes of this rock is as follows: growth of large hypersthene, corrosion of rims and growth of magnetite along crystallographic planes, growth of enstatite rims, slight corrosion, and growth of groundmass augite.

Volcanic breccias are present around the crest (29.29.32). True craters are no longer present, although the areas northeast and southeast from the U. S. Coast and Geodetic Survey triangulation station may be parts of the crater rim, and the ridge to the east may be a slightly later cone in the larger crater. These cirquelike depressions may possibly be glacial in origin, although there are no cirques reported for so low an elevation from nearby glaciated regions.

Specimens collected on the south flank differ from those of the north flank in that the former show an increase in size of plagioclase crystals and a decrease in anorthite content ($An_{25\text{-}30}$) of the plagioclase. In addition, there is a slight increase in the fusion index of the rock as a whole (1.550 vs. 1.535).

Collins (1949, p. 1030) notes olivine basalt and feldspathoidal basalt at various places around the base. Based on our brief survey, however, it appears that the main bulk of Sierra Grande is a pyroxene andesite.

The basalt cropping out near Des Moines (29.29.15.21), at the north base of Sierra Grande, is light olive gray (5Y6 /1) and aphanitic to glassy, with numerous elongate vesicles usually filled with chalcedony. The tops of columnar joints of 2-foot average diameter are recognizable on the upper surface of the flows. Alluviation has partially obscured the margins of the flows.

Under the microscope, rare altered olivine phenocrysts are visible. The alteration consists of magnetite forming rims and bands within the phenocrysts. The groundmass consists largely of stubby, partially alined plagioclase (An_{55}) needles 0.1 mm long and dark-brown partially devitrified glass. Magnetite grains, either clustered with small yellowish-green augite crystals or scattered at random, constitute the remainder of the groundmass. Part of the groundmass is oxidized from the typical dark brown to a light tan.

Vesicles comprise as much as 30 percent of the rock and are filled with slightly anisotropic chalcedony in concentric layers or radiating needles. Small needles of plagioclase are commonly alined along the margins of the cavities.

Basalt from the area 2 miles west of Des Moines (29.29.17.210) is very similar to that just described. For this flow, the tops of the exposed columns show an average diameter of 3 feet. The fusion index of 1.547 suggests that this may be slightly more basic than the flow near Des Moines.

Chemically and petrographically, Sierra Grande andesite resembles most nearly the Red Mountain dacite of Collins (1949, p. 1033). The stratigraphic position of Sierra Grande could not be determined except that it is later than the first eruptive period of Lee and Mertie and earlier than Capulin basalt. It appears to be younger than the vent at 29.29.36, which supplied basalt to the broad Clayton-basalt sheet (here believed to be of the second eruptive period of Lee and Mertie—lateRaton basalt). If it is a correlative of the Red Mountain dacite, it must also be earlier than Clayton basalt (Collins, 1949, p. 1023). In this report, it is grouped with Clayton basalt. On chemical inferences, it may represent an early silicic differentiate of the later subsilicic Clayton basalts.

Dunchee Hill

Dunchee Hill (29.29.3.42), a low hill 1 mile north of Des Moines, is the eroded remnant of a volcano. A sill-like mass, apparently injected into the lower part of the cone, holds up the topographically high areas. Figure 19 illustrates the structure of this sill. In general, there is an inward-dipping portion and also an outward-dipping portion. Together they form a horseshoe around what was probably the center of the cone. The remainder of the vent area is composed of pyroclastic material. Flow rock from this vent extends southeast for at least 3 miles.

In the hand specimen, the principal phenocrysts are small iridescent olivine partially altered to red iddingsite. Rare quartz grains and rounded plagioclase phenocrysts are also visible. The rock is medium dark gray (N4) to medium gray (N5) and holocrystalline. Vesicles are usually flattened and absent in the sill, and may contain calcite.

Microscopically, the rock composition was found to be (in percent): olivine, 20; augite, 15; plagioclase (anorthite content unknown), 25; magnetite, 20; very fine-grained groundmass that appears to be equally divided between plagioclase and augite, 20. The flow and the outward-dipping rim of the sill have abundant small iddingsite-altered olivine crystals, whereas the inward-dipping rim of the sill has in addition larger olivine phenocrysts (up to 0.7 mm), with iddingsite alteration found only

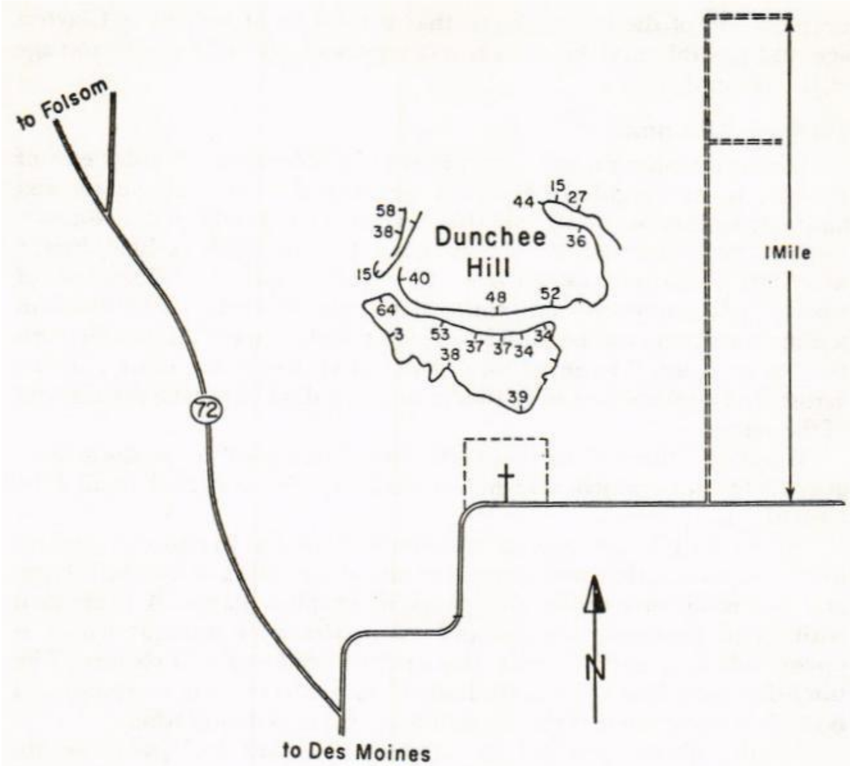


Figure 19

DUNCHEE HILL SILLS

Location and dips of sill-like basalt that forms the present eroded rim of the crater.

around the margins and in the cracks. A few augite phenocrysts are slightly pleochroic (pale green, reddish, greenish), and many are highly altered, with a narrow, clear rim. Some of the glomerocrysts of augite in the inward-dipping rim have altered cores and clear optically continuous rims. Rare partially resorbed plagioclase phenocrysts up to 1.5 mm long are present in the inward-dipping rim as well. The inward-dipping rim of the sill contains more and larger olivine phenocrysts and less augite than either the outward-dipping rim of the sill or the flow rock. Only a trace of feldspathoidal minerals (nepheline) was detected by stain tests in spite of the high fusion index.

The relative age of Dunchee Hill in the Clayton sequence is unknown, as overlapping flows from nearby volcanoes are not present. The relative age of Sierra Grande and Dunchee Hill basalt is not known, because of the alluvial cover, although the siliceous nature of Sierra Grande suggests that it is a late member of earlier silicic eruptions. The deep erosion of the cone suggests that it must be of very early Clayton age and possibly may be the earliest representative of the Clayton-age eruptions in this area.

Gaylord Mountain

Gaylord Mountain (also known as Carr Mountain), 4 miles east of Folsom, is an irregularly eroded cone capped with agglomerate and haüynite-nepheline basalt (pl. lb). A nonfeldspathoidal basalt forms a low step or terrace east of the main cone. Collins (1949, p. 1030) briefly described a volcanic breccia from this vent composed of fragments of scoria, pink sandstone, and white limestone. Abundant inclusions of sedimentary rocks can be found in a small cinder quarry in the northern part of the vent. The pyroclastic material is mostly less than 4 inches across, and agglomerate beds 10 feet or more thick form the eastern rim of the vent.

Hand specimens of the haüynite-nepheline basalt are medium dark gray (N4), fine grained, and holocrystalline, with scattered small blue haüynite phenocrysts.

Under the microscope, the haüynite is subhedral to euhedral and up to 2.0 mm in length, with minor amounts of alteration along the margin and inclusions of bubbles along crystallographic planes. It is rimmed with small pyroxene crystals and an unidentified mineral which is opaque black or red in needles that are arranged in a grid pattern. The intensity of the blue color in the haüynite varies across single crystals and is masked along the margins by yellow-brown or red alteration.

Smaller phenocrysts (0.1 to 0.3 mm) of olivine and pyroxene are abundant. The olivine is typically colorless and has a minor amount of hematite or iddingsite alteration along the margin of the grains. The pyroxene is weakly pleochroic (pale yellow, yellowish brown, pale greenish yellow) but sometimes contains a clear core of a low birefringent pyroxene(?). This core is probably pigeonite, because the 2V is small. The shape of the pyroxene crystals is commonly equant, although some are elongate.

Phenocrysts constitute about 50 percent of the rock, with the pyroxene (20 percent) slightly more abundant than either the haiiynite (15 percent) or the olivine (15 percent).

The fine-grained groundmass has the following estimated composition (in percent): magnetite grains, 15; interstitial nepheline (may include some feldspar), 20; pyroxene, 15.

CAPULIN BASALTS

INTRODUCTION

Excellent examples of volcanic features associated with basalt flows and cinder cones are exhibited by the well-preseved Capulin basalts (pl. 10B, I IA, 12-17). Wind-blown deposits and alluviation along the flow margins obscure some relationships.

All the Capulin-basalt vents are restricted to the central portion of this volcanic province. They all lie along the Sierra Grande arch, and all but one are northwest of both Sierra Grande and the arch. The restricted position, recency of eruption, and similarity of rocks suggest a common magma source, with only minor differentiation between successive eruptions.

From the asymmetry and the accumulation of pyroclastic rocks east of the Capulin-age cones, it would appear that the prevailing winds during the time of eruption were westerly. Landes (1928) suggests that the volcanic ash of western Kansas was derived from this portion of New Mexico. Collins (1949, p. 1031) regards the Red Mountain dacite (Clayton age) as chemically more suitable. The dacite vents are too small, however, to have furnished the enormous volume of ash necessary. Sierra Grande may have been responsible for the Fort Collins ash of southwestern Kansas because they are mineralogically similar. It seems, likely, however, that the eruptions of this region were too small to have furnished the enormous volume of ash (Pearlette) distributed over the High Plains. The vents forming the great Valle Grande caldera west of Santa Fe, New Mexico, could have furnished the necessary volume of ash.

FOLSOM VENTS

Two small cinder cones and associated basalt, herein named Folsom Vents (31.27.35.410; 31.27.36.310), cover less than one-half square mile near the mouth of Hereford Park, 1 mile west of the Union County line on New Mexico State Highway 72 (fig. 28). The basalt flow from this vent furnishes the clearest evidence as to its age of eruption. The cone rests on one of the terraces graded across the Bellisle Mountain basalt to the Robinson Mountain basalt level. The basalt flowed off this terrace (nearly 100 feet of relief) onto a broad alluvial flat that forms the floor of Hereford Park. The Folsom Vent basalt rests on 5 feet of alluvial sands and gravels, which in turn rest directly on sediments of the Cretaceous Niobrara group.

After the eruption, the stream lowered that portion of the valley not covered by Folsom Vent basalt to at least 20 feet below the base of the basalt-covered gravels. This valley cutting was followed by two stages of alluviation. The older of the alluvial fills can be traced a few miles upstream into the type Folsom Man locality, which contained Folsom Man artifacts and associated bison bones (Folsom State Park). Folsom remains have been dated elsewhere as about 10,000 years before the present; thus, the age of this vent is pre-Folsom Man and probably late Wisconsin.

The extreme youth of this vent compared with the main Folsom sequence and its resemblance to small Capulin-type cinder cones suggest that it should be grouped with the Capulin sequence. On the other hand, it resembles petrographically the undifferentiated Clayton-basalt sheets, and its eruption before Folsom Man (all other Capulin basalts in Des Moines quadrangle are younger than Folsom Man) suggests a Clayton age assignment. Paleomagnetic age assignments were attempted (Muehlberger and Baldwin, 1958) but were not definitive. It is here assigned to early Capulin age, in contrast with the earlier reports of Muehlberger (1956) and Muehlberger and Baldwin (1958).

Hand specimens are dark gray; scattered small red-brown olivine (7 percent) and plagioclase crystals (3 percent) can be seen with a strong hand lens. The rock is fine grained, holocrystalline, and vesicular to scoriaceous.

The groundmass plagioclase (An", 60 percent) is coarser (0.3 to 0.7 mm) than that from any other Capulin-age vent studied. Rare 2.0-mm plagioclase crystals are found. Tiny olivine (20 percent) grains partially altered to iddingsite, and small grains of magnetite (10 percent), make up the remainder of the rock. Vesicles are partially filled with calcite.

CAPULIN MOUNTAIN

Pyroclastics and lavas from Capulin Mountain cover much of the southwestern corner of Des Moines quadrangle. The lava flows are concentrated in two principal areas as a result of the location of the lava vent at the west base of Capulin Mountain. The largest volume is found south and southwest of the cone, where the flows blocked the drainage of the ancestral Piña Viente. This formed the closed depression, known as Capulin Basin, which extends from the village of Capulin westward into Colfax County. The other concentration of lava occupies an area of about 5 square miles north of the vent and southwest of Folsom.

The flows originated in a low vent lying at the west base of the pyroclastic vent (p1. 14, 17). The road, onto the main cone skirts the south base of the "boca." The "boca" has a levee surrounding it, and the several breaches in it are the heads of flows. The picnic grounds of the National Monument lie within the natural levee that directed several of the latest flows moving south from the cone. Wind-blown deposits and alluviation have partially obscured the flow phenomena. Pressure ridges are well displayed on the flow immediately south of the cone. Small domelike squeezeups on the tops of flows are abundant along the road immediately northwest of the "boca." Individual flows can be observed readily on the aerial photographs. The main lava mass north of the cone is blocky and now supports a pine forest.

Pyroclastic material is principally concentrated in the cone and in a small area to the east of the cone (pl. 10B). The crater rim is lowest on the west edge and highest on the east edge.

The basalts derived from the Capulin Mountain center have a very distinctive mineralogy and can be differentiated in the hand specimen from other basalts in this quadrangle. The characteristic features are the large (up to 5 mm) equant, glassy, colorless plagioclase and small (0.1 to 0.2 mm) green olivine phenocrysts set in an aphanitic or glassy matrix. By using these mineralogic characteristics in conjunction with the detailed mapping of individual flows, the author has demonstrated that the Capulin Mountain basalt never flowed past Folsom in the Dry Cimarron River drainage.

Hand specimens of Capulin Mountain basalt are medium dark gray to dark gray, porphyritic, and vesicular, with phenocrysts totaling about 10 percent of the rock. Phenocrysts of olivine and feldspar are about equal in quantity, although the feldspar is characteristically found as larger crystals. The groundmass is usually too fine grained to disclose any minerals beyond a few laths of feldspar. Flow structure is outlined by elongation of vesicles and is relatively common and easy to recognize.

Under the microscope, the plagioclase phenocrysts (8 to 10 percent) are zoned with a core of bytownite to labradorite, and with a border near andesine (An_{50}) (Stobbe, 1949, p. 1054). The average length is 1 mm, although the phenocrysts may be as long as 3 mm. One crystal had 13 distinguishable zoning bands. After zoning, the crystals were corroded, and a rim of tiny magnetite grains was deposited, which were then surrounded by a clear, narrow outer band of plagioclase (An_{50}).

Olivine occurs as euhedral phenocrysts (4 percent) about 1.0 mm long. Stobbe (1949, p. 1055) indicates that the cores are richer in magnesium than the rims. That the crystals are not uniform in composition is shown by the wavy extinction.

The groundmass is composed of tiny (0.1 mm) euhedral grains of augite (36 percent) and about equal amounts of plagioclase (35 percent) in either elongate twins (0.1 mm by 0.03 mm) or equant, zoned (0.1 to 0.2 mm) crystals. Abundant tiny (0.01 mm) magnetite grains (15 percent), some of which are reddish, constitute the bulk of the remainder of the rock.

Quartz-grain inclusions (sand from sedimentary units at depth?) are sometimes found. They invariably have a tiny reaction rim of what appears to be a fibrous pyroxene.

Capulin Mountain erupted between 8000 B. C. and 2400 B. C. (Muehlberger, 1955). A single flow from Capulin Mountain entered the valley of the Dry Cimarron River. Exposures along the walls of the river at 30.28.14.443, although not perfect, indicate that the Capulin Mountain basalt is younger than the older alluvium (containing no fragments of Capulin basalt) and older than the younger alluvium (containing talus fragments from the basalt at all levels). These alluvial fills are readily distinguishable throughout this area and can be traced upstream into the type Folsom Man locality (31.27.33.122). The older, yellowish, caliche-bearing alluvium is similar to other Folsom-bearing deposits of the Southern High Plains, which have radiocarbon ages of about 8000 B. C. Erosion of the older alluvium occurred before deposition of the dark, humus-rich, younger alluvium. Charcoal found in a fire pit close to the base of the younger alluvium near the Folsom Man locality has a radiocarbon age of 2350 (± 250) B. C. (Johnson, 1951, p. 11, 16).

TWIN MOUNTAIN

Twin Mountain (30.29.19.400) is an elongate cinder cone that lies 3 miles southeast of Folsom. Its long axis strikes N. 70° E. and is about 3,000 feet long. The cone has a trough along this axis, dividing the mountain into two parts; thus the origin of the name (pl. 15). Probably a fissure eruption, the elongated vent is composed of cinders, ash, and bombs, in well-bedded layers. Short basalt flows issued from the ends and moved north for a few miles. The flows from the Purvine Hills fissure eruptions are indistinguishable in hand specimen from those of Twin Mountain; therefore, the flow remnants in the Dry Cimarron River valley may be from either vent. Their proximity and lithologic similarity suggest their essential contemporaneity, although the Purvine Hills flows must be younger in part in view of their overlying the east edge of Twin Mountain.

In hand specimen, the rock is medium dark gray to medium gray, vesicular, and aphanitic, with rare phenocrysts of yellowish-brown olivine. Flow structure is outlined by vesicles and feldspar needles. On the cone, the vesicles (up to 25 percent of the rock) are commonly equidimensional and range in size from 0.2 to 2.0 mm.

Microscopically, it is found that the dark color is caused by extremely abundant (30 percent) tiny magnetite grains. Plagioclase (An_{55}) occurs as laths, which are partially resorbed, or zoned, or have frayed ends. The laths are as much as 0.3 mm in length and constitute about 50 percent of the rock. Rare (3 percent) subrounded plagioclase phenocrysts occur, 0.2 to 0.3 mm long, partially resorbed and with altered rims full of inclusions, but they do not have a clear border as do specimens from the Capulin Mountain basalt. In rare instances is more than 7 percent of the rock composed of olivine. The olivine occurs mostly as euhedral crystals 0.3 to 0.6 mm long, with a few phenocrysts as much as 2 mm long, which are partially altered to magnetite and iddingsite. Magnetite bands are crystallographically controlled and cause the olivine to appear zoned. The remainder (10 percent) of the rock is glass.

PURVINE HILLS

Because they lie on the Purvine ranch, a group of four small volcanic vents are here named the Purvine Hills. Three of the vents are spatter cones elongated along fissures striking N. 75° E. (pl. 11, 12, 15). The vents are en echelon along an east-trending line (from 30.29.29.212 to 30.29.27.111). The extension of this east-west line 1 mile to the west intersects Twin Mountain, and 21/2 miles farther west, Baby Capulin. The last three volcanic events in Des Moines quadrangle thus took place along a single short segment of fracturing.

The spatter cones are small, rarely over 50 feet high, and have been the source of extensive flow. Basalt from the westernmost vent moved west, across the flank of Twin Mountain, and then moved northward into the main drainage of the Dry Cimarron River. Basalt from the eastern pair of vents moved eastward across the plains to the head of Briggs Canyon; there, it flowed into the canyon and down into the valley of the Dry Cimarron. Whether it reached the main valley is not known, because of extensive alluviation since the cessation of volcanic activity. The volume of lava is not known but is probably comparable to that emitted by Baby Capulin, although Baby Capulin, in addition, erupted large volumes of pyroclastics.

Hand specimens of the basalts from Purvine Hills arc indistinguishable from those from Twin Mountain. Very rare, small phenocrysts of either yellowish-green olivine or plagioclase are found. The groundmass is aphanitic to glassy and has no visible crystals except tiny plagioclase needles.

Microscopically, the olivine is in small (0.1 to 0.2 mm) euhedral crystals, with internal alteration to magnetite along crystallographic planes. Rare large olivine (few percent) phenocrysts (to 1.0 mm) are altered along cleavage planes to magnetite and minor iddingsite. The single euhedral plagioclase phenocryst observed has been partially resorbed and rounded; tiny magnetite grains grew around the perimeter; finally, an outer euhedral zone in slightly different optical orientation was crystallized. Groundmass plagioclase (An") 0.3 to 0.5 mm long comprises nearly 50 percent of the rock. Magnetite grains are extremely abundant and may reach 30 percent in some samples. A low-index isotropic substance, probably a zeolite, fills some of the vesicles.

The fourth vent is a small pyroclastic cone about midway between, and slightly south of, the western pair of the fissure vents. It too is elongated slightly along a N. 75° E. line, but only minor amounts of flow rock issued from it. The tuff contains grains of quartz, microcline, plagioclase, olivine, and biotite, as well as fragments of granite, basalt, and sandstone, cemented in a frothy, glassy groundmass. The length of the fragments ranges up to 5 cm, but most are less than 1 cm. Calcite is the common vesicle filling and forms part of the groundmass as well. The tuff is a pale yellowish brown (10YR6/2) instead of the medium dark gray (N4) prevalent in the flow rocks.

BABY CAPULIN

Baby Capulin (30.28.36.11) is a small cinder cone that lies about midway between Capulin Mountain and Folsom village (p1. 15). Only a few hundred feet high, it is small in comparison with the bulk of Capulin Mountain to the south. Its position in a relatively low area makes it still less conspicuous. Basalt from Baby Capulin flowed north and northeast from the vent, surrounding the Augite Vents (Clayton basalt), then into the drainage of Piña Viente, and finally into the main valley of the Dry Cimarron River, 1 mile downstream (east) of Folsom. At this point, it must have formed a large lava lake and then flowed northeastward down the Dry Cimarron River valley for 20 miles. Earlier workers (Lee, 1922; Collins, 1949, p. 1031) have indicated that the long flow down the Dry Cimarron River was from Capulin Mountain. This study has shown that Capulin Mountain basalt never reached the area east of Folsom. The fact that the individual flows could be traced in the field, coupled with a distinctive mineralogy for Capulin Mountain basalt, as already pointed out, has made it possible to correct the earlier reconnaissance work.

Pyroclastic material is concentrated in the cone and in a number of smaller conelets flanking the south and east bases of the main cone.

In hand specimen, the rock is medium dark-gray (N4) porphyritic vesicular basalt. The only common phenocrysts are dark greenish-brown olivine, totaling 5 percent of the rock. Rare, partially resorbed plagioclase phenocrysts are found.

In thinsection, the olivine phenocrysts are found to be subhedral to euhedral and less than 1 mm long. The single plagioclase phenocryst observed was clear, zoned, and about 1 mm long (composition unknown). The groundmass has an intersertal texture made up of plagioclase needles, plus augite and magnetite grains.

Basalts from Baby Capulin, Twin Mountain, and Purvine Hills are all very similar, and their essentially contemporaneous eruptions led to some apparently contradictory overlapping relations. Usually, Baby Capulin basalt has scattered, large olivine phenocrysts; in places, however, they are absent, and it is then indistinguishable from either Twin Mountain or Purvine Hills basalt. Using the criterion of olivine phenocrysts as indicating basalt from Baby Capulin, the long flow down the Dry Cimarron Valley is from Baby Capulin Mountain. This flow was the last volcanic event of northwestern Union County, because Baby Capulin basalt lies within levees of Twin Mountain or Purvine Hills basalt. At the waterfall at 30.29.6.222, Baby Capulin olivine-bearing basalt can be found overlying the Twin Mountain-Purvine Hills basalt, which does not normally contain olivine phenocrysts.

In the lava plain north of these vents and southeast of Folsom, the poorly exposed basalt suggests that the last basalt from Twin Mountain partially buried Baby Capulin basalt, and that each of these is partially buried by Purvine Hills basalt. The similarity of rock and the fact that all the vents lie along a single line indicate the probability that eruption was simultaneous from Baby Capulin, Twin Mountain, and Purvine Hills, or that these vents at least tapped the same magma chamber. If this line is continued westward for 11 miles into Colfax County, two other Capulin-age vents are found along it; in hand specimen, basalt from these vents is indistinguishable from Baby Capulin basalt. Also on this same line is the Clayton-age vent Jose Butte, of different mineralogy, indicating a continuity of stress pattern through at least a major portion of the volcanism.

Volcanic Rocks in the Remainder of Union County

UNDIFFERENTIATED CLAYTON BASALT

INTRODUCTION

The main mesas of Clayton basalt were studied petrographically as part of a paleomagnetic reconnaissance study designed to correlate these flows with the known stratigraphic sequence determined in the northwestern part of the county. Inconsistent paleomagnetic results (Muehlberger and Baldwin, 1958) precluded any age correlations.

The broad basalt-capped mesa east of Sierra Grande, in central Union County, constitutes Collins' (1949, p. 1023) type for Clayton basalt. This broad upland mesa cap is apparently a solid sheet in western Union County, but farther east it consists of many long tongues. For ease of discussion, these basalt tongues have been named, from south to north, the Carrizo, Herringa, Clayton Mesa, Apache, Seneca, Gaps, and Van Cleve flows (pl. 7). Without exception, the basalts rest on sand and gravel of Ogallala-like material in ancient valleys. These earlier valleys today form the rims of the present valleys. Still higher, and older, is the Ogallala formation, into which the broad valleys were cut.

The vents that gave rise to these basalts are unknown. All later Clayton basalts, as, for example, the Folsom sequence in Des Moines quadrangle, form steep pyroclastic or composite cones and areally restricted flows. The undifferentiated Clayton basalts because of their length, thinness, and wide distribution must have been very fluid. The ease of escape of gas from this type of lava probably would prevent the construction of steep-walled cinder cones. Burro Mountain, a shield volcano, may have been the source of the Seneca flow. The identical nature and elongation of the Clayton Mesa, Herringa, Carrizo, and Gaps flows indicate a more westerly source, possibly near Sierra Grande. Both the Van Cleve and Gaps flows radiate from the vicinity of Sierra Grande and may have their source in that region as well. The bulk of Sierra Grande, however, which seemingly rests on or is surrounded by the undifferentiated Clayton basalts, is composed of pyroxene andesite, a volcanic rock more silicic than any other known in Union County. No flows of pyroxene andesite were found; only basalt flows surround Sierra Grande.

Its fluid nature, composition, and eruption early in the dissection of the Ogallala formation suggest the possibility that the type Clayton basalt, the extensive basalt-capped mesas, may actually be contemporaneous with the younger group (Qb^2 of Lee and Mertie, in Lee, 1922, p. 9) of Collins' Raton basalts. In any case, the Clayton basalt of Collins (or Lee's third period of eruption) is represented by a sequence of seven sets of flows in the Folsom area.

The erosional interval between the undifferentiated Clayton-basalt mesas and the Clayton basalts of the Folsom stratigraphic sequence may be insignificant. Topographically, the difference in elevation between the Purvine Mesa level (part of the Folsom sequence) and the adjacent earlier Raton-basalt floor (Qbl of Lee) is only the thickness of the Ogallala and lower Graneros formations in this area, about 75 feet. The Purvine Mesa level is about at the topographic position of the projected younger Raton basalt from Colfax County and about at the level of the undifferentiated Clayton basalts of central Union County. The small amount of dissection in central Union County means that regardless of age the valleys that were occupied by flow rock were at about the same elevation in spite of the large difference in topographic position visible in Colfax County.

CARRIZO, HERRINGA, AND CLAYTON MESA FLOWS

This group of flows has uniform field and petrologic characteristics and, therefore, may have come from a single vent. Only the individual tongues of basalt were studied during the paleomagnetic reconnaissance. Thinsections from the crater of a small vent at 27.30.5.412 and a knob at 27.30.1.314, and a specimen from 26.32.4.444, are identical with thinsections from the tongues of basalt. This suggests that the basalt-covered plain southeast of Sierra Grande is the main outcrop area of the basalt type found in the Carrizo, Herringa, and Clayton Mesa flows.

Hand specimens are medium-gray (N5) porphyritic holocrystalline medium-grained olivine basalts. Small yellow-brown olivine crystals, 2 to 3 mm in diameter, are the only visible phenocrysts (5 to 10 percent). Platy flow structure is outlined by groundmass plagioclase, elongated vesicles, and platy fractures. Stubby columnar jointing is present almost everywhere.

In thinsection, the olivine phenocrysts have an iddingsite alteration rim that is surrounded by a clear thin rim of olivine in optical continuity. The groundmass has the following estimated composition (in percent): thin plagioclase laths (0.4 to 1.0 mm), 40; olivine (0.2 to 0.4 mm), 10; augite (in part poikilitic, 0.2 to 0.4 mm), 20 to 30; magnetite (0.1 mm), 5 to 10.

APACHE FLOW

The basalt rim along the north side of Apache Canyon is called herein the Apache flow. No thinsections were made. Hand specimens resemble the Clayton Mesa flow. On the western side of the valley at 26.34.6.200, the basalt resembles the Seneca flow. If so, this valley marks the southwestern edge of the Apache flow, inasmuch as the eastern side of the valley is of the Apache-flow type.

SENECA FLOW

The basal basalt north of Rabbit Ear that forms the south rim of Seneca Creek valley is herein named Seneca flow. The character of this flow is almost the same as that of the Clayton Mesa-Herringa-Carrizo flows. Hand-specimen differences are slight, but the Seneca flow is more vesicular, and the olivine phenocrysts are iridescent and slightly larger than those in the Clayton Mesa flow. Although the actual differences are difficult to describe, comparison of specimens in the field shows slight visual differences. In thinsection, the olivine phenocrysts are found to be fractured and to be faintly altered along their margins. The principal distinction from the Clayton Mesa flow is the presence of numerous (40 percent) tiny augite (dominant) and olivine grains scattered throughout the slide. No obvious alinement of the small (1 to 2 mm long) plagioclase laths (35 percent) can be observed. Magnetite grains (5 to 10 percent) appear to be slightly more abundant, though smaller. The overlying Rabbit Ear basalt has prominent, small olivine phenocrysts and no large plagioclase laths. Specimen 47-D-7 from the Seneca flow has an index of refraction of the fused glass of 1.593.

GAPS FLOW

No significant petrographic differences could be discovered to distinguish the Gaps flow from the Clayton Mesa-Carrizo basalts. Hand specimens and general field appearance are also identical. Excellent examples of vertical vesicular tubes 1 to 3 inches in diameter, which appear to have been formed by gases streaming up through the lava during cooling, are present in the upper part of the flow along the east side of Sand Gap.

RELATIONSHIPS BETWEEN THE MAIN UNDIFFERENTIATED CLAYTON BASALTS

The description of the main undifferentiated Clayton basalts demonstrates the difficulty of subdivision. Their fusions indicate chemical similarity, and field and petrographic differences are minute. The only criterion for naming each of these flows is their individual topographic expression as separate and distinct mesas. Their similarity and apparent merging westward into a continuous sheet near Grenville suggest a single magma for all of these.

Similarity of hand specimens and thinsections shows that this basaltic type filled broad valleys over an area extending at least 30 miles east-west and 24 miles north-south. The westward continuation of this basalt mass has not been determined, but it continues as far west as Little Grande (28.30.18).

Thinsections from the vents at 27.30.1.300 and 27.30.5.420 show identity with the main undifferentiated Clayton basalt mesas. These two vents probably supplied some of the lava for the basalt sheets. Most

TABLE 4

Analyses by R. B. Ellestad (L), J. G. Fairchild (RMD, A2, A3), W. H. Hillebrand (SRF, SG, NB2), G. Steiger (RBI, RB2, NB1, CB), and H. W. Wiik (RBC, CM, VC, RE, CV, EP, AV, BC).

EXPLANATION OF SYMBOLS

RBI—Raton basalt of Collins; Qb^1 of Lee (earlier Raton *basalt);* Tb of Union County. East rim of Barilla Mesa, Colfax County. Reference: Lee, 1922.

RBC—Raton basalt of Collins; Qb· of Lee (earlier *Raton basalt);* Tb of Union County. Specimen 21-C-54 from 30.28.32.121 (Raton rim west of Capulin Mountain), Union County. Artificial glass index of refraction: 1.592. Magnetism parallel to earth's field.

RB2—Raton basalt of Collins; Qb^2 of Lee (later Raton *basalt).* South rim of Barilla Mesa, Colfax County. Reference: Lee, 1922.

CM—Clayton basalt of Collins (the type *Clayton basalt,* which in this report is correlated tentatively with Qb^2 of Lee, i.e., later Raton basalt). Specimen 72-B-5 from 35.26.22.133 (roadcut on north rim of mesa), Union County. Artificial glass index of refraction: 1.601. Magnetism reverse of earth's magnetic field.

SRF—San Rafael flow, Clayton basalt(?); possibly Gaps flow of this report. Specific locality unknown; east of Raton quadrangle. *Reference:* Cross, 1900.

Rhin—Red Mountain dacite, type *Red Mountain dacite.* Red Mountain, Colfax County (on Johnson Mesa). Reference: Lee, 1922.

L—Latite, *Red Mountain dacite.* Goemmer Butte, near La Veta, Las Animas County, Colorado. Reference: Knopf, 1936.

SG—Sierra Grande andesite, *Red Mountain dacite.* Union County. Specific locality on Sierra Grande not known; mineralogy suggests that the specimen was from main mass and not from any of the satellitic flows or vents. Reference: Cross, 1900.

A2—Andesite, *Red Mountain dacite.* Meloche Mesa, Colfax County. Reference: Lee, 1922.

AS—Andesite. Mesa east of Meloche Mesa, Colfax County. Reference: Lee, 1922. Included *in Clayton basalt* by Wood et. al., 1953.

VC—Van Cleve flow, *Clayton basalt.* Union County. Specimen 46-B-2 from 31.29.19.333, near Wetherly Lake. Artificial glass index of refraction: 1.590. Strongly magnetized parallel to earth's field.

RE—Rabbit Ear Vent, *Clayton basalt.* Union County. Specimen 48-C-2 from 27.35.31.144, at Rabbit Ear triangulation station. Artificial glass index of refraction: 1.590. Direction of magnetic field not determined.

CV—Unnamed vent, *Clayton basalt.* Union County. Specimen 46-B-1 from 28.30.24.342. southwest of Gaps flow. Artificial glass index of refraction: 1.622. Direction of magnetic field not determined.

NBI—Nepheline basalt, *Clayton basalt.* Yankee volcano, Colfax County. Reference: Lee, 1922.

NB2—Nepheline basanite, *Clayton basalt.* Ciruella, Colfax County. Reference: Cross, 1900.

EP—Emery Peak basalt; earlier member of Folsom sequence of *Clayton basalt.* Des Moines quadrangle, Union County. Specimen 21-C-53 from 29.30.5.113, west end of flow on east side of the Dry Cimarron River. Artificial glass index of refraction: 1.616. Faintly magnetic parallel to earth's field.

AV—Augite Vent—Purvine Mesa basalt; part of Folsom sequence of *Clayton basalt.* Des Moines quadrangle, Union County. Specimen 21-C-53 from 29.30.6.411, at BM R145 on New Mexico Highway 325. Artificial glass index of refraction: 1.606. Strongly magnetized parallel to earth's field.

CB—Capulin Mountain basalt, type Capulin *basalt.* Union County. Reference: Lee, 1922. Other specimens from cone are strongly magnetic parallel to earth's field. Artificial glass from specimens on flows have an index of refraction of 1.560 ± .002.

BC—Baby Capulin basalt, *Capulin basalt.* Union County. Specimen 2I-A-43 from 29.31.24. 411, south side of New Mexico Highway 325, about 2 miles east of junction with road to Branson, Colorado.

of the possible source vents were not sampled during this reconnaissance study. The alinement of vents parallel to the main flow mass suggests a multistage eruptive cycle starting with fluid fissure eruptions of olivine basalt, continuing with basalts with small amounts of nepheline, and ultimately finishing with feldspathoidal basalts of local extent.

The Van Cleve flow described below is distinctively different from those described above.

VAN CLEVE FLOW

In contrast to the other tongues of undifferentiated Clayton basalt, the Van Cleve basalt is very fine grained. Olivine phenocrysts are fewer (5 percent) and smaller (1 mm), and the rims are strongly altered to iddingsite. The groundmass minerals are finer grained, although their proportions are about the same as in the other undifferentiated Clayton basalts. The groundmass has the following estimated composition (in percent): plagioclase laths (0.2 mm long), 40; augite grains (0.1 mm diameter), 30 to 40; iddingsite-stained olivine, 10-15; magnetite (0.1 mm diameter), 5. Plagioclase is alined and outlines the flow structure. The fusion index of refraction suggests that a moderate proportion of the plagioclase and much of the fine-grained interstitial material are nepheline.

The vent that supplied the lava for this flow has not been located. The nearest possibility is Dunchee Hill, although the basalt is finer grained and contains less plagioclase than that from the latter locality.

DON CARLOS HILLS

In southwestern Union County is a group of 14 alined volcanic vents, the Don Carlos Hills, surmounting a basalt-covered plateau that covers most of 25.28-30, as well as parts of some of the surrounding townships. Baldwin (pl. lc) has distinguished four groups of flows on the basis of topographic expression and hand-specimen differences. The petrographic studies described herein support his subdivisions. Our paleomagnetic studies did not help in correlating this isolated volcanic pile with the main volcanic region. The suggested correlations herein are tentative and based principally on petrographic similarities. The close spacing of the vents (14 in 12 miles), petrographic similarities, and the fact that they are nearly all alined suggest a fissure eruption with a common magma.

The following petrographic descriptions (locations of samples on p1. 8) will be from oldest to youngest, as based on Baldwin's mapping. All samples were stain tested in addition and found to contain less than 5 percent nepheline. Only the southeast vent contains visible hailynite in hand specimens, although none was found in the single thinsection (this basalt also has the highest fusion index [1.623] of the Don Carlos Hills, suggesting a very low silica content).

TABLE 5. INDEX OF REFRACTION OF ARTIFICIAL GLASS FROM THINSECTIONED SAMPLES FROM DON CARLOS HILLS

THINSECTION	INDEX OF REFRACTION	RELATIVE AGE	
69-D-8	1.589	QTb_3—cone	
69-D-5	1.605	QTb_3—cone	
70-C-4C	1.623	QTb_3—cone	
69-A-6	1.611	QTb_3	
69-D-7	1.593	QTb_3	
69-D-6	1.593	QTb_2	—eastern platform
69-A-5	1.601	QTb_2	
69-A-4	1.595	QTb_2	—western platform
69-D-9	1.595	QTb_2	
69-D-2a	1.595	QTb_2	—topographically lower, but probably part of western platform.
69-C-2	1.595	QTb_2	
69-D-3	1.610	QTb	—Pasamonte flow
70-C-2	1.613	QTb	
70-B-4	1.611	QTb	
70-C-6	1.618	QTb	
69-D-10	1.608	QTb	
69-C-1	1.599	QTb	—isolated mass into Ute Creek
69-A-2	1.618	Tb	—younger Raton?
69-A-3	1.605	Tb	
70-C-5	1.602	Tb	

OLDEST BASALT (Tb)

The oldest basalt (pl. I c) forms the central platform of the Don Carlos Hills. Augite phenocrysts standing in relief on weathered surfaces make this basalt easily distinguishable from others in the Don Carlos Hills. Intense iddingsite alteration of the olivine, plus the fact that these flows (at least three along the southern scarp) lie on Ogallala sands and gravels and that the flows stand several hundred feet above

TABLE 4. CHEMICAL ANALYSES AND NORMATIVE MINERALS OF LATE CENOZOIC VOLCANIC ROCKS FROM COLFAX AND UNION COUNTIES, NEW MEXICO, AND LAS ANIMAS COUNTY, COLORADO

	Raton basalt of Collins			Clayton basalt of Collins†		Red Mountain dacite of Collins					Clayton basalt of Collins (restricted) (all feldspathoidal)							Capulin basalt of Collins	
	earlier		later																
	RB1	RBC*	RB2	CM*	SRF	RMD	L	SG	A2	A3	VC*	RE*	CV*	NB1	NB2	EP*	AV*	CB	BC*
SiO_2	51.68	48.37	49.73	48.25	48.35	67.98	60.75	60.16	54.08	53.52	45.24	46.81	38.54	40.72	42.35	43.18	42.64	53.27	50.70
TiO_2	1.54	1.61	1.59	1.46	1.33	0.34	0.84	0.84	0.98	1.15	1.62	1.37	1.60	0.99	1.82	1.81	1.76	1.30	1.43
Al_2O_3	15.05	14.22	15.46	15.00	15.47	15.53	16.55	15.34	21.87	17.88	14.69	15.01	12.93	15.03	12.29	14.52	13.77	15.43	15.37
Fe_2O_3	5.22	9.77	3.32	3.18	4.80	2.68	3.63	3.07	5.22	4.21	3.74	5.89	6.50	5.52	3.81	4.36	5.16	2.43	6.35
FeO	5.64	0.86	8.14	8.78	7.58	0.18	2.49	2.18	0.88	3.51	7.71	4.56	4.21	6.86	7.05	7.14	5.85	6.50	4.64
MnO	0.12	0.14	0.13	0.18	0.21	0.04	—	0.08	0.09	0.11	0.16	0.17	0.26	0.18	0.21	0.20	0.19	0.12	0.17
MgO	5.63	7.49	7.20	8.83	8.15	1.47	1.68	3.41	2.69	3.90	8.82	8.82	9.63	8.29	13.09	10.60	10.71	6.16	6.47
CaO	8.30	9.91	9.63	9.28	8.81	3.39	4.86	5.79	5.53	7.36	11.48	10.18	15.73	13.95	12.49	10.64	12.25	8.18	8.51
Na_2O	3.75	3.18	3.30	3.18	3.09	4.53	4.29	3.88	5.46	5.19	3.23	3.27	3.92	4.01	2.74	3.04	3.13	3.51	3.65
K_2O	1.39	1.70	0.87	0.67	0.95	3.00	3.54	2.59	2.88	2.39	0.84	1.23	1.51	2.34	1.04	0.92	0.70	1.71	1.11
P_2O_5	0.45	1.10	0.42	0.52	0.33	0.33	0.49	0.46	0.91	1.26	0.67	1.14	2.05	1.75	0.99	1.09	1.50	0.50	0.51
H_2O^+	0.62	0.62	0.32	0.35	0.73	1.05	—	1.79	none	none	0.75	0.61	1.23	0.32	1.50	1.68	1.69	0.62	0.77
H_2O^-	0.72	0.17	0.16	0.11	0.28	0.11	—	0.25	0.16	0.15	0.10	0.25	0.47	0.12	0.32	0.45	0.45	none	0.05
CO_2	none	0.00	none	0.00	—	—	—	—	—	—	1.21	0.00	0.71	—	—	0.00	0.00	none	0.00
S	—	—	—	—	tr	—	—	—	—	—	—	—	—	—	tr	—	—	—	—
Total	100.11	99.14	100.27	99.79	100.26‡	100.63	99.10	100.15§	100.75	100.62	100.26	99.31	99.29	100.80	100.19‖	99.63	99.80	99.73	99.73
Quartz	1.56	—	—	—	—	21.90	12.24	13.50	—	—	—	—	—	—	—	—	—	1.14	1.57
Orthoclase	8.34	10.08	5.00	3.90	5.56	17.79	20.57	15.01	17.24	14.46	5.00	7.24	8.91	—	6.12	4.71	3.93	10.01	6.65
Albite	31.96	26.76	27.77	26.75	26.20	38.25	35.63	33.01	45.59	42.97	22.00	27.77	15.72	—	3.93	15.21	16.23	29.34	30.92
Anorthite	20.02	19.74	25.02	24.73	25.58	13.07	15.85	16.68	21.68	18.07	24.00	22.51	13.36	16.12	18.35	25.00	20.85	21.41	21.94
Leucite	—	—	—	—	—	—	—	—	—	—	—	—	—	10.46	—	—	—	—	—
Nepheline	—	—	—	—	—	—	—	—	0.28	0.57	2.84	—	9.02	18.46	10.08	5.68	6.24	—	—
Diopside	14.71	8.35	16.01	14.39	12.98	1.51	4.13	7.13	—	6.72	16.79	16.30	—	31.36	29.55	17.80	20.60	12.61	13.09
Olivine	—	2.25	7.62	14.64	9.92	—	—	—	4.76	5.44	16.38	8.87	16.84	9.03	18.41	17.75	14.58	—	—
Hypersthene	10.84	15.50	9.50	6.18	8.84	3.00	2.66	5.20	—	—	—	1.00	—	—	—	—	—	17.34	11.72
Magnetite	7.66	—	4.87	4.62	9.96	—	5.34	4.64	—	6.03	5.34	7.22	9.45	7.89	5.57	6.27	7.47	3.48	9.23
Hematite	—	9.77	—	—	—	2.68	—	—	5.22	—	—	—	—	—	—	—	—	—	—
Ilmenite	2.89	1.95	3.04	2.74	2.28	0.46	1.52	1.67	1.82	2.13	3.04	2.59	3.04	1.82	3.50	3.49	3.35	2.43	2.36
Apatite	1.01	2.67	1.01	1.25	0.67	0.67	1.34	1.01	1.01	3.02	1.62	2.59	4.68	4.03	2.35	2.65	4.30	1.34	1.24
Corundum	—	—	—	—	—	—	—	—	1.73	—	—	—	—	—	—	—	—	—	—
Calcite	—	—	—	—	—	—	—	—	—	—	—	—	1.61	—	—	—	—	—	—
Casilite	—	—	—	—	—	—	—	—	—	—	—	—	14.62	—	—	—	—	—	—
Total	98.99	97.27	99.84	99.20	101.99	99.33	99.28	97.85	99.33	99.41	97.01	95.79	97.25	99.17	97.86	98.56	97.55	99.10	98.72
CIPW Class	III 53'4(5)	III 544	II(III) 534	III 525	II(III) 534	I 424	II 433	II 432	I(II) 5'34	II 52(3)4	III 644	III 534	III 634	III 834	III 644	III 524	III 635	II(III) 534	III 535

*New chemical analyses.

† Probably later Raton basalt.

‡ ZrO_2-none, Cr_2O_3-0.10, V_2O_3-0.04, NiO, CoO-0.03, SrO-0.09, BaO-0.10, Li_2O-tr, SO_3-0.05, Cl, F-undet.

§ ZrO_2-none, Cr_2O_3-tr, NiO, CoO-tr, SrO-0.08, BaO-0.14, Li_2O-tr, SO_3-0.08, Cl, F-undet.

‖ ZrO_2-none, Cr_2O_3-0.10, V_2O_3-0.04, NiO, CoO-0.03, SrO-0.09, BaO-0.10, Li_2O-tr, SO_3-0.05, Cl, F-undet.

the surrounding land in an area well away from streams, suggests that this basalt (Tb) is the Raton basalt of Collins.

The four samples studied are very similar (one was finer grained than the other three, though identical in other characteristics). Olivine (10 to 15 percent), heavily altered to iddingsite, occurs in euhedral crystals 0.4 to 0.6 mm in diameter. Augite (30 percent) is found both as small phenocrysts and as groundmass grains. Labradorite (50 percent) forms the bulk of the groundmass in laths averaging 0.2 mm long. Magnetite (5 percent) occurs in larger grains (0.1 to 0.15 mm) than in any other basalt of the Don Carlos Hills.

PASAMONTE FLOW AND RELATED ROCKS

The Pasamonte flow (QTb), together with its topographic continuation around the east and north flank of the hills, was sampled at five places on the paleomagnetic reconnaissance. It was found to be normally magnetized for the most part, in contrast to the oldest basalt, which was dominantly reversely magnetized (Muehlberger and Baldwin, 1958, p. 359-360). These samples, in addition to one collected earlier at the south tip of the flow, were studied in thinsection. The four samples near the southern tip of the flow are identical, but those from the east-central portion of the flow are much finer grained and may be from a separate eruption (or the magma changed composition during the eruptive period). These hypotheses have not been checked in the field, and detailed field work may not provide the answer because of eolian and colluvial cover over much of the central portion of the flow.

In thinsection, the four southern samples are identical with the main undifferentiated Clayton basalt. The flow (labeled QTb) into Ute Creek at the southwestern edge of the Don Carlos Hills is also petrographically the same, although its fusion index (1.599) is lower than that of the four others (1.608 to 1.618). These basalts have the following estimated composition (in percent): iddingsite-rimmed olivine (0.3 to 0.6 mm), 15; intersertal augite, 35; labradorite (0.3-mm laths), 45; magnetite (0.05 to 0.10 mm), 5.

Although nearly identical to the above description, the other two samples of the Pasamonte flow are very fine grained, slightly higher in olivine content (20 percent), and darker, because of fine-grained magnetite that "dusts" the slides.

MAIN-PLATFORM BASALT

The main platform surrounding the vents is in two large areas separated by a topographically low area underlain by the oldest basalt. Two specimens from the eastern edge of the western platform are similar to each other. Olivine (10 percent) in 0.4-mm euhedral crystals, groundmass augite (25 percent), small laths of labradorite (0.1 mm, 60 percent), and tiny magnetite grains (5 percent) dusting the entire slide constitute the bulk of the slide. Although the flow in 24.29.5 is shown in Plate lc as QTb_2, it was mapped originally as having a slightly different topographic expression from the QTb_2 just to the north; in thinsection, this flow in 24.29.5 is the same as the Pasamonte flow (i.e., Clayton Mesa basalt type).

The eastern pile of youngest basalt was studied in two thinsections. The sample from the northwest edge is identical with the samples from the main Pasamonte flow already described. The sample from the southwest edge is nearly opaque and contains large (2.0 mm) iddingsite-rimmed olivine phenocrysts (15 percent), with a groundmass of augite (35 percent), labradorite (45 percent), and tiny magnetite (5 percent).

YOUNGEST FLOWS

The few specimens from the flows (QTb_3) immediately surrounding the vents are generally very fine grained and contain opaque areas. Unaltered olivine and augite, as phenocrysts as well as groundmass, are the only differences noted.

The average rock contains the following percentages of the minerals listed, with the range indicated in parentheses: labradorite, 50 (40-75); augite, 25 (8-40); olivine, 15 (7-20); magnetite, 7 (5-15); nepheline, 3, (0.5-5.0). The average crystal sizes are: labradorite, 0.2 mm; augite (phenocrysts), 2.0 mm; augite (groundmass), 0.02 mm; olivine, 0.4 mm; magnetite, 0.04 mm.

MISCELLANEOUS PETROGRAPHIC DATA

INTRODUCTION

Thinsections from isolated volcanic areas (pl. 8) along the northern margin of the county, Rabbit Ear Peak, and a group of small vents at the west edge of the county are briefly described in this section.

HARDESTY PEAK (32.31.20.233)

No phenocrysts, holocrystalline, fine-grained. Estimated composition (in percent): euhedral iddingsite-rimmed olivine grains, 0.1 to 0.2 mm in diameter, 20; alined plagioclase needles, 0.1 to 0.2 mm long, 40; tiny augite, 0.05- to 0.10-mm grains, 10 to 15; plagioclase laths up to 1.0 mm long (An_{55}), 55 to 60; brownish ophitic augite, 0.3 to 0.6 mm, 20; magnetite in grains up to 0.1 mm, 5 to 10.

BLACK MESA (31.36.1.344, 32.36.30.414)

Small (1.0 mm) euhedral olivine phenocrysts (5 percent) completely altered to iddingsite are set in a groundmass of the following estimated composition (in percent): partially iddingsite-altered olivine (0.2 to 0.3 mm), 10; augite, in part intersertal (0.1 to 0.2 mm), 30; plagioclase laths (0.2 mm), 50; large grains of magnetite, 5. Some areas of groundmass are filled with innumerable exceedingly tiny magnetite grains. This basalt is probably early Raton basalt (Tb).

RABBIT EAR MOUNTAIN (27.25.31.144, at triangulation station)

Small (0.5 to 1.0 mm) unaltered euhedral olivine phenocrysts (5 percent) are set in an exceedingly fine-grained matrix of tiny alined laths of plagioclase (60 percent) too small to identify, anhedral(?) augite (20 percent), and tiny grains of magnetite (15 percent). Dark bands observed in thinsection have nearly twice as much magnetite as the remainder of the rock. This rock is probably feldspathoidal, because of its similarity to other known feldspathoidal specimens in the region. A thinsection of a specimen from a flow (27.34.26.422) associated with this vent is identical to the specimen described above. This mountain is a Clayton-basalt vent (QTb_3).

VENTS IN 26.28

A row of small vents and associated flows of Clayton basalt (QTb) in 26.28 were studied briefly by means of single thinsections from each. Three alined vents at 26.28.17.133, 26.28.16.114, and 26.28.22.114 are very similar to each other and probably represent a single magma source. They each have large (1.0 to 2.0 mm) nearly euhedral plagioclase laths (25 percent) with broad twin bands (An_{55}?), and small partially iddingsite-altered olivine phenocrysts (0.2 to 0.3 mm, 5 percent), in a very fine-grained groundmass of plagioclase (30 percent), augite (25 percent), and magnetite (15 percent).

A sample from 26.28.27.441 near the south end of a 4-mile-long flow is different from the above in having no large plagioclase laths and a greater abundance of olivine phenocrysts, in spite of the fact that the bases of all 4 flows stand less than 50 feet above the present creek levels. Olivine phenocrysts (15 percent, 1 to 3 mm) are embayed and rimmed with iddingsite. Second-generation olivine, nearly euhedral but iddingsite-altered in 0.2-mm grains, constitutes another 10 percent of the rock. The remainder of the groundmass is composed of small, elongate, non-oriented plagioclase prisms (35 percent), tiny augite grains (30 percent), magnetite in scattered large and small grains (10 percent), and a small amount of nepheline(?). This rock has a coarser grained groundmass than the others described in the preceding paragraph.

SOUTHWESTERN CORNER OF UNION COUNTY

Baldwin has mapped the basalt in 23.28 (pl. lc) as undifferentiated Clayton basalt. No specimens were available for study by this author. Extensive cover apparently made it impossible for subdivision by reconnaissance field methods. Wood et al. (1953) show the continuation **of** this mass into Colfax County as late-Raton basalt (Qb_2 of their legend).

A thinsection[1] from the southern continuation of this basalt near Bueyeros, Harding County, is identical in appearance to the main undifferentiated Clayton-basalt mesa of central Union County (which this author believes may actually be correlative with the younger Raton basalt of Colfax County). Thus, it is possible that this basalt may be late Raton and correlative with the main undifferentiated Clayton-basalt mesa.

1. Specimen furnished by courtesy of C. J. Mankin.

Paleomagnetic Studies

Studies of the paleomagnetism of basalts in Iceland (Hospers, 1958, p. 475) disclosed reversals of magnetic field. On the assumption that these reversals were caused by reversals of the earth's magnetic field and, therefore, could be recognized throughout the world, a study was made of the gross magnetic orientation of the basalts in Union County, using a field technique as described by Muehlberger and Baldwin (1958), in an attempt to correlate and thus date these basalts. Initial reconnaissance study of the Folsom sequence indicated a reversal between the eruption of Mud Hill and Bellisle Mountain that matched the reversal straddling the earliest glacial moraine in Iceland, thus suggesting a Pliocene-Pleistocene age for the Clayton basalts. Later studies of the

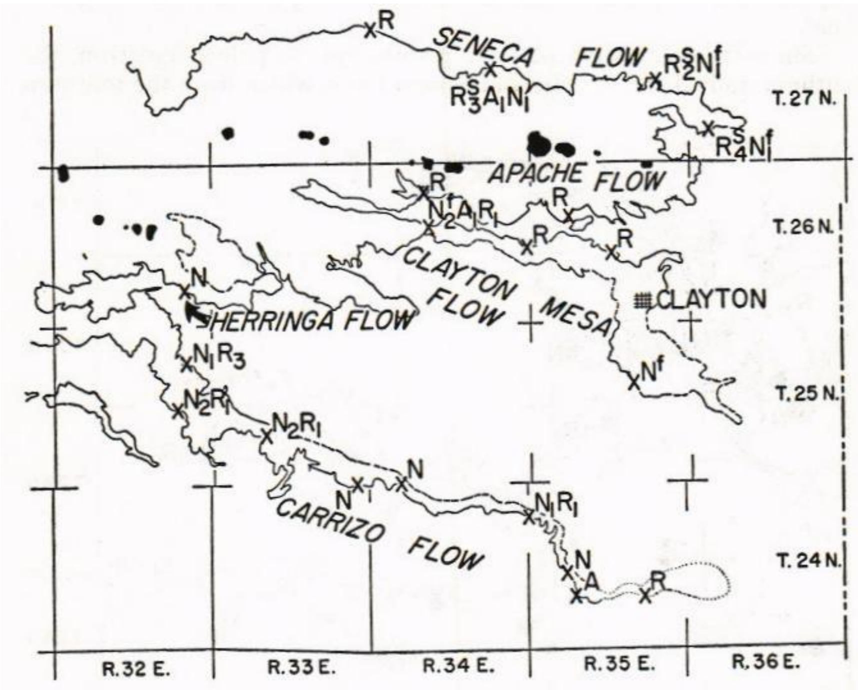


Figure 20

PALEOMAGNETIC OBSERVATIONS ON UNDIFFERENTIATED CLAYTON BASALT MESAS IN EASTERN UNION COUNTY

Type *Clayton basalt* of Collins; may be younger Raton basalt. Subscripts indicate relative proportions of tested samples having magnetization N (normal), A (anomalous), R (reverse to earth's present magnetic field), f (small deflection of sensitized compass needle), S (strong deflection of sensitized compass needle). Modified from Muehlberger and Baldwin (1958).

undifferentiated Clayton basalts gave inconsistent directions of magnetization for a single flow, as summarized in Figures 20, 21, and 22. Petrographic and polished sections of samples of Baby Capulin basalt showing both normal and reverse magnetization from a single outcrop do not show any discernible differences. However, the high percentage of TiO_2 in the chemical analyses suggests an ilmenitic magnetite which may self-reverse during cooling (Nagata, 1953; for theoretical aspects, see Neel, 1955). Balsely and Buddington (1958, p. 788-789) have shown how the direction and intensity of magnetization vary in iron-titanium oxide minerals with increasing intensity of oxidation. This suggests that the variation observed in single flows in Union County may be the result of local oxidation by hydrothermal activity during cooling or possibly even later during weathering. This probability of reversal of magnetism by mineralogic variation provides an alternative to the need of explaining reversals by reference to the reversing of the earth's magnetic field.

Since the submission of their manuscript on paleomagnetism, the authors studied the Apache and Seneca flows, which form the southern

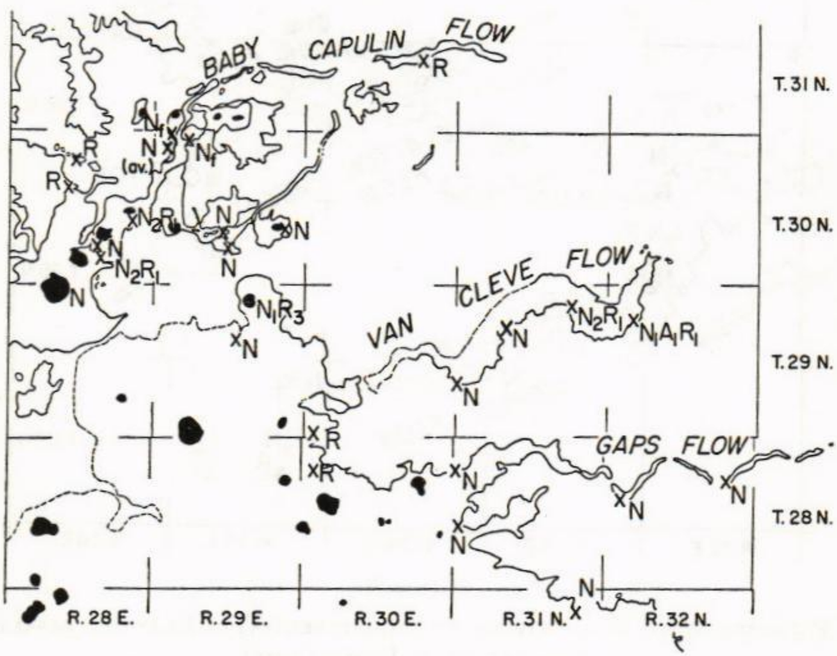


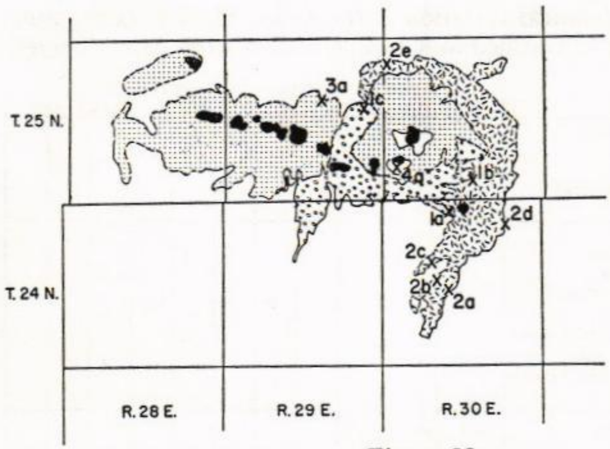
Figure 21

Paleomagnetic observations on Clayton and Capulin basalts in northwestern Union County

Symbols same as in Figure 20. Modified from Muehlberger and Baldwin (1958).

and northern rims of the upland on which the Rabbit Ear eruptions occurred. Figure 20 shows the location and results for each sample locality. In contrast to the inconsistent results on the other undifferentiated Clayton-basalt mesas (as reported in Muehlberger and Baldwin, 1958), practically all samples taken from these two flows showed intense reverse magnetization. The few normally magnetized specimens barely deflected the compass needle.

A careful study to determine the reason for the inconsistency in magnetization direction in these basalts should aid in making paleo-magnetism a useful tool in stratigraphic correlation and subdivision.



	Locality	Paleomagnetic readings
CONE	4a	$N_1 A_1 R_2$
QTb2	3a	N_3
QTb Pasamonte flow	2e	N_1^f R_2
	2d	$N_2 A_1 R_1$
	2c	N_3
	2b	N_2 R_1^f
	2a	$N_2 A_1$
Tb	1c	$A_1 R_1$
	1b	$N_1 A_1 R_1$
	1a	N_1 R_2

Figure 22

PALEOMAGNETIC DIRECTIONS ON DON CARLOS HILLS, SOUTHWESTERN UNION COUNTY

Tb, Raton(?) basalt platform; QTb, Pasamonte flow, oldest flow on east side of hills; QTb_2, youngest flows forming main hills; cone, one of the vents (black areas) probably contemporaneous with QTb_2. Modified from Muehlberger and Baldwin (1958).

Petrology

Chemical data concerning igneous rocks can be presented in many ways. Table 4 lists all the complete chemical analyses found in the literature, in addition to new ones for the late Cenozoic volcanic rocks of northeastern New Mexico and southeastern Colorado. The analyses are listed, as far as possible, in the sequence of eruption. The locality and, therefore, probable position in the sequence of some of the older analyses is not known; therefore, their position in the table is based on chemical analogies, as well as the main eruptive group to which they were assigned by the original author.

FUSION-INDEX STUDIES

More than 80 specimens from Des Moines quadrangle and vicinity were fused, and refractive-index determinations of the artificial glass were made for correlation purposes and for aid in understanding the mineralogical and chemical variation of the rocks. These data are summarized in Figure 23 (modified and supplemented from Muehlberger,

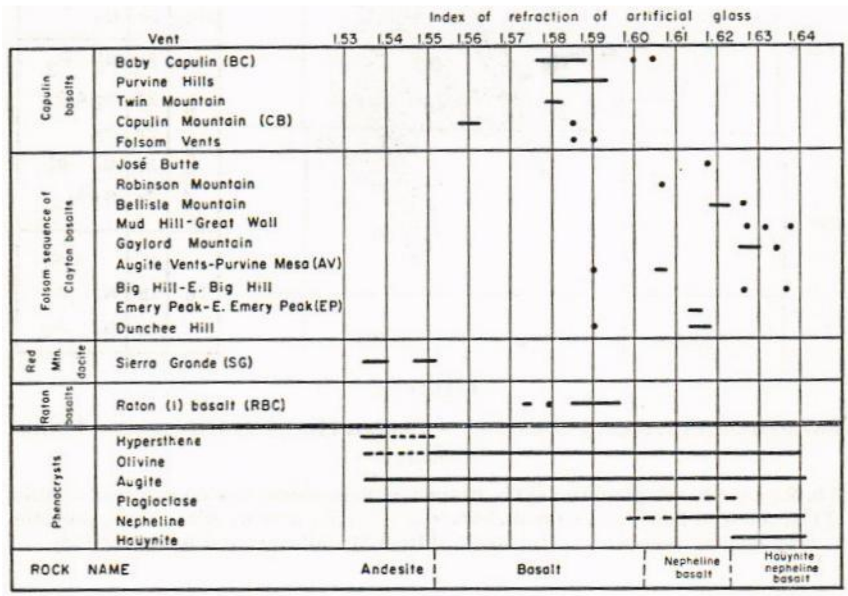


Figure 23

STRATIGRAPHIC SEQUENCE AND INDEX OF REFRACTION OF ARTIFICIAL GLASS IN DES MOINES QUADRANGLE AND VICINITY

Youngest at top, oldest at bottom. For a given source, the range of index of refraction can be read at top; phenocrysts observed, and rock name, at bottom.

1956). Fusion studies of the Don Carlos Hills are shown in Table 5. The index of refraction versus SiO_2 is shown in Figure 24. The new points derived from the present study lie below the average curve for New Mexico volcanic rocks (Sun and Baldwin, 1958, p. 49), and most are above the curve for the alkalic volcanic rocks of trans-Pecos Texas (Rix, 1951). This suggests that the northeastern New Mexico volcanic province tends to be slightly alkalic compared with the average New Mexico volcanic rock. This tendency toward an alkalic nature is shown also on the Harker variation diagram (fig. 25), from which the alkali-lime index is found to be about 56, the dividing line between the calcic and calc-alkaline classes of Peacock (1931).

DIFFERENTIATION

Evidence for magmatic differentiation can be seen from inspection of the chemical analyses, fusion indices, and petrographic data already presented. This can be visualized more easily by the chemical-variation diagram (Harker diagram; fig. 25), the triangular FeO-MgO-

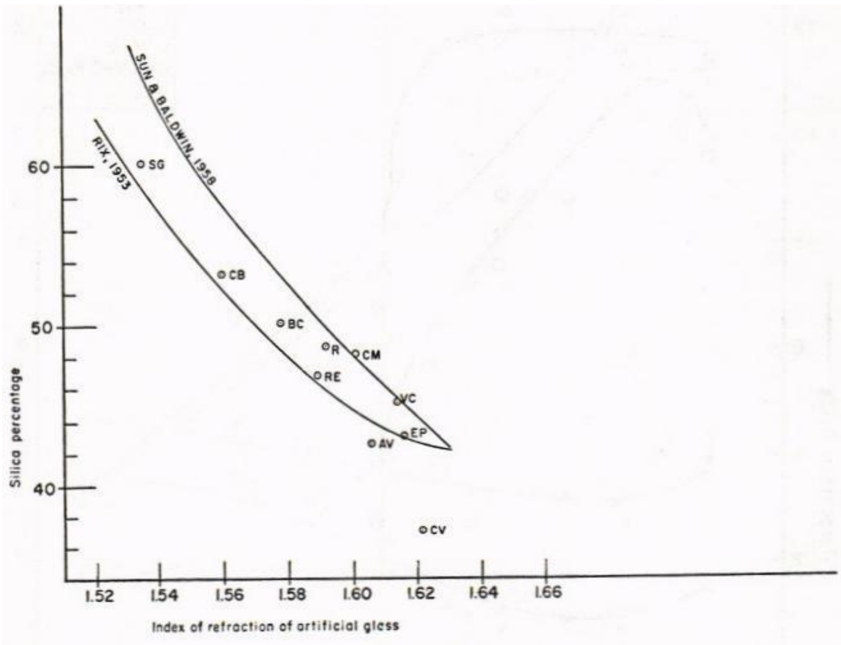


Figure 24

PLOT OF SILICA PERCENTAGE AGAINST INDEX OF REFRACTION OF ARTIFICIAL GLASS

Symbols for Union County rocks same as in Table 4. Curves for the west Texas alkalic volcanic province (Rix, 1953) and average New Mexico volcanic rocks (Sun and Baldwin, 1958) included for comparison.

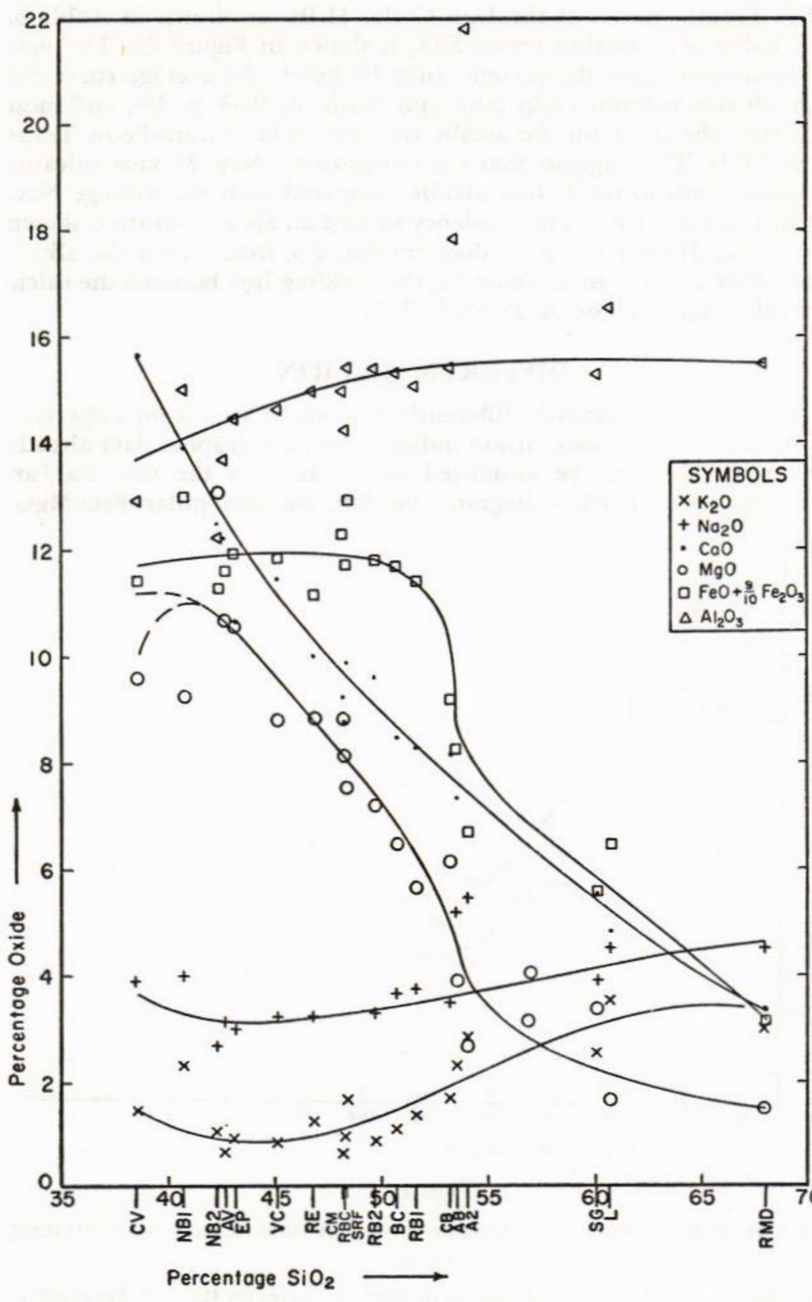


Figure 25

CHEMICAL-VARIATION DIAGRAM OF VOLCANIC ROCKS LISTED IN TABLE 4

Code on analyses listed along abscissa same as in Table 4.

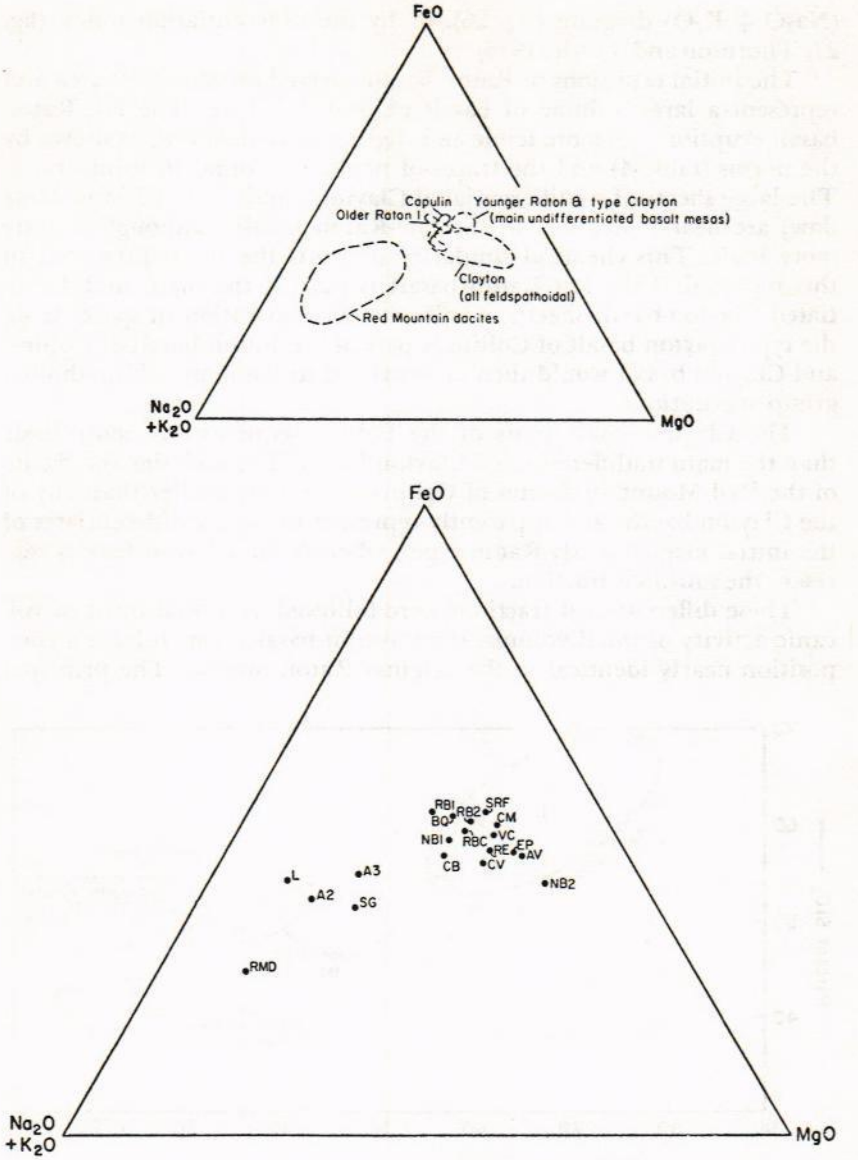


Figure 26

MGO — FEO TOTAL — (NA_2O + K_2O) TRIANGULAR DIAGRAM OF VOLCANIC ROCKS LISTED IN TABLE 4

Grouping (in upper diagram) by eruptive sequence shows variation in time.

(Na_2O --I- K_20) diagram (fig. 26), or by the differentiation index (fig. 27; Thornton and Tuttle, 1956).

The initial eruptions of Raton basalt covered an enormous area and represent a large volume of basalt of tholeiitic type. The late-Raton basalt eruptions are more femic and slightly silica deficient, as shown by the norms (table 4) and the traces of nepheline found in thinsections. The large sheets of undifferentiated Clayton basalt (e.g., Clayton Mesa flow) are nearly identical to the late-Raton basalts, although slightly more basic. This chemical similarity supports the thesis presented in this report that the late-Raton basalt is part of the main undifferentiated Clayton-basalt sheets, in spite of their separation in space. If so, the type Clayton basalt of Collins is part of the Raton basalt of Collins, and Clayton basalt would then be restricted to the more feldspathoidal group of eruptions.

The Clayton-basalt vents of the Folsom sequence are more basic than the main undifferentiated Clayton basalt. The andesite and dacite of the Red Mountain dacites of Collins are slightly earlier than any of the Clayton basalts and apparently represent the silicic differentiates of the initial magma (early-Raton type), whereas the Clayton basalts represent the subsilicic fraction.

These differentiated fractions were followed by a final burst of volcanic activity of small volume, the Capulin basalts, which have a composition nearly identical to the original Raton magma. The principal

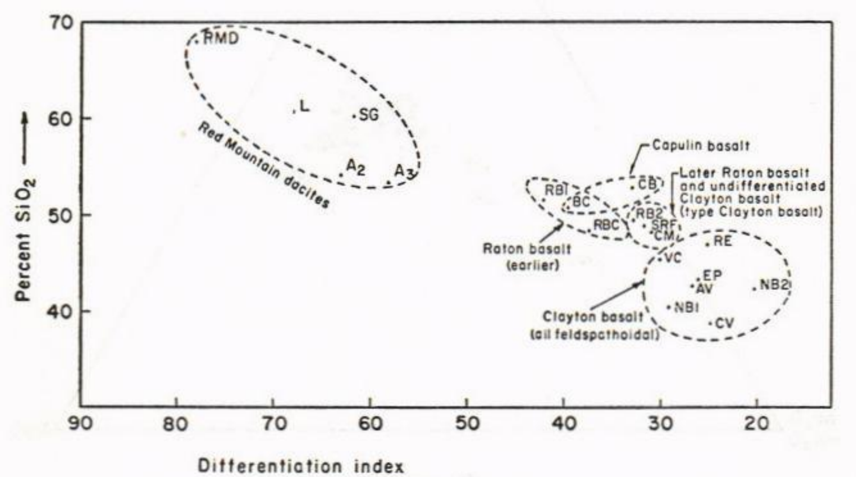


Figure 27

Plot of percent silica against differentiation index for volcanic rocks listed in Table 4

Eruptive sequences grouped by relative age. Differentiation index is the sum of normative quartz, orthoclase, and albite (Thornton and Tuttle, 1956).

difference is in the formation of cinder cones and local flows during the Capulin sequence, whereas the Raton basalts must have been very fluid to cover such large areas.

ertie (Lee, 1922, p. 11) proposed a progressive development of phenocrysts through time for the Raton region: olivine (Qb^1, early-Raton basalt of Collins); olivine and augite (Qb^2, late-Raton basalt of Collins); olivine, augite, and plagioclase (Qb^3, Clayton basalt of Collins). No Capulin-age vents were in his area. In addition, he states that plagioclase decreases and the amount of glass increases. As a generalization, this holds for the Union Couhty volcanic rocks, although exceptions can be found. An increase in the amount of feldspathoids can be shown as well. The Capulin-basalt sequence does not fit in this progressive evolution because it appears to belong to a new cycle or to regeneration of the original magma type.

Summary and Late Cenozoic Geologic History of Des Moines Quadrangle

The late Cenozoic history of Des Moines quadrangle is divided into three major stages based on the physiographic position of volcanic remnants which have preserved pqrtions of the older land surfaces. From oldest to youngest, these stages are Raton (in two substages), Clayton, and Capulin.

A number of east-northeast-trending small grabens are found north of the Dry Cimarron River in the northeastern portion of the quadrangle (fig. 22). These may be pre-Raton in age and are known to be younger than any of the Cretaceous rocks in this region. They may be related to the Laramide deformation of the Sierra Grande arch, across which they lie. None of them are overlapped by Raton volcanic rocks; many are now filled with basaltic dikes, which may be related to some of the Raton-age flows. Displacements on these grabens are small; never more than about 80 feet.

RATON-BASALT STAGE

The Raton basalts cap the highest mesas and are parts of a surface sloping southeast from the Sangre de Cristo Mountains. Near the city of Raton, these basalts are nearly 3,000 feet above the present level of the major stream drainages. In Des Moines quadrangle, they range from 400 to 1,000 feet above the major drains. At intermediate levels, averaging 100 to 200 feet above the present stream grades in Des Moines quadrangle, but greater to the west and less to the east, are the flows and surfaces of Clayton age. Occupying parts of the recent valley bottoms are basalts from the Capulin-age eruptions.

The Ogallala formation, which underlies the Raton basalt, is about 80 feet thick in Des Moines quadrangle. The lower half is commonly a pebble-cobble gravel, whereas the upper part is composed of coarse sand. Directly overlying this formation, with no apparent erosional break, are the Raton basalts. The individual flows may be 20 to 40 feet thick. Although 5 or more flows are found in the northwest corner of the quadrangle, only 3 flows are present in the easternmost part. The source for these flows is unknown. The few minor vents and dikes within this quadrangle, principally on Oak Canyon Mesa and the Emery Peak Mesa, may only have been local fissures and hornitos on the solid crust of the moving flow. The Raton flows are invariably olivine basalts, in which the olivine has been heavily altered to iddingsite. The most obvious characteristic of this sequence is the fact that the flows cap the highest mesas within the region.

The reported presence of basalt scoria (Reed and Longnecker, 1932) in the early Hemphillian deposits of the Texas Panhandle (part of the Ogallala formation) may be some of the earliest fragments eroded from the Raton basalts. The overall appearance of the Ogallala formation is that of a broad alluvial-plain deposit at the foot of the ancestral Sangre de Cristo Range. The Raton flows, then, may be Pliocene, rather than Pleistocene, as proposed by Collins (1949, p. 1022) and Lee (1922, p. 9).

An interval of active downcutting followed the early-Raton basalt eruptions, resulting in the graded surfaces found capped by the late-Raton basalts west of Union County, many hundreds of feet below the early-Raton level. The southeastward slope of the surface beneath the early-Raton flows is such that at about the location of the village of Des Moines, this surface and the present erosional surface are almost coincident. This fact, plus the chemical similarity between late-Raton basalt and the type Clayton basalt of Collins (the Clayton flow of the undifferentiated Clayton basalt in central Union County), suggests that the type Clayton basalt could be Raton basalt.

Although no age dating is possible for these broad sheets at this time, it appears likely that they are earliest Pleistocene or latest Pliocene, based on: (1) the assumption that reversals of the earth's magnetic field occur and that the paleomagnetic data for Union County have some statistical validity, so that they can be correlated with the Icelandic reversals; and (2) possible correlation of one of the Clayton-age basalts in the Folsom sequence with basalt cobbles found associated with Illinoisan fossils in terrace deposits lying on the Meade formation in Meade County, Kansas (Hibbard, 1944, p. 712). Specimens furnished the writer by Dr. Claude W. Hibbard are petrographically similar only to the basalt from Mud Hill (part of the Folsom sequence of Clayton basalts), although the fusion index of these specimens is low compared with those from Mud Hill.

It seems probable that the undifferentiated Clayton basalt was extruded during at least part of the time interval represented by the Folsom sequence of Clayton-age basalt of Des Moines quadrangle.

FOLSOM SEQUENCE OF CLAYTON BASALT

The opening events of the Folsom-basalt sequence began with eruptions from Emery and East Emery Peaks. Although a thin layer of deformed sediments separates the Emery Peak basalt from the overlying Big Hill basalt, these vents, as well as East Big Hill, may have erupted contemporaneously. All four are along a short straight line and are petrographically identical, suggesting closely spaced vents from a common magma source moving upward along a single fissure. The Emery Peak eruptions furnished most of the lava that flowed over the rim of the Raton-capped platform down into the ancestral Dry Cimarron River valley. About 3 miles northeast of the village of Folsom (30.29.6.222), this flow blocked the drainage of the main river and formed a lake up-stream from this point to Folsom. The volcanic deposits in this lake furnish much of the stratigraphic data on the Clayton sequence (fig. 16-18). The lowest known deposits are from the augite-rich Purvine Mesa basalts and Augite Vents basalts, whose vents are south and southeast of Folsom. Lying on top of the augite flow is from 10 to 30 feet of tuffs from the Mud Hill-Great Wall eruptive center. About 20 feet of gravel overlies the tuff sequence, which in turn is capped in places by small remnants of basalt from Bellisle Mountain, a vent lying more than 20 miles west on Johnson Mesa. The Bellisle Mountain basalts appear to have filled in the lake to the upper surface of the dam formed by the Emery Peak basalt. Upstream from Folsom and directly overlying the Bellisle Mountain basalts are flows from Robinson Mountain, which in turn are overlain by flows from Jose Butte. These flows filled the ancestral Dry Cimarron River valley. With the deposition of broad alluvial deposits, the drainage was integrated once again. Remnants of these deposits are still prominent as terraces along the northern flank of Hereford and Fisher Parks (fig. 28). The gradients on these Clayton-age streams were steeper than those of the modern drainages, as the topographic difference between the two levels increases upstream from Folsom.

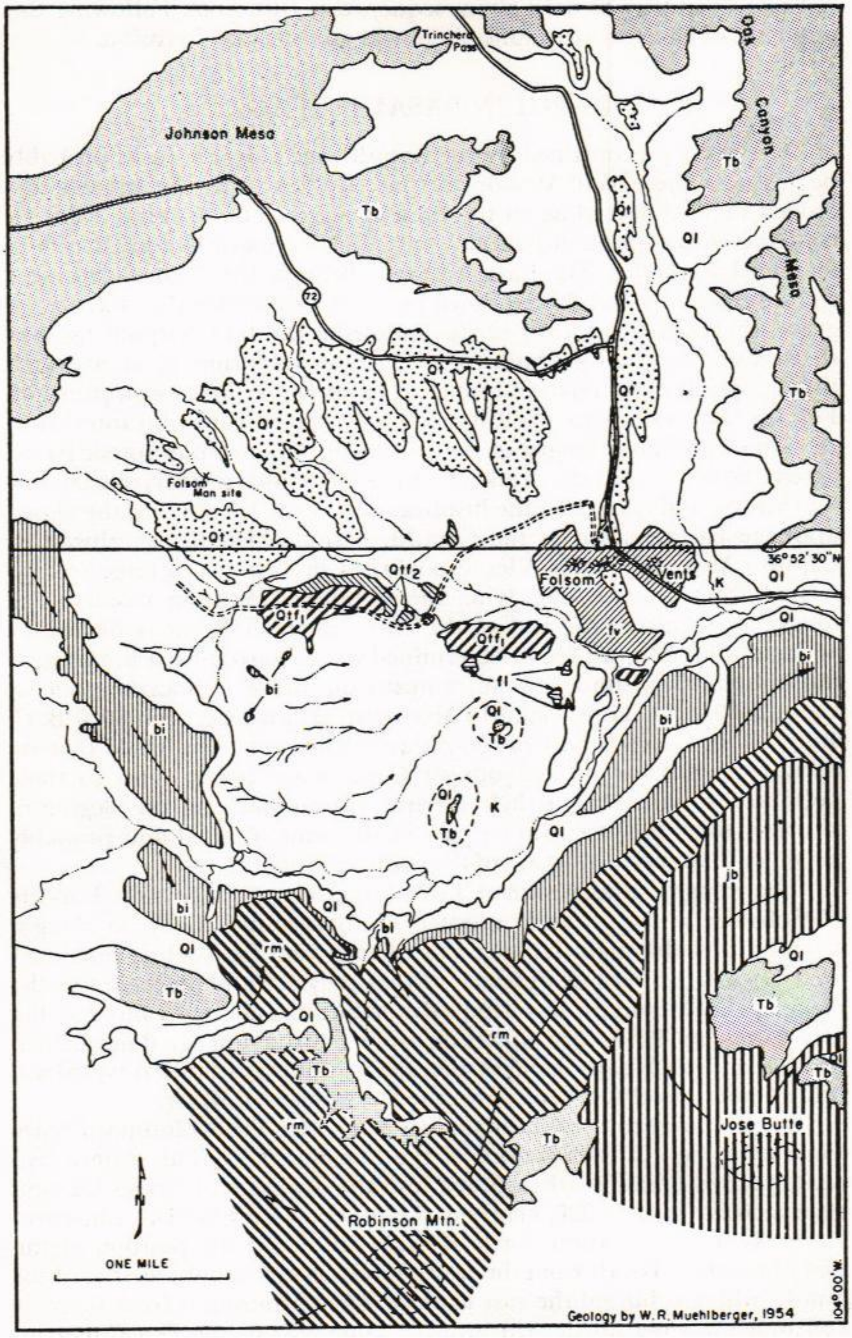
When Gaylord Mountain erupted during this sequence is not known, but it must have been at nearly the same time as the eruption of Emery Peak. The two basalts are not in contact; the age designation is based on geomorphic remnants which are essentially at the same elevation above modern stream level. Lava from Gaylord Mountain flowed northward into the ancestral Briggs Canyon, where remnants capping high terraces are found near the canyon head.

The possible correlation of the basalt scoria cobbles in the Illinoisan terrace deposits of Kansas with the Mud Hill basalt gives a possible

Figure 28

SEQUENCE OF EVENTS IN HEREFORD PARK BETWEEN ERUPTION OF RATON BASALTS AND BREACHING OF LAKE BEHIND FOLSOM VENTS BASALT

From oldest to youngest: Tb, Raton basalt of Collins (Qb^1 of Lee); bi, Clayton basalt of Collins from Bellisle Mountain (volcano 3 miles west of map area on Johnson Mesa); rm, Clayton basalt of Collins from Robinson Mountain; jb, Clayton basalt of Collins from Jose Butte; Qt, gravel-capped surfaces graded to level of Jose Butte basalt; fv, Capulin basalt (oldest eruption included in Capulin basalt in this report) from Folsom Vents; fl, lake muds deposited upstream from Folsom Vents basalt; Qtf,, alluvial deposits graded to top of inferred dam formed by Folsom Vents basalt; Qtf,, alluvial deposits graded to stream level after breaching of dam formed by Folsom Vents basalt. Alluvial deposits younger than those shown on map include older alluvium, which contains Folsom Man artifacts; younger alluvium, which unconformably overlies the older; and landslide deposits (QI), which, in part, may be older than the Clayton basalt sequence. Older geologic units which underlie blank areas include the Ogallala (not shown on map), Niobrara, and Pierre formations (K, undifferentiated Cretaceous formations).



Trinchera Pass
Johnson Mesa
Oak Canyon Mesa
Tb
Ql
Qf
72
Folsom Man site
Qtf2
Qtf1
Folsom
Vents
K
36°52'30"N
fv
bi
fl
jb
bl
rm
Jose Butte
Robinson Mtn.
N
ONE MILE
104°00'W
Geology by W. R. Muehlberger, 1954

dating of this part of the Folsom sequence as Illinoisan. Following this sequence of Clayton eruptions, there was an interval of erosion.

CAPULIN-BASALT STAGE

The history as outlined by the Capulin-age volcanic rocks probably begins near the end of Wisconsin time. By this time, the streams had eroded their valleys close to the present levels. The opening event recorded is the eruption of Folsom Vents, 1 mile west of Union County in Hereford Park (fig. 23). Lava erupted through the high Clayton-age terrace remnants and flowed down into a stream valley that was cut on gravel-veneered Cretaceous rocks. Following the lava outpouring, further erosion lowered the valley 20 feet below its former level, at which time a period of alluviation occurred, from which *Bison antiquus* and Folsom Man points (ca. 8000 B. C.) are preserved. After an interval of erosion of unknown length of time, Capulin Mountain erupted; its extensive flows blocked the drainage of the Dry Cimarron River near Folsom village and converted the headwaters of Piña Viente into the closed drainage basin known as the Capulin basin, which lies southwest of Capulin Mountain. Piña Viente now rises in a group of large springs issuing from gravels underlying the Capulin Mountain basalts. The tongue of basalt in the bed of the Dry Cimarron River is buried by younger alluvium, which, as determined from charcoal in a firepit near the Folsom Man site a few miles upstream, has a radiocarbon age of about 2500 B. C. Thus, Capulin Mountain erupted between 8000 B. C. and 2500 B. C. No good stratigraphic evidence has been found that indicates the relation of the younger Capulin-age basalt vents to these radiocarbon dates. From their general appearance and the degree of alluvial cover, they seem to be part of the same interval and probably are older than most, if not all, of the younger alluvium.

The elongate cinder cone of Twin Mountain, and the three Purvine Hills fissure vents, probably erupted simultaneously. They lie along a straight line, although the long axis of each vent lies slightly northeast of the east-trending line of vents, so that they are all en echelon to the right. Twin Mountain flows moved northward and again blocked the Dry Cimarron River just upstream from the Clayton-age dam formed by Emery Peak basalt. Some of the Twin Mountain flows traveled another 6 miles northeastward down the Dry Cimarron River.

Contemporaneous with, or slightly after, the Twin Mountain eruptions were the fissure eruptions of the Purvine Hills. The eastern two vents poured basalt northeastward into the drainage of Briggs Canyon at least as far as 31.30.320, nearly to the junction with the Dry Cimarron River. Heavy alluviation north of 31.30.320 masks the position of the end of the flow. Basalt from the westernmost fissure moved westward for 1 mile, where it buried the east flank of Twin Mountain; from there, it continued flowing northward into the same area of the Dry Cimarron

River valley as did the Twin Mountain basalt. The identical nature of the basalt from these vents and colluvial cover prevent determining which vent furnished the lava which flowed down the Dry Cimarron River as far as is shown on the geologic map.

The eruption of Baby Capulin Mountain is the last volcanic event in this region. The vent lies along the western continuation of the line drawn through the Purvine Hills fissures and Twin Mountain. Baby Capulin basalt can be distinguished from the other basalts along the alinement only by the presence of as much as 6 percent olivine phenocrysts. In places, however, the phenocrysts of olivine are absent, and the basalts from this line of vents cannot be separated. Olivine-bearing basalt, identical in hand specimen to that from Baby Capulin Mountain, can be found extending for more than 20 miles down the Dry Cimarron River. Earlier studies have indicated that these flows are from Capulin Mountain, but Capulin Mountain basalt contains abundant plagioclase phenocrysts, which are not found in the long flows. Only olivine phenocrysts are found.

All the volcanoes of Capulin age have asymmetrical cones. Their western edges are lower than the eastern edges. This is represented especially well in Capulin and Baby Capulin Mountains. Prevailing westerly winds apparently blew across this region during the times of eruption of these cones.

Alluviation of the valleys continued until the present epoch of gullying reversed the process. A number of small lakes (generally dry) in the region immediately west of the village of Des Moines are in deflation depressions in the Dakota sandstone. These depressions extend down to the shaly beds that separate the upper from the main cliff-forming Dakota sandstone. To the east of these lakes, small stabilized dunes represent sand removed from the sites of the lakes.

Of local importance are the alluvial deposits (now terraces), whose upper surfaces are graded to the tops of the various lava flows behind which they were deposited. Landslides are extensive, principally surrounding the basalt-capped or Dakota-sandstone-capped mesas and plateaus. These landslides thoroughly mask much of the bedrock geology and probably started forming as soon as streams had eroded through the resistant cliff-forming units.

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Type faces:	Text in 10-pt. linotype Baskerville leaded one point References in 8-pt. linotype Baskerville leaded one point Display heads in 18-pt. Foundry Baskerville, letterspaced two points
Presswork:	Miehle Single Color Offset Harris Single Color Offset
Binding:	Smyth sewn
Paper:	Cover on 17-pt. Kivar Text on 60-lb. White Offset Plate section on 50-lb. Mead White Opaque
Ink:	Cover—PMS 320 Text—Black
Press Run:	750